



FACULTY OF AGRICULTURE
ADEKUNLE AJASIN UNIVERSITY,
AKUNGBA AKOKO, ONDO STATE, NIGERIA

1ST INTERNATIONAL CONFERENCE

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2025

Theme

HARNESSING PRECISION AGRICULTURE
FOR FOOD SECURITY AND
SUSTAINABLE DEVELOPMENT

@ NELSON MANDELA HALL, ADEKUNLE AJASIN UNIVERSITY,
AKUNGBA-AKOKO, ONDO STATE, NIGERIA

Editors

Gbadamosi, A.E., Olaniyi, W.A., Oyedokun J.O., Olaniyan, O.A. and Abe, O.S.



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9th - 13th November, 2025

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Held at

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Editors

Gbadamosi, A.E., Olaniyi, W.A., Oyedokun J.O., Olaniyan, O.A. and Abe, O.S.

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(A Keynote Paper Presented at the Maiden International Conference of the Faculty of Agriculture, Adekunle Ajasin University, Akungba-Akoko, with the theme: "Harnessing Precision Agriculture for Food Security and Sustainable Development")

HARNESSING PRECISION AGRICULTURE FOR FOOD SECURITY AND SUSTAINABLE DEVELOPMENT

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INTRODUCTION

This conference theme, "*Harnessing Precision Agriculture for Food Security and Sustainable Development*," could not have been more timely and vital. It comes at a moment when the world, and indeed Nigeria, stands at a crossroads between technological advancement and agricultural necessity, between the science of innovation and the moral obligation to feed our people.

Agriculture remains the bedrock of Africa's sustenance. Yet, despite the vast arable land, abundant youth population, and rich biodiversity, Nigeria still ranks among the world's most food-insecure countries. The 2025 *Global Hunger Index* places Nigeria 115th out of 123 nations, reflecting a "serious" level of hunger. Recent estimates from the FAO (2025) revealed that over 33 million Nigerians were projected to experience acute food insecurity between June and August 2025, a troubling indication of systemic weaknesses in food production and distribution. Unfortunately, Nigeria spends more than \$10 billion annually on food imports despite its immense agricultural potential, revealing a persistent production deficit that calls for urgent and proactive interventions (The Punch Newspaper, 2025).

As climate crisis deepens, agricultural lands continue to degrade, and population pressure intensifies, the demand for sustainable food systems becomes increasingly urgent. Nigeria's population is projected to exceed 250 million by 2030, requiring agricultural production to increase by at least 70% without expanding arable land, exhausting water resources, or further degrading the environment. This global reality mirrors a wider demographic shift, with the world's population expected to reach 9.7 billion by 2050, underscoring the inadequacy of traditional farming systems to meet future food needs. Within this mounting pressure, precision agriculture emerges not as a technological luxury but as a developmental necessity, a transformative strategy for enhancing efficiency, sustainability, and resilience in food production. By integrating data-driven insights with resource, smart technologies, precision agriculture offers a viable pathway to feed growing populations while preserving the ecological balance on which agriculture ultimately depends.

Precision Agriculture: Beyond Technology

Precision agriculture, also known as smart or digital farming, is an innovative farming approach that integrates modern technologies and data-driven intelligence to enhance decision-making and optimize agricultural operations. Precision agriculture combines agronomy, geospatial science, data analytics and automation to improve efficiency and sustainability. Lowenberg-DeBoer and Erickson, (2019) defined Precision agriculture as a management strategy that uses electronic information and other technologies to gather, process, and analyze spatial and temporal data for the purpose of guiding targeted actions that improve efficiency, productivity, and sustainability of agricultural operations. Conceptually, it encompasses four fundamental elements: geographic positioning, data collection, data analysis, and precise processing (Figure 1). This framework enables critical functions such as data acquisition, decision support, and variable-rate control (Xu *et al.*, 2024).

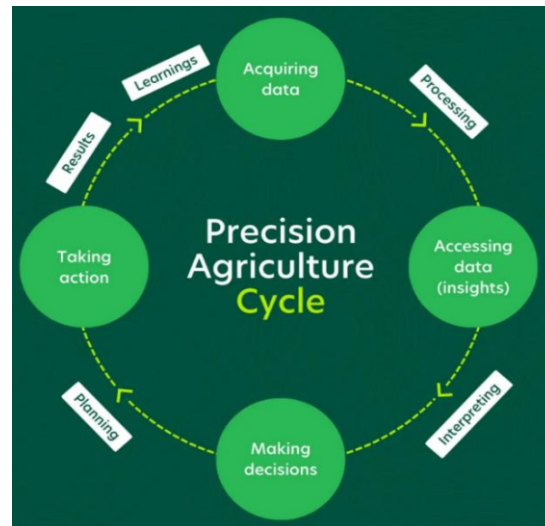


Figure 1: Conceptual Framework of Precision Agriculture
Source: Farm21 (2025)

Precision agriculture employs a range of advanced tools such as geographic information systems (GIS), global positioning systems (GPS), Remote Sensing (Satellites and Drones), Internet of Things (IoT) sensors, Variable Rate Technology (VRT), robotics, nanotechnology and machine learning algorithms that interpret soil health, plant vigour, and climatic variability in real time. (Adekunle, 2013, Zhang *et al.*, 2021, Sharma *et al.*, 2024). It is the science of applying the right input, in the right quantity, at the right time, and in the right location. Rather than managing entire fields uniformly, precision agriculture tailors the application of inputs, such as fertilizers, water, pesticides, and seeds, to specific field conditions (Eni, 2022). By optimizing resource use, it minimizes waste, lowers production costs, and reduces the environmental footprint of agriculture, thus promoting sustainable land management (Getahun *et al.*, 2024).

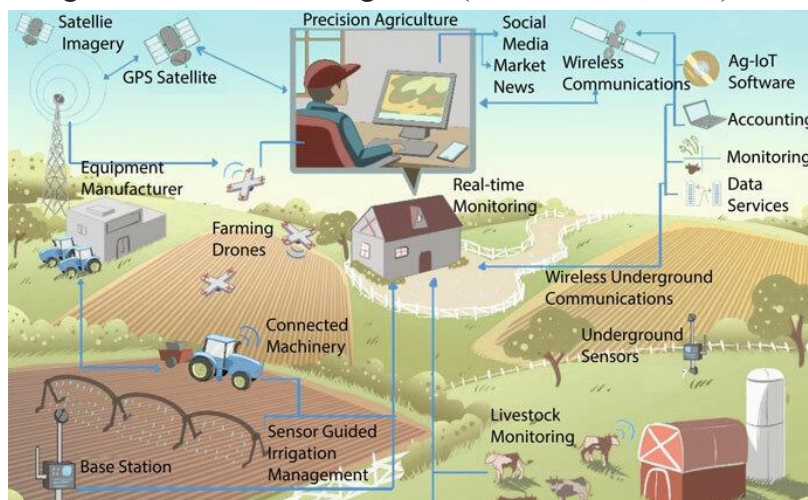


Figure 2: Modern Technology and Digital Tools used in Precision Agriculture
Source: Salam, (2024)

Globally, the adoption of precision agriculture has yielded transformative results. In the United States and parts of Europe, yield increases of 15–25% and input savings of up to 30% have been achieved through variable-rate technologies (Zhang *et al.*, 2021). In Asia, precision irrigation and sensor-based nitrogen management have enhanced water-use efficiency by as much as 40% (Singh & Sharma, 2022). Across Africa, adoption is gradually increasing, though progress remains constrained by limited access to technology, high implementation costs, and weak digital infrastructure (Kala, 2023).

Ultimately, these advances underscore precision agriculture's pivotal role in strengthening food security and environmental sustainability, enhancing food availability, improving resource efficiency, and fostering climate-resilient agricultural systems capable of supporting a rapidly growing population.

Importance of Precision Agriculture Modern Farming System

Precision farming plays a vital role in modern agriculture for several key reasons (Saniga *et al.*, 2024):

1. **Improved Efficiency:** Through the use of advanced technologies to accurately manage inputs such as water, fertilizers, and pesticides, precision farming ensures optimal use of resources and promotes greater operational efficiency.
2. **Higher Productivity:** By applying data-driven insights to manage specific areas within a field, farmers can achieve better crop yields, resulting in improved productivity and profitability.
3. **Environmental Protection:** Precision farming minimizes the overuse of chemicals, prevents soil degradation, and conserves water. These practices help reduce the negative environmental effects of conventional farming and support sustainable production systems.
4. **Reduced Costs:** Efficient input management and higher yields contribute to lower production expenses, enabling farmers to achieve better economic returns and sustain their farming businesses over time.
5. **Data-Based Decision Making:** Information gathered from sensors, drones, and satellite imagery allows farmers to make well-informed choices on crop management, input distribution, and risk control.
6. **Climate Change Adaptation:** Precision farming provides tools that help farmers respond to changing climate conditions by modifying planting schedules, selecting climate-tolerant crop varieties, and adopting efficient irrigation systems.

Tools and Technologies Used in Precision Agriculture for Sustainable Food Security

For sustainable food security, precision agriculture equipment and systems (Gokool *et al.*, 2023, Saniga *et al.*, 2024, Lakhia *et al.*, 2024) that focus on efficiency, resource optimization, and data-driven decision-making are critical. These tools and technologies include:

1. **Remote Sensing:** Remote sensing technology utilizes satellites, drones, and aircraft-mounted sensors to gather high-resolution imagery and spectral data from farmlands. These data enable continuous monitoring of crop performance, detection of nutrient deficiencies, identification of pest or disease outbreaks, and assessment of overall field conditions. By interpreting remote sensing outputs, farmers can make data-driven adjustments to irrigation scheduling, fertilizer distribution, and pest management (Gokool *et al.*, 2023, Sangeetha *et al.*, 2024). The integration of remote sensing enhances spatial precision, improves input efficiency, and supports sustainable yield optimization across diverse agricultural (Figure 3).

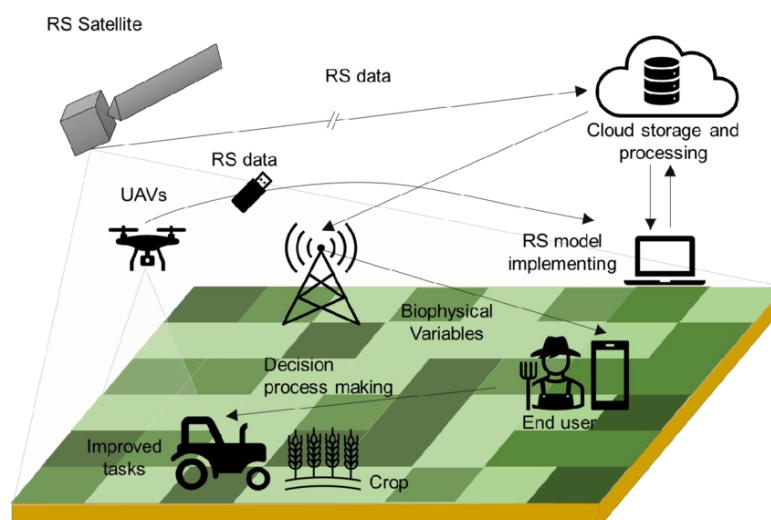


Figure 3: Remote sensing and applications in Precision Agriculture

Source: Erazo-Mesa *et al.*, (2022)

2. **Global Positioning System (GPS):** Global Positioning System (GPS) technology provides real-time positional accuracy essential for precision field mapping, boundary delineation, and monitoring of crop health indicators. It guides farm machinery through a pre-set paths during planting, spraying, and harvesting with centimeter-level accuracy derived from Global Navigation Satellite Systems (GNSS). Integrated with auto-steering and section-control systems, GPS enables automated navigation that

minimizes overlap, reduces fuel use, and enhances operational efficiency (Figure 4). The data generated can be synchronized with digital farm management platforms to monitor performance and support site-specific management. When combined with soil and crop sensors, GPS provides spatially referenced data that improve input application and yield prediction. By facilitating precise, data-driven field operations, GPS technology enhances productivity, profitability, and sustainability in agricultural systems (Getahun *et al.*, 2024).

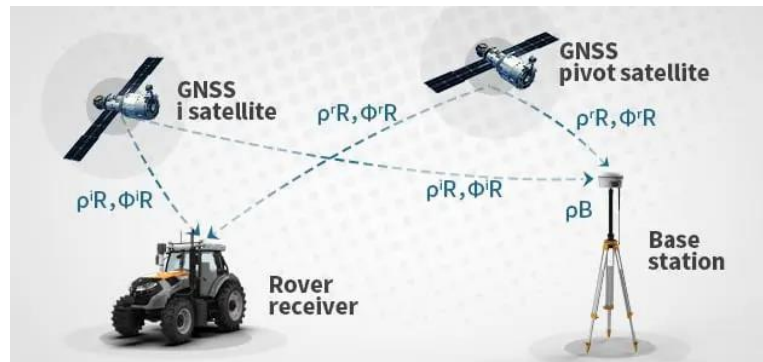


Figure 4: GPS application in Agriculture for Precision Farming
Source: Fjdynamics, (2025)

3. **Geographic Information Systems (GIS):** Geographic Information Systems (GIS) serve as a vital analytical tool in precision agriculture by integrating spatial data from diverse sources such as satellites, drones, and field sensors. These systems support land-use planning, soil assessment, and crop health evaluation through accurate mapping of land cover, vegetation vigour, and terrain characteristics (Figure 5). GIS software facilitates the collection, integration, and visualization of spatial data, including soil composition, topography, and yield patterns. By combining these datasets, GIS helps generate prescription maps for variable rate input applications. The technology provides a powerful analytical framework for identifying variability within fields and developing management zones (Sangeetha *et al.*, 2024). As a result, GIS enhances the precision and environmental responsibility of farming practices, ensuring more efficient use of resources and improved farm productivity.

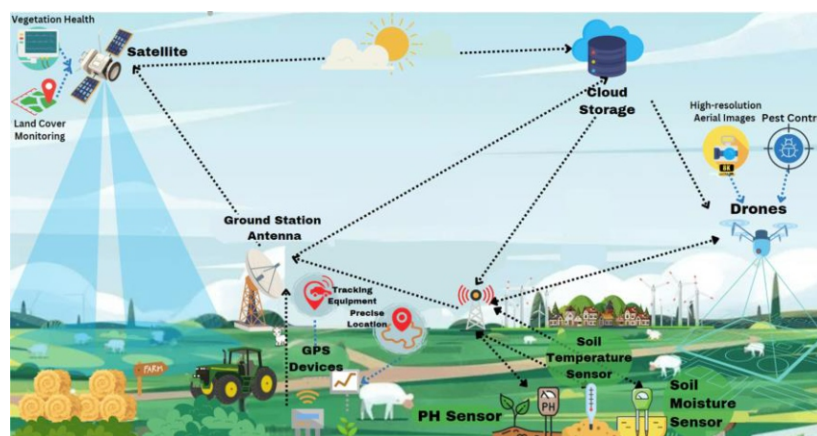


Figure 5: Geographic Information Systems (GIS) application in Smart Farming
Source: Padhiary *et al.*, (2025)

4. **Sensors and Monitoring Devices:** Precision farming relies on a range of field sensors that provide real-time information on environmental and crop conditions. These include soil moisture probes, nutrient sensors, weather stations, and crop health detectors (Figure 6). Soil sensors help regulate irrigation by determining water availability, while nutrient sensors support accurate fertilizer application. Similarly, weather stations supply localized meteorological data, enabling better scheduling of farming activities. Multispectral and hyperspectral crop sensors detect plant stress, diseases, and nutrient deficiencies early (Lakhia *et al.*, 2024, Onyango *et al.*, 2021). The integration of these sensor networks within farm management systems allows for site-specific interventions that enhance productivity and promote environmental sustainability.

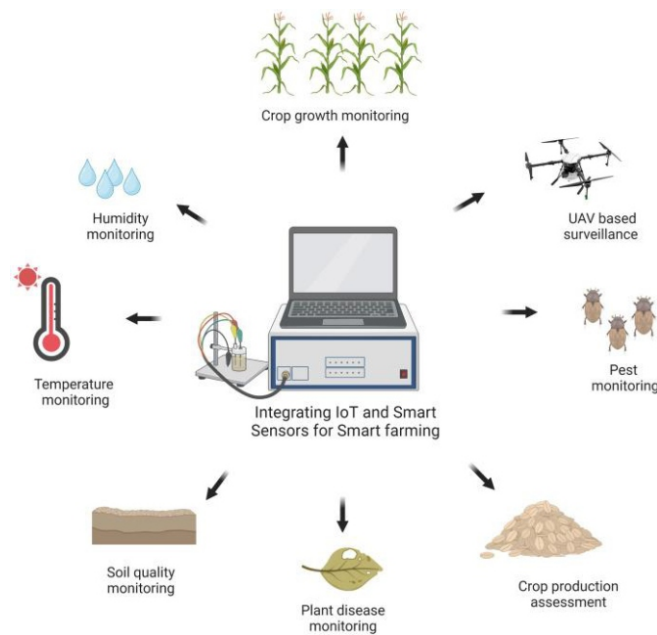


Figure 6: Application of Internet of Things and smart sensors in agriculture
Source: Rajak *et al.*, (2023)

5. **Variable Rate Technology (VRT):** VRT enables the differential application of agricultural inputs, such as fertilizers, pesticides, and irrigation water, based on the specific needs of different zones within a field. Using data derived from soil analyses, yield monitors, GPS, and remote sensing, VRT systems generate prescription maps that guide equipment to apply optimal input rates. For instance, spatial data on soil properties and crop conditions are analyzed to generate prescription maps that guide input application. These maps, when integrated with GPS-enabled equipment, automatically regulate the quantity of inputs applied as the machinery moves across the field as illustrated in Figure 7. This precision minimizes resource wastage, reduces environmental pollution, and ensures uniform crop performance (Getahun *et al.*, 2024). Consequently, VRT enhances economic efficiency and sustainability by aligning input use with actual field variability.

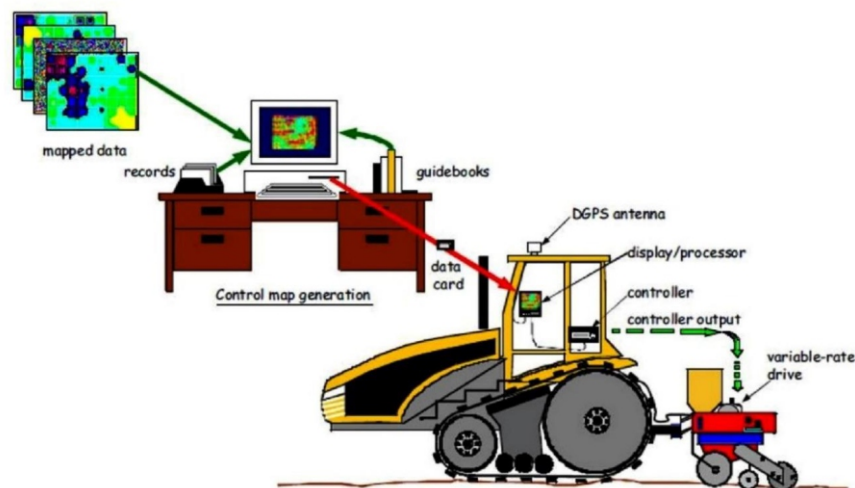


Figure 7: Variable Rate Technology Application in Guiding Farm Machinery in Precision Agriculture
Source: Ess *et al.*, (2001)

6. **Data Analytics and Decision Support Systems (DSS):** Modern precision agriculture leverages advanced data analytics and DSS platforms to convert vast datasets from sensors, drones, and satellites into actionable insights. These tools employ machine learning algorithms and predictive models to identify spatial and temporal patterns in soil fertility, weather, and crop performance (Getahun, 2024). DSS provide recommendations for optimal input allocation, yield forecasting, and pest management strategies. The integration of such analytical tools empowers farmers to make informed, adaptive decisions that enhance efficiency, productivity, and environmental stewardship (Figure 8).

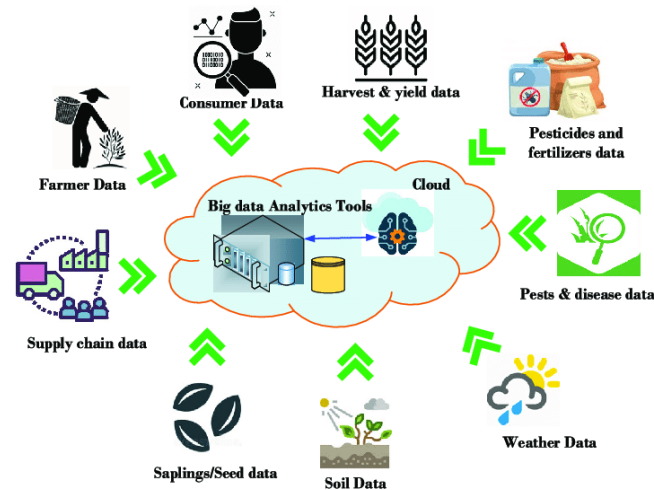


Figure 8: Application of Big Data-Based Analytics and Decision support system in Smart Farming

Source: Bhat and Huang, (2021)

7. **Automated and AI-Driven Machinery:** Automation and artificial intelligence (AI) are transforming agricultural operations by enabling high-precision, labour-efficient mechanization. Automated tractors, planters, and harvesters, equipped with GPS-guided steering, section control, and embedded sensors, carry out field operations with remarkable accuracy. These machines reduce input overlap, improve uniformity, and collect valuable data for continuous process optimization (Figure 9). AI-driven advisory systems further support decision-making by analyzing real-time field data to provide tailored recommendations (Agrawal and Arafat, 2024). Collectively, these innovations reduce operational costs, enhance resource management, and promote long-term agricultural sustainability.

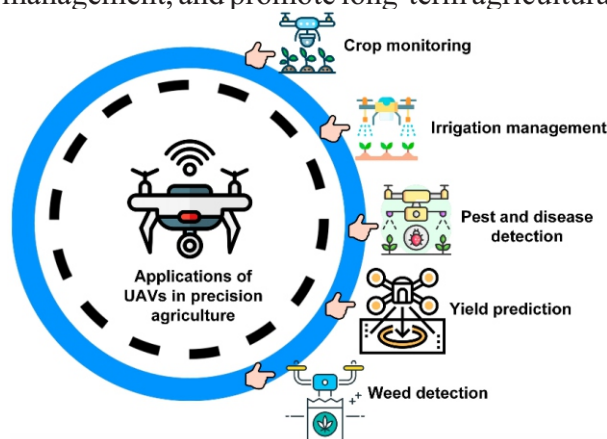


Figure 9: Application of AI-Powered UAV Technologies in Precision Agriculture

Source: Agrawal and Arafat, (2024)

Integrating Precision Agriculture into Food System Resilience and Sustainable Productivity

Food security is not merely about producing more, it is about producing better, smarter, and sustainably. Precision agriculture aligns perfectly with the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Empirical studies in Sub-Saharan Africa show that integrating precision agriculture technologies enhances both productivity and resilience within food systems. For instance, Nyaga *et al.* (2021) analyzed 82 peer-reviewed studies across 16 African countries and found that site-specific nutrient management, precision irrigation, and variable-rate seeding improved average crop yields by 18–25%, while reducing fertilizer and water inputs by 15–30%. Similarly, a recent field trial in Nigeria by Mamman *et al.* (2025) demonstrated that precision maize farming using soil sensors and GPS-guided variable-rate application increased grain yield by 22.6% and profitability by 17.8% compared to conventional practices. These findings affirm that precision agriculture not only boosts efficiency and profitability but also strengthens food system resilience by conserving inputs, enhancing soil health, and reducing greenhouse gas emissions, key components of sustainable agricultural transformation.

Contributions of Precision Agriculture to Food Security

Precision agriculture enhances food security by increasing crop yields, improving product quality, and ensuring efficient resource use (Figure 10). Through technologies that enable early detection of crop stress and precise application of water, fertilizers, and pesticides, farmers can manage weeds, pests, and diseases more effectively while minimizing waste and production costs. This site-specific management reduces environmental pollution and safeguards soil and water resources, key foundations for sustainable agriculture and long-term food security (Erickson & Fausti, 2021; Ibukun *et al.*, 2024). Precision agriculture contributes significantly to food security by strengthening all four pillars (availability, access, utilization, and stability), through improved productivity, affordability, nutritional quality, and resilience to climate variability (Erickson and Fausti, 2021, Gokool *et al.*, 2023).

Precision agriculture strengthens food availability and stability by raising site-level productivity while lowering resource waste, and by reducing yield variability across seasons. By enabling precise management, precision agriculture can lead to significant increases in crop yields and improve the quality of food products. It ensures stable food supply by helping to manage risks from pests and diseases through early detection and timely intervention, contributing to a more stable and reliable food supply. Reviews and empirical syntheses show that site-specific management (soil and plant sensing, variable-rate application, and precision irrigation) routinely increases nutrient-use efficiency and can raise yields without extra, while also damping losses from pests, disease and water stress (Getahun *et al.*, 2024; Nyaga *et al.*, 2021). Systematic reviews and meta-analyses report improvements in nutrient-use efficiency (20%), soil-health gains (20–30%) and measurable reductions in crop losses from pests and diseases (15–25%) when precision tools inform timing and placement of inputs; precision irrigation studies further document large water-use savings and yield gains under water-limited conditions (Lakhier *et al.*, 2024; Getahun *et al.*, 2024). By shortening the time between detection and management (remote sensing, sensors, decision support), these technologies reduce year-to-year production volatility and improve seasonal supply reliability, critical to the “stability” pillar of food security (Erickson & Fausti, 2021).

Precision approaches also improve food access and utilization by lowering per-unit production costs, enabling more efficient input use, and by improving product quality and traceability. For commercial farmers, it reduces input costs and increases productivity, while for smallholder farmers who rely on selling produce. Targeted fertilizer and pesticide application reduces input bills and can raise net margins for adopters (Getahun *et al.*, 2024; Nyaga *et al.*, 2021). Low-cost remote sensing (including UAVs) gives smallholders timely diagnostics for nutrient and water stress, enabling earlier corrective action that preserves marketable yield and quality, which supports household incomes and market access (Gokool *et al.*, 2023). Beyond production, digital traceability and better on-farm monitoring, help reduce postharvest losses, improve hygienic handling, and supply higher-quality produce to consumers, thereby strengthening utilization (nutritional quality and food safety) as well as market access for smallholder households (Getahun *et al.*, 2024; Erickson & Fausti, 2021).



Figure 10: Contribution of Precision agriculture to food security
Source: Quintessence Environmental Consult (2025)

Contributions of Precision Agriculture to Sustainable Development

Precision agriculture improves resource efficiency and reduces environmental pressure by enabling site-specific input application and water-saving management. In sub-Saharan Africa, technologies such as soil sensors, remote sensing and variable-rate nutrient application have been reported to improve input-use efficiency even without increasing average input rates (Onyango *et al.*, 2021). Precision water and fertilizer application technologies using sensors, machine-learning and variable-rate systems have been shown to cut water and nutrient use by 20-30% while maintaining or improving yields (Getahun *et al.*, 2024, Lakhia *et al.*, 2024). These reductions minimize environmental burden by lowering runoff and reducing the carbon and energy footprint of farming operations (Sangeetha *et al.*, 2024), thereby promoting more sustainable production systems. A randomized evaluation of site-specific nutrient management (SSNM) findings in northern Nigeria reported measurable increases in fertilizer management adoption and incremental yield and revenue gains (Maertens *et al.*, 2023), demonstrating that locally adapted precision approaches both save inputs and improve productivity. Beyond efficiency, precision agriculture strengthens environmental protection, resilience, and long-term viability. By minimizing nutrient leaching and pollution, these technologies protect water and soil quality and reduce greenhouse gas emissions associated with excess fertilizer use (Getahun *et al.*, 2024, Maertens *et al.*, 2023). Precision systems also enhance the resilience of cropping systems by enabling adaptive management, real-time monitoring of soil moisture, crop stress and pest incidence empowers farmers to respond more rapidly to climate shocks and variability (Lakhia *et al.*, 2024). Economically, the combination of cost-savings from lower input use and yield gains improves profitability for farms, thus reinforcing the long-term viability of agricultural enterprises (Gokool *et al.*, 2023). These findings indicate that precision agriculture, if adapted to local Agroecologies and scaled with inclusive policies, advances multiple dimensions of sustainable development.

Case Studies of Precision Agriculture in Farming Systems

Case Studies from Developing and Developed Countries

- a. **Israel:** Israel's pioneering use of drip irrigation exemplifies how precision resource management can sustain agriculture in water-scarce environments. Developed in response to chronic aridity, drip systems deliver water and nutrients directly to plant root zones, drastically improving efficiency. Studies report water savings of up to 90% compared to conventional irrigation, with consistently high yields across horticultural and field crops (Bucknall, 2010; Akshaya, 2025). This targeted approach minimizes evaporation and nutrient leaching, demonstrating how innovation in irrigation technology can secure food production while conserving scarce natural resources, an important model for arid and semi-arid regions worldwide.
- b. **United States:** The United States illustrates how large-scale adoption of advanced precision agriculture technologies can transform both productivity and sustainability. Farmers across major grain-producing states employ GPS-guided machinery, remote sensing, and Variable Rate Technology (VRT) to optimize fertilizer, seed, and pesticide applications at sub-field resolution. Such data-driven management has increased soybean yields by up to 15% while significantly cutting input costs (Akshaya, 2025). Notably, improvements in input efficiency enabled U.S. producers to achieve 2018 wheat output levels using nearly 8 million fewer acres than in 1990, evidencing substantial gains in land-use efficiency and reduced environmental footprint through precision-based farming systems (Figure 11).

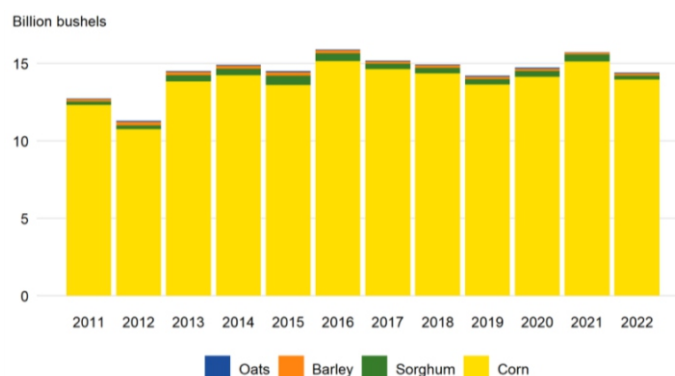


Figure 11: United States Feed Grain Production

Source: Akshaya, (2025), USDA, National Agricultural Statistics Service, 2022

- c. **Brazil:** Brazil's experience demonstrates the power of integrating digital agriculture with open data ecosystems. Satellite monitoring, machine learning models, and AI-driven yield prediction tools are now central to managing extensive sugarcane and soybean operations (Table 1). In a study, multispectral satellite imagery was collected over two growth seasons across two sites to estimate sugarcane (*Saccharum officinarum* L.) yield (tons per hectare) using various modelling techniques (Vasconcelos *et al.*, 2025). The analysis found that vegetation indices combined with accumulated precipitation during growth phases strongly predicted final yield. The study showed that Remote-sensed temporal vegetation data, when aligned with weather and agronomic context, can explain the majority of yield variability in large commercial fields, supporting yield prediction and management decisions. In addition, a study carried out on soybean yield forecasting in southern Brazil using machine learning and weather data (Schwalbert *et al.*, 2020) showed that including weather variables alongside spectral indices reduced mean absolute error (MAE), root mean square error (RMSE) and mean squared error (MSE) by 16%, 15% and 30% respectively. The study thus demonstrates that machine-learning based yield forecasting can provide useful in-season predictions for large-scale cropping systems. Integrating remote-sensing + weather + machine-learning significantly improves yield forecast accuracy, enabling near real-time decision-support.

Table 1: Precision Agriculture Case Studies from Brazil

Case Study	Objective	Data Inputs	Key Findings / Quantitative Results	Implications / Lessons for Developing Countries
Sugarcane Yield Prediction (Vasconcelos <i>et al.</i> , 2025)	To predict sugarcane yield using temporal satellite imagery and statistical/machine learning models.	Vegetation indices (EVI2, NDVI, GNDVI), cumulative rainfall, soil type, crop cycle.	<ul style="list-style-type: none"> - Best model (gamma regression) achieved $R^2 = 0.89$ for yield prediction. - Key predictors: vegetation indices + precipitation. - Demonstrated feasibility of satellite-driven yield monitoring at field scale. 	<ul style="list-style-type: none"> - Temporal satellite imagery can achieve high yield prediction accuracy. - Requires reliable weather & field data integration. - Shows potential for adaptation in large-scale crops like sugarcane, cassava, or maize in West Africa.
Soybean Yield Forecasting (Schwalbert <i>et al.</i> , 2020)	To forecast soybean yield using satellite indices and weather data with ML models.	Weather data (precipitation, temperature), vegetation indices, ground yield data.	<ul style="list-style-type: none"> - Adding weather variables reduced MAE, RMSE, and MSE by 16%, 15%, and 30%, respectively. - Best algorithm (LSTM) achieved MAE = 0.24 Mg/ha (mid-season) and 0.42 Mg/ha (early season). - Provided reliable early-season yield forecasts. 	<ul style="list-style-type: none"> - Machine-learning + weather + remote sensing synergy improves yield forecasts. - Early warnings enable better resource planning. - Demonstrates scalability and relevance for national food system monitoring.

Case Studies from Nigeria and African Countries

- a. **Maize Farm Production in Northern Nigeria:** A field study in the semi-arid region of Nigeria compared IoT-assisted fertilisation, recommended agronomic practice and conventional farmer methods (Mamman *et al.*, 2025). The IoT method improved yield over farmer practice, compared to the farmers' conventional practice, though it still trailed the recommended agronomic practice (yield: 4,963 kg ha⁻¹ under recommended practice). Profitability analysis showed that while the recommended practice achieved the highest net returns, the IoT approach offered promising economic advantages in more favourable agro-ecologies (Mamman *et al.*, 2025). This research study this recommend that precision agriculture technologies (IoT sensors, data-driven fertilisation) can deliver yield and economic benefits, but only when they are adapted to specific agro-ecological conditions and run alongside strong agronomic practices.
- b. **Drone Technology in South-East Nigeria:** A recent case study involving smallholder farmers in South-East Nigeria highlighted the transformative potential of drone technology in advancing

precision agriculture. The deployment of unmanned aerial systems for geospatial mapping, farm data acquisition, and soil fertility distribution analysis demonstrated superior performance compared to conventional field assessment methods. Moreover, the integration of input-spray drones equipped with Variable Rate Technology (VRT) resulted in an estimated 60% reduction in agricultural input wastage, underscoring the effectiveness of site-specific management practices in enhancing resource-use efficiency (Eni, 2022).

- c. **Maize productivity in Kwara State:** A study of soil heterogeneity across Asa and Moro LGAs in Kwara State collected 70 geo-referenced soil samples and applied GIS and geostatistical mapping to identify spatial variability in major soil properties (Wahab *et al.*, 2024). Results showed substantial differences: in Asa LGA moisture content was 46.74%, porosity 49%, organic carbon 1.6%, phosphorus 24.5 mg/kg but pH was low (5.4 in water). In Moro LGA bulk density was 1.29 g cm⁻³, and hydraulic conductivity 23.5 mm hr⁻¹ (Wahab *et al.*, 2024). The authors recommended tailored site-specific management: lime in high erosion zones, organic amendments where bulk density high, rather than uniform blanket input application. Consequently, implementing precision agriculture in Nigeria requires baseline spatial mapping (soil, topography, moisture) to inform prescription maps.
- d. **Scaled digital advisory and water-saving models in West Africa and East Africa:** Digital advisory platforms and precision irrigation hubs across Africa provide proof that affordable, scalable PA models are feasible. In Ghana, commercial and public e-extension services have reached hundreds of thousands of farmers with localized weather, market and input advice via SMS/voice. In East Africa, reviews of precision irrigation report water-use improvements often in the range of 30–50% (depending on method and crop), with drip and sensor-based irrigation repeatedly cited for substantial water savings and yield stability (Lakhiar *et al.*, 2024). Such outcomes indicate that when combined with local delivery models (SMS advisory, community hubs, subsidized equipment), precision approaches can be extended affordably to smallholders. Scalable digital advisory systems and affordable irrigation technologies can produce large resource-savings and climatic resilience benefits, but impact depends on uptake pathways.

Integration of Agroforestry in Climate-Smart Precision Agriculture: Precision Agroforestry

Agroforestry, the intentional integration of trees, crops, and sometimes livestock within the same agricultural landscape, represents a cornerstone of climate-smart agriculture (CSA) due to its multifunctional benefits for carbon sequestration, soil health, and livelihood resilience. When combined with precision agriculture (PA), agroforestry systems can evolve from traditional, experience-based practices into data-driven, adaptive production systems that optimize environmental and economic outcomes. Precision tools such as remote sensing, drones, and geographic information systems (GIS) enable real-time monitoring of tree-crop interactions, canopy cover, soil moisture, and carbon dynamics (Sangeetha *et al.*, 2024, Liang *et al.*, 2025). These technologies help determine optimal tree density, species mix, and spatial configuration, ensuring that agroforestry interventions complement rather than compete with crop productivity, in terms of light, water, and nutrient dynamics.

Integrating PA into agroforestry facilitates site-specific management of soil fertility and water resources. Variable Rate Technology (VRT) and Internet of Things (IoT) sensors can regulate irrigation and nutrient delivery based on microclimatic and soil heterogeneity data, thereby improving efficiency and reducing input waste. In Nigeria's Guinea and Derived Savannah zones, precision agroforestry can address issues of land degradation and erratic rainfall by promoting trees. In the Sudano-Sahelian region, where desertification and drought are major threats, sensor-based soil monitoring and drip irrigation supported by solar-powered IoT systems can optimize water use efficiency, increasing productivity. Similarly, in the humid forest zones of southern Nigeria, integrating cocoa and oil palm systems with precision-based nutrient and pest management can reduce chemical, improving both profitability and ecosystem health. Beyond productivity gains, precision agroforestry could contribute to climate mitigation and adaptation by sequestering carbon, restoring degraded lands, and regulating microclimates.

Ultimately, merging agroforestry with precision agriculture embodies the evolution of climate-smart agriculture (CSA) from a conceptual framework to a measurable and technology-enabled practice. It shifts focus from maximizing yield per hectare to optimizing ecosystem function per landscape, fostering a circular bioeconomy that sustains both productivity and environmental integrity. This synergy is pivotal for building

resilient food systems in Nigeria and across sub-Saharan Africa, where climate variability increasingly threatens rural livelihoods and food security.

Challenges and Opportunities in the Adoption of Precision Agriculture in Nigeria and Africa

While the promise of precision agriculture is compelling, its adoption in sub-Saharan Africa, and particularly in Nigeria, faces a complex web of systemic barriers. Understanding and addressing these challenges is central to transforming vision into practice.

- 1. Limited Access to Technology and Infrastructure:** Precision agriculture rests on connectivity, reliable energy, and access to equipment. Yet the World Bank (2024) reports that rural electrification in Nigeria remains below 40 % and internet penetration in farming communities is significantly lower. Without digital connectivity, remote sensing, real-time sensors and IoT systems cannot reliably operate. Smallholder farmers often lack capital to invest in GPS-enabled implements, drones or cloud-based data services. However, low-cost drones, open-source satellite data (e.g., from Sentinel or Landsat missions), and solar-powered IoT devices are making digital farming feasible even in low-resource contexts.
- 2. Data Gaps and Fragmented Information Systems:** Nigeria lacks a coordinated national repository for soil, crop, and weather data. What exists remains siloed among ministries, research institutes, and international agencies. Without harmonized data, predictive modeling becomes unreliable, and policy interventions are often misaligned with on-ground realities. As Onyango, *et al.*, (2021) emphasized, while precision technologies have been trialled in sub-Saharan Africa, they remain largely experimental. To close this gap, the Nigerian government and universities can establish a National Agricultural Data Observatory, a multi-institutional hub that aggregates soil fertility maps, weather data, and yield trends accessible to farmers, researchers, and extension agents alike.
- 3. Human Capacity and Knowledge Barriers:** Precision agriculture demands new skill sets, data analytics, geospatial science, agrorobotics and machine learning. Yet many Nigerian universities still emphasise conventional agronomy rather than digital agronomy. This is where Akungba University, its faculty and students can lead: by embedding modules in precision agriculture, forming partnerships with technology start-ups, and training students not simply to plant but to programme.
- 4. Financing and Incentives:** Access to capital remains a major constraint for smallholders and agritech entrepreneurs. The Central Bank's Anchor Borrowers Programme, though laudable, has yet to mainstream technology-based lending criteria. Financial models should reward precision-oriented practices, offering credit incentives for farmers who adopt smart irrigation, soil testing, or digital recordkeeping.
- 5. Socio-Cultural and Behavioural Barriers:** Adoption is not only technical but also cultural. Many smallholders trust experience over data. Bridging this behavioural gap requires trust-based extension models, where farmers see technology as an ally, not an intrusion. Here, demonstration farms, youth-led farmer schools, and digital storytelling can change narratives, proving that data-driven agriculture is not the future; it is the present redefined.

Solutions to the Challenges Militating against the Adoption of Precision Agriculture and Sustainable Transitions

Precision agriculture is a stepping stone to what I term agro-ecological intelligence, a system where we not only optimize productivity but regenerate ecosystems. Through data, we can monitor soil carbon sequestration, track biodiversity in farmlands, and measure water footprints, turning sustainability from a slogan into a measurable outcome. The integration of precision technologies with renewable energy, such as solar-powered irrigation, creates low-carbon production systems. Similarly, the application of AI for climate forecasting helps farmers make adaptive decisions, reducing vulnerability to drought and flood events. Ultimately, the goal is resilience, the capacity of agricultural systems to absorb shocks, recover, and thrive amid uncertainty.

The successful adoption of precision agriculture in developing countries depends on addressing structural barriers such as high capital costs, poor infrastructure, and limited digital literacy. Strengthening policy frameworks, promoting cooperative models, and improving access to technology financing can significantly accelerate adoption (Table 2, Figure 12). Collectively, these measures enhance productivity, sustainability, and resilience within smallholder-dominated agricultural systems (Saniga *et al.*, 2024).

Table 2: Challenges and proposed solutions to the adoption of Precision Agriculture in Nigeria.

S/N	Challenges	Proposed Solutions
1	High Initial Investment Costs	Introduce flexible financing mechanisms such as government subsidies, low-interest credit schemes, and public-private partnerships to reduce capital barriers. Leasing and "technology-as-a-service" models can make precision agriculture tools like drones, sensors, and GPS systems more accessible to smallholders (Popoola, 2024).
2	Weak Infrastructure Base	Strengthen rural infrastructure by prioritizing investment in electricity supply, mobile network expansion, and reliable Internet connectivity—critical enablers for real-time data transmission and precision farming analytics (Adekunle, 2013).
3	Limited Digital and Technical Capacity	Implement practical training and agricultural extension programs in local languages to enhance farmers' ability to interpret precision data and utilize mobile-based decision support platforms effectively (Popoola, 2024).
4	Small and Fragmented Land Holdings	Promote the formation of cooperative societies or farmer clusters that can collectively acquire, operate, and maintain advanced farming technologies, thereby improving cost efficiency and economies of scale (Eni, 2022).
5	Policy and Institutional Weaknesses	Establish coherent national policies and regulatory frameworks that foster AgTech innovation, ensure fair data governance, and attract private investment in digital agriculture systems (Adekunle, 2013).

Adapted from Saniga et al., (2024)

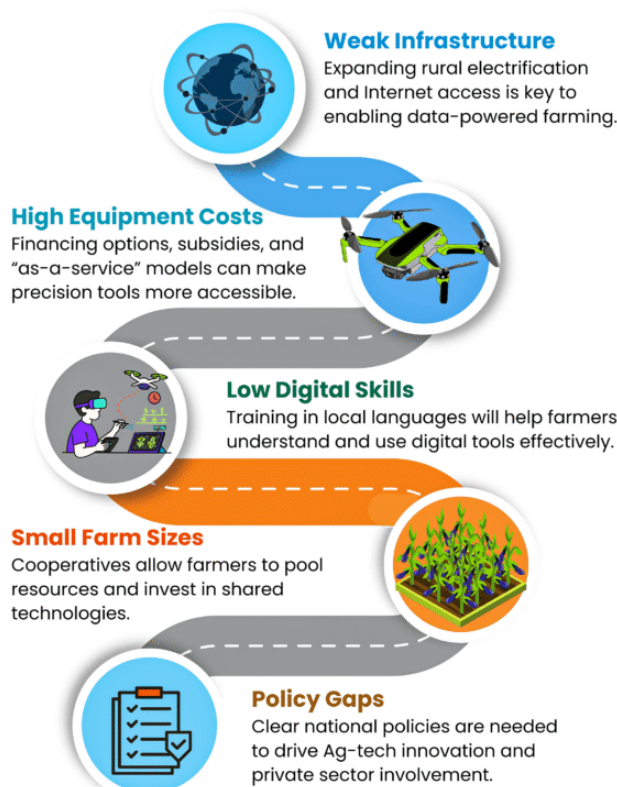


Figure 12: Solutions to Challenges of Precision Agriculture in Nigeria

Source: Quintessence Environmental Consult (2025)

Toward a National Framework for Precision Agriculture and Sustainable Food Systems

To institutionalize these ideas, I propose a Five-Point National Framework:

1. **Knowledge Infrastructure:** Establish Centers of Excellence for Precision Agriculture in each geopolitical zone.
2. **Data Integration:** Develop a National Open Agricultural Data Platform linked to NiMet and NASRDA datasets.
3. **Capacity Building:** Incorporate precision agriculture in tertiary curricula and train extension agents nationwide.
4. **Incentivized Innovation:** Support start-ups through innovation grants, hackathons, and venture partnerships.
5. **Monitoring and Evaluation:** Embed data-driven performance tracking into the national food security strategy, moving away from blanket metrics to spatially and temporally precise key performance indicators (KPIs).

This framework can position Nigeria as a regional leader in Africa's agricultural digital transition.

CONCLUSION

Let me close with a thought, “the next agricultural revolution will not be fought in the soil alone; it will be fought in the realm of data, knowledge, and coordination”. We stand at the dawn of what I call “The Era of Agricultural Enlightenment”, where every hectare speaks, every seed is counted, and every decision is informed. Precision agriculture offers us the tools to restore both productivity and ecological balance. Let us remember that technology alone will not feed Nigeria. What will feed our people is the intelligent union of science, policy, and human will.

Effective integration of precision agriculture in Nigeria requires coordinated action across multiple stakeholders. The government should prioritize investment in rural infrastructure while providing fiscal incentives such as tax reliefs and subsidies to attract private sector participation in technology deployment.

Academic and research institutions need to generate localized data and models tailored to Nigeria's varied soil conditions and cropping systems. Universities are the intellectual bedrock of national transformation. Precision agriculture presents an interdisciplinary frontier that merges natural sciences, computing and engineering. The days of academic silos are over. Precision agriculture requires agronomists who code, computer scientists who understand soil physics, economists modelling ecosystem services and data scientists fluent in field realities. This demands curriculum integration of geo-informatics, artificial intelligence, data ethics and agronomy. We need to research with relevance, teach with purpose and innovate with integrity. If we harness precision, we will harvest prosperity. Theory must meet the soil. Universities should create living labs: instrumented maize fields, monitored with sensors and drones, where students, farmers and researchers co-learn. Imagine Akungba University's Faculty of Agriculture managing a live maize plot monitored in real-time using cloud dashboards, an experiential classroom on steroids.

Meanwhile, private enterprises must focus on developing cost-effective, easy-to-use, and durable solutions such as mobile-based advisory and drone applications. Crucially, farmers should be actively involved in the design and implementation process to ensure that the technologies are contextually relevant, practical, and widely adopted.

Precision agriculture, alongside agroforestry, and the use of drought-tolerant crop varieties, plays a pivotal role in enhancing sustainability and climate adaptation. By leveraging data-driven technologies for site-specific management, precision agriculture optimizes resource use, minimizes waste, and strengthens resilience to climatic variability. Achieving long-term food security and sustainable development, however, requires collaborative triple helix action among governments/industry, researchers, and farmers to design supportive technologies, policies, and frameworks that advance climate-smart agricultural practices.

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THE PROACTIVE FARM: HOW ARTIFICIAL INTELLIGENCE IS REWRITING THE RULES OF AGRICULTURE FOR FOOD SECURITY AND SUSTAINABLE DEVELOPMENT

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ABSTRACT

The historical trajectory of agricultural development has been largely reactive, with farmers responding to pests, diseases, and weather events after they occur. Precision Agriculture introduced a more measured, data-informed approach but remained largely diagnostic. This paper posits that Artificial Intelligence (AI) is the pivotal technology catalyzing a fundamental paradigm shift from reactive and measured farming to truly proactive agricultural management. We define and elaborate on the concept of the "Proactive Farm" as an intelligent, closed-loop system that anticipates biotic and abiotic stresses, prescribes pre-emptive interventions, and autonomously optimizes resources for maximal productivity and minimal environmental impact. This new paradigm is built upon a sophisticated AI architecture integrating multi-modal perception, predictive intelligence, and prescriptive action. The paper elucidates this framework through three core, interconnected pillars: Anticipatory Agronomy, which leverages predictive models for hyper-local yield forecasting and disease pre-emption; Autonomous Action, utilizing robotics for targeted, timely intervention; and Adaptive Optimization of the entire agricultural value chain, from input logistics to consumer markets. While the potential for radically enhancing food security and sustainability is profound, the widespread adoption of this paradigm in the Nigerian and broader West African context faces a significant "Proactivity Gap". This gap is characterized by a trifecta of challenges: a data desert impeding model training, a skills chasm between agronomy and data science, and a critical infrastructure deficit. The paper concludes with a strategic, multi-stakeholder framework for Nigeria to bridge this gap, emphasizing the critical, vanguard role of academic institutions in leading the development of a homegrown, context-aware Agri-AI ecosystem. This involves pioneering new interdisciplinary curricula, establishing "Proactive Ag" living labs, and championing the creation of national agricultural data assets.

Keywords: Artificial Intelligence, Proactive Agriculture, Precision Agriculture, Food Security, Sustainable Development, Predictive Analytics, Autonomous Systems, Machine Learning, Agricultural Robotics, Digital Agriculture.

1. INTRODUCTION: THE IMPERATIVE FOR A PARADIGM SHIFT

The global agricultural sector stands at a critical juncture, caught in a vice of compounding pressures. It must nourish a population projected to reach 9.7 billion by 2050, a task complicated by shifting dietary preferences towards resource-intensive proteins and processed foods (United Nations, 2022). Concurrently, it must bolster its resilience against the escalating, tangible impacts of climate change—erratic rainfall, prolonged droughts, and novel pest and disease pressures (IPCC, 2022). All this must be achieved within the planetary boundaries of finite resources like arable land and freshwater, while remaining economically viable for billions of stakeholders along the value chain (Rockström et al., 2009).

For centuries, the success of a farm has been predominantly determined by the farmer's skill in reacting—to an outbreak of fall armyworm, to a sudden drought, or to a glut in the market. This reactive model, honed over generations, is fundamentally vulnerable in the face of 21st-century challenges. It is a paradigm of loss and

damage control. The advent of Precision Agriculture (PA) promised a revolution, moving from blanket treatments to spatially and temporally targeted interventions based on GPS and sensor data (Gebbers & Adamchuk, 2010). Yet, for many, PA has remained a sophisticated diagnostic tool, providing a high-resolution picture of *what is* or a detailed history of *what has been*. It tells a farmer where a problem has occurred, but seldom predicts where the next one will strike.

The next—and most critical—evolutionary leap is towards a proactive model. A proactive farm does not simply respond to a blight; it anticipates its pathogenic potential and prevents its establishment. It does not merely measure soil moisture deficit; it predicts the onset of water stress and irrigates pre-emptively to maintain optimal growth conditions, thereby conserving water and protecting yield. This paper argues that Artificial Intelligence (AI), particularly machine learning (ML) and its sub-fields, is the essential engine of this transition. AI moves us beyond merely observing the farm to orchestrating it, creating a system that is predictive, pre-emptive, and perpetually self-optimizing.

The primary objective of this lead paper is to articulate a comprehensive vision of the "Proactive Farm" as the new foundational paradigm for achieving food and nutrition security and genuine sustainable development. To this end, the paper is structured as follows: First, we deconstruct the core architectural stack—the "digital nervous system"—that makes proactivity technologically possible. Second, we demonstrate the application of this architecture across three transformative pillars of the agricultural value chain. Third, we provide a clear-eyed diagnosis of the "Proactivity Gap" that hinders the adoption of this paradigm in Nigeria, identifying key barriers. Finally, we propose a concrete, actionable strategic framework for Nigeria to bridge this gap, positioning the nation not as a consumer, but as a co-creator of its agricultural future.

2. The Architectural Stack of the Proactive Farm

The Proactive Farm is not defined by any single piece of hardware or software but by an integrated, intelligent system. Its operational core is a continuous, closed-loop cycle of perception, prediction, and prescription. This stack functions as the farm's central nervous system.

2.1. The Perception Layer: The Sensory Tapestry

This foundational layer involves a dense, heterogeneous network of sensors that provides a real-time, high-fidelity, multi-dimensional view of the agro-ecosystem. It moves beyond periodic, manual sampling to persistent, automated monitoring.

- **Macro-Scale Remote Sensing:** Satellite constellations (e.g., Sentinel, Planet) provide daily, multispectral and synthetic-aperture radar (SAR) imagery, enabling the monitoring of vegetation indices (NDVI), soil moisture, and biomass changes across vast geographies.
- **Micro-Scale Proximal Sensing:** Unmanned Aerial Vehicles (UAVs or drones) equipped with hyperspectral and thermal cameras capture centimetre-resolution data, identifying early-stage water stress, nutrient deficiencies, or pest hotspots invisible to the naked eye.
- **In-Situ IoT Sensor Networks:** A mesh of in-ground sensors continuously logs soil moisture, temperature, pH, and NPK (Nitrogen, Phosphorus, Potassium) levels. Microclimate stations track hyper-local air temperature, humidity, wind speed, and solar radiation.
- **Bio-Sensing and Acoustic Monitoring:** Emerging technologies include plant-wearable sensors that monitor sap flow and xylem pressure, and acoustic sensors placed in fields that detect the specific chewing sounds of target pests like locusts or fall armyworm, providing direct, real-time biological threat alerts (Mankin et al., 2011).

2.2. The Predictive Intelligence Layer: The Anticipatory Cortex

This is the cognitive core where Machine Learning (ML) models transform the torrent of raw, unstructured sensor data into actionable foresight. It is here that proactivity is born.

- **Machine Learning for Pattern Recognition:** Supervised learning algorithms, particularly Convolutional Neural Networks (CNNs), are trained on vast, labeled datasets of imagery to perform tasks like weed species classification, disease lesion identification, and fruit counting with superhuman accuracy (Kamilaris & Prenafeta-Boldú, 2018).
- **Predictive Analytics and Time-Series Forecasting:** More complex models, such as Long Short-Term

Memory (LSTM) networks, analyze sequential data. They fuse historical yield data, real-time sensor readings, and short-to-medium-range weather forecasts to predict future states. For instance, they can forecast final yield with high spatial accuracy weeks before harvest (Khaki & Wang, 2019) or model the probabilistic risk of a fungal disease outbreak based on a confluence of factors: leaf wetness duration, relative humidity, ambient temperature, and known host plant susceptibility.

2.3. The Prescriptive Action Layer: The Autonomous Effector System

Foresight without the capacity for action is merely academic. This critical layer translates algorithmic predictions and insights into concrete, timely, and optimized interventions, closing the loop.

- **Prescriptive Analytics and Decision Support:** The system evolves from flagging a problem to recommending a specific, optimized solution. It does not just say, "There is a 70% probability of powdery mildew in Zone B-3." It prescribes: "Apply 150 ml/hectare of fungicide X to Zone B-3 within the next 48 hours for optimal efficacy and minimal environmental impact, considering a 30% chance of rain in 60 hours."
- **Autonomous Actuation and Robotics:** These digital prescriptions are executed with robotic precision and endurance. Autonomous ground rovers or drones apply the prescribed fungicide only to Zone B-3. Smart irrigation systems deliver the exact water volume predicted to prevent stress, drop by drop. Robotic harvesters with computer vision identify and pick only ripe produce, operating day and night. This seamless integration of intelligence and mechanics creates a self-optimizing, proactive agricultural organism.

3. The Pillars of Proactivity: Transformative Applications

The architectural stack described above enables a suite of transformative capabilities, which can be categorized into three interconnected pillars that span the agricultural lifecycle.

3.1. Pillar I: Anticipatory Agronomy

This pillar represents the modernization of core agronomic science, shifting its ethos from treatment to prevention, from cure to immunity.

- **Pre-emptive Pest and Disease Management:** Instead of calendar-based spraying, ML models fuse satellite-derived canopy health data, hyper-local weather station information, and pest life-cycle models to generate dynamic risk maps. A system can alert a yam farmer of a high probability of tuber rot in a specific, poorly-drained section of a field *days before* any rot is visible. This enables a targeted, preventative application of biopesticides or soil amendments, using far less chemical input, reducing costs, and preventing yield loss proactively.
- **Predictive Nutrient Management:** AI models move beyond soil testing to predict the plant's nutrient uptake patterns throughout its phenological stages. By modeling the interaction between soil chemistry, weather, and plant physiology, these systems can generate variable-rate fertilizer prescriptions that meet the crop's *future* nutritional demands, thereby minimizing nitrogen leaching into waterways and maximizing nutrient use efficiency. This is a proactive strike against both pollution and input waste.

3.2. Pillar II: Autonomous Action

Proactivity often requires a capacity for immediate, precise, and tireless intervention that surpasses the logistical and physical limitations of human labour.

- **Robotic Weeding and Mechanical Management:** Autonomous robots, using real-time computer vision, can distinguish between crops and weeds based on leaf shape, texture, and colour. They can then mechanically eliminate the weed through micro-spraying, laser ablation, or physical removal. This provides a 24/7 proactive defense against weed competition, reducing or eliminating herbicide use and its associated environmental and health impacts (Slaughter et al., 2008).
- **Selective Harvesting and Quality Control:** AI-powered harvesters identify and pick only ripe produce based on colour, size, and even softness (using tactile sensors), dramatically reducing waste from damaged or unripe goods. This proactively addresses the significant post-harvest losses that chronically undermine food security, especially for perishable fruits and vegetables, while ensuring optimal quality for the market.

3.3. Pillar III: Adaptive Optimization

The intelligence of the Proactive Farm extends beyond the field gate to optimize the entire socio-technical system of the food value chain.

- **Predictive Supply Chains and Logistics:** AI models can forecast the post-harvest quality decay and optimal delivery windows for perishable goods. If a model predicts that a truckload of tomatoes will spoil within four days if sent to a distant market, the system can *proactively* reroute it to a closer processing plant or fresh market, optimizing for freshness and minimizing waste (FAO, 2019). This is a critical application for reducing the estimated 30-40% of food lost in sub-Saharan Africa post-harvest.
- **Dynamic Resource Orchestration and Fintech:** At a systems level, AI can proactively manage shared resources. For a farming cooperative, it could predict water demand across all fields and optimize irrigation schedules to prevent conflict and maximize collective benefit. Furthermore, by analyzing satellite data and farm management records, AI can create digital footprints for smallholder farmers, enabling financial institutions to proactively offer tailored credit and insurance products, de-risking agricultural investment.

4. Diagnosing the Proactivity Gap: The Nigerian Context

The vision of the Proactive Farm is technologically feasible and is being implemented in parts of the Global North. However, its realization in Nigeria, and much of West Africa, faces a significant implementation gap—a "Proactivity Gap"—stemming from three fundamental, interconnected barriers.

4.1. The Data Desert: The Fuel for Intelligence is Missing

AI models, particularly deep learning models, are notoriously data-hungry. Their performance and reliability are directly correlated to the volume, quality, and relevance of their training data. The most profound barrier is the absence of large, curated, and labeled datasets for indigenous African crops (cassava, yam, cowpea), local soil types, and endemic pests and diseases, all within their specific agro-ecological contexts. An AI model for leaf disease detection trained on images of wheat from the American Midwest will fail catastrophically when presented with images of cassava infested with green mites in Ondo State. This "data desert" means we lack the fundamental fuel to train the AI engines for our own agricultural reality.

4.2. The Skills Chasm: A Missing Generation of Architects

The design, development, deployment, and maintenance of Proactive Farms require a new, hybrid breed of professional: the "Agri-AI Specialist." This individual must be fluent in the language of agronomy—understanding plant physiology, soil science, and pest dynamics—and equally competent in data engineering, software development, and ML ops. The current siloing of these disciplines in Nigerian universities and the labour market represents a critical chasm. We have brilliant agronomists and talented software developers, but few who can bridge the gap to translate complex agricultural problems into robust, AI-solvable frameworks.

4.3. The Infrastructure Deficit: A Fragile Circulatory System

The continuous, high-volume data flow from the perception layer and the real-time command-and-control required for the prescriptive action layer are impossible without persistent, reliable electrical power and robust, low-latency internet connectivity (e.g., 4G/5G). The state of rural infrastructure in many parts of Nigeria actively inhibits proactivity. Intermittent power and poor network coverage create data blackouts and operational paralysis, rendering a cloud-dependent, real-time AI system inoperable. This deficit effectively locks out the very heartland of Nigerian agriculture—the smallholder farmers in rural communities—from this technological revolution.

5. A Strategic Framework for a Proactive Nigerian Agriculture

Bridging the Proactivity Gap is not a task for a single entity but a national project requiring a coordinated, multi-stakeholder strategy. The following framework outlines the roles and responsibilities for key actors.

5.1. For Academia: The Vanguard of the Proactivity Revolution

Nigerian universities, particularly institutions like Adekunle Ajasin University with its strong agricultural faculty, must be the epicenters and ethical guardians of this transition.

- Establish Interdisciplinary "Proactive Ag Labs": Create physical and virtual hubs that forcibly break down disciplinary silos. These labs should co-locate faculty and students from Agriculture, Computer Science, Engineering, and Environmental Science to work on common, challenge-led projects (e.g., "Developing an AI-powered early warning system for Cassava Brown Streak Disease").
- Pioneer New Academic Curricula: Urgently develop and accredit new undergraduate and postgraduate programs such as B.Sc./M.Sc. in "Agricultural Data Science" or "AI for Sustainable Food Systems." These programs should provide a dual foundation in core agricultural principles and advanced computational skills, producing the much-needed Agri-AI specialists.
- Champion the Creation of National Agricultural Data Repositories: Lead a concerted, nationally-funded effort to collect, clean, label, and curate open-source datasets of Nigerian crops, soils, and pests. This is a public good of strategic importance for national food security and must be treated as such.

5.2. For Government and Industry: Creating the Enabling Environment

- Policy-Driven Innovation and Incentives: The government should fund challenge grants and innovation prizes for startups and researchers focused on developing frugal, context-aware, and scalable AI solutions for smallholder challenges. Tax incentives could be offered to agribusinesses that adopt and validate these technologies.
- Strategic Investment in Enabling Infrastructure: Public and private investment must treat rural digital and power infrastructure with the same strategic urgency as roads and ports. Expanding and stabilizing the national grid and accelerating the deployment of mobile broadband in rural areas are not ICT projects; they are 21st-century agricultural projects.
- Foster Public-Private Data Trusts: Encourage collaboration between government agencies, research institutions, and agribusiness companies to build shared, ethically governed data assets. These trusts would manage data access rights, ensure farmer data sovereignty, and facilitate secure data sharing for the public good.

6. CONCLUSION

The transition from a reactive to a proactive model of agriculture represents the most significant opportunity in a generation to simultaneously address the intertwined challenges of food security, environmental sustainability, and rural economic development. Artificial Intelligence, with its capabilities in prediction, pattern recognition, and optimization, is the indispensable catalyst for this transition. It enables a future where farms are not passive subjects of environmental and economic forces but active, intelligent managers of their own productivity, resilience, and ecological footprint.

The journey to the Proactive Farm is, however, as much a socio-technical challenge as it is a technological one. For Nigeria, it is a national project in capacity building, infrastructure development, and educational reform. The barriers—the data desert, the skills chasm, the infrastructure deficit—are significant, but they are not insurmountable. They demand a deliberate, strategic, and collaborative response. The choice facing Nigeria is not *if* this agricultural transformation will occur, but *who* will lead it and on whose terms. By taking proactive, concerted, and visionary steps today to build our data assets, nurture our human capital, and strengthen our digital foundations, we can ensure that Nigeria becomes a pioneer and architect—and not merely a passenger or consumer—in the dynamic and intelligent future of global agriculture. The time to plant the seeds of the Proactive Farm is now.

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WHAT FOOD SECURITY IS TO SUSTAINABLE DEVELOPMENT: THE ROLE OF EDUCATION, CAPACITY BUILDING AND INSTITUTIONAL REFORM IN NIGERIA

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1.1. Introduction

Food is a basic necessity of life. Its importance at the household level is obvious, since it is a basic means of sustenance (Olorunfemi and Ajibefun 2007, Aderinola, Olorunfemi and Ajibefun, 2006).

The followings submission about food can be given:

- i. Food is rated as the most basic of all human needs.
- ii. Man needs food for life's sustenance, prevention of sickness and in providing energy for the normal psychological activities of the body, including the normal state of mind.
- iii. The need for food security becomes pertinent, as it eventually affects a nation's productivity and growth (Olorunfemi 2011, 2013).

1.2. What Is Food Poverty/Insecurity?

Food poverty is the state of being without reliable access to food (Olorunfemi, 2007). Many people live every day with hunger or food insecurity as their constant companion. The United Nation Sustainable Development Goals are of the initiatives aimed at achieving food security in the World. Figure 1 shows that food insecurity leads to sickness, non-productive life and various growth challenges. The food insecurity in Nigeria is a recurrent and double-digit problem.



Figure 1: Vicious Circle of Food Insecurity
Source: Olorunfemi (2006)

From Figure 1, there is circular constellation of forces and this means that; (i) without food security, poverty deepens, inequality widens, and social unrest can increase. (ii) malnutrition and hunger reduce physical and mental capacity, affecting school performance, workforce efficiency, and innovation all of which are vital for development, (ii) a hungry population cannot sustain growth or contribute meaningfully to national progress and (iv) food insecurity often leads to higher import bills, straining foreign exchange reserves and weakening economic growth.

1.3. WHAT IS FOOD SECURITY?

Food is a cornerstone of sustainable development. Food security is a complete reduction in starvation and hunger. Food security has been conceptualized in different but complimentary ways. The World Bank (1991) defined it as a condition where everyone has access to sufficient food to live a healthy and productive life. The Africa Bureau of the United States Agency for International Development (USAID, 1999); Chimaobi Valentine Okolo and Chizoba Obidigbo (2015) and Kainga, Ekunwe And Ogueri, (2016) defined it as a situation where everyone has physical, social, and economic access to sufficient food to meet their dietary needs and stay healthy. According to the food and Agricultural Organization (FAO, 2006), food security exists when all people at all times have physical, social, and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. From the above perspectives, food security entails a production of diverse, safe, and nutritious food that can sustain the consumption demand of the population. It also requires that availability of food is backed by the consumers purchasing power to acquire desired food varieties that promote their well-being and wellness. Meeting this goal in the face of myriad development challenges confronting Nigeria remains a daunting exercise

Hunger is ravaging the land. Worse, there is no end in sight as the forecast by the FAO (2022) strongly projects that Nigeria's efforts to achieve zero hunger by 2030 are being seriously undermined. At the 2018 World Food Day, the Rome-based agency warned of the dangers ahead, citing climate change and the ethno- religious conflicts plaguing the country.

1.4. Some Facts of the Nigeria Economy

- i. Several reports showed that many Nigerians are food insecure. These reports include FAO (2024), that showed that 26.5 million are vulnerable and UN report put the number to be above 33million
- ii. Child stunting remains very high. The child stunting was put at 37%, making Nigeria one of the countries with the highest absolute burden of stunting.

Table 1: Level of Children Malnutrition

Types of Malnutrition	Nigeria	West and Central Africa	World
Stunting (Too short to age)	37%	36%	25%
Underweight (weight too low for age)	29%	23%	15%
Wasting (weight too low to height)	18%	11%	8%

- iii. Agriculture continues to be a major employer and drive for GDP. The sector employs a large share of the workforce (estimates often cite a majority of rural labourers and a high share of smallholder farmers).
- iv. Extreme poverty has risen sharply: World Bank analysis indicates the share of Nigerians living under the international poverty line rose to 41.8% in 2022 to 2023.
- v. Population scale and demographic pressure: Nigeria's population exceeds 230 million and is among the fastest growing globally — this rapid growth increases demand for food and services.

Table 2: Estimated Population in Nigeria

Year	Population	Yearly % Change
2025	237,527,782	2.08%
2024	232,679,478	2.1%
2023	227,882,945	2.12%
2022	223,150,896	2.12%
2021	-	-
2020	213,996,181	2.33%

Source: Worldometer (2025)

As a result of all these facts about Nigeria economy there is need to look at the problem confronting agriculture, since it is the saving 'grace' for economy challenges. This is so because a stable food supply helps control inflation and ensures price stability.

The Protracted Agricultural Problem: Causes and Effects in Nigeria

i. Subsidy reform and inflation

Policy changes (subsidy reforms) and macro shocks contributed to high inflation and rising food prices. The

result was reduced purchasing power for many households, increasing acute food insecurity. Several analyses link economic policy shifts in 2023–2024 to a deterioration in household food access.

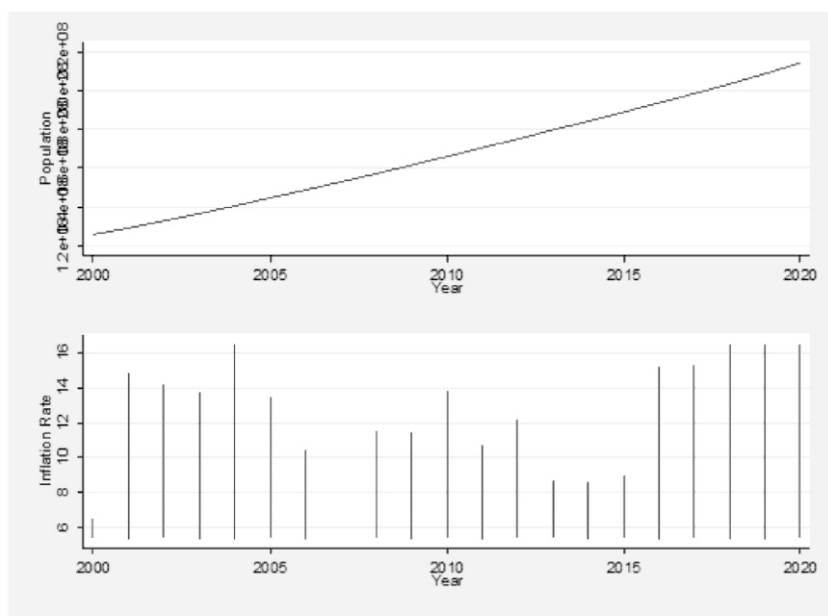


Figure 2: Population Growth and Inflation in Nigeria

Figure 2. shows that theoretically when there is rising inflation and growing population, there will be macroeconomic issues that will eventually affect food crisis that may happen in any country and this is the situation in Nigeria. Figure 3 on the hand shows that as population is increasing, food production is coming is coming down. Figure 4 equally shows similar problems of macroeconomics issues.

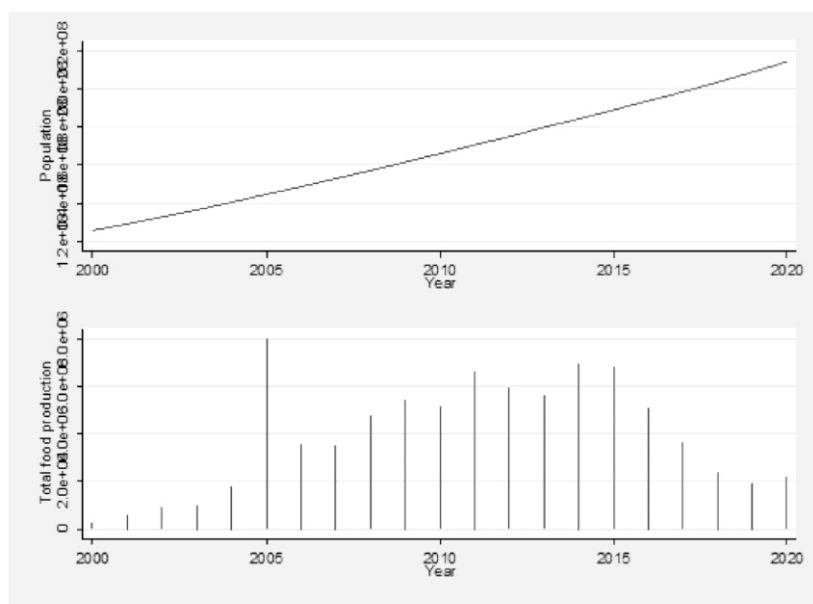


Figure 3: Population Growth and Food Production in Nigeria

ii. Conflict, displacement and climate shocks

Insecurity in parts of northern Nigeria forces farmers off their lands and disrupts planting cycles; floods have destroyed large areas of cropland (reports mention millions of hectares affected), further reduced local supply and raised prices.

iii. Structural weaknesses in agriculture and value chains

Although agriculture contributes a substantial share to GDP and employs many Nigerians, productivity remains low for many staple crops, post-harvest losses are high, access to finance and mechanisation is

limited, and value-chain processing is underdeveloped. Many smallholders lack access to improved seeds, fertilisers, extension and storage.

iv. Human-capital and nutrition deficits

High rates of child stunting and acute malnutrition indicate both food-quantity and food-quality problems. Poor maternal nutrition, low dietary diversity, and inadequate access to health and WASH services perpetuate malnutrition.

Can Sustainable Economic Development Be Achieved in the Midst of All the Challenges Facing Agriculture in Nigeria with What It Is Set Out to Achieve?

Sustainable economic development in Nigeria is set out to:

- i. Achieve inclusive growth (benefiting all citizens)
- ii. Reduce poverty and inequality
- iii. Protect the environment for future generations
- iv. Diversify the economy and ensure long-term stability
- v. Promote social justice and good governance

Understanding the Interrelated Dimension of Food Security:

To be able to attain sustainable economic development in Nigeria, there is the need to understand the interrelated dimension of food security. According to Olorunfemi et al (2013), the food security problem can be simplified by focusing on three distinct, but inter-related dimensions which include food availability, food access, and food utilization.

According to the USAID (1999) definition:

- i. Food availability is achieved when sufficient quantities of food are consistently available to all individuals within a country. Such food can be supplied through household production, other domestic output, commercial imports, or food assistance;
- ii. Food demand access is ensured when households and all individuals within them have adequate resources to obtain appropriate foods for a nutritious diet. Access depends on income available to the household, on the distribution of income within the household and on the price of food and,
- iii. Food utilization is the proper biological use of food, requiring a diet providing sufficient energy and essential nutrients. Effective food utilization depends in large measure on knowledge of food storage and processing techniques, basic principles of nutrition and proper child care, and illness management.

Olorunfemi (2011) notes that food intake sources are less diversified and that carbohydrate food dominates the diets in the three states of the south western Nigeria, which the study covered. The average energy intake in all the three States was about 2371.32 kilocalories per capita per day, which is marginally above food energy adequacy. However, the average intake for proteinous food in all the studied states was lower than the threshold, implying an unstable food security situation. Notwithstanding the finding on food situation from each of the states, a high percentage of the surveyed respondents claimed they were fully food-secured when asked the extent to which they were food-secured. To them it is 'kinu sa ti kun' as they say it in Yoruba. This might be so because the respondents, lack adequate education, as they did not know the adequacy of both calories and protein intake per capita per day.

3.0. Education, Capacity Building and Institution Reform as a Way to Go

3.1 Education

Education increases the ability of households to access information, adopt improved agricultural practices, diversify livelihoods and manage finances. Nutrition education (maternal and community levels) improves complementary feeding and care practices, reducing stunting. Integrating agricultural curricula and vocational training into formal and non-formal education (including youth programmes) creates pathways out of poverty and into productive agribusiness. Available evidence shows that extension and farmer field schools increase adoption of improved inputs and techniques when combined with credit and market access.

3.2 Capacity building

Capacity building strengthens technical skills (soil management, pest control, climate-smart agriculture), business skills (record keeping, aggregation, value-addition), and organisational skills (cooperative

management, contract enforcement). At the local government level, capacity building is needed for planning, budgeting for agriculture and nutrition, and delivering social protection and disaster response.

3.3 Institutional transformation

Institutional reformation is needed to: (a) put together agricultural, nutrition and social-protection policies; (b) improve public spending quality and targeting; (c) streamline land policies, market regulation and trade; (d) decentralise service delivery so subnational governments can respond quickly to local shocks; and (e) strengthen monitoring, evaluation and early-warning systems. It must be noted that without institutional reform, investment effort in education and capacity building will be unsustainable as it will not last.

CONCLUSION

Without food security, Nigeria cannot achieve sustainable development because hunger and malnutrition weaken human capital, increase poverty, destabilize the economy, and threaten peace and the environment. Therefore, ensuring food security is both a goal and a precondition for sustainable development in Nigeria.

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PERCEIVED EFFECT OF HYBRID EXTENSION SERVICES ON AGRICULTURAL EXTENSION WORKERS' PRODUCTIVITY IN ONDO STATE, NIGERIA

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ABSTRACT

This study investigated the perceived effect of hybrid extension services on the productivity of agricultural extension workers in Ondo State, Nigeria. A complete enumeration was adopted, covering all 50 extension workers in the Agricultural Development Programme (ADP). Data were collected using a well-structured and validated questionnaire and analyzed with descriptive (frequency count, percentage, mean, and standard deviation) and inferential (Linear regression) statistics. Findings from the study showed that the workforce was predominantly female (56%), with a mean age of 47 years and an average of 18 years of experience. Results also revealed that the most used hybrid service components included integrated communication platforms such as WhatsApp platforms ($x=2.5$), farmers' contact/call centres ($x=2.36$) and hybrid farmer field schools ($x=2.32$). Hybrid services were mainly applied in crop management ($x=3.48$), pests and disease control ($x=3.32$), post-harvest handling ($x=3.30$), and technology adoption ($x=3.26$). The major constraints to the use of hybrid extension services included limited ICT devices, high digital service costs, and low digital literacy. Moreover, the extent of hybrid extension service delivery had a significant and positive influence on the extension workers' productivity ($B = 0.460$; $t = 8.507$; $p < 0.05$). The study concludes that hybrid extension services enhance productivity but require improved ICT infrastructure, digital skills training, and supportive policies for sustainability. It was therefore recommended that hybrid extension services should be positioned as complementary rather than a substitute for traditional extension delivery.

Keywords: Hybrid, Extension Services, Productivity, WhatsApp, E-training

INTRODUCTION

Agricultural extension services remain crucial for transferring knowledge and innovations to farmers. Hybrid extension services, which combine traditional face-to-face outreach with digital tools and platforms, have emerged as an innovative solution (Aker, 2022). Hybrid extension services, which integrate face-to-face methods with digital platforms, have emerged as a promising solution to strengthen extension delivery. Similarly, Ajani (2022) posited that hybrid extension improves information delivery, reduces costs, and expands farmers' access to advisory services. Moreover, according to Ogunniyi and Sulaiman (2022), they observed that hybrid models bridge the gap between extension agents and farmers by promoting inclusiveness and improving productivity. Zulu and Tschirley (2022) also avowed that combining digital tools with traditional methods enhances service efficiency and fosters stronger interaction between extension agents and farmers. However, the traditional agricultural extension system is often criticized for being rigid and top-down with several limitations (source). These include inadequate funding, lack of qualified personnel, poor logistics, and insufficient farmer participation (source). Furthermore, the system had been reported to struggle with weak linkages to research and other relevant institutions, limited access to technology, and a lack of responsiveness to diverse farmer needs (Olawoye, Ajayi and Kolawole, 2022). Therefore, this study examined how agricultural extension workers in Ondo State perceive the effect of hybrid extension services on their productivity, focusing on socio-economic characteristics, major components of hybrid extension services and level of use, **extension services carried out with hybrid extension and** extent of service delivery, perceived effect on extension workers' productivity and constraints to the use of hybrid extension services. The study hypothesized that the extent of hybrid extension service delivery will not influence productivity.

LITERATURE REVIEW

Agricultural extension services have long been recognized as a vital mechanism for transferring scientific research and new technologies to farmers to improve agricultural productivity, food security, and rural livelihoods (Food and Agriculture Organization, 2022). In Nigeria, where agriculture remains a key economic sector, effective extension services are essential for bridging knowledge gaps, encouraging adoption of innovations, and achieving national food security goals (Ogunniyi and Sulaiman, 2022).

Traditionally, extension services in Nigeria rely on in-person interactions such as farm visits, community meetings, and demonstration plots. While effective, this model has proven insufficient to meet the demands

of modern agriculture due to high farmer-to-agent ratios, poor infrastructure, and limited funding (Abdullahi, Bello and Musa 2021). These challenges are compounded by the vastness and remoteness of many farming communities, making it difficult for extension workers to maintain consistent contact. Against this backdrop, the integration of information and communication technologies (ICTs) into extension delivery often termed hybrid extension services has emerged as a practical innovation to complement physical outreach and expand service delivery (Aker, 2021). This literature review explores the concept, components, perceived benefits, and constraints of hybrid extension services, with a focus on their influence on the productivity of extension workers. However, the conventional extension system characterized by face-to-face visits, demonstration farms, and group meetings faces multiple constraints such as poor funding, high extension agent-to-farmer ratios, limited logistics, and infrastructural deficiencies (Abdullahi and Musa., 2021; Ajani, 2022). These challenges have necessitated innovative approaches to extension delivery, especially the integration of modern information and communication technologies (ICTs). The term “hybrid extension services” broadly refers to the blending of conventional face-to-face advisory methods with modern ICT tools and digital communication channels (Ajani, 2022). A hybrid extension system typically integrates various tools and platforms. The goal is to harness the strengths of both approaches to overcome limitations associated with each when used in isolation. While conventional methods ensure personal contact, demonstration of practices, and trust-building, ICT methods provide speed, wider coverage, and facilitate cost-effective service delivery (Ayoola, Musa and Ayanwuyi, 2023). Globally, hybrid extension systems gained traction as mobile technology penetration expanded across Africa and Asia. Aker (2021) notes that the use of mobile phones for agricultural advice became more prominent in the early 2000s when governments and development partners began testing SMS-based weather updates, input price alerts, and pest outbreak warnings for farmers. According to Akpan and Yusuf (2023) the commonly used components include:

- a) Conventional/Physical methods (face-to-face) methods: On-farm demonstrations, Farmer field schools, Community meetings. Advisory farm visits and Village-level workshops.
- b) ICT-based methods: Mobile phone calls/SMS (including bulk messages for pest outbreaks), Interactive Voice Response (IVR) systems,

Community radio programs in local languages, Agricultural TV segments, WhatsApp and Telegram groups for farmer clusters, E-learning modules for continuous training, and online video tutorials. In line with this, Ayoola, Musa and Ayanwuyi (2024) noted that these components work best when carefully aligned. For example, an extension agent may visit a community physically once a month but send weekly updates via WhatsApp or radio programs in the local language. Community radio programs in local languages have also proven effective for reaching low-literacy farmers who may not use smartphones (Ajani, 2022).

MATERIALS AND METHODS

The study was conducted in Ondo State, Nigeria. The population comprised all 50 extension workers under the state Agricultural Development Programme, hence a complete enumeration was adopted. Primary data were collected through a well-structured and validated questionnaire, while secondary information was obtained from relevant literature. Descriptive statistics (frequency count, percentage, mean, and standard deviation) were used to analyze the stated objectives, while inferential statistics (linear regression) were applied to test the hypothesis of the study.

RESULTS AND DISCUSSION

Selected socio-economic characteristics of the extension workers

The workforce was predominantly female (56%), with a mean age of 47 years and an average of 18 years of experience, indicating a mature but less digitally flexible population. Most respondents (70%) had a tertiary education, suggesting potential for digital skills adoption with appropriate training. This finding aligns with Sani, Mamman, and Adejare (2025), who reported higher educational attainment among extension workers in Northwestern Nigeria, which often translates to greater adaptability and openness to new methods of service delivery. The implication is that while age and long years of service may limit quick adaptation to digital tools, the high level of formal education provides a strong foundation for capacity building in hybrid extension services.

Major components of hybrid services and level of use

Results in Table 2 showed that the Integrated Communication Platform, including WhatsApp ($x=2.5$), farmers' contact/ call centres ($x=2.36$) and hybrid Farmer Field School ($x=2.32$) were the hybrid extension components with high use among the extension workers. The findings agree with Devanand and Kamala (2019) who had earlier reported that WhatsApp groups were the most convenient and suitable way of

communicating innovations to farmers. This suggests that these hybrid extension tools should be leveraged to ensure sustainable agricultural extension service delivery among the extension workers.

Table 1: Distribution of the Respondents Based on Their Selected Socioeconomic Characteristics

Variables	Freq	%	Mean	SD
Sex				
Male	22	44		
Female	28	56		
Age				
39-44	14	28		
45-50	22	44	47	4.31
51 and above	14	28		
Level of Educational Attainment				
No formal Education	-	-		
Adult Literacy	-	-		
Primary Education	-	-		
Secondary Education	-	-		
Tertiary Education	35	70		
Others	15	30		
Years of Experience				
9-16	19	38		
17-23	29	58	18	4.142
24 and above	2	4		
How often do you provide extension services to farmers?				
Daily	2	4		
Weekly	25	50		
Monthly	14	28		
Occasionally	9	18		

Source: Field Survey, 2025

Table 2: Major Components of Hybrid Extension Services and their level of use

Variables	Yes	Low	Moderate	High	Mean
farmers contact/Call centers	50	9	14	27	2.36
Farmer Field School (Online or Hybrid)	50	2	30	18	2.32
Integrated Communication Platform (WhatsApp or other messaging apps)	50	-	25	25	2.5
Social media platforms (e.g., Facebook, Instagram, Twitter)	49	6	27	16	2.22
Virtual knowledge network	50	4	31	15	2.22
On-the-job training of farmers	48	11	25	12	2.02
Climate change knowledge advertorial	50	17	21	12	1.9
GPS (global positioning system) for guided farm visits and data-driven advice to farmers	46	21	20	5	1.7
Use of community radio	43	21	19	3	1.62
Agriculture apps for precision agriculture	40	21	17	2	1.58
E-commerce	40	26	10	4	1.4
Resources, e.g., AGORA, OARE	31	20	8	3	1.24

Source: Field Survey, 2025

Table 3: Extension Services Carried Out with Hybrid Extension Services and Extent of the Service Delivery

Variables	Yes	Rarely	Sometimes	Often	Always	Mean
Agricultural advisory services	49		4	30	16	3.24
Crop management (e.g., planting, fertilization)	50		3	20	27	3.48
Pest and disease control	50		4	26	20	3.32
Livestock management (e.g., feeding, health care)	50		7	24	19	3.24
Weather forecasting and climate adaptation strategies	49		15	24	11	2.92
Market price information and market linkages	50		5	30	13	3.2
Post-harvest management and storage techniques	49		2	31	17	3.30
Financial literacy and access to credit	45	11	9	19	11	2.6
Technology adoption in agriculture	50	1	3	28	18	3.26

Source: Field Survey, 2025

Mean $\geq$ 2.0- High service delivery

Table 4: Perceived Effect of Hybrid Extension Services on Productivity

Items	Strongly agree Freq (%)		Agree Freq %		Undecided Freq %		Disagree Freq %		Strongly disagree Freq %		Mean	SD
Hybrid extension services have improved my overall agricultural productivity	23	46	23	46	4	8	0	0	0	0	4.38	0.635
Access to both in-person and digital extension support makes information more timely and useful	6	12	41	82	3	6	0	0	0	0	4.06	0.424
Hybrid extension services have made it easier to adopt modern farming techniques	7	14	32	64	10	20	1	2	0	0	3.9	0.647
Combining traditional and digital methods provides a more comprehensive support system	3	6	34	68	11	22	1	2	1	2	3.74	0.694
I feel more confident in making farm decisions because of hybrid extension services	9	18	21	42	16	32	4	8	0	0	3.7	0.863
Hybrid extension services are more flexible and convenient than traditional methods alone	3	6	24	48	23	46	0	0	0	0	3.6	0.606
I am able to access expert advice more frequently due to digital extension platforms	1	2	20	40	20	40	9	18	0	0	3.26	0.777
Hybrid extension services are too complicated to understand and use effectively	1	2	14	28	21	42	14	28	0	0	2.96	0.807
Digital platforms used in hybrid extension services are often unreliable or inaccessible	0	0	10	20	21	42	18	36	1	2	3.2	0.782
I prefer traditional methods because digital tools feel impersonal and less trustworthy	0	0	13	26	20	40	1	32	1	2	3.1	0.814
There is little to no improvement in productivity from using hybrid extension services	0	0	13	26	13	26	17	34	7	14	3.36	1.025
Technical issues often hinder my ability to benefit from the digital part of the service	1	2	14	28	11	22	20	40	4	8	3.24	1.021
I don't feel adequately trained to use the technology involved in hybrid services	0	0	16	32	23	46	3	16	3	6	2.96	0.856
Hybrid extension services favor tech-savvy farmers, leaving others behind	0	0	12	24	18	36	16	32	4	8	3.24	0.916

Source: Field Survey, 2025

Mean $\geq$ 3.0- High usage**Table 5: Constraints to the Use of Hybrid Extension Services**

Items	A Constraint Freq %		Not a Constraint Freq %		Mean	SD
Limited ICT devices			50	(100)	2	0
Low digital literacy among extension workers	1	(2)	49	(98)	1.98	0.141
High cost of accessing digital services	-		50	(100)	2	0
Farmers' resistance to change	1	(2)	49	(98)	1.98	0.141
Lack of consistent follow-up or support from extension agents	1	(2)	49	(98)	1.98	0.141
Security and data privacy concerns			50	(100)	2	0
Lack of policy support or institutional framework	7	(14)	43	(86)	1.86	0.351
Language barriers and content barriers	6	(12)	44	(88)	1.88	0.328
Digital divide between rural and urban areas	4	(8)	46	(92)	1.92	0.274
Limited hybrid service offerings in rural areas	11	(22)	39	(78)	1.78	0.418

Source: Field Survey, 2025

Table 6: Significant Influence of the extent of hybrid extension service delivery on extension workers' productivity

Variables	B-value	Standard Error	R ² -value	T	P-value
	0.460	0.054	0.775	8.507	0.000*

Source: Field Survey, 2025

Extension services carried out with hybrid extension services and the extent of the service delivery

Findings on Table 3 revealed that hybrid services were mostly applied in crop management (Mean = 3.48), pest and disease control (Mean = 3.32), post-harvest management (Mean = 3.30), and technology adoption (Mean = 3.26). Limited applications were observed in financial literacy (Mean = 2.60) and climate adaptation (Mean = 2.92). This finding is in line with Aker (2022), who emphasized that digital and hybrid extension tools are often first adopted in core production areas where farmers see immediate benefits, while areas like financial services and climate adaptation receive less attention due to lower awareness and specialized knowledge requirements. The implication is that extension training and policy support should focus on expanding hybrid service applications beyond crop-focused practices, ensuring that farmers also gain critical skills in finance and climate resilience.

Perceived effects of hybrid extension services on productivity

Respondents strongly agreed that hybrid extension improved productivity (Mean = 4.38) and timeliness of information delivery (Mean = 4.06). However, concerns included unreliability of platforms, technical issues, inadequate training, and perceived impersonality of digital methods. This finding is in line with Ogunniyi and Sulaiman (2022), who reported that while hybrid services enhance efficiency and output, challenges of digital infrastructure and limited technical support often reduce effectiveness. The implication is that sustained investment in reliable ICT infrastructure, regular capacity building, and strategies to humanize digital interactions are essential to maximize the benefits of hybrid extension services.

Constraints to the use of hybrid extension services

Key barriers included limited ICT devices (100%), high cost of digital services (100%), low digital literacy (98%), and poor network coverage. These constraints restricted the adoption of advanced hybrid services. This finding is in line with Zulu and Tschirley (2022), who observed that infrastructural deficits, affordability issues, and inadequate digital skills remain major obstacles to effective integration of technology in agricultural extension systems across sub-Saharan Africa. The implication is that overcoming these barriers will require government support, private sector investment, and targeted training programs to ensure equitable access and sustainable adoption of hybrid extension services.

Hypothesis testing

Linear regression results on Table 5 revealed a strong and positive influence of the extent of hybrid extension service delivery on productivity ($B = 0.460$; $t = 8.507$; $p < 0.05$), confirming that hybrid extension service delivery enhances productivity. This finding is in line with Ajani (2022), who reported that hybrid extension approaches significantly improve the efficiency and output of extension workers by combining the strengths of digital and face-to-face methods. The implication is that scaling up hybrid extension delivery through supportive policies and adequate resources can serve as a strategic pathway to boost extension workers' effectiveness and overall agricultural productivity.

CONCLUSION

The study concludes that hybrid extension services positively influence extension workers' productivity but require improved ICT infrastructure, digital skills training, and supportive policies for sustainability in Ondo State. While simple tools such as WhatsApp and Farmers 'call/ contact centres have enhanced communication and outreach, advanced ICT applications remain underutilized due to structural and capacity-related barriers. Therefore, hybrid services should be positioned as complementary rather than a substitute for traditional extension. With adequate ICT infrastructure, digital literacy training, and supportive policies, hybrid services can transform extension delivery in Nigeria.

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EFFECTS OF RESPONSE STRATEGY DIMENSIONS ON AQUACULTURE ENTERPRISE PERFORMANCE IN LAGOS STATE, NIGERIA

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ABSTRACT

There has been growing demand for fish and fish products globally which, all things being equal, should be at the advantage of fish producing nations like Nigeria and other stakeholders in the fisheries value-chain. Nigeria's aquaculture production rose spontaneously with other sources of fish production from 200.535 metric tons in 2010 to 317.727 metric tons in 2015. Also, Lagos State aquaculture production rose from 14.911 metric tons in 2010 to 45.500 metric tons in 2014. However, these growing trends were under threats of increasing costs of fish feeds, poor storage facilities, poor planning and worsened by economic, social-political and natural crises. The COVID-19 pandemic of 2019/2020 which ravaged the world posed serious threats to aquaculture fishery in Nigeria and this prompted the objective of this study, to assess the sustainability of aquaculture fisheries under well developed strategy dimensions even in crisis periods. The study investigated 5 selected fish farms in Lagos state with a population of 4012 and the Crejcie and Morgan formula was adopted in determining the sample size of 350 which was shored up by 70 in consideration of envisaged failures to return questionnaires. Structured questionnaires and cross sectional surveys were adopted for the study using stratified sampling techniques among the three established strata of workers (top management, middle management and operational staff). 95% success of return was recorded. Descriptive and inferential statistics were used to analyze personal information of respondents and the hypothesis of the study respectively. The results show that the average weighted means for the analysis of the descriptive statistics were 4.70 (strategic planning), 5.04 (exploratory innovation and 4.05 (market sensing capability) while the multiple regression and ANOVA results were ($R=0.287$ with $p=0.000$ and Adj. R square= 0.075 with F -value of 11.738 and P -value= 0.000) respectively. The ANOVA result shows a statistical significance at 95% confidence level establishing that response strategy dimensions affect aquaculture profitability thus, encouraging its performance in Lagos State. The study recommends that aquaculture firms must reinvent their innovation and marketing activities to include value chain; pay attention to collaborative engagement and engage in strategic management for the purpose of training employees on deploying response strategies.

Keywords: *Aquaculture, Performance, Response Strategy Dimensions, Profitability, Lagos State, Nigeria.*

INTRODUCTION

Royalties and other fishing agreements generated from aquaculture fisheries are a significant source of revenues for state economies. Further, aquaculture serves as a vital source of employment while helping to provide for the nutritional needs of the low-income populations. Therefore, it is imperative for the aquaculture enterprise to consistently improve corporate performance especially at a time the world is confronted with a series of political and security imbroglio and economic quagmire. In this vein, aquaculture fisheries operations should deploy timely strategies that will meet the needs of stakeholders as well as generating its profitability going-concern status in these challenging times. Nigeria leads the pack in West Africa fishery resources with 1,169,480 mt followed closely by Senegal, Ghana and Sierra Leone in that order (C.P. Rocha et al 2022).

Statement of the Problem

The Nigerian Aquaculture fish production grew from 200,535 mt in 2010 to about 316,727 mt in 2015 and Lagos State recorded growth as well, from 14.911mt in 2010 to 45,500 mt in 2014. But production dropped both at the national and state levels, reaching its lowest level in 2019 and 2020, resulting in loss of jobs with its consequences of loss of income and poor animal protein provision (C.P. Rocha et al 2022). The demand for fish is growing, yet supply is lagging behind. Prospective consumers are limited to certain species (mainly *clarias gariepinus*) of farmed fish which may not be preferred. This issue points to the inability of fish farmers to introduce new products in fish varieties to complement several customers' erratic demand. Also, fish farmers need appropriate response strategies to deal with the uncertainties and intense complexities of today's business environment if they are to achieve performance. Entrepreneurial mindset is a crucial success factor for aquaculture fish farmers in Lagos State, Nigeria, above and beyond the potential relevance of response strategy and adaptive resilience.

The major challenges facing aquaculture fisheries include rising cost of feeds, operational costs, poor management techniques, fish diseases, lack of standard for fish pricing and marketing strategies, insecurity and lack/poor response strategies to shocks such as the COVID-19 shock which stagnated the economy for a period. The effects of the shock (COVID-19) are still manifesting in most economies till date. Therefore, aquaculture practitioners need appropriate response strategies such as strategic planning, marketing and innovative capability to deal with uncertainties and intense complexities of today if they are to achieve significant performance.

Objectives of the Study

The major objective of the study was to investigate the effects of response strategy (strategic planning, marketing sensing capability and adaptive innovation capability) so as to provide information on the relevance of response strategy needed to drive performance measures, profitability and competitiveness in aquaculture production.

The specific objectives of the study are to examine the effects of response strategy on aquaculture production in Lagos State, Nigeria, and to assess the effects of response strategy on new products development.

MATERIALS AND METHODS

The study covered 4012 employees of five selected aquaculture firms in Lagos state and across three levels of management - low, medium and high management. The farms were selected based on their registration with relevant fisheries agencies of the federal and Lagos State governments, productivity (active), adherence to environmental laws amongst others.

Information for this study was collected by the use of structured questionnaires and a cross-sectional survey approach was adopted for the study. The 6-point Likert scale type was used in the questionnaire. The population for study was four thousand and twelve (4012) employees of the five (5) selected fish farms in Lagos state, Nigeria. 420 samples was determined and adopted using the Krejcie and Morgan's formular (for finite population) to determine the sample size

$$S = \frac{x^2 NP(1-P)}{d^2 (N-1) + x^2 P(1-P)}$$

A stratified random sampling technique was used to select 420 participants from the population. While descriptive statistics was used to analyze respondents' information, inferential statistics was used to analyze the hypothesis of the study.

RESULTS AND DISCUSSION

401 completed questionnaires were retrieved out of the 420 administered and 397 (94.5% success) were certified usable. 84, 125 and 211 questionnaires were distributed to top, middle and operational managements respectively and 81, 118 and 202 completed questionnaires were retrieved from the respondents in the categories as stated above. The summary (weighted means) of the descriptive analysis of responses on Response Strategy is shown in Table 1. The respondents indicated that they encourage staff input in planning strategy (mean equals to 4.7). At a mean of 5.04, respondents indicated that they consistently explore opportunities to develop strategies for innovation and at mean 4.05, respondents indicated that market sensing capability was consistently considered and were quick to adapt their business to suit the changing environment.

Table 1: Weighted mean of Responses on Response Strate

S/N	Strategy	Mean
1	Planning (strategic)	4.70
2	Exploratory Innovation	5.04
3	Market Sensing Capability	4.05

Source Researcher's Field Survey Results (2023)

The hypothesis of the study states that "Response Strategy dimensions have no significant effect on the resultant profitability of aquaculture, thus its development in Lagos state". In order to test the hypothesis,

linear multiple regression analysis was used where the values of profit ability were regressed on the values of each of the values of response strategy dimensions. The data for response strategy dimensions was generated by summing responses of all items for strategic planning, explorative innovation and market sensing capability respectively while that of profitability was generated by adding responses of all items used to measure the variable. The result of the regression is presented in Table 2.

Table 2: Summary of multiple regression analysis for the effect of response strategy dimensions on profitability of aquaculture in Lagos State, Nigeria.

Model	Beta	t	sig	R	R ²	Adj R ²	Anova sig	f(df)
Constant	4.512	21.607	0.000	0.287 ^a	0.082	0.075	0.000 ^b	11-738(3,393)
Strategic planning	-0.001	0.028	0.998					
Explorative Innovation	0.197	5.133	0.000					
Market Sensing Capability	-0.204	-4.789	0.000					

^a. Dependent variable; Profitability

^b. Predictor: (Constant), strategic planning, explorative Innovation, market sensing capability

Source: Researcher's field survey Results (2023)

The multiple regression (table 2) shows that Response Strategy dimensions have positive but weak relationship with profitability of aquaculture $R=0.287$, $P=0.000$.

The Adj. R^2 of 0.075 according to Cohen's Adj. R^2 criterion suggests that Response Strategy dimensions affect aquaculture production in Lagos State, but not a major factor. However, the ANOVA analysis (in Table 2) revealed that combined response strategy dimensions have a significant effect on profitability of aquaculture in Lagos State (f-value 11.738 and Low P-value 0.000 which is statistically significant at 95% confidence interval).

CONCLUSION

Based on the empirical findings, this study concluded that there was a statistically significant effect of response strategy (strategic planning, market sensing capability and exploitative innovation) on performance of aquaculture in Lagos State, Nigeria which includes profitability, new products development and competitiveness. Theoretically, the outcome of this study is in line with the ADKAR theory, dynamic capability theory and the contingency theory which provided the underpinnings for the study. The ADKAR theory emphasises that the activities that make up the dimension of response strategy are change activities that hold potential for enhancing the performance of aquaculture enterprise in Lagos State. The strength of the dynamic capability theory (DCT) provided the link between the aquaculture enterprise and the macro-environment in which they operate. While the contingency theory (CT) of fit as a moderator suggests that when the interaction between independent variable and dependent variable is enhanced with the introduction of a third variable, then a moderating effect takes place.

Therefore, the ability of an aquaculture enterprise to grasp the changing business environment for the purpose of sustaining itself especially in crisis periods, requires that it possesses or adopts appropriate and efficient response strategy dimensions.

Recommendations

-The study suggests that more effort is required by management with regards to strategic planning and market sensing capability.

-Aquaculture firms in Lagos must pay attention to collaborative engagement because of its significant relative effect on firm competitiveness.

Contribution to Knowledge

Research: The study identified and filled conceptually gaps in literature regarding the response strategy.

Practitioners: The study offered significant contribution to knowledge and has practical implications for aquaculture firms that were studied and

Policy: the study provides information to serve as a basis for policy formulation with regards to enabling business environments.

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ADOPTION OF CLIMATE-SMART AGROFORESTRY PRACTICES IN A SEMI-ARID REGION: AN ASSESSMENT OF CONSTRAINTS IN KEBBI STATE, NIGERIA

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ABSTRACT

Climate-smart agroforestry (CSA) is an effective approach to improving climate resilience and food security in semi-arid areas. Nonetheless, its implementation is still restricted. This study assessed the socio-demographic attributes, knowledge and adoption levels of climate-smart agroforestry and to identify the unique challenges encountered by farmers in Kebbi State. A multistage sampling technique was employed to select 900 respondents across the three senatorial districts of Kebbi State. From each district, three Local Government Areas (LGAs) and two farming communities were purposively and randomly selected, with 100 farmers drawn from each LGA. A standardised questionnaire was employed to gather socio-demographic information and assess farmers' knowledge and perceived obstacles. Descriptive statistics were utilized such as frequency, means and percentage were used for data analysis. The results on knowledge indicated a substantial number of farmers (89%) recognised agroforestry and most (76%) had noted climatic changes, familiarity with specific climatic-Smart Agriculture methods was limited (<31%). The main limits were significant views of competition between trees and crops for resources (74-89% agreement) and substantial economic impediments, including labour expenses and an extended gestation time. A significant discovery was the almost complete absence of institutional assistance, with more than 80% of farmers indicating no access to sufficient extension services. Notwithstanding these obstacles, 70% of participants indicated a readiness to implement more practices, pinpointing training, inexpensive seedlings, and access to financing as essential support requirements. The study indicates that bridging the adoption gap in semi-arid Nigeria necessitates interventions that rectify misunderstandings through effective information distribution while concurrently addressing economic barriers through enhanced institutional support and tailored incentives.

Keywords: Climate-Smart Agriculture, Agroforestry, Adoption Constraints, Smallholder Farmers, Semi-Arid.

INTRODUCTION

Agriculture in the semi-arid parts of Sub-Saharan Africa is significantly susceptible to climate change, marked by rising temperatures, unpredictable precipitation, and recurrent droughts (IPCC, 2022). These concerns directly affect food security and the lives of millions of smallholder farmers reliant on rain-fed agriculture. In Nigeria, where the economy is significantly dependent on agriculture, these changes affect national stability and developmental objectives (FAO, 2021). In response, Climate-Smart Agriculture (CSA) has arisen as a vital strategy to augment production, bolster resilience, and mitigate emissions (Lipper *et al.*, 2018). A fundamental method of Climate-Smart Agriculture (CSA) is agroforestry, which involves the integration of trees with crops and animals. This approach is advocated as a sustainable system that alleviates climate risks while offering socio-economic advantages, including enhanced soil fertility, water conservation, and diversified income (Mbow *et al.*, 2014).

Adopting agricultural innovations like agroforestry involves a complex interplay of various factors, including social, economic, personal, and institutional elements (Oriangi *et al.*, 2020). A commonly referenced obstacle is the perceived competition between trees and crops for water, nutrients, and sunshine, which dissuades farmers who favour short-term yields over long-term advantages (Coe *et al.*, 2014). Economic restrictions are crucial; the initial expenses for seedlings, increased labour demands, and extended gestation periods pose substantial challenges for resource-limited farmers (Coulibaly *et al.*, 2017). Farmers greatly benefit from extension services that provide training and guidance, which can boost adoption rates (Amadu *et al.*, 2020). However, underfunded extension systems in Sub-Saharan Africa often fail to reach farmers effectively, creating a significant barrier (Akpan *et al.*, 2022). Moreover, insecure land tenure remains a major challenge, as farmers are reluctant to invest in long-term initiatives like tree planting without secure land rights (Salau *et al.*, 2020). The significance of these characteristics is extremely context-dependent, differing by area, culture, and agricultural system (Sida *et al.*, 2018). This necessitates localised research to comprehend the distinct arrangement of restrictions in certain regions such as Kebbi State, which

this paper examines.

Notwithstanding its established advantages and promotional initiatives, the uptake of agroforestry among Nigerian smallholders is still sporadic and constrained (Akpan *et al.*, 2022). A substantial disparity exists between its theoretical promise and practical implementation. Farmers in Kebbi State, situated in Nigeria's semi-arid northern region, encounter ongoing poor production and climatic hardship. Preliminary findings indicate awareness, but the degree of implementation of certain climate-smart actions remains uncertain. The fundamental issue is that the limits impeding adoption are not clearly comprehended in this particular setting. Unless these barriers—whether perceptual, economic, or institutional are diagnosed, promotional activities will continue to be ineffectual. This study aims to evaluate the socio-demographic attributes, knowledge and adoption levels of climate-smart agroforestry and to identify the unique challenges encountered by farmers in Kebbi State.

METHODOLOGY

Study Area

The study was conducted across Kebbi State, located in Northwestern Nigeria. The state lies within the Sudan savanna zone and is characterized by semi-arid climatic conditions, with low and erratic rainfall, high temperatures, and seasonal farming activities.

Sampling Technique and Sample Size

A multistage sampling technique was employed to ensure fair representation across the three senatorial districts of Kebbi State: Kebbi Central, Kebbi North, and Kebbi South. Each district contributed 300 respondents, making a total sample size of 900 peasant farmers.

Data Collection

Data were collected using structured questionnaires that included both open- and close-ended questions. Section B of the questionnaire included multiple-response questions to capture diverse opinions and experiences. The data collected covered socio-economic characteristics, awareness and adoption levels of agroforestry, energy sources, types of agroforestry systems practiced, crops and tree species cultivated, benefits derived, and constraints encountered.

RESULTS

Socio-demographic Attributes of the participants

The respondents were predominantly middle-aged men with extensive experience in agriculture. Most were married, with a significant percentage (87%) having a stable family life. They lived in relatively large houses, with about 71% residing in big homes, and had household sizes ranging from 6 to 10 members. Their farming experience was substantial, with 63% having cultivated the land for over 20 years. The majority operated small to medium-sized farms, typically between 1 and 5 hectares in size, which accounted for about 89% of the respondents. In terms of crop production, cereals were the most common, cultivated by 59% of the farmers, while cash crops were grown by 41%.

Land ownership among the respondents was largely secure, with 69% having acquired their land through inheritance. This suggests a strong sense of tenure and stability in their farming practices. Education levels were relatively high, with most respondents having completed at least secondary school.

The income levels from agriculture were varied but generally favorable, with 69% of the farmers earning more than ₦200,000 annually. Many supplemented their agricultural income with other occupations, such as trade or craftsmanship, which helped to diversify their household earnings and potentially improve their economic stability.

Knowledge of climate smart agroforestry

A significant percentage of farmers (76%) saw alterations in the climate, especially regarding rainfall patterns (56%). The general understanding of the phrase "agroforestry" was very high at 89%. This concealed

a significant deficiency in understanding certain techniques. Awareness was elevated for basic applications such as live fences (31%), but significantly diminished for more intricate, advantageous methods such as alley cropping (16%) and silvopasture (9%). Farmers predominantly appreciated trees for their immediate economic advantages, such as fruit and timber (47%), or for their function as windbreaks (26%), while severely underestimating long-term ecological benefits, including soil enhancement (7%) and climate resistance (9%).

Perceived Limitations

The most significant obstacles were the pronounced feeling of rivalry between trees and crops. The majority of farmers (89% agreement) stated that trees diminish agricultural yields and (74% agreement) compete for water, sunshine, and nutrients. Significant economic restrictions were substantial labour demands (59% agreement), limited access to financing (54%), and the protracted maturation period of trees (59%). The deficiency of institutional assistance was pronounced: the majority of farmers indicated no consistent access to extension services (82% disagreement) and perceived government policies as unsupportive (85% disagreement).

The Willingness to Adopt and the Path Forward

Notwithstanding the obstacles, a significant majority (70%) indicated a readiness to embrace further agroforestry methods. The principal motivators were economic and immediate: creating supplementary cash (50% concurrence) and offering shade and protection for crops (58% concurrence). Farmers described their primary assistance needs as effective training (31%), access to complimentary or subsidised seedlings (29%), and improved finance facilities (23%). Their primary sources of information were fellow farmers (97%) and agricultural radio broadcasts (87%).

DISCUSSION

The findings illustrate a complex landscape of adoption possibilities in Kebbi State. The elevated awareness of agroforestry juxtaposed with little knowledge of specific methods corresponds with the findings of Mbow *et al.* (2014) in semi-arid West Africa, where farmers hold traditional knowledge yet lack technical comprehension of enhanced systems. The significant dependence on peer-to-peer learning and radio, as opposed to formal extension, underscores the inadequacy of institutional knowledge pathways, a deficiency also recognised by Amadu *et al.* (2020).

The primary obstacles of perceived rivalry and economic limitations are extensively documented challenges (Coe *et al.*, 2014; Coulibaly *et al.*, 2017). Such impressions frequently stem from insufficient understanding of species selection and spatial management that might mitigate competition (Sida *et al.*, 2018). The information deficit is further intensified by the disastrous collapse of the extension system, as evidenced by earlier research in northern Nigeria (Akpan *et al.*, 2022), compelling farmers to depend on their own observations centred on immediate hazards.

In contrast to conventional narratives (Zhanga *et al.*, 2018), land tenure did not provide a substantial obstacle owing to established hereditary rights, which serve as a considerable benefit for long-term investment (Mwangi & Meinzen-Dick, 2019). Motivators were immediate economic benefits, reinforcing the assertion that agroforestry must be financially appealing for successful adoption (Coulibaly *et al.*, 2017).

The strong inclination to adopt, along with explicit demands for assistance, delineates a clear framework for intervention, reinforcing recommendations in the literature for supporting policies such as capacity building, input subsidies, and financial access (Kpadonou *et al.*, 2017).

CONCLUSIONS AND RECOMMENDATIONS

The farmers of Kebbi State are eager to adopt, but limited. They have the land, expertise, and will to implement climate-smart agroforestry, yet are impeded by a confluence of beliefs and a significant deficiency in support networks.

The study indicates that bridging the adoption gap necessitates a coordinated effort to:

1. Reinstate Institutional Support: Enhance extension services to deliver focused, pragmatic training that dispels misconceptions regarding competition and imparts appropriate tree Management techniques.
2. Offer Economic Incentives: Implement initiatives for providing cost-effective seedlings and developing loan facilities specifically designed for agroforestry projects.

3. Initiate Awareness Campaigns: Utilise efficient media such as radio and agricultural cooperatives to provide information that emphasizes the economic and ecological advantages of agroforestry.

Overcoming these institutional and perceptual obstacles is essential for realising the substantial promise of climate-smart agroforestry in Nigeria's semi-arid areas, hence improving resilience and livelihoods for smallholder farmers.

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UTILIZATION OF RENEWABLE ENERGY SOURCES IN FISH FARMING IN EKITI STATE, NIGERIA

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ABSTRACT

The utilization of renewable energy sources in fish farming operations presents a promising avenue for enhancing the sustainability, efficiency and productivity of the industry. The study explores the utilization of renewable energy sources in fish farming. A multistage sampling technique was used in selecting 200 respondents for the study. Primary data were collected with the aid of a well-structured questionnaire. Descriptive statistics such as frequency counts, percentages, mean and weighted mean score (WMS) were used to describe the study's stated objectives while Pearson product moment correlation (PPMC) was used to test the study's hypothesis. The findings revealed that solar energy (WMS=1.60), biomass energy (WMS=1.51), wind energy (WMS=1.31) and hydropower energy (WMS=1.11) were the common sources of renewable energy utilized in fish farming. Reduction in operational costs (WMS=1.83), enhanced sustainability (WMS=1.74), improved energy independence (WMS=1.54) and increased productivity (WMS=1.31) were the common effects of utilizing renewable energy sources for fish farming and a low level of utilization of renewable energy sources among the fish farmers (52.5%). Benefits of utilizing renewable energy sources in fish farming include lower energy costs (WMS=1.96), sustainable eco-friendly farming practices (WMS=1.94), resource efficiency (WMS=1.91) and increased energy independence (WMS=1.88). Constraints to the effective utilization of renewable energy sources in fish farming were high initial investment costs (WMS=1.82), lack of training requirements (WMS=1.81), lack of technical skills (WMS=1.79) and knowledge gaps (WMS=1.75). There was a significant relationship between the types of renewable energy sources utilized in fish farming ($r=0.596$; $p=0.000$) and the utilization of renewable energy sources in fish farming. Conclusively, the utilization of renewable energy sources presents a transformative opportunity for the fish farming sector and it was recommended that increased funding for research in renewable energy applications specific to fish farming can lead to innovative solutions that optimize efficiency and lower costs. Collaborative efforts between academia, industry and government can foster advancements in this area.

Keywords: *Utilization, Renewable, Energy sources, Fish farming, Sustainability*

INTRODUCTION

Fish farming is one of the fastest-growing sectors in the food production industry, with an estimated annual growth rate of 5.8% (Food and Agriculture Organization (FAO), 2020). The global fish farming industry has witnessed remarkable growth in recent decades, becoming a crucial source of food protein for billions of people and economic activity globally, providing nearly half of the fish consumed by humans (FAO, 2020). In 2020, fish farming contributed approximately 46% of the total fish supply for human consumption (FAO, 2022). As the demand for fish continues to rise due to population growth and dietary changes, the fish farming industry faces increasing pressure to produce fish sustainably, necessitating innovative approaches to fish farming. The adoption of renewable energy sources presents an opportunity to reduce reliance on fossil fuels and enhance sustainability in fish farming (FAO, 2020). Traditional fish farming methods often rely heavily on electricity derived from fossil fuels, and the reliance on fossil fuels for fish farming operations presents significant environmental issues including habitat destruction, greenhouse gas emissions, escalating operational costs, degradation and reliance on non-renewable resources (Shahsavari *et al.*, 2024). The rapid expansion has raised concerns regarding environmental sustainability, energy consumption and overall ecological impact of fish farming practices.

Energy is a vital component in fish farming operations, used for various activities such as water circulation, aeration, heating and feed production. Energy costs can account for up to 30% of the total operational cost in fish farming and reliance on non-renewable energy sources not only increases operational cost but also poses risks related to energy price volatility, supply chain disruption, environmental challenges, including pollution and climate change implications (Enna, 2025). Renewable energy sources have shown great potential in reducing energy costs and environmental impacts in fish farming operations. Solar energy in particular, has

gained traction due to its relatively low installation costs and ability to generate energy in remote locations (Shahsavari & Akbari, 2018). The integration of renewable energy sources into fish farming practices has the potential to revolutionize the fish farming industry by enhancing sustainability, reducing operational costs and minimizing environmental impacts (Enna, 2025). Renewable energy refers to energy derived from sources that are replenished naturally over short timeframes, thereby providing sustainable alternatives to fossil fuels. In the context of fish farming, renewable energy encompasses various technologies and practices that harness these natural resources to power fish farming operations, thereby reducing reliance on non-renewable energy sources and maximizing the environmental impact of fish farming. The utilization of renewable energy can lead to substantial cost savings; reduce dependence on grid electricity and lower operational costs by up to 40% in fish farming operations (Thi Thu Em *et al.*, 2021). Employing renewable energy sources contributes to reducing the carbon footprint of fish farming. Enna (2025) emphasizes that renewable energy reduces greenhouse gas emissions associated with conventional energy sources, enhancing the sustainability of fish farming. The environmental implications of fossil fuel usage on fish farming are profound, as burning fossil fuel contributes to greenhouse emissions, which are a major driver of climate change, as the extraction and transportation can result in habitat destruction and pollution (Gurdeep *et al.*, 2021).

In light of these challenges, the utilization of renewable energy sources in fish farming presents a promising solution. Renewable energy can help reduce operational costs, lower carbon emissions and promote the sustainability of fish farming practices. Elezuo *et al.* (2024) emphasized that the adoption of renewable energy technologies in agriculture, including fish farming, can lead to significant energy savings and reduced environmental footprints. Enna (2025) highlighted the successful utilization of solar-powered fish farms where the adoption of solar energy resulted in a 40% reduction in energy costs, showcasing both economic and environmental benefits. The upfront costs associated with installing renewable energy systems can be prohibitive for many fish farmers, particularly small-scale fish farmers. According to Gurdeep *et al.* (2021), the initial capital needed for renewable energy technologies can deter farmers from making the switch, despite long-term savings. According to the report of the International Renewable Energy Agency, many smaller operators lack access to financial mechanisms that could help offset these high initial investments (IRENA, 2021). Many fish farmers remain unaware of the benefits and feasibility of renewable energy utilization and the lack of knowledge regarding available technologies, financial incentives and operational efficiencies which can impede the adoption of sustainable practices (García-Jiménez *et al.*, 2024). According to Zhang *et al.* (2023), implementing renewable energy systems requires specific technical expertise and infrastructure and many existing fish farms may not have the necessary facilities to accommodate these technologies, leading to implementation challenges. Inadequate training and technical support limit the ability of fish farmers to transition to renewable energy solutions, diminishing the potential benefits (García-Jiménez *et al.*, 2024). Zhang *et al.* (2023) posited that the efficiency and effectiveness of renewable energy systems can be influenced by geographical and climatic factors as fish farms situated in areas with less sunlight may face challenges in relying solely on it. Renewable energy sources can be intermittent, leading to concerns regarding reliability.

Fish farming operations often require a consistent and reliable energy supply for critical functions. Hwang and Cha (2018) highlighted that without effective energy storage solutions or backup systems, the dependence on renewable energy can present challenges to operational stability as many fish farmers lack the technical knowledge necessary to implement and maintain renewable energy systems effectively. Koričan *et al.* (2022) highlighted a significant skills gap in the fish farming industry regarding the deployment of renewable technologies, which can lead to inefficiencies and underutilization of available resources. In some regions, inadequate regulatory frameworks and policies regarding renewable energy can restrict the adoption of these technologies in fish farming as government support and incentives are often lacking, making it difficult for fish farmers to transition to renewable energy sources (Zhang *et al.*, 2023; Bryson *et al.*, 2013). However, the environmental impact of conventional fish farming practices, particularly their reliance on fossil fuels, poses significant challenges.

This study examined the utilization of renewable energy sources in fish farming in Ekiti State, Nigeria.

Specifically, the study identifies the types of renewable energy sources utilized in fish farming, effects of utilizing renewable energy sources in fish farming, level of utilization of renewable energy sources in fish farming, benefits of utilizing renewable energy sources in fish farming and constraints to the effective utilization of renewable energy sources in fish farming.

It was hypothesized that there is no significant relationship between the types of renewable energy utilized in fish farming and the utilization of renewable energy sources in fish farming.

METHODOLOGY

Ekiti State is a state in Southwestern Nigeria and is bounded to the north by Kwara State, to the northeast by Kogi State, to the south and southeast by Ondo State, and to the west by Osun State. The Yorubas make up the majority of the state's population. Ekiti State was formed from a part of old Ondo State in 1996 and has its capital in the city of Ado-Ekiti. The state is divided between the Nigerian lowland forests in most of the state and the drier Guinean forest-savannah mosaic in the north. Ekiti State is partially based on agriculture, mainly of yams, rice, cocoa, and cassava crops. The State is mainly an upland zone, rising over 250 meters above sea level. It lies in an area underlain by metamorphic rock. It is generally an undulating part of the country with a characteristic landscape that consists of old plains broken by step-sided outcrops that may occur singularly or in groups or ridges. The State enjoys a tropical climate with two distinct seasons. These are the rainy season (April–October) and the dry season (November– March). The temperature ranges between 21° and 28 °C with high humidity. The southwesterly wind and the northeast trade winds blow in the rainy and dry (Harmattan) seasons respectively. Tropical forest exists in the south, while savannah occupies the northern peripheries. The state is characterized by a derived savannah agro-ecological zone and utilizes three ADP zones for agricultural activities, which include producing crops such as cocoa, cassava, oil palm, yams, rice, maize, and cashew. Ekiti State falls under the derived savanna zone, indicating a specific type of vegetation and climate suitable for certain agricultural practices.

The state is divided into three ADP zones namely Aramoko (Zone 1), Ikere (Zone 2) and Isan-Ekiti (Zone 3) to manage agricultural development and extension services. These zones cover all the Local Government Areas (LGAs) within the state. A multistage sampling technique was used in selecting respondents for the study. Aramoko (Zone 1) and Ikere (Zone 2) both consist of 5 extension blocks while Isan-Ekiti (Zone 3) consists of 6 extension blocks. In the first stage, two (2) ADP zones were randomly selected namely Aramoko (Zone 1) and Isan-Ekiti (Zone 3). The second stage involved the use of simple random sampling techniques to select five (5) blocks each from the selected zones and two (2) extension cells each was randomly selected from the two blocks making a total of twenty (20) extension cells and lastly, ten (10) fish farmers were randomly selected from the twenty (20) making a sample size of two hundred (200) fish farmers. Both primary and secondary data were used for the study. Primary data was collected with the aid of a well-structured questionnaire. Data collected was analysed using both descriptive statistics such as frequency counts, percentage, mean and WMS while inferential statistics for testing the stated hypothesis is Pearson product moment correlation (PPMC).

RESULTS AND DISCUSSION

Types of renewable energy sources utilized in fish farming

Result presented in Table 1 shows that solar energy ranked 1st with a weighted mean score of 1.60, biomass energy ranked 2nd with a weighted mean score of 1.51, wind energy ranked 3rd with a weighted mean score of 1.31 and hydropower energy ranked 4th with a weighted mean score of 1.11 were the common types of renewable energy sources utilized in fish farming. This indicates that the integration and utilization of renewable energy sources in fish farming present an opportunity to enhance the ecological and economic sustainability of fish farming as each energy type offers unique advantages that can be leveraged to create more resilient, environmentally friendly and economically viable fish farming practices. This implies that solar energy can significantly decrease electricity costs, making fish farming more economically viable as well as reducing operational costs for water pumping, aeration and heating. This finding is in tandem with the report of Puri *et al.* (2023) that by reducing reliance on fossil fuels, solar energy lowers greenhouse gas emissions associated with fish farming operations. Biomass energy can be generated from fish waste and

agricultural residues, promoting a circular economy and reducing waste disposal issues in fish farms. This finding is in line with the report of IPCC (2018) that using biomass can lead to the development of sustainable feed resources, enhancing nutrient recycling and reducing environmental impacts from conventional feed sources. By harnessing wind energy, fish farms can achieve greater energy independence and resilience against energy price fluctuations. This finding is in line with the report of Sakti *et al.* (2023) that wind energy can be used in conjunction with solar panels to provide a more consistent energy supply, particularly in areas with variable weather. Water offers a reliable and consistent energy source, particularly in regions near rivers or water bodies suitable for generating hydropower. This finding supports the report of Enow *et al.* (2025) that hydropower integrated within fish farming systems can enhance water circulation and oxygenation, which are crucial for fish health.

Table 1: Distribution of the respondents by types of renewable energy sources utilized in fish farming

Types of renewable energysources	WMS	Rank
Hydrogen energy	0.84	8 th
Algae Biofuels	1.06	7 th
Tidal and wave energy	1.07	6 th
Geothermal energy	1.10	5 th
Hydropower energy	1.11	4 th
Wind energy	1.31	3 rd
Biomass energy	1.51	2 nd
Solar energy	1.60	1 st

WMS-Weighted mean score

Source: Field Survey, 2025

Effects of utilizing renewable energy sources in fish farming

Reduction in operational costs ranked 1st with a weighted mean score of 1.83, enhanced sustainability ranked 2nd with a weighted mean score of 1.74, improved energy independence ranked 3rd with a weighted mean score of 1.54 and increased productivity ranked 4th with a weighted mean score of 1.31 were the common effects of utilizing renewable energy sources in fish farming (Table 2). This indicates the positive outcomes associated with transitioning to renewable energy in fish farming. This shift not only alleviates the environmental pressures associated with traditional energy sources but also paves the way for a more sustainable and efficient fish farming industry. This implies that initial investments in renewable technologies can be offset by long-term savings due to reduced fuel costs and maintenance. This is in line with the findings of Puri *et al.* (2023) that renewable energy sources provide a cost-effective alternative to conventional energy sources. Fish farming facilities can significantly reduce utility bills, leading to lower overall operational costs. Utilizing renewable energy sources promotes waste recycling and minimizes environmental pollution. This is in tandem with the report of IPCC (2018) that renewable energy sources lower greenhouse gas emissions, contributing to climate change mitigation and reducing the ecological impact of fish farming. Renewable energy systems can ensure a steady energy supply, particularly in remote or off-grid locations, enhancing the operational reliability of fish farming practices. This finding corroborates the findings of García-Jiménez *et al.* (2024) that fish farms utilizing renewable energy can decrease their dependency on fossil fuel markets, shielding them from price volatility and supply chain disruptions. Renewable energy facilitates the expansion of fish farming practices without the proportional increase in energy costs, allowing farms to increase production capacity sustainably. This is in line with the findings of Scroggins *et al.* (2022) that access to a reliable energy supply allows for improved management of critical factors, leading to healthier fish and higher growth rates.

Level of utilization of renewable energy sources in fish farming

Table 3 shows that more than half of the fish farmers (52.5%) indicated that there is a low level of utilization of renewable energy sources in fish farming. This indicates that the low level of renewable energy utilization among fish farmers has wide-ranging implications, such as increased operational costs, negative environmental impacts, reduced energy independence, limitations on productivity and lost opportunities for innovation which can collectively hinder the growth and sustainability of the fish farming sector. This implies that the low level of renewable energy utilization among fish farmers may lead to financial burden from

energy expenses which can discourage investment in technology and infrastructure improvements, perpetuating inefficiencies in production. This finding supports the report of Owusu (2025) that fish farmers relying on conventional energy sources face higher operational costs due to fluctuating fossil fuel prices as this reliance diminishes profit margins and can limit the competitiveness of fish farming. The use of non-renewable energy sources can result in pollution, affecting water quality and the overall sustainability of fish farming practices. This is in line with the findings of Sintayehu (2018) that continued dependency on fossil fuels contributes to greenhouse gas emissions and environmental degradation, impacting aquatic ecosystems and biodiversity. Also, a lack of investment in renewable energy infrastructure leaves farmers at the mercy of the prevailing energy market, making them less resilient to shocks. This finding corroborates the report of Agbabiaka and Okeke (2024) that fish farming operations are vulnerable to energy supply disruption and price volatility, which can significantly affect production stability and planning and can lead to operational inefficiencies and uncertainties. The low level of renewable energy utilization among fish farmers can lead to an inability to scale operations efficiently due to energy constrain, limiting potential output and profitability. This supports the findings of Saleh and Hassan (2024) that low utilization of renewable energy can hinder advancements in fish farming technology that rely on reliable energy sources for critical operations which can lead to lower fish growth rates and health problems. Similarly, the fish farmers' low level of renewable energy utilization may be due to their reluctance to adopt renewable energy technologies which may hinder fish farms from adapting to changing market trends and consumer preferences for sustainable products. This corroborates the findings of Lv (2023) that underutilization of renewable energy stifles innovation in sustainable fish farming practices; thus, without investment in renewable technologies, the potential for developing new, more efficient farming methods diminishes.

Table 2: Distribution of the respondents by the effects of utilizing renewable energy sources in fish farming

Effects of utilizing renewable energy sources	WMS	Rank
Community development	1.05	13 th
Job creation	1.09	12 th
Market competitiveness	1.13	11 th
Innovation and technological advancement	1.16	10 th
Waste management	1.19	9 th
Increased energy efficiency	1.21	8 th
Enhanced resilience	1.24	7 th
Enhanced fish health and growth	1.25	6 th
Resource efficiency	1.28	5 th
Increased productivity	1.31	4 th
Improved energy independence	1.54	3 rd
Enhanced sustainability	1.74	2 nd
Reduction in operational costs	1.83	1 st

WMS-Weighted mean score

Source: Field Survey, 2025

Table 3: Distribution of the respondents by level of utilization of renewable energy sources in fish farming

Level of utilization of renewable energy sources	Frequency	Percentage
High	35	17.5
Moderate	60	30
Low	105	52.5
Total	200	100

Source: Field Survey, 2025

Benefits of utilizing renewable energy sources in fish farming

As shown in Table 4, the benefits of utilizing renewable energy sources in fish farming include lower energy costs ranked 1st with a weighted mean score of 1.96, sustainable eco-friendly farming practices ranked 2nd

with a weighted mean score of 1.94, resource efficiency ranked 3rd with a weighted mean score of 1.91 and increased energy independence ranked 4th with a weighted mean score of 1.88. This indicates that the integration and utilization of renewable energy sources in fish farming generates numerous benefits and these benefits not only improve the economic viability of fish farming operations but also contribute to environmental sustainability and resilience in the face of global energy challenges. This implies that by harnessing renewable energy, fish farms can significantly lower their electricity bills, making operations more cost-effective and contributing to overall profitability. This finding supports the report of FAO (2015) that renewable energy sources provide stable pricing compared to fossil fuels, shielding fish farmers from price volatility and fluctuations in energy markets. Transitioning to renewable energy sources significantly reduces greenhouse gas emissions and the overall ecological footprint of fish farming which aligns fish farming practices with global sustainability goals. This finding is in tandem with the report of Brye (2023) that eco-friendly fish farming practices can increase marketability, attracting consumers who prioritize sustainable and environmentally responsible products. Utilizing renewable energy sources can lead to nutrient recycling within the fish farming sector thereby minimizing environmental impacts and promoting sustainability. This is in line with the findings of Lv (2023) that renewable energy technologies allow for more efficient use of resources leading to enhanced productivity and reduced waste. Furthermore, with renewable energy, fish farms can reduce their dependence on traditional energy grids and fossil fuel supply chains, enhancing their energy security and operational resilience. This is in line with the findings of Enna, (2025) that increased independence allows fish farms to operate more freely, particularly in remote areas where energy infrastructure may be lacking, facilitating the setup of sustainable operations.

Table 4: Distribution of the respondents by the benefits of utilizing renewable energy sources in fish farming

Benefitsof utilizingrenewableenergysources	WMS	Rank
Policy incentives and support	1.59	13 th
Improvedpublic image and marketability	1.63	12 th
Minimized water usage	1.68	11 th
Reduced carbon footprint	1.72	10 th
Conservation of natural resources	1.75	9 th
Waste reduction	1.77	8 th
Disease management	1.79	7 th
Stableenvironment	1.81	6 th
Long-term financial stability	1.85	5 th
Increased energy independence	1.88	4 th
Resource efficiency	1.91	3 rd
Sustainable ecofriendly farming practices	1.94	2 nd
Lower energy costs	1.96	1 st

WMS-Weightedmean score

Source: Field Survey, 2025

Constraints to the effective utilization of renewable energy sources in fish farming

As shown in Table 5, constraints to the effective utilization of renewable energy sources in fish farming were high initial investment costs ranked 1st with a weighted mean score of 1.82, lack of training requirements ranked 2nd with a weighted mean score of 1.81, lack of technical skills ranked 3rd with a weighted mean score of 1.79 and knowledge gaps ranked 4th with a weighted mean score of 1.75. This indicates that high initial investment costs, lack of training requirements, lack of technical skills and knowledge gaps create formidable barriers to the effective utilization of renewable energy sources in fish farming. This implies that high initial investment costs can deter fish farmers from adopting renewable energy technologies which is particularly pronounced in small-scale farming operations lacking access to capital or credit. This finding supports the report of Cui (2025) that the upfront cost of renewable energy infrastructure can be a significant hurdle for smallholder farmers. Also, Bathaei and Štreimikiene (2023) reported that while renewable energy can lower long-term operational costs, the reluctance to invest initially prevents many farmers from realizing its benefits. Furthermore, the absence of training requirements may lead to inefficient usage of renewable energy technologies as farmers may not fully understand how to integrate them into their operations, resulting

in suboptimal performance and underutilization of available resources. This supports the findings of Hungevu *et al.* (2025) that effective training and capacity building are essential for the successful adoption of renewable technologies in fish farming as farmers without foundational training may struggle with maintenance and operational efficiency, potentially leading to equipment failure and increased costs over time. Likewise, a lack of technical skills among fish farmers can hinder their ability to implement and manage renewable energy systems as skills deficits might lead to reliance on external technicians, thereby increasing operational costs and creating dependency on outside experts. This is in line with the report of FAO (2019) that many fish farmers lack the technical expertise needed to effectively incorporate renewable energy into their operations. Knowledge gaps regarding the benefits, operations and maintenance of renewable energy systems can prevent fish farmers from embracing new technologies as this often leads to scepticism about the economic viability of renewables and perpetuates a cycle of reliance on traditional energy sources. This supports the findings of Pinkse and Groot (2020) that greater awareness about the benefits and mechanics of renewable energy can significantly encourage its uptake among farmers.

Table 5: Distribution of the respondents by constraints to the effective utilization of renewable energy sources in fish farming

Constraints to the effective utilization of renewable energy sources	WMS	Rank
Consumer awareness and demand	1.51	12 th
Insufficient policy support	1.55	11 th
Grid connectivity	1.59	10 th
Site-specific constraints	1.61	9 th
Site suitability	1.64	8 th
Compatibility issues	1.66	7 th
Intermittent energy supply	1.68	6 th
Competing priorities	1.72	5 th
Knowledge gaps	1.75	4 th
Lack of technical skills	1.79	3 rd
Lack of training requirements	1.81	2 nd
High initial investment costs	1.82	1 st

WMS - Weighted mean score

Source: Field Survey, 2025

Hypothesis testing

There is no significant relationship between the types of renewable energy sources utilized in fish farming and the utilization of renewable energy sources for fish farming

Relationship between the types of renewable energy sources utilized in fish farming and the utilization of renewable energy sources in fish farming

Correlation analysis presented in Table 6 shows that there was significant relationship between the types of renewable energy sources utilized in fish farming ($r=0.596$; $p=0.000$) and the utilization of renewable energy sources in fish farming. This indicates that the significant relationship existing between types of renewable energy sources utilized in fish farming ($r=0.596$; $p=0.000$) and utilization of renewable energy sources in fish farming can serve as a catalyst for advancement in the field of fish farming and its sustainability. This implies that utilizing renewable energy sources in fish farming can enhance sustainability by reducing reliance on fossil fuels. This finding corroborates the report of Enna (2025) that the adoption of renewable energy can lower the carbon footprint associated with fish farming operations. Also, Scroggins *et al.* (2022) reported that as fish farmers often grapple with environmental challenges, utilizing renewable energy aligns with sustainable fishery management practices. The significant relationship between types of renewable energy sources and their utilization can suggest cost reductions in the long run as investing in renewable technologies, fish farms can decrease operating costs related to energy consumption. This is in line with the findings of Dirma *et al.* (2024) that renewable energy sources provide a stable energy price, which can mitigate the volatility associated with conventional energy sources and make fish farming more economically feasible. Different renewable energy sources may complement each other, enhancing overall operational efficiency in fish farming settings. This is in line with the report of Ang *et al.* (2022) that integration can lead to

better resource management and lower overall costs for fish farmers. The significant relationship may influence policymakers to promote renewable energy adoption in fish farming, as demonstrating a significant relationship between various renewable sources may encourage regulatory support and incentives for fish farmers to transition away from fossil fuels (Scroggins *et al.* 2022), which could lead to the development of frameworks that facilitate renewable energy projects specifically tailored for fish farming. Similarly, the significant relationship may stimulate further investigation and innovation within the realm of renewable energy applications in fish farming. This is in line with the report of Wang *et al.* (2023) that recognizing which types of renewable energy sources are most effective for fish farming can motivate research into improving these technologies or developing new solutions, ultimately leading to more sustainable practices. Furthermore, a significant relationship between types of renewable energy sources utilized in fish farming and utilization of renewable energy sources in fish farming may imply enhanced conditions that promote better productivity in fish farming operations. This supports the report of Mustafa *et al.* (2024) that the use of renewable energy can indirectly impact fish growth and health as energy-efficient systems improve water quality management, which is critical for fish health. The significant relationship may also imply a trend or a cultural shift towards the adoption of renewable sources in fish farming practices. This could lead to increased awareness among fish farmers and consumers regarding the environmental impacts of energy use in fish farming, thereby pushing for broader adoption of sustainable practices (Tran *et al.* 2023).

Table 6: Summary of Correlation analysis showing the relationship between the types of renewable energy sources utilized in fish farming and the utilization of renewable energy sources in fish farming

Variable	r-value	p-value	Decision
Types of renewable energy sources utilized in fish Farming	0.596	0.000	Significant

Significant at 5% level of significance

Source: Field Survey, 2025

CONCLUSION

In conclusion, the utilization of renewable energy sources presents a transformative opportunity for the fish farming sector. The primary renewable energy sources currently employed in fish farming include solar, biomass, wind and hydropower. The utilization of these energy types significantly reduces operational costs, enhances sustainability and promotes resource efficiency, thereby improving productivity and energy independence for fish farming operations. However, despite these clear advantages, the current utilization level of renewable energy sources in fish farming remains disappointingly low. Additionally, renewable energy can aid in improving the resilience of fish farming operations against climate change by reducing greenhouse gas emissions and promoting the circular economy.

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CLIMATE-SMART PRACTICES USED AMONG SMALL-SCALE CASSAVA FARMERS IN AKOKO NORTH-WEST LOCAL GOVERNMENT AREA, ONDO STATE, NIGERIA

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ABSTRACT

Climate-smart agriculture is a necessary strategy for mitigating the effects of climate change on agri-food systems in rural communities. This study examines climate smart practices among small scale cassava farmers in Akoko Northwest Local Government Area of Ondo State, Nigeria, assessed the socioeconomic characteristics of the cassava farmers, analysed perceptions of climate change, ascertained climate smart practices used and identified constraints to adoption of climate-smart practices by cassava farmers. Quantitative data were obtained from 120 cassava farmers through a two-stage random sampling procedure and analysed using percentages, mean and correlation analysis. One-half of the respondents (50%) were aged between 31-40 years, mostly male (66.7%) and had secondary education (25%). Farmers perceived that “temperature is not normal in recent time” ($\bar{x}=3.02$), “there is a noticeable drying of streams and rivers” ($\bar{x}=2.76$) and “human activity is responsible for climate variability” ($\bar{x}=2.67$). The most widely used climate-smart practices were adoption of improved seeds varieties ($\bar{x} = 2.80$), crop rotation ($\bar{x} = 2.77$) and minimum tillage ($\bar{x} = 2.70$). The severe constraints to adoption of climate-smart practices were lack of adequate irrigation facilities (54.2%), unpredictable weather conditions (44.2%), lack of knowledge of appropriate climate-smart practices (44.2%), inadequate government support (37.5%), and lack of information about potential climate variability (34.2%). The study recommended adequate provision of irrigation infrastructure by the government, efficient communication of climate forecasts and early warning signals to farmers by the meteorological agency.

Keywords: climate smart practices, cassava farmers, constraints, perceptions, Ondo State

INTRODUCTION

Sub-Saharan Africa is vulnerable to the adverse effects of climate change due to its predominantly rain-fed agricultural systems dominated by smallholder farmers relying heavily on traditional agricultural practices. The consequences have been low crop productivity, escalating food prices, mounting food insecurity and heightened food imports (Oyelami *et al.*, 2023). Specifically, Oluwatimileyin and Ayanlade (2023) projected a 5–17% decline in crop yield, especially for key staples by 2050 due to rising temperatures and rainfall volatility in the region. Climate change occurrence in Nigeria manifests largely in land degradation, flash floods, and gully erosion; ravaging crops, decimating farmlands and destroying rural infrastructure. By 2009, an estimated 6,000 gullies were damaging infrastructure and farmlands across rural and urban Nigeria (Haider, 2019). In 2022, climate-induced pests and diseases impacted 1.5–200,000 hectares of land, triggered crop losses of up to 80% in some communities and unleashed after-harvest losses for several crops across states in Nigeria (Okoronkwo, 2024).

Cassava (*Manihot esculenta* Crantz) is a major root crop cultivated in many developing countries particularly those in low latitude regions (Mohidin *et al.*, 2023). Aside from the edible root, cassava has multiple applications as vegetable for soups or as processed food varieties depending on culture. It could also be dried-fed to livestock, while the stem could be utilised for plant propagation and grafting. Cassava is useful in the manufacture of yeast, alcohol and ethanol for fuel or starch for various industrial uses in the textile, paper, plywood, and pharmaceutical industries (Krajang, *et.al.* 2021)

Nigeria is the world's largest producer of cassava, generating about 63 million tonnes out of the 308 million tonnes produced globally in 2021, which is approximately 26% of world output (Onyediako and Adiele, 2022). However, roughly 90% of the commodity is processed and consumed domestically, about 10% is channelled into industrial production, and less than 1% is exported, placing the country 59th on the global cassava export ranking in 2021 (FAOSTAT, 2022). Majority (95%) of cassava farmers in Nigeria operate small farms, cultivating less than two hectares and depending heavily on rain-fed agricultural systems. Climate change affects cassava yields, outputs and quality, reducing productivity and eroding profitability and incomes of the farmers (Ekundayo *et al.*, 2021). While inadequate rainfall shrivels cassava tubers

developing in the soil, spurring deterioration, shrinking their size and diminishing their market value, excessive rainfall propagates various pests and diseases that devour cassava leaves and undermine the photosynthetic process of the plants (Paul *et al.*, 2019).

Climate-smart agriculture (CSA) is a crucial strategy for mitigating the effects of climate change on agri-food systems in rural communities. CSA integrates modern methods with deep-seated traditional practices based on local knowledge, cultures and values, to generate sustainable solutions for adapting agricultural production to climate variability (Tsado, 2019). According to FAO (2023), CSA has potentially transformative effect on agri-food systems toward green and climate-resilient practices (FAO, 2023). Indeed, CSA provides a vehicle for accelerating farm productivity, developing resilience to climate change, and strengthening capacity for minimising agriculture-induced greenhouse gas emissions in rural settings (Ariom, *et al.*, 2022; Abegunde and Obi, 2022). In the context of sub-Saharan Africa, indigenous farmers and rural communities have historically adapted traditional agriculture to climate change by leveraging a range of methods and approaches developed over centuries (Singh and Singh, 2017). These includes altering planting dates, cover cropping, integrating crop-livestock farming, intercropping, organic composting and land management schemes, that counter climate change effects and bolster crop productivity (Mashi *et al.*, 2022). The advantages of these practices which typically utilise locally available resources, is their cost-effectiveness, energy-efficiency, high productivity, and sustainable agroecological features (Singh and Singh, 2017).

This study examined climate smart practices used among small scale cassava farmers in Akoko Northwest Local Government Area of Ondo State, Nigeria. Specifically, it described their socioeconomic characteristics, examined their perceptions of climate change, ascertained climate smart practices used and identified constraints to adoption of climate-smart practices by the farmers.

Test of Hypothesis

H₀₁: There is no significant relationship between socioeconomic characteristics and use of climate-smart practices by the cassava farmers

MATERIALS AND METHOD

The study was conducted in Akoko North-West Local Government Area (LGA) of Ondo state Nigeria. The Akokos are a large Yoruba cultural sub-group in the northeastern part of Yoruba land. They make up 20.3% of the population of Ondo state and mainly domiciled in four out of 18 LGAs in the state (Olutumise, 2024). Respondents were selected using a two-stage sampling procedure. First, ten (10) out of the eighteen (18) communities in the study area were purposively selected due to pervasive cassava production activities in the areas. Secondly, twelve (12) respondents from each community were selected using simple random sampling, making a total of 120 respondents. Data was collected using a structured questionnaire and analysed using frequencies, percentages and means, while correlation analysis was used to test the relationship between the variables.

Socioeconomic characteristics such as age, farming experience, household number, farm size were measured at interval and nominal levels. To measure farmers' perceptions on climate change, a five-point Likert-type scale with scores of strongly agree (5), agree (4), undecided (3), disagree (2) strongly disagree (1) was assigned for positive worded statement and the reverse for negative worded statements. To measure climate-smart practices, respondents were asked to tick from a list of items which were measured using a 5-point Likert-type scale of always (5), often (4), sometimes (3), rarely (2), and never (1). The mean score was calculated and used to rank climate smart practices from the most used to the least used. To measure constraints impeding the use of climate-smart practices, respondents were asked to tick from a list of constraints which were measured using a three-point Likert-type scale of severe constraint, mild constraint and not a constraint.

RESULTS AND DISCUSSION

Socio-economic characteristics of respondents

The socioeconomic characteristics of respondents reported in Table 1 reveals that majority (66.7%) were male while 33.3% were female. The age distribution shows that 25.8% were aged 20-30 years, 50% were aged 31 to 40 years, and 15.8% were aged 41 to 50 years, suggesting a dominance of productive age respondents. Okoronkwo *et al.* (2024) confirmed the preponderance of middle-aged farmers in their study on climate smart agriculture in sub-Saharan Africa. Most of the respondents were in monogamous marriages (66.7%) while 33.3% were polygamous. Saadu *et al* (2024) found mostly male and polygamous respondents, with an average household size of about 17 for adopters of climate smart practices in Northwestern, Nigeria. Only 33.3% of the respondents had no formal education, 20.8% had primary education, 25% had secondary education, 12.5% had tertiary education and 8.4% had other qualifications, indicating a high level of literacy among the respondents which should facilitate their awareness and inclination to adopt climate smart farming

Table 1: Socioeconomic characteristics of respondents

Variables	Frequency	Percentage (%)
Sex		
Male	80	66.7
Female	40	33.3
Age($\bar{x}$ =43.64)		
20 – 30years	31	25.8
31 – 40years	60	50.0
41 – 50years	19	15.8
51 years and above	10	8.4
Type of marriage		
Monogamous	80	66.7
Polygamous	40	33.3
Educational qualification		
No formal Education	40	33.3
Primary school education	25	20.8
Secondary education	30	25.0
Tertiary education	15	12.5
Others...	10	8.4
Household size($\bar{x}$ =9.20)		
1-5	15	12.5
6 – 10	50	41.7
11 – 15	30	25.0
16 and above	25	20.8
Years offarming experience		
1-5 years	80	66.7
6 – 10years	30	25.0
11years and above	10	5.4
Size of your farm		
1-5 hectares	75	62.5
6 – 10 hectares	10	8.3
11-15 hectares	10	8.3
16 hectares and above	5	4.1
Do you belong to cooperative society		
Yes	20	16.7
No	100	83.3
Source of capital		
Personal savings	60	50.0
Credit institutions	20	16.7
Family	30	25.0
Others	10	8.3
Access to credit		
Yes	30	25.0
No	90	75.

Source: Field Survey, 2023.

practices. Ruba, *et al.* (2024) validated the high level of education among farmers in the Haor area of Bangladesh implementing climate smart agriculture practices. Respondents' family sizes were 1 to 5 (12.5%), 6 to 10 (41.7%), 11 to 15 (25%), 16 and above (20.8%). Ayeni *et al.* (2023) discovered an average household size of five among crop farmers in North Central Nigeria. Majority of the respondents had farming experience of 1 to 5 years (66.7%), 25% had been engaged in farming for 6 to 10 years and 5.4% had been farming for 11 or more years.

Respondents (62.5%) with farm sizes of 1 to 5 hectares were dominant, 8.3% operated farm size of 6 to 10 hectares, 8.3% managed farm sizes of 11 to 15 hectares and 4.1% worked farms of 16 hectares or more. This indicates that the farmers mostly ran small farms perhaps due to limited capital for expansion. Kalu and Mbanasor (2023) corroborated the dominance of small farm sizes among smallholder farmers with almost three-quarters of their study respondents maintaining farm sizes of 1-4 hectares.

Most (83.3%) of the respondents did not belong to any cooperative association suggesting they would not be able to leverage certain benefits accruing from such membership including financial and social capital. Personal savings (50%) was the dominant source of capital which is typical of small enterprises in Nigeria. However, 16.7% drew capital from credit institutions, 25% from family members and 8.3% from other sources. Finally, majority (75%) of the respondents did not have access to credit. This is likely due to inability to meet stringent conditions attached to credit access especially by formal financial institutions. Ndung'u *et al.* (2023) found that almost 60% of the respondents in Kakamega County, Kenya implementing climate smart agriculture, lacked access to agricultural credit, attributing it to elevated interest rates on loans and the absence of collateral.

Farmers' perceptions of climate change

Farmers' perception of climate change reported in Table 2 shows that most respondents ($\bar{x}=2.67$) had negative perceptions of climate change regarding the statements: "human activity is responsible for climate variability" "temperature is not normal in recent times" ($\bar{x}=3.02$),^t and "rainfall does not start and end in normal periods" ($\bar{x}=2.66$). Similarly, most respondents ($\bar{x}=2.76$) had negative perception of climate change regarding the statement: "there has been noticeable drying of streams and river". However, most respondents ($\bar{x}=2.49$) had marginally positive perception of climate change about "there has been noticeable desertification in some land areas".

Evidently, certain causes of climate change are conceptualised as *anthropogenic*, meaning "caused by human beings". In agriculture, climate change is triggered by food systems emissions across the value chain from production through processing, transport and packaging to consumption. These activities accounted for 34% of total Green House Gases (GHG) emissions globally in 2015 (Crippa *et al.* 2021). Much of these (71%) arose from land modification actions in agriculture and others from sundry activities including retail, fuel, waste management, industrial processes and packaging (Crippa *et al.* 2021). The modernisations of agricultural practices have dramatically altered the delicate balance between the soil and climate. Specifically, the agricultural sector is associated with large scale emissions of nitrous oxide and methane. The quest for higher crop yields propelled the extensive application of chemical fertilizers and other crop-management techniques, resulting in agriculture contributing about three-quarters of atmospheric nitrous oxide (Omotoso and Omotayo, 2024). Similarly, much of the emitted atmospheric methane flowing from the digestive processes of cattle and other ruminants, are traceable to massive livestock production.

Saguye (2017) affirmed that majority of the farmers' perceived warmer temperature, high intensity rainfall over shorter periods, and prolonged and frequent drought in Geze Gofa District of Ethiopia. Meanwhile, Nyang'au *et al.* (2021) confirmed that most of the respondents in Masaba south, Kisii, Kenya perceived a decrease in rainfall, reduced rainfall distribution, late onset of rain and heightened temperature in the area.

Climate-smart practices of cassava farmers

Table 3 reveals that the most widely used climate-smart practices were adoption of improved seeds varieties ($\bar{x}= 2.80$), crop rotation ($\bar{x}= 2.77$) and minimum tillage ($\bar{x}= 2.70$). Other climate-smart practices were mixed

Table 2: Farmers' perceptions of climate change

S/n	Perception statements	Responses						
			SA	A	U	D	SD	($\bar{x}$)
1	Human activity is responsible for climate variability	Freq.	70	16	14	13	7	2.67
		%	58.3	13.3	11.7	10.8	5.8	
2	Temperature is not normal in recent time	Freq.	50	34	15	15	6	3.02
		%	41.7	28.3	12.5	12.5	5.0	
3	Rainfall does not start and end at normal period	Freq.	29	50	32	6	3	2.66
		%	24.2	41.7	26.7	5.0	2.5	
4	There is increase in volume of rainfall	Freq.	36	40	27	6	11	2.55
		%	30.0	33.3	22.5	5.0	9.2	
5	Some plants and animal species are no longer in existence	Freq.	31	25	30	3	31	2.54
		%	25.8	20.8	27.5	2.5	25.8	
6	There is increase in temperature and drought	Freq.	69	27	9	5	10	2.62
		%	57.5	22.5	7.5	4.2	8.3	
7	There has been increase in intensity and frequency of weather event.	Freq.	53	46	10	3	8	2.51
		%	44.2	38.3	8.3	2.5	6.7	
8	There has been noticeable desertification in some land areas	Freq.	46	36	20	8	10	2.49
		%	38.3	30.0	16.6	6.7	8.3	
9	There has been noticeable drying of streams and river	Freq.	62	30	11	5	12	2.76
		%	51.7	25.0	9.2	4.2	10.0	
10	All your crops have been failing due to the variations of climate change	Freq.	51	30	21	8	10	2.56
		%	42.5	25.0	17.5	6.7	8.3	
Grand Mean total = 2. 63 Standard mean score = 2.50								2.63

Source: Field Survey, 2023.

Table 3: Climatesmart practices used by cassava farmers

Climatesmart practices	Always	Often	Sometimes	Rarely	Never	($\bar{x}$)	Rank
	%	%	%	%	%		
Change in planting date	54.2	16.7	10.0	10.0	9.2	2.19	9 th
Use of improved varieties	26.7	25.0	23.3	15.8	9.2	2.80	1 st
Crop rotation	44.2	25.0	23.3	5.8	1.7	2.77	2 nd
Mixed cropping	31.7	25.0	22.5	14.2	6.7	2.66	4 th
Minimum tillage	34.2	33.3	22.5	6.7	3.3	2.70	3 rd
Intercropping	22.5	33.3	24.2	7.5	12.5	2.63	5 th
Relocation of farmland	38.3	25.0	19.2	10.8	6.7	2.53	7 th
Early planting	30.0	21.7	16.7	23.3	8.3	2.45	8 th
Late planting	29.2	26.7	25.0	9.2	10	2.55	6 th

Source: Field Survey, 2023

cropping ($\bar{x}$ =2.66), intercropping ($\bar{x}$ =2.63) and late planting ($\bar{x}$ =2.55) in that order. The least used climate-smart practices were relocation of farmland ($\bar{x}$ =2.53), early planting ($\bar{x}$ =2.53) and change in plant dates ($\bar{x}$ =2.19).

Ali *et al.* (2019) corroborated the use of resistant crop varieties as buffer against climate change effects due to their resilience over their life cycles despite difficult environmental conditions, thereby constituting a useful climate-smart strategy (Barasa *et al.*, 2021). Similarly, Jellason *et al.* (2022) referenced intercropping, use of improved crop varieties and soil and water management practices as helpful climate-smart strategies to lessen the effects of climate change in sub-Saharan Africa.

Terdo and Adekola (2014) identified on-farm diversification practices including fisheries and aquaculture; bee, mushroom, orchard and garden farming as crucial to strengthening resilience to climate change and desertification in Northern Nigeria.

Constraints to use of climate-smart practices by the cassava farmers

The constraints to use of climate-smart practices by the cassava farmers reported in Table 4 revealed that 54.2% of them were severely constrained by lack of adequate irrigation facilities, 44.2% by unpredictable weather conditions and lack of knowledge of appropriate climate-smart practices, 37.5% by inadequate government support and 34.2% by lack of information about potential climate variability and inadequate extension officers.

Meanwhile, 36.7% were mildly constrained by lack of information about potential climate variability and inadequate extension officers; 34.2% by lack of own land and 31.7% by lack of credit and loan services and shortage/high cost of required farm inputs.

Afade et al. (2024) concluded that limited access to information and extension services, financial difficulties, poor infrastructure, and pest and disease infestations are constraints to adoption of climate smart strategies among cassava farmers in Delta state, Nigeria. Takahashi et al. (2020) buttressed the important role of extension services in spreading information on climate-smart practices, improving farmers' knowledge and facilitating the effective adoption of sustainable farming methods.

Table 4: Constraints to use of climate-smart practices

Constraints	Severe constraints (%)	Mild constraints (%)	Not a constraint (%)
Lack of adequate irrigation facilities	54.2	25.8	20.0
Lack of own land	26.7	34.2	39.1
Unpredictable weather condition	44.2	26.7	29.1
Lack of credit and loan services	31.7	31.7	36.7
Lack of information about potential climate variability	34.2	36.7	29.2
Lack of knowledge on appropriate climate-smart practices	44.2	26.7	29.1
Shortage and high cost of required farm inputs	31.7	31.7	36.7
Inadequate extension officers	34.2	36.7	29.2
Inadequate government support	37.5	28.3	34.2

Source: Field Survey, 2023

Test of Hypothesis result

Table 5 shows that there was a significant relationship between socioeconomic characteristics and use of climate-smart practices by the cassava farmers ($r=0.809$; $p\leq 0.05$), indicating that respondents socioeconomic status enhanced their ability to relate with climate issues and exposed them to more climate smart practices. Uduma and Nwaobiala (2024) affirmed that socioeconomic factors such as age, marital status, education, farm income and farming experience positively influenced cassava farmers' adoption of climate smart agricultural practices in Imo State, Nigeria.

Table 5: Test of relationship between socioeconomic characteristics and use of climate-smart practices by the cassava farmers

Variables	Mean	SD	df	<i>p</i>	<i>r</i>	Decision
Socioeconomic characteristics	12.46	3.28	198	0.05	0.809*	Rejected
Climate smart practices	28.31	6.40				

Significant at $P\leq 0.05$

CONCLUSION AND RECOMMENDATIONS

Smallholder cassava farmers in Akoko Northwest Local Government Area of Ondo State, Nigeria utilized climate smart agricultural practices especially improved seeds varieties, crop rotation, and minimum tillage. It is therefore recommended that the farmers should be provided with necessary support in form of improved flood and drought resistant seeds and irrigation infrastructure by the government while climate forecasts and

early warning protocols should be efficiently communicated to the farmers by the meteorological agency.

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HOW DO DIGITAL TOOLS AND INCOME STABILITY SHAPE AGRIPRENEURIAL SATISFACTION FOR AGRIBUSINESS PROSPECT? A HECKMAN-CORRECTED ANALYSIS.

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ABSTRACT

This study investigates the complex, joint influence of digital adoption and income stability on agripreneurial satisfaction in Nigeria, addressing a significant gap in the literature which has treated these factors in isolation. Employing a robust methodological design, data was collected from 293 agripreneurs across the value chain. To correct for inherent sample selection bias, whereby technology adopters are not a random subset, a Heckman two-step econometric model was deployed to yield unbiased and precise estimates. Our novel finding reveals a critical and counterintuitive insight: digital tool adoption significantly diminishes satisfaction ($\beta \approx -0.609$, $p < 0.001$) under conditions of income volatility. This demonstrates that technology, without foundational economic security, can exacerbate frustration rather than alleviate it. The study concludes that digitalization is a necessary but insufficient condition for transformation. We therefore recommend a decisive policy pivot from siloed digital access programmes toward integrated "stability-first" frameworks. This entails synergizing digital tools with robust risk-mitigation instruments, such as embedded insurance, forward markets, and financial stabilizers, to build a resilient ecosystem where technological adoption can finally translate into tangible entrepreneurial satisfaction and sustainable sectoral growth.

Keywords: Digital Agriculture, Income Stability, Agripreneurial Satisfaction, Heckman Model, Technology Adoption Paradox

Background, Rationale, and Study Objectives

Agribusiness stands as a vital lifeline for Nigeria, Africa's largest economy, holding the transformative potential to combat youth unemployment, ensure food security, and catalyze a crucial shift away from oil dependency (Ikuemonisan, 2024; Mghenyi *et al.*, 2022). Yet, this promise remains perpetually unfulfilled. The sector is hamstrung by a paradox of potential versus reality: despite abundant resources, it is dominated by smallholders grappling with structural inefficiencies, pervasive informality, and critically, profound income instability (Siankwilimba *et al.*, 2025; Ikuemonisan, 2024). This volatility erodes confidence, discourages investment, and suffocates the long-term commitment of agripreneurs, thereby undermining the very foundation of sustainable agricultural development (Ackello-Ogutu, 2019).

Therefore, this study is designed to cut through this complexity. Its primary objective is to empirically determine how digital tool adoption and income stability *jointly* shape agripreneurial satisfaction and optimism for agribusiness prospects in Nigeria. Recognizing that the decision to adopt technology is not random, a key methodological objective is to employ a robust Heckman two-step selection model to correct for this sample selection bias, ensuring unbiased and precise estimates. The ultimate objective is to move beyond fragmented insights and provide policymakers, development partners, and investors with evidence-based clarity, informing integrated interventions that synergize digitalization with robust risk-mitigation frameworks to finally unlock the sector's vast potential.

Conceptual Framework

The study is anchored in three complementary theoretical frameworks that provide distinct yet interconnected lenses for analysis. Diffusion of Innovation Theory (Rogers, 2003) explains the adoption process of digital tools, emphasizing how perceived relative advantage, compatibility, and complexity influence agripreneurs' decisions to embrace new technologies. This theory helps conceptualize digital adoption as a variable influenced by both technological attributes and user perceptions. Expectation-Confirmation Theory (Oliver, 1980) provides the mechanism for understanding satisfaction formation, positing that agripreneurial satisfaction depends on whether the outcomes of digital tool usage meet or exceed

prior expectations. This theoretical lens is particularly valuable for explaining why adoption alone may not guarantee satisfaction. The Sustainable Livelihoods Framework (Chambers & Conway, 1992) integrates these perspectives by conceptualizing income stability as a form of financial capital that buffers against shocks and vulnerabilities. This framework suggests that the relationship between digital adoption and satisfaction is contingent on stable livelihood assets, particularly reliable income flows. Together, these theories provide a comprehensive foundation for examining how digital tools and income stability interact to shape agripreneurial satisfaction. Building on these theoretical foundations, we propose a "Stability-First Digital Agribusiness" conceptual model that integrates digital tools with income stabilization mechanisms.

MATERIALS AND METHODS

This study employed a robust mixed-methods research design that strategically combined descriptive and inferential approaches to address its complex research objectives. The sampling strategy targeted 381 formally registered agribusiness enterprises across Nigeria's entire agricultural value chain, employing a census-based approach via email-administered questionnaires that yielded a robust 79.3% initial response rate. After rigorous data validation, 293 questionnaires were retained for analysis, representing a 76.9% valid response rate that ensures both statistical reliability and analytical representativeness (Hair *et al.*, 2019). A 7-point Likert scales to capture nuanced perceptions was employed.

The analytical approach centred on the Heckman two-step selection model, which was essential for correcting potential sample selection bias arising from non-random participation in digitally-supported agribusiness (Heckman, 1979). This sophisticated modeling strategy involved first estimating a selection equation for agribusiness engagement followed by an outcome equation for satisfaction determinants, thereby producing unbiased estimates of how digital adoption and income stability shape agripreneurial satisfaction while controlling for socio-economic and operational factors. The integration of primary survey data with secondary income records for objective stability measurement further strengthened the methodological validity, ensuring both contextual depth and statistical rigor in addressing the study's research questions.

RESULTS AND DISCUSSION

Table 1 reveals widespread digital adoption across Nigeria's agribusiness landscape, with 84% of the 293 surveyed agripreneurs utilizing digital tools, demonstrating that this technological integration is now an integral feature across the entire value chain—from primary production (e.g., Agric Farms at 80%) and processing (82%) to specialized input and service sectors like Fertilizer (89%) and Agro-Advisory (88%). This broad uptake signals a structural shift towards digitalization, enabling efficiency and market access even in traditionally manual sectors, though a small but persistent non-adopter minority (16%) indicates an ongoing digital divide. These descriptive findings set the stage for subsequent multivariate analysis, which employed a Heckman correction to precisely quantify the impact of digital adoption on agripreneurial satisfaction while controlling for demographic and sectoral factors and correcting for potential sample selection bias inherent in the study's sampling frame.

Table 2 reveals that adopters of digital tools are predominantly young to middle-aged (mean age 37.4), highly educated (mean 14.5 years of schooling), and experienced agripreneurs (mean 18.8 years in business), indicating that digital uptake is driven by a capable and established demographic segment. Despite high perceived relevance of digital tools (mean 5.03/7), users report low operational flexibility (2.39) and satisfaction (2.19), alongside moderate institutional support (3.83) and very weak network characteristics (1.62), suggesting significant barriers to translating technology use into tangible business benefits. Furthermore, extreme income inequality among adopters highlights considerable economic disparities, implying that while digital tools are widely adopted, their effectiveness and impact vary substantially across different segments of the agribusiness sector.

Table 3 reveals that Non-adopters of digital tools demographically mirror adopters in age (mean 37.1 years) and education level (mean 14.3 years), but are significantly less experienced (mean 11 years vs. 18.8), indicating that practical exposure to agribusiness challenges, not age or formal education, is a primary driver

of technology adoption. Despite similar average incomes, non-adopters operate within a much narrower income band, suggesting they are predominantly small to medium-scale operators who report higher perceived flexibility (4.43) and satisfaction (4.30) with their current operations, potentially due to stronger traditional networks (3.90) that reduce their perceived need for digital tools, while weaker institutional support (3.07) and lower perceived relevance of technology (4.11) further reinforce their resistance to adoption. This profile reveals a cohort that is not technologically excluded but rather selectively reliant on established, non-digital systems that currently meet their operational needs.

Table 1: Distribution of Respondents by Agripreneurial Sector & Digital Adoption

Agripreneurial Sector	No Adoption (.00)	%	Adoption (1.00)	%	Total
Agric Equipment	4	1.37	21	7.17	25
Agric Farms	7	2.39	28	9.56	35
Agro-Allied Products	4	1.37	19	6.48	23
Agro Oil	3	1.02	14	4.78	17
Chemicals & Pesticides	3	1.02	16	5.46	19
Commodity Products	4	1.37	19	6.48	23
Fertilizer	1	0.34	8	2.73	9
Livestock Farming	6	2.05	28	9.56	34
Livestock Feeds	4	1.37	23	7.85	27
Palm Fruit & Kernel	2	0.68	13	4.44	15
Produce Processing	5	1.71	23	7.85	28
Cocoa Merchants	3	1.02	16	5.46	19
Agro-Advisory Service Providers	2	0.68	14	4.78	16
Agritech Firms	1	0.34	3	1.02	4
Grand Total	47	16.04	246	83.96	293

Source: Field Survey, 2025

Table 2: Descriptive Statistics of Adopters of Digital Tools

	N	Minimum	Maximum	Mean	Std. Deviation
Age	246	19.00	64.00	37.4431	9.73835
Experience in Agribusiness	246	8.00	36.00	18.8331	5.62882
Years spent in School	246	3.00	22.00	14.5122	3.31445
Mean of Income (000)	246	187134.17	548581.13	193259.5126	40017.09697
Variance of Income (000)	246	1484559.63	107437851.40	10199930.634	11237001.404
Perception of Operational Flexibility (POF)	244	1.17	6.70	2.3854	2.60227
Agripreneurial Satisfaction (AS)	242	1.40	7.00	2.1909	2.61117
Relevance & Use of Remote Farm Management & Digital Tools in Agribiz (RDM)	236	1.20	6.58	5.0271	2.63556
Perception of Institutional Support (PIS)	246	1.35	6.95	3.8292	2.2704
Perception of Network Characteristic (NC)	234	.20	5.77	1.6202	2.4774

Source: Field Survey, 2025

Table 3: Descriptive Statistics -Non-Adopters of Digital Tools

Descriptive Statistics -Non-Adopters of Digital Tools	N	Minimum	Maximum	Mean	Std. Deviation
Age	47	20.00	63.00	37.1277	9.79045
Experience in Agribusiness	47	3.00	37.00	11.0219	8.26683
Years spent in School	47	8.00	22.00	14.2979	3.21623
Mean of Income (000)	47	57239.24	319185.01	193365.8939	61184.41634
Variance of Income (000)	47	6205640.09	128127499.40	34728624.906	23985425.687
POF	45	1.17	6.17	4.4333	2.60240
PAW	45	1.08	7.00	4.3022	2.64754
RDM	45	1.20	6.83	4.1111	2.56285
Perception of Institutional Support (PIS)	47	1.00	4.95	3.0722	1.9519
Perception of Network Characteristic (NC)	45	1.00	6.88	3.8992	2.0632

Source: Field Survey, 2025

3.1 Regression Results

Table 4 presents the Heckman Two-Step Regression Results. The Heckman-corrected model reveals that agripreneurial satisfaction is significantly enhanced by education, experience, operational flexibility, higher mean income, and strong networks, while being severely diminished by income volatility, an effect that is exacerbated by digital tool usage, as evidenced by a significant negative interaction term ($\beta \approx -0.609$, $p < 0.001$) which indicates these tools provide less satisfaction under financial instability. The selection equation further demonstrates that adoption itself is driven by skilled, well-networked, and experienced agripreneurs with stable incomes and institutional support, while income variability strongly discourages uptake. Consequently, effective policy must not only promote digital access and literacy but also prioritize income stabilization measures, as the benefits of digital tools are critically contingent upon reducing financial uncertainty in agribusiness operations.

Table 4: Heckman Two-Step Regression Results

	Coefficient	Std. err.	Z	P> z	[95% conf. interval]	
Agripreneurial Satisfaction (AS)						
RDM	0.018644	0.04966	0.37541985	0.7073	0.006131	0.059761
Education	0.0349584	0.0094453	3.7011424	0.0002	0.023471	0.083554
POF	0.0259343	0.0088128	2.9427991	0.0033	0.002166	0.0869737
Mean income	4.11E-04	8.02E-05	5.1311539	0.0000	1.20E-05	5.21E-04
Varincome	-4.41E-06	5.39E-09	-818.9239	0.0000	-3.50E-07	-1.20E-05
Experience	0.014339	0.0029738	4.8217769	0.0000	0.006076	0.050359
NC	0.0113043	0.0011898	9.5010086	0.0000	0.006363	0.020278
Zrdm*Varincome	-0.609228	0.025289	-24.091013	0.0000	-0.555013	-0.850417
_cons	0.7814817	0.1124991	6.9465596	0.0000	-0.027002	1.589965
Digitally Supported Agribusiness						
RDM	0.3796471	0.1527179	2.485937	0.0129	0.478969	0.7196744
Mean income	5.77E-06	2.91E-06	1.982818	0.0474	6.80E-08	0.0000115
Var income	-1.78E-08	7.82E-09	-2.276215	0.0228	-3.32E-09	-2.49E-07
Experience	0.1025938	0.009932	10.329621	0.0000	-0.016873	0.0220602
PIP	0.2368732	0.1187157	1.995298	0.0460	-0.208347	0.682093
POF	0.2083267	0.0982528	2.120313	0.0340	-0.378497	0.2418431
Education	0.0617436	0.0094054	6.564697	0.0000	-0.217375	0.0938881
NC	0.741387	0.02418	30.66129	0.0000	0.509583	0.8068052
Zrdm*Varincome	-0.886999	0.393086	-2.256500	0.0240	-0.855013	-0.950417
_cons	1.071561	0.3364176	3.185211	0.0014	-0.763784	2.9069061
/mills						
Lambda	.1506129	.0506881	2.971366	0.0030	-1.320709	1.621935

Source: Field Survey, 2025

CONCLUSION

This study concludes that while digital adoption in Nigerian agribusiness is widespread and transformative, it constitutes a necessary but insufficient condition for improving agripreneurial outcomes. The full potential of digital tools is contingent upon foundational enablers, particularly income stability, robust institutional support, and strong networks, that determine whether technology adoption translates into meaningful satisfaction and productivity gains. Consequently, policymakers must pivot from promoting digital access alone toward implementing integrated strategies that simultaneously address financial volatility, strengthen institutional ecosystems, and leverage existing networks to ensure that digitalization delivers tangible improvements in livelihoods and sectorial resilience.

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ASSESSMENT OF MAIZE PRODUCTION ON HOUSEHOLD INCOME AMONG SMALL SCALE FARMERS IN BOSSO LOCAL GOVERNMENT AREA, NIGER STATE NIGERIA.

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ABSTRACT

The study focused on assessment of the effect of maize production on small-scale farming households in Bosso L.G.A Niger State, Nigeria. A multistage sampling technique was used for the selection of 122 smallholder maize farmers for the study. A well-structured questionnaire containing both open- and closed-ended questions was used to collect the data for the study. Descriptive statistics such as percentages and frequencies and multiple regression analysis were used to achieve the objectives of the study. The findings revealed that majority (87%) of the farmers were male, 93% were married, 33.41% were between the age range of 31-40 years, 39.34% had no formal education. On factors affecting maize production, 73.77% have no access to credit, 68.03% have no access to modern farm implements, 88.53% have no access to extension services and 92.62% have no access to irrigation. On the effects of maize production on household income for four years, the result of the multiple regression analysis showed that farm size (coefficient of 0.108), experience (coefficient of 0.039), and age (coefficient of 0.013) were all statistically significant at 1% probability level (< 0.01), while access to modern implements (coefficient of 0.189) was statistically significant at 10% probability level (< 0.10). Identified challenges facing maize farmers within the study area were high cost of inputs, climate change, high interest rate, absence of training programs, and lack of access to market support. Major recommendations were to subsidize farm inputs and modern farm implements, provide a low interest rate, and allocate more land for agricultural purposes.

Keyword; Production, Income, Household, Farmers, Small Scale.

INTRODUCTION

Maize (*Zea mays*) is a tall, robust grass that produces cereal grain, and is propagated by humans. With a total production that frequently exceeds that of wheat and rice, maize is a staple food in many parts of the world and a substantial source of protein, minerals, carbohydrates, and vitamin B (Wikipedia, 2025). According to Karimov *et al.* (2014), it is considered to be one of the most extensively consumed basic food crops worldwide, including in Nigeria. Been one of the world's main cereal crops and is essential to Nigeria's food system; it is widely consumed, and makes a substantial contribution to agro-processing, livestock feed, and food security (Abdulaleem *et al.*, 2019). Due to its many uses, including as a locally consumed food and others, maize is one of the most widely grown cereal crops in Niger State, which has a large amount of land available for agriculture. Small-scale farming significantly contributes to the diversification of the agricultural landscape metrics and consequently, to the supply of many ecosystem services. It is closely associated with more sustainable agricultural practices (Agro-Ecology, 2024). Globally, over two billion people rely on the 500 million smallholder farms for their livelihoods. Approximately 80% of the food consumed in Asia and Sub-Saharan Africa is produced by these small farms (IFAD, 2024). Subsistence farmers, who own small farm holdings ranging from 0.5 hectares to roughly 4 hectares, make up the majority of farmers in Africa.

Given that the majority of people in Sub-Saharan Africa (SSA) depend on smallholder family farming for a living, it is imperative to uphold the agenda for economic growth and poverty reduction, and promotion of the innovations of smallholder farmers (Rieko, 2019). In Bosso Local Government Area, the majority of Gidan-Mangoro and Dama Community's population are small-scale farmers who engage in agriculture as a major source of livelihood. Maize is regarded a primary crop cultivated by small-scale farming households due to its tolerance to varied agro-climatic conditions and short maturity period (Ubandoma *et al.*, 2024). Despite the economic potential and adaptability of maize cultivation, small-scale farmers in Gidan-Mangoro and Dama communities face persistent production challenges. These include limited access to improved inputs like certified seeds and fertilizers, irregular rainfall, poor soil fertility, pests and diseases, inadequate storage and processing facilities, and minimal institutional support (Sanusi *et al.*, 2010; Ojo and Mohammed, 2007). These constraints significantly reduce productivity and threaten food security and household income. Based on the foregoing, the study aimed to:

1. examine the socio-economic characteristics of small-scale maize farming household in the study area
2. assess the effects of maize production on household income among small-scale maize farmers in the study area.

METHODOLOGY

Niger State, a fully autonomous state in Nigeria, was established in 1976 and comprises 25 Local Government Areas, with a population of 3,954,772 according to the 2006 census. (NPC, 2006). Niger State shares boundaries with Zamfara, Kaduna, and the Federal Capital Territory (FCT) in the north, east, and south, respectively. Niger State's fertile land produces staple crops like yam, cassava, and rice, with farming being the primary activity, employing 80% of the workforce and providing abundant natural vegetation (NSBS, 2012). Niger State experiences 1209.7 mm of precipitation annually, with August and December being the wettest and driest months (Weather and Climate, 2024). A multistage sampling technique was adopted. Respondents were selected using a random sampling technique. In the first stage, one (1) L.G.A. was selected; in the second stage, two (2) communities were randomly selected from the L.G.A. earlier

Table 1: Sampling outlay of the respondents

L.G. A	Communities	Sample Frame	Sample Size (90%)
Bosso	Gidan -Mangoro	100	90
	Dama	72	61
Total		172	151

Source: Gbadamanda Cooperative Society, Gidan -Mangoro, 2025.

Primary data were used for the study. Primary data or information on demography, economy, operation, and environment were collected or obtained through personal observations and the use of a systematic closed-ended survey questionnaire that was customized to the goals of the study. One hundred and ten structured questionnaires geared toward the goals of the study were administered to the target respondents, who were small-scale maize farmers in the study area, through the use of the KoboCollect data collection mobile application. Data were retrieved from the KoboCollect cloud-based online platform for further statistical analysis. farmer, education level, farm size, years of experience, access to input, access to credit, access to market, access to agricultural extension services, and access to modern farm implements (mechanized farm

RESULTS AND DISCUSSIONS

Gender The frequency of male farmers was higher, having a value of 87, which accounted for 71.31% of total small-scale maize farmers identified. Female small-scale farmers made up a frequency of 35, accounting for 28.69% of the total small-scale maize farmers selected. This indicates that males are more into maize farming within the study area than females.

Marital status A total of 93 of the farmers were married, which accounted for 76.23% of the total number of identified farmers; 25, which accounted for 20.49%, were single; and a total of 4 farmers, which accounted for 3.28%, were widowed, while none were divorced. This implies that the majority of the farmers are married.

Age(years) A total of 6 farmers, which accounted for 4.92% of the total number of identified farmers, were under 20 years of age; a total of 25 farmers, accounting for 20.49%, fall within the age range of 21-30 years. 41 farmers within the age range of 31-40 years accounted for 33.61%, a total of 39 farmers within the age range of 41-50 accounted for 31.97%, while only 11 farmers, which accounted for 9.02%, were above 50 years. This implies that farmers between the age range of 31-40 are more involved in maize farming within the study area.

Education level A total number of 48 farmers, which accounted for 39.34%, were with no formal education; 23 of them, which accounted for 18.85%, had a primary education; a total of 39, accounting for 31.97%, had a secondary education; while only 12 of the farmers, which accounted for 9.84%, admitted having a tertiary education. This implies that farmers with no formal education were more common compared to other levels of educational background within the study area.

Household size A total of 7 farmers, which accounted for 5.74%, have a household size in the range of 1-3 persons; a total of 53 farmers, which accounted for 43.44%, admitted to having a household range between 4-6 persons; a total of 36 farmers, which accounted for 29.51%, have a range of 7-9 persons; while 10 of the

farmers, accounting for 20.49%, have a household size of above 10 persons. This implies that the majority of the farmer's household sizes are in the range of 4-6 persons.

Table 2: Socio-Economic Characteristics of Small -scale Household Maize Farmers

Socio-Economic Characteristics	Frequency	Percentage (%)
Gender		
Male	87	71.31
Female	35	28.69
Total	122	100
Marital status		
Married	93	76.23
Single	25	20.49
Widowed	4	3.28
Divorced	0	0
Total	122	100
Age of farmers		
Under 20	6	4.92
21-30	25	20.49
31-40	41	33.61
41-50	39	31.97
Above 50	11	9.02
Total	122	100
Education level		
No Formal Education	48	39.34
Primary	23	18.85
Secondary	39	31.97
Tertiary	12	9.84
Total	122	100
Household Size		
1-3	7	5.74
4-6	53	43.44
7-9	36	29.51
10 and above	25	20.49
Total	122	100

Occupation; A total of 50 farmers, which accounted for 40.98% of the total farmers identified, admitted farming being their only occupation; a total of 61 of the identified farmers, which accounted for 50%, were into farming and trading. A total of 8 farmers, which accounted for 6.56%, were into farming as well as civil service, while only 3, which accounted for 2.46%, mentioned other occupations such as fabrication and barbing. This implies that the majority of the identified small-scale maize farmers were into both farming and trading.

Farming experience(years); A total of 3 farmers, which accounted for 2.46% of the total farmers, have an experience below 3 years; a total of 15 farmers, accounting for 12.3%, have an experience ranging from 3 to 6 years. A total of 24 farmers, which accounted for 19.67%, have an experience range of 7-10 years, while a total of 80 farmers, accounting for 65.57%, have a farming experience of above 10 years. This implies that the majority of the identified small-scale maize farmers have a farming experience that is more than 10 years.

Method of land acquisition; A total of 63 farmers, accounting for 51.64%, admitted owning the lands they farm on; a total of 31, accounting for 25.41%, rented their lands; while a total of 28 of the farmers, which accounted for 22.95%, farm on both rented and owned lands. This implies that the majority of the farmers were landowners and farmed on their own lands.

Farm size(ha); A total of 15 farmers, which accounted for 12.3%, cultivate on less than 1 hectare of land, and a

total of 73 farmers, which accounted for 59.84%, cultivate on hectares ranging from 1 to 2. A total of 28 farmers, accounting for 22.95%, cultivate on a range between 3 and 4 hectares, while a total of 6 farmers, which accounted for 4.92% of the total farmers, cultivate on hectares of land above 5. This implies that the majority of the small-scale maize farmers cultivate or farm on 1-2 hectares of farmland within the study area.

Table 3: Socio-Economic Characteristics of Small-scale Household Maize Farmers cont.

Gender	Frequency	Percentage
Occupation of farmers		
Farming only	50	40.98
Farming and trading	61	50
Farming and civil service	8	6.56
Others	3	2.46
Total	122	100
Farming experience of farmers		
Below 3yrs	3	2.46
3-6yrs	15	12.3
7-10yrs	24	19.67
Above 10yrs	80	65.57
Total	122	100
Method of land acquisition		
Own	63	51.64
Rent	31	25.41
Both	28	22.95
Total	122	100
Farm size		
Less than 1 hectare	15	12.3
1-2 hectares	73	59.84
3-4 hectares	28	22.95
Above 5 hectares	6	4.92
Total	122	100

Source: Field Survey, (2025).

Effects of Maize Production on Household Income among Small-scale Maize Farmers in the Study Area

Table 4; illustrates maize production impacting factors on household income among small-scale maize farmers within the study area. The computed R-squared was 0.583, implying that approximately 58% of the variation in the dependent variable (income of small-scale household maize farmers) was explained by the included independent variables. The remaining 42% did account for other important variables not captured. An F-value of 5.735 was significant at 1% ($p < 0.01$), implying that the entire model is fit for the data used. Coefficient of determination, R-square at 0.340, implies that 34% of the impact of maize production on household income among small-scale maize farmers in the study area is captured in the model, whereas 64% remains uncaptured by the model.

Farm size(ha); The coefficient of farm size is positive at 0.108 and statistically significant at 1% ($p < 0.01$), implying that at every increase in farm size, the income generated by small-scale household maize farmers increases by 0.108 units (11%), while holding other variables constant. This is in agreement with the outcome of studies by Ninh (2021) and Ezike *et al.* (2024) that farm size has significant impacts on rice and maize outputs, respectively. Farm size, as reported by Mohammed (2021), had a positive influence on the quantity of maize production. Obi and Ayodeji (2020) equally stated how farm size is a key determinant of economic and technical efficiencies in maize production. Larger farm size allows for more maize cultivation and more income generation by maize farmers. Findings such as this highlight the importance of making lands more available so as to enhance the productivity and income-generating capacity of maize household farmers within the study area.

Experience(years); The coefficient of experience is positive at 0.039 and statistically significant at 1% ($p < 0.01$), implying that for any additional year of farming experience, income generated by a small-scale maize farming household increase by 3.9%, holding other factors constant. This agreed with a study by Utonga (2022), that experience facilitates farmers in improving production techniques through reasonable thinking.

Farmers with many years of farming experience are practically exposed to maize cultivation and tend to achieve higher earnings due to accumulated skills and better decision-making, as well as improved resource management over time. Ideally, they are always the ones who mentor young farmers that are new to farming due to their years of experience.

Age (years); The coefficient of the farmer's age is positive at 0.013 and statistically significant at 1% ($p < 0.01$), implying that each additional year of age corresponds to a 1.3% increase in household income generated by the farmer, with other factors being constant. Mature adult farmers have more skills, strength, and ideas compared to younger ones and tend to generate higher household income, likely due to accumulated farming skills, stronger social networks, and better resource management. A mature farmer has more needs to take care of and sees the reason to engage more in production so as to meet those needs through the income generated from the production of maize as well as having enough for his family's consumption. The older a farmer is, the more experience he will have in managing challenges that will negatively impact maize production. Maturity and long-term engagement in agriculture seem beneficial for maize production and what can be regarded as marketing outcomes. This agreed with finding by Adeola *et al.* (2024) that factors such as age, farm size, education level, and credit availability have significant impact on a farmer efficiency and maize output.

Access to modern farm implements Access to modern farm implements having a positive coefficient value of 0.189 and being statistically significant at 10% ($p < 0.10$) implies that, holding other factors constant, a small-scale maize farmer who has access to modern farm implements earns approximately 18.9% more of household income than those with no access. A maize farmer's access to implements such as tractors, ploughs, planters, ridges, and others is associated with higher income generated from maize production. As a result of their aid in improving production efficiency and yields, resulting in higher sales and earnings, access to affordable farm implements could be a practical intervention for boosting the income of small-scale household maize farmers within the study area.

Table 4; Effects of maize production on household income among small -scale maize farmers in the study area

Variable	Coefficients	Standard Error	t-value	P-value
Intercept	12.000	0.568	21.100***	1.199E-40
Farm Size(ha)	0.108	0.038	2.836***	0.005
Experience(yrs)	0.039	0.014	2.753***	0.006
Age(yrs)	0.013	0.004	2.782***	0.006
Education level	0.027	0.047	0.585	0.559
Access to extension or agricultural advisory support	-0.091	0.161	-0.568	0.570
Access to credit	-0.102	0.111	-0.914	0.362
Access to modern implements	0.189	0.102	1.843*	0.067
Access to Inputs	-0.314	0.468	-0.670	0.504
Household Size	0.012	0.017	0.734	0.464
Access to irrigation	0.213	0.212	1.004	0.317
At 1%	< 0.01	—		Multiple R
At 5%	< 0.05	—		R Square
At 10%	< 0.10	—		Adjusted R Square
F-value (5.735)	6.66E-07	*		

Source: Field Survey, (2025).

CONCLUSION AND RECOMMENDATIONS

The study evaluated the effect of maize production on small-scale farming households in Gidan-Mangoro and Dama communities, Bosso L.G.A., Niger State, Nigeria. Findings showed that maize production is important for maintaining livelihoods, increasing household income, and promoting food security. According to the

socioeconomic characteristics, the majority of farmers were male, in their active working years, and had varied levels of education and farming experience. However, climatic and market-related issues, as well as restricted access to modern farm implements, irrigation, credit facilities, extension services, and improved inputs, hindered productivity.

From the regression analysis results, household income from maize farming was highly impacted by a number of characteristics, including farm size, age, years of farming experience, and access to modern farm implements. This emphasizes how crucial it is to implement focused interventions to increase farmers' access to training and productive resources. The study also found that although structural obstacles prevent maize from reaching its full potential in reducing poverty, it is still a staple crop in the region and is largely used for household consumption and income production.

Increasing maize productivity in these communities necessitates a multipronged strategy that includes market connections, supportive infrastructure, and improved access to high-quality inputs, credit, and extension services. In addition to increasing maize yields, addressing these issues with well-crafted policies and community-based support networks will also boost food security, increase household welfare, and encourage sustainable rural development.

Based on the findings, the following recommendations are made.

- i. More land should be allocated to agriculture than infrastructure. More land will encourage large-scale farming, which will enhance more maize production and more income generation by farming households.
- ii. High cost of inputs such as fertilizer, improved seeds, and chemicals poses a great challenge to maize farmers in actualizing a greater income. Subsidizing farm inputs by the government and NGOs will not only make them available but also affordable for maize farmers to access.
- iii. Low-interest loans should be available for maize farmers; a low-interest loan will encourage more people, especially youths, to go into farming, as loans at a lower rate are readily available to access. Making available these loans by the government through Banks of Agriculture, NGOs, and the Ministry of Agriculture will encourage the purchase of modern farm implements, renting more farmlands, as well as the purchase of more inputs.
- iv. Extension services provide a medium by which farmers obtain modern agricultural practices. Extension workers communicate recent innovations and technologies geared towards improving farming practices. The service also provides a forum by which the government implements agricultural programs that are beneficial to farmers with regard to farmers identified challenges. Availability of more of such services will ensure identified challenges are addressed through programs and initiatives

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DETERMINANTS OF CONSUMERS' SOCIO-ECONOMIC CHARACTERISTICS ON WILLINGNESS TO PAY FOR SAFE FOOD IN SOUTH-WESTERN NIGERIA.

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ABSTRACT

Food safety remains a critical public health challenge in Nigeria, where weak regulatory systems and limited consumer awareness contribute to persistent foodborne illnesses. Socio-economic characteristics of any population are crucial to measure its capacity to pay premiums for safe food, to maintain a healthy lifestyle and thus improve longevity. While it is general knowledge that food consumers in advanced economies are willing to pay more for safe foods, little is known about Marginal Willingness To Pay (MWTP) for safe food in Nigeria. This study examines the interplay between socioeconomic factors and MWTP for certified safe food in Nigeria. Using a quantitative, cross-sectional design, we surveyed 257 civil servants across four southwestern states, selected through a multi-stage stratified sampling approach. Multinomial Logit model (MNL) was used to identify socioeconomic determinants of consumers which influence their MWTP for safe foods. Our analysis reveals that Education (OR=1.242) and urban residence (63.4% vs. 36.6% WTP) strongly predict MWTP, while income effects are non-monotonic. These findings challenge conventional applications of behavioural theories in low-income, collectivist contexts and highlight the need for culturally tailored policy interventions. We propose targeted consumer education and progressive subsidy models to align market incentives with public health goals.

Keywords: Food safety, willingness to pay, socio-economic characteristics, Nigeria.

INTRODUCTION

According to the World Health Organisation (WHO, 2022), unsafe food causes an estimated 600 million illnesses and 420,000 deaths worldwide each year. Globally, the rising cost of safe foods is a major cause for consumption of unsafe and low-quality foods. This observation is more evident among people in the African continent where most countries had over the years, being negatively affected by unsustainable debt burdens, low productivity in farming and lower earning potential when compared with consumers in other continents in the world. Most Nigerians in particular, have limited capacity to consume safe foods due to several constraints. Firstly, Adekunle et al. (2021) reported that food safety systems remain fragmented and underdeveloped and consumers face significant information asymmetry that makes it difficult to distinguish between safe and unsafe food products. Furthermore, the nature of several factors which influence affordability of safe foods is unknown. There remains a significant gap in understanding how consumers' socio-economic demographics influence their willingness to pay (WTP) for certified safe food. This study aims to address this critical knowledge gap by investigating the relationship between socio-demographic factors and marginal WTP for safe food in the Nigerian context.

This research offers analytical insights for understanding how Nigerian consumers value food safety which is essential for building a healthier, more sustainable food system in Africa's most populous nation. The objective of this study is to examine how socioeconomic factors (age, education, income, and location) influence consumers' marginal willingness to pay (WTP) for safe and nutritious food in Nigeria.

The hypothesis which was tested in this study is stated thus:

H₁: Higher levels of education and income are positively associated with greater marginal WTP for safe and nutritious food in Nigeria.

MATERIALS AND METHODS

Study Area and Sampling Strategy

The study was conducted in four strategically selected states within Southwest Nigeria, chosen to reflect the

region's diverse socioeconomic landscape (National Bureau of Statistics, 2022). They are; Lagos, Oyo, Ondo and Ekiti States. To determine an appropriate sample size, Cochran's (1977) finite population formula was employed using a 95% confidence level ($Z = 1.96$), an assumed maximum variance ($p = 0.5$), and a 5% margin of error. Given the finite population of civil servants ($N = 12,450$) across the four selected states, the formula was corrected accordingly, following Bartlett et al. (2001), resulting in a final sample size of 272 respondents. A rigorous multi-stage sampling protocol was adopted to ensure proportional representation. In the first phase, stratified random sampling was utilized to select 27 Local Government Areas (LGAs), representing 30% of the total LGAs in the four states. Stratification was based on relative population sizes and the distribution of public sector workers, in line with data from the National Population Commission (NPC, 2023) and Yamane's (1967) methodological guidance. The second phase employed probability proportional to size (PPS) sampling to select five key departments within each chosen LGA, further stratifying administrative units by employment grade to capture diversity in job roles. In the final phase, simple random sampling was conducted to select 272 civil servants, achieving a representative mix across demographic and occupational strata: 52% male, 48% female, with 40% in junior positions, 35% in middle-level roles, and 25% in senior cadres.

Data Analysis

Model Justification

Since the dependent variable (Willingness to Pay – WTP) has four ordered but non-hierarchical categories, a Multinomial Logistic Regression (MNL) model is appropriate (Long and Freese, 2014). This model helps assess how socio-demographic factors influence consumers' marginal WTP for safe food (Hosmer et al., 2013).

Variables Specification

Dependent Variable (Y): Willingness to Pay (WTP) is in categories: Category 1 (Reference): WTP with no price increase, Category 2: WTP if price increases up to 10%, Category 3: WTP if price increases up to 20% and Category 4: WTP if price increases more than 20%.

Independent Variables (X) are: (i) Age (Continuous) (ii) Education level (iii) Total Household Income (Continuous) (iv) Household Size (Discrete).

Model Formulation

Following the procedure of Agresti (2018), the MNL model estimates the probability of a consumer falling into WTP Category 1, 2 or 3 relative to the reference (Category 4).

Probability Equations:

For four categories ($J = 4$), the probabilities are:

i. Reference Category (No Increase in WTP):

Where:

- i. X_i = Vector of independent variables for individual i
- ii. β_j = Coefficients for Category j

Model Fit and Validation

- i. Pseudo R^2 (McFadden's) assesses goodness-of-fit (McFadden, 1974)..
- ii. Hosmer-Lemeshow Test checks calibration. (Hosmer et al., 2013).

The assumption of this study is that MNL model effectively captures how socio-demographic factors influence consumers' WTP for safe food under different price increase scenarios (Long and Freese, 2014). The results will help policymakers and food producers understand consumer behaviour and tailor pricing strategies accordingly (Louviere et al., 2015).

Hypothesis Testing

Wald Test checks if coefficients (β_j) are statistically significant (Menard, 2002).

RESULTS

Descriptive Statistics

Socioeconomics of Respondents

Table 1 shows that younger consumers, aged 35 years and below, are more likely to pay up to 10% more (57.8%), which reflects their growing awareness of health and nutrition. In contrast, middle-aged consumers (46-55 years) demonstrate a higher willingness to pay 20% or more (35.3%), likely due to greater financial stability and heightened health concerns. Older consumers, aged 66 and above, are less willing to pay extra, possibly because of fixed incomes or long-established consumption habits that prioritize affordability over premium food options.

Education also plays a critical role in shaping WTP. Respondents with 13-18 years of education are the most willing to pay up to 10% more (45.8%), suggesting that higher levels of education correlate with greater nutrition knowledge and health consciousness. On the other hand, those with fewer years of education (≤ 6 years) are less willing to pay extra, potentially due to limited awareness of the benefits of nutritious food or financial constraints that make it difficult to prioritize premium options.

Income levels further influence WTP, with higher-income groups (210,001.00+) showing a greater willingness to pay more than 20% extra (15.4%). This indicates that financial capacity is a key determinant in consumers' ability and willingness to invest in healthier food choices. Conversely, lower-income groups ($\leq 35,000.00$) are less willing to pay extra, as budget constraints often force them to prioritize affordability over nutritional value.

Community status also impacts WTP, with urban respondents showing a higher willingness to pay up to 10% more (63.4%). This is likely due to better access to information, higher average incomes, and greater exposure to health trends in urban areas. Rural respondents, on the other hand, are less willing to pay extra, possibly because of lower incomes or limited access to diverse and premium food options.

Employment status further underscores the influence of financial stability on WTP. Employed and self-employed respondents are more willing to pay up to 10% more (57.1% and 60.0%, respectively), reflecting their financial stability and heightened health awareness. Unemployed respondents, however, are less willing, likely due to income constraints that limit their ability to prioritize premium food choices.

Influence of Consumers' Socio-economic Characteristics on their Marginal Willingness to Pay for Safe Food

Model Fitting Information

The model fitting information (Table 3) demonstrates that the final logistic regression model provides a significantly better fit to the data than an intercept-only (null) model, as evidenced by the substantial reduction in -2 Log Likelihood from 777.259 to 658.433 and the highly significant likelihood ratio test ($\chi^2=118.826$, $df=30$, $p<0.001$). The pseudo-R-square values in Appendix 2 (Cox and Snell=0.287, Nagelkerke=0.322, McFadden=0.153) indicate that the model explains a moderate proportion of the variance in willingness to pay for safe food, with Nagelkerke's value suggesting the model accounts for approximately 32.2% of the explainable variation, which is considered reasonably good for behavioural research models of this nature. These statistics collectively confirm that the specified model with all included predictors fits the data significantly better than a null model and has meaningful explanatory power for understanding Nigerian consumers' willingness to pay premiums for safe food.

Multinomial Regression Output (Reference Category: More than 20%)

Education level emerges as the most consistent socioeconomic predictor, showing significant positive effects across all premium levels (0%: OR=1.242, $p<0.001$; 10%: OR=1.152, $p=0.001$; 20%: OR=1.147, $p=0.005$). This robust pattern confirms that education enhances valuation of food safety, likely through greater health knowledge and disposable income. Household income shows significant but non-linear effects, mattering most at price extremes (0% and 20% premiums), suggesting income operates differently at various premium thresholds - acting as both an enabling factor and a constraint. Wald tests confirms that coefficients of

Table 1: Percentage Distribution of Socioeconomics Across WTP Categories**Age (Binned) vs. WTP**

Age (Binned)	0%	Up to 10% more	Up to 20% more	More than 20% more	Total
<= 35.00	11.1%	57.8%	22.2%	8.9%	100.0%
36.00 - 45.00	13.6%	63.6%	13.6%	9.1%	100.0%
46.00 - 55.00	0.0%	47.1%	35.3%	17.6%	100.0%
56.00 - 65.00	0.0%	66.7%	33.3%	0.0%	100.0%
66.00+	0.0%	100.0%	0.0%	0.0%	100.0%
Total	9.1%	58.0%	22.7%	10.2%	100.0%

Education Level vs. WTP

Education Level	0%	Up to 10% more	Up to 20% more	More than 20% more	Total
<= 6.00	0.0%	63.2%	21.1%	15.8%	100.0%
7.00 - 12.00	0.0%	90.0%	10.0%	0.0%	100.0%
13.00 - 18.00	16.7%	45.8%	27.1%	10.4%	100.0%
19.00 - 24.00	0.0%	70.0%	20.0%	10.0%	100.0%
25.00+	0.0%	100.0%	0.0%	0.0%	100.0%
Total	9.1%	58.0%	22.7%	10.2%	100.0%

Total Household Income vs. WTP

Total Household Income	0%	Up to 10% more	Up to 20% more	More than 20% more	Total
<= 35000.00	0.0%	100.0%	0.0%	0.0%	100.0%
35001.00 - 70000.00	14.3%	42.9%	28.6%	14.3%	100.0%
70001.00 - 105000.00	25.0%	37.5%	37.5%	0.0%	100.0%
105001.00 - 140000.00	10.0%	40.0%	40.0%	10.0%	100.0%
140001.00 - 175000.00	22.2%	55.6%	22.2%	0.0%	100.0%
175001.00 - 210000.00	9.1%	54.5%	27.3%	9.1%	100.0%
210001.00+	3.8%	65.4%	15.4%	15.4%	100.0%
Total	10.7%	56.0%	24.0%	9.3%	100.0%

Education level vs. WTP

Educational level	0%	Up to 10% more	Up to 20% more	More than 20% more	Total
Tertiary Education	9.6%	59.0%	21.7%	9.6%	100.0%
Secondary Education	0.0%	25.0%	50.0%	25.0%	100.0%
Primary Education	0.0%	100.0%	0.0%	0.0%	100.0%
Total	9.1%	58.0%	22.7%	10.2%	100.0%

Community Status vs. WTP

Community Status	0%	Up to 10% more	Up to 20% more	More than 20% more	Total
Urban	2.4%	63.4%	22.0%	12.2%	100.0%
Semi-Urban	16.7%	46.7%	26.7%	10.0%	100.0%
Rural	13.3%	66.7%	13.3%	6.7%	100.0%
Total	9.3%	58.1%	22.1%	10.5%	100.0%

Employment Status vs. WTP

Employment Status	0%	Up to 10% more	Up to 20% more	More than 20% more	Total
1.00 (Employed)	7.1%	57.1%	28.6%	7.1%	100.0%
2.00 (Self-Employed)	10.0%	60.0%	16.7%	13.3%	100.0%
3.00 (Unemployed)	4.8%	61.9%	23.8%	9.5%	100.0%
4.00 (Other)	22.2%	44.4%	22.2%	11.1%	100.0%
Total	9.1%	58.0%	22.7%	10.2%	100.0%

Table 2: Multinomial Regression Output

Percentage	Respondents' details	B	Std. Error	Wald	Df	Sig.	Exp(B)
0%	Intercept	-8.198	2.915	7.907	1	.005	
	Age	-.044	.036	1.524	1	.217	.957
	Education level	.217	.062	12.175	1	.000***	1.242
	Total Household Income	.000	.000	7.060	1	.008***	1.000
	Household Size	.105	.181	.335	1	.563	1.110
Up to 10% more	Intercept	-2.593	1.833	2.000	1	.157	
	Age	.016	.021	.564	1	.453	1.016
	Education level	.141	.044	10.395	1	.001***	1.152
	Total Household Income	.000	.000	.561	1	.454	1.000
	Household Size	-.050	.121	.175	1	.676	.951
Up to 20% more	Intercept	-4.500	2.065	4.750	1	.029	
	Age	.043	.023	3.420	1	.064	1.044
	Education level	.137	.049	7.973	1	.005***	1.147
	Total Household Income	.000	.000	5.172	1	.023**	1.000
	Household Size	-.210	.134	2.437	1	.118	.811

*** and ** indicates level of significance at 1% and 5% respectively

Table 3 : Model Fitting Information

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	777.259			
Final	658.433	118.826	30	.000

Table 4 : Pseudo R -Square

Cox and Snell	.287
Nagelkerke	.322
McFadden	.153

education level and household income of consumers are significant. Therefore, the hypothesis for this study which states that education and income are positively associated with greater MWTP for safe and nutritious food in Nigeria is accepted and the null hypothesis is rejected. Furthermore, age and household size show minimal effects, though age approaches significance at 20% premium (OR=1.044, $p=0.064$), possibly reflecting lifecycle spending patterns.

DISCUSSION

Socioeconomic Determinants Through Theoretical Lenses

The robust education-WTP relationship (OR=1.242) strongly supports the knowledge-attitude-practice (KAP) framework (WHO, 2014), while the urban-rural divide (63.4% vs 36.6% WTP) exemplifies Rogers' (1962) Diffusion of Innovation theory in action. However, the nonlinear income effects challenge standard Consumer Choice Theory assumptions - while higher income generally increased WTP, its impact varied non-monotonically across premium levels. This nuanced finding reconciles conflicting evidence from Kyung *et al.* (2023) and Ali (2020), suggesting that income operates through multiple pathways: as an enabling factor at low premiums but as a budget constraint at higher levels. The age gradient (younger consumers more willing to pay) contradicts Gracia *et al.*'s (2012) European findings but aligns with Nigeria's unique demographic dividend context, where youth are both more health-conscious and more exposed to global food safety discourses (UNFPA, 2022).

CONCLUSION

The study's policy implication gain depth when contextualized within Nigeria's institutional framework. The progressive subsidy proposal synthesizes lessons from Brazil's Fome Zero program (FAO, 2013) and Kenya's

mobile money innovations (Jack & Suri, 2016). This research makes one theoretical advance: it reveals nonlinear socioeconomic effects that challenge standard consumer theory. Future research should explore how this finding generalizes across other collectivist, rapidly-urbanizing food markets, and investigate the longitudinal effects of the recommended policy intervention. The socioeconomic patterns confirm education's pivotal role in food safety adoption and the need for a robust food subsidy programme targeted at the most vulnerable households in Nigeria.

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A TECHNICAL REPORT ON ENHANCING AGRICULTURAL PRODUCE GRADING AND STANDARDISATION IN NIGERIA: INSTITUTIONAL ROLES, CHALLENGES, AND EMERGING INNOVATIONS

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1. Introduction

Agricultural produce quality assurance remains a cornerstone of food safety, trade competitiveness, and economic sustainability across developing economies. In Nigeria, the Nigeria Produce Inspection Services (NPIS), comprising the Federal Produce Inspection Services (FPIS) and the State Produce Inspection Services (SPIS), serves as the primary regulatory body responsible for the inspection, grading, and certification of agricultural commodities. Operating under statutory mandate, the NPIS ensures that both export-bound and domestically consumed produce meet established quality and safety benchmarks. This function is critical to protecting consumers, safeguarding public health, and maintaining Nigeria's credibility in regional and international markets.

Grading and standardization form the foundation of this quality assurance architecture. Grading refers to the systematic classification of agricultural produce based on measurable attributes such as size, shape, texture, moisture content, colour, and defect levels. Standardization, by contrast, involves the formulation and enforcement of uniform specifications that define acceptable quality thresholds across markets. Together, these processes establish a transparent framework that allows producers, traders, processors, and consumers to share a common understanding of product value and quality expectations.

Globally, grading and standardization are recognized as essential tools for integrating agricultural products into competitive markets. Compliance with internationally recognized standards, such as those defined by the International Organization for Standardization (ISO), United Nations Economic Commission for Europe (UNECE), and the Federation of Cocoa Commerce (FCC), is increasingly a prerequisite for accessing high-value export destinations, including the European Union, North America, and Asia. These systems ensure that products are traceable, safe, and consistent in quality, thereby enhancing buyer confidence and market transparency. In this context, uniform grading systems reduce transaction ambiguities and enable fair pricing mechanisms, ultimately fostering equitable trade relations.

From a public health perspective, standardized grading serves as a preventive control mechanism by ensuring that substandard or contaminated produce is identified and excluded from supply chains. Through the detection of defects such as mould, insect damage, or chemical residues, grading contributes directly to food safety and consumer protection. Additionally, traceable and graded commodities facilitate efficient product recalls and monitoring during contamination events, aligning Nigeria's food control systems with international best practices. The economic implications of these processes are equally significant. As noted by Giovannucci and Reardon (2000), well-defined grades and standards (G&S) systems lower transaction costs, reduce information asymmetry, and enhance the participation of smallholder farmers in formal markets. In developing economies like Nigeria—where agriculture remains a major contributor to employment and foreign exchange earnings—strengthening grading and standardization systems represents a strategic pathway to improving export performance and ensuring compliance with evolving global trade protocols.

Despite their importance, Nigeria's grading and standardization frameworks face persistent institutional and operational challenges, including inadequate infrastructure, weak enforcement mechanisms, and low awareness among producers. This paper therefore examines the current landscape of grading and standardization in Nigeria, highlighting institutional roles, crop-specific grading practices, challenges, and emerging technological innovations that could reshape agricultural quality assurance. By bridging policy,

technology, and market perspectives, the study aims to provide actionable insights for enhancing Nigeria's agricultural competitiveness and alignment with international quality frameworks.

Concepts and Definition of Grading and Standardization

Grading and standardization are two interdependent but distinct pillars of agricultural quality assurance. Together, they provide the technical and regulatory foundation for the classification, certification, and commercialization of agricultural produce in both domestic and international markets. Their integration ensures that agricultural products are safe, consistent, and market-ready, attributes that are indispensable for trade competitiveness and consumer confidence.

Grading

Grading is the systematic process of classifying agricultural produce into defined categories or “grades” based on measurable attributes such as size, shape, colour, texture, moisture content, weight, and defect tolerance. These physical and sensory characteristics collectively determine the market value, usability, and storability of the product. In the case of cocoa, for example, grading involves assessing bean size, fermentation quality, mould and slaty content, and foreign matter levels, all of which influence export eligibility and pricing under international trade standards. The purpose of grading extends beyond visual assessment; it is a mechanism for value differentiation and quality signaling across the supply chain. By aligning product categories with market preferences, grading reduces transaction ambiguity, enhances price transparency, and enables producers—particularly smallholder farmers—to be rewarded commensurate with product quality. For buyers, processors, and exporters, grading minimizes risk by providing reliable indicators of processing suitability and expected yield outcomes.

Contemporary grading systems increasingly incorporate technological innovations such as digital imaging, hyperspectral sensors, and non-destructive testing tools, which offer faster, objective, and replicable assessments compared to manual inspection. These tools are vital for ensuring consistency and accuracy in large-scale commodity evaluation and for meeting the stringent quality requirements of international markets.

Standardization

Standardization complements grading by establishing uniform quality benchmarks that define acceptable product characteristics, testing procedures, and compliance thresholds. It encompasses the formulation, documentation, and enforcement of specifications designed to ensure that all market participants operate under consistent quality expectations. These standards may be national, developed by institutions such as the Standards Organisation of Nigeria (SON), or international, formulated by bodies such as the International Organization for Standardization (ISO), Federation of Cocoa Commerce (FCC, UK), United Nations Economic Commission for Europe (UNECE), and Codex Alimentarius Commission (FAO/WHO). Effective standardization ensures interoperability and mutual recognition of quality grades across borders, a prerequisite for seamless international trade. It provides a basis for traceability, food safety compliance, and consumer protection. Standardization also facilitates certification and labeling systems—for example, ISO 22000 (Food Safety Management), ISO 34101 (Sustainable Cocoa Production), and GlobalG.A.P.—which enhance the global competitiveness of agricultural exports.

In the Nigerian context, standardization underpins the transition from informal quality assessment to regulated certification systems, aligning domestic grading protocols with international frameworks. By establishing predictable quality norms, standardization also strengthens supply chain governance, improves market confidence, and supports the integration of smallholder farmers into formal value chains.

The Roles of SON and NPIS in Quality Governance

While both the Standards Organisation of Nigeria (SON) and the Nigeria Produce Inspection Services (NPIS) are central to the quality assurance ecosystem, their mandates and operational scopes differ significantly yet complement one another.

The Standards Organisation of Nigeria (SON) serves as the national standards-setting authority. It is

responsible for developing, harmonizing, and enforcing standards across all sectors of the economy, including agriculture. SON's role is macro-level and policy-oriented, encompassing standard formulation, testing, metrology, and certification infrastructure. It provides the regulatory backbone for Nigeria's national quality policy and ensures alignment with international norms.

The Nigeria Produce Inspection Services (NPIS), by contrast, operates as a sector-specific enforcement and inspection agency under the Federal Ministry of Agriculture and Food Security. NPIS is responsible for the field-level implementation of standards through produce grading, sampling, inspection, and certification—particularly for export commodities such as cocoa, cashew, coffee, palm kernel, and grains. It acts as the operational bridge between policy formulation and on-ground execution, ensuring that produce destined for export meets both national and international quality thresholds.

In essence, SON establishes the standards, while NPIS enforces and operationalizes them. Their coordinated roles ensure that Nigeria's agricultural produce adheres to global trade requirements, sustains consumer trust, and enhances the country's reputation in the international marketplace.

Grading Parameters

Grading of agricultural produce is based on a combination of physical, chemical, and sensory attributes, which help determine the quality, usability, and marketability of the product. These parameters are used across crops to sort produce into grades that reflect their value and suitability for different markets or end-uses.

Physical Attributes

Physical characteristics are the most common and immediately visible indicators of quality. They include:

Size and shape: Uniformity in size and regularity in shape are often associated with premium grades. For instance, in cocoa, the bean count per 100g is used to categorize beans into main crop and light crop.

Colour and texture: Produce is visually assessed for brightness, freshness, and the absence of discoloration or wrinkling, which can indicate poor storage or pest damage.

Foreign matter: The presence of extraneous materials such as stones, husk, or insect parts is a key grading concern, especially in grains and nuts. In relation to cocoa, it refers to any substance other than cocoa beans, Cocoa-Related Matter, flat beans, and sievings.

Cocoa Related Matter (CRM): It means bean clusters, broken beans, and pieces of shell that do not pass through the sieve.

Contaminants: It means a substance, not natural to cocoa, which is revealed during the cut test or physical inspection of a sample of cocoa.

Chemical Attributes

Chemical parameters often require laboratory testing but provide critical information on the produce's internal quality and safety. These include:

Moisture content: A major determinant of shelf life and storability. For example, cocoa beans should typically not exceed 7.5% moisture content, and grains are expected to have $\leq 13\%$ moisture content to avoid mould and insect infestation.

Free Fatty Acids (FFA): High FFA levels, particularly in palm kernel and nuts, indicate spoilage or poor post-harvest handling.

Pesticide residues and contaminants: Produce for export must meet international safety thresholds for chemical residues, heavy metals, and mycotoxins such as Ochratoxin A (OTA).

Sensory Attributes

These refer to qualities perceived by human senses, particularly taste, aroma, and texture. While more subjective, they are vital for certain commodities:

- a. Coffee is graded using cupping tests, where trained tasters evaluate its aroma, flavour, acidity, body, and balance.
- b. Kolanut grading relies heavily on flavour, bitterness, size, and freshness, often assessed through traditional knowledge systems.

Cocoa-Specific Grading Parameters

Cocoa grading combines all three attribute types and is a useful example of integrated assessment:

- a. Fermentation is evaluated qualitatively, often via a cut test, which involves slicing beans to observe internal colour and consistency. Well-fermented beans typically display a uniform brown interior and no slaty appearance.
- b. Mouldy beans, slaty beans, and other defects (e.g., insect damage, germinated beans) are measured in percentages:
 - *Grade I*: Max 3% mould, 3% slaty, and 3% other defects.
 - *Grade II*: Max 4% mould, 8% slaty, and 6% other defects.
- c. Bean size is inferred from bean count (number of beans per 100g), with smaller beans typically indicating a light crop and larger beans representing the main crop.

Grading based on these parameters allows for fair pricing, better market alignment, and consistency in quality, factors that are crucial in maintaining both domestic consumer confidence and international buyer trust.

Crop-Specific Grading Models

Grading criteria vary by crop, depending on each commodity's biological, commercial, and regulatory characteristics. Below is an overview of Nigeria's major agricultural exports and staples, outlining the grading parameters and standards applied to each:

Cocoa Beans

Cocoa grading in Nigeria is among the most structured, with inspections conducted at gazetted stations and registered storage facilities. These facilities must be rainproof, pest-free, and well-ventilated, with qualified storekeepers holding valid licenses.

i. Bean Count Classification:

- Main Crop: Bean weight per 100g sample > 310g
- Light Crop: < 310g per 100g

ii. Grading Standards:

- **Grade I:**
 - Mould $\leq 3\%$
 - Slaty beans $\leq 3\%$
 - Other defects $\leq 3\%$
- **Grade II:**
 - Mould $\leq 4\%$
 - Slaty beans $\leq 8\%$
 - Other defects $\leq 6\%$

- iii. Additional assessments include foreign matter, bean size, and mycotoxin presence (e.g., OTA).

Palm Kernel

Palm kernel grading is based on both visual inspection and laboratory analysis to determine oil quality and cleanliness.

Key Grading Factors:

- Moisture content
- Free Fatty Acid (FFA) levels
- Colour and odour (e.g., greyish/dull appearance indicates dampness or spoilage)
- Absence of excessive milkiness or off-odours
- Packaging: Standard bag weight is 79kg; 13 bags = 1 metric ton (MT)
- Proper sealing and stitching, including coded steel seals, are mandatory.

Coffee

Coffee is graded using both physical and sensory methods, with international protocols such as those from the Specialty Coffee Association (SCA) and UNECE often applied.

i. Grading Factors:

- Defect analysis (primary vs. secondary defects)
- Cupping/sensory evaluation (aroma, flavour, acidity, balance)
- Moisture content
- Bean screen size

- Roast profile and altitude of origin
- ii. **Grading System:**
 - Grade 1 (Specialty Grade): 0 primary defects
 - Grade 2: Up to 6 defects
 - Grade 3: Up to 13 defects

Packaging standards require bags weighing 60–70kg with proper sealing and lock stitching, stored on white-washed dunnages.

Cashew

Cashew kernels are graded based on size, shape, colour, and defects, using the internationally accepted UNECE DDP-17 standard.

- i. **Common Grades:**
 - W180 = Large, whole white kernels (~180 per pound)
 - W240, W320 = Medium and small-sized whole kernels
- ii. **Grading Factors:**
 - Kernel integrity (whole vs. broken)
 - Color grading (white, scorched, or dessert)
 - Defect level (mold, insect damage, blemishes)
- iii. Each bag typically weighs ~80kg, with mandatory stitching and coded sealing for traceability.

Kolanut

Kolanut grading in Nigeria lacks a formalized standard. Grading is often done through traditional knowledge, and depends on visual and sensory parameters.

- i. **Grading Methods:**
 - Random sampling and classification into:
 - Good Kolanut (GK)
 - Defective Kolanut (DK) (e.g., insect-damaged, wrinkled, blackened)
- ii. **Grading Factors:**
 - Size, colour (white vs. red), number of lobes (cotyledons)
 - Flavour, freshness, and taste
- iii. **Traditional Packaging:** Wrapped in Abora leaves, then tied with twine and wrapped in cement paper. Each pack weighs between 3–10kg.

Rubber

Rubber grading is based on both physical appearance and laboratory-tested chemical properties of natural rubber latex and processed rubber sheets. In Nigeria, grading is guided by international specifications such as the Ribbed Smoked Sheet (RSS) grades and Technically Specified Rubber (TSR) system. The grading process ensures that the rubber meets industrial processing requirements and export market expectations.

- i. **Forms Graded:**
 - *Field latex*: Fresh rubber sap tapped from trees; graded by Dry Rubber Content (DRC)
 - *Rubber sheets*: Processed from coagulated latex, then air- or smoke-dried
 - *TSR blocks*: Industrial-grade rubber made from field coagula, cup lumps, and latex
- ii. **Key Grading Factors:**
 - Dry Rubber Content (DRC): Indicates the % of rubber solids in latex. Good quality latex has $\geq 30\%$ DRC.
 - Dirt content: Measured as non-rubber impurities (e.g., bark, sand, debris). Export standards require $\leq 0.05\%$ for premium grades.
 - Ash content: Measures inorganic matter after burning. High-grade rubber typically has $\leq 0.75\%$.
 - Color and appearance: Lighter, clearer sheets are more desirable. Smoke-cured sheets are visually graded into categories (RSS 1X to RSS 5).
 - Plasticity Retention Index (PRI): Assesses thermal resistance and processing quality—especially for TSR. Higher PRI indicates better oxidative stability.
- iii. **Standard Packaging:**
 - *Ribbed Smoked Sheets*: Packed in bales, usually weighing 33.33kg or 50kg per bale.
 - *TSR blocks*: Packed in polythene-lined wooden crates or metal containers, 33.33kg or 35kg per block.

iv. Grading Classification Examples:

- RSS 1X: Cleanest sheet, nearly translucent, no bubbles or blemishes
- RSS 1–5: Permits increasing levels of air bubbles, spots, or discoloration
- TSR 10, TSR 20: Technically specified based on lab tests for ash, dirt, volatile matter, and PRI

v. Inspection Environment:

- Grading is conducted in processing factories, often supported by NEPC, NPIS, or SON certification units.
- Rubber must be dried properly to avoid souring, mould, or microbial contamination.
- Good tapping and coagulation practices are essential to achieving high-quality grades.

Grains (e.g., Maize, Cowpea, Sorghum, Millet, Soybeans, Sesame)

Grains are tested for dryness, contamination, and insect infestation before being graded.

i. Grading Parameters:

- Moisture content: $\leq 13\%$
- Extraneous matter: $\leq 2\%$
- Insect damage: $\leq 5\%$ for maize and cowpea; $\leq 2\%$ for others
- Infestation levels: Not more than 2%

ii. Sample Testing:

- 50% of bags from a 100-bag lot are tested using a grain scoop.

iii. Packaging: Standard bag weights are 50kg or 100kg, with clear markings and batch identifiers.

These commodity-specific grading models form the operational foundation of Nigeria's produce quality management and determine whether agricultural products are eligible for export certification, price premiums, or domestic value chain inclusion.

Challenges

Despite the recognized importance of grading and standardization in enhancing agricultural quality and trade, several systemic and operational challenges hinder their widespread adoption and effectiveness in Nigeria and other developing economies.

Infrastructure Limitations

One of the most pressing challenges is the lack of infrastructure to support effective grading operations. Many rural and peri-urban areas lack access to:

- Certified grading stations or laboratories
- Storage facilities with climate control or pest-proofing
- Basic grading tools and equipment (e.g., moisture meters, sieves, weighing scales)

Without modern infrastructure, produce is often exposed to post-harvest deterioration, reducing quality before it even reaches the market.

Absence or Weak Implementation of Standards

While agencies such as the Standards Organisation of Nigeria (SON) and Nigeria Produce Inspection Services (NPIS) have developed standards for some crops, many agricultural commodities still lack codified grading protocols. Even when standards exist, they are often outdated, poorly harmonized with international norms, or not widely disseminated to stakeholders across the value chain.

High Cost of Compliance

Complying with grading and standardization requirements can be financially burdensome, especially for smallholder farmers who dominate Nigeria's agricultural sector. Costs arise from:

- Inspection and certification fees
- Purchase of testing equipment
- Transportation to certified grading stations
- Packaging materials that meet export specifications

These expenses can discourage voluntary compliance, especially when the price incentives for higher grades are unclear or unreliable.

Perishability of Produce

Many agricultural products, especially fruits, vegetables, and fresh roots/tubers, are highly perishable, making timely and accurate grading a logistical challenge. In the absence of cold chain systems or rapid testing tools, producers often sell perishable goods without grading to avoid spoilage losses.

Regulatory and Institutional Gaps

Coordination between multiple regulatory agencies (e.g., NPIS, SON, NEPC, Customs) is often fragmented, leading to overlaps, conflicting directives, or bureaucratic delays. Furthermore, limited funding, a shortage of trained personnel, and the lack of performance monitoring systems weaken enforcement.

Poor Adoption by Smallholder Farmers

A large proportion of smallholder farmers remain unaware of the benefits of grading and standardization. This is due to:

- Low literacy and technical knowledge
- Minimal exposure to structured markets
- Lack of training or access to extension services

As a result, many continue to rely on traditional grading methods or ignore quality controls altogether, leading to product rejection in formal markets and lost export opportunities.

Addressing these challenges requires targeted policy interventions, including investments in grading infrastructure, capacity building, public-private partnerships, and incentive frameworks that reward quality compliance.

Technological Innovations

The landscape of agricultural quality assessment is rapidly evolving with the integration of advanced technologies that enhance the accuracy, speed, and objectivity of grading and standardization. These innovations are helping to address many of the challenges associated with manual inspection, especially in high-volume or export-oriented value chains.

Transition from Manual to Automated Grading

Traditional grading methods—relying heavily on visual inspection, hand-sorting, and subjective judgment—are increasingly being replaced or complemented by automated and digital systems. These technologies allow for the consistent assessment of physical and chemical characteristics without damaging the produce.

Key examples include:

- i. Optical and computer vision systems: Used to evaluate size, shape, colour, and surface defects in commodities like grains, fruits, and nuts.
- ii. Hyperspectral imaging: Allows for the detection of internal defects or contamination (e.g., mould or mycotoxins in cocoa and groundnuts) that are not visible externally.
- iii. Electronic noses and odour sensors: Designed to detect off-smells or volatile compounds indicating spoilage or contamination, particularly relevant in cocoa and coffee grading.
- iv. Digital moisture meters and FFA analyzers: Provide rapid chemical analysis of moisture content and free fatty acids, crucial for shelf-life estimation.

Use of Mobile and ICT Tools

Mobile-based apps and handheld grading devices are increasingly accessible to smallholder farmers and inspectors. These tools often integrate with cloud-based platforms to:

- Capture and analyze grading data on-site
- Track produce through blockchain-enabled traceability systems
- Issue digital certificates of inspection and origin

Such systems improve transparency and facilitate compliance with international quality protocols.

Non-Destructive Testing (NDT)

Non-destructive technologies allow for internal quality assessments without physically cutting, breaking, or altering the produce. This is particularly beneficial for:

- High-value crops like cashew and coffee, where kernel integrity is crucial
- Fresh produce where post-grading shelf life is limited
- Export commodities requiring pre-shipment quality validation

For example, cocoa beans can now be scanned to identify fermentation quality, internal mould, or insect infestation without the need for time-consuming cut tests.

Potential Impact in Nigeria

While these technologies are still emerging in Nigeria, pilot implementations have shown promise. Adoption can significantly enhance:

- Speed of inspection and certification
- Consistency and reliability of grading outcomes
- Market access, especially for smallholders linked to export or processor-driven supply chains

However, success depends on capacity building, infrastructure upgrades, and policy support to ensure affordability and local relevance of imported technologies ([Alfatni et al., 2013](#); Akinrotimi et al., 2024; Akinrotimi, 2025).

In summary, technological innovations in grading and standardization offer transformative potential for Nigeria's agricultural sector, but must be embedded within a broader system of training, incentives, and institutional reform to achieve meaningful impact.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Grading and standardization remain vital pillars of agricultural development, ensuring that produce meets the expectations of buyers, adheres to food safety standards, and qualifies for domestic and international trade. In the Nigerian context, institutions like the Nigeria Produce Inspection Services (NPIS) and the Standards Organisation of Nigeria (SON) play key roles in maintaining quality assurance across various agricultural commodities.

However, several systemic challenges—ranging from infrastructural deficits and regulatory gaps to low adoption among smallholder farmers—continue to hinder the full realization of these practices. The lack of awareness, inadequate access to testing facilities, high cost of certification, and informal market dynamics all contribute to the limited implementation of grading and standardization across the country.

Encouragingly, recent technological innovations such as non-destructive testing methods, digital inspection tools, and automated grading systems are beginning to offer scalable solutions to many of these issues. Their integration into national and sub-national inspection systems could revolutionize Nigeria's agricultural quality control framework—provided that they are accompanied by institutional reform, training, and sustained investment.

Recommendations

To strengthen grading and standardization in Nigeria's agricultural value chain, the following actionable recommendations are proposed:

1. Capacity Building and Manpower Development

- Recruit and train more produce inspectors, graders, and extension officers at both federal and state levels.
- Develop a national curriculum for grading and quality control certification to professionalize the field.

2. Upgrade Infrastructure and Equipment

- Invest in modern grading stations, quality testing labs, and mobile inspection units, especially in key producing areas.
- Ensure facilities meet minimum international standards to boost export competitiveness.

3. Strengthen Public Awareness and Farmer Education

- Conduct nationwide sensitization campaigns on the economic and trade benefits of grading and standardization.
- Promote Good Agricultural Practices (GAP) and post-harvest handling protocols among smallholder

farmers.

4. Harmonize and Expand Quality Standards

- Update and align national standards (via SON and NPIS) with global frameworks such as ISO, FCC, and UNECE.
- Develop and disseminate commodity-specific grading manuals accessible in local languages.

5. Support Technological Adoption

- Promote public-private partnerships to scale the deployment of non-destructive testing tools and mobile grading technologies.
- Provide subsidies or incentives for cooperatives or agro-processors to acquire inspection equipment.

6. Improve Regulatory Coordination and Funding

- Strengthen collaboration among agencies like NPIS, SON, NEPC, and NAFDAC to avoid duplication and streamline enforcement.
- Increase budgetary allocation to grading and inspection departments, especially in key export zones.

By addressing these priorities, Nigeria can ensure that its agricultural produce not only meets domestic quality expectations but also competes effectively on the global stage, unlocking greater value for farmers, exporters, and the economy at large.

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CHALLENGES IN ADOPTING CLIMATE-SMART AGRICULTURAL TECHNOLOGIES AMONG SMALL-SCALE AGRIBUSINESS FARMERS IN NIGERIA

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ABSTRACT

Climate variability and change in climatic factors have greatly impacted agricultural production in Nigeria. Climate Smart Agriculture (CSA) has become an essential strategy for achieving sustainable agricultural development and food security. its adoption and implementation have become a challenge for small-scale farmers. The study identified the socioeconomic factors that influence the adoption and implementation of the CSA technologies by the small-scale farmers in Nigeria. A cross-sectional research design with multistage sampling was implemented. Four hundred structured questionnaires were used to gather information from small-scale farmers. Respondents were selected from the farmers' association. The data for the study were analyzed through cross-tabulation and bivariate percentage analysis. The results indicate that 59.5% of respondents are male and 41% are female, engaged in various parts of farming methods, which includes, Crop production (50.7%), forestry (1%), fishing (11.5%), livestock (29.5%), and mixed farming (48%), with 51.7% possessing over 10 years of experience. The study identified various challenges affecting agricultural climate-smart adoption decisions, which include access to credit, suitable farm equipment and tools, farm size, high-cost and inadequate farm inputs and materials, flooding resulting in soil infertility, and access to information, knowledge, and skills pertinent to climate-smart agriculture. This study recommends that the government/ financial institutions improve credit accessibility for farmers, regulate the costs of agricultural inputs and materials, and implement educational campaigns to raise awareness about CSA practices. These practices aim to promote sustainable food production and food security, as well as inform policy formation in Nigeria.

Keywords: Climate variability, Climate Change, Climate-Smart Agriculture, small-scale, Agriculture Production

INTRODUCTION

The agricultural sector is an important economic activity globally. The global food system is currently facing profound challenges related to ensuring the food security of a rising population and climate change, with extreme and unpredictable weather patterns, which jeopardize agricultural growth and the resilience of food production systems (Ajire *et al.*, 2025; Pagliacci *et al.*, 2020; Long *et al.*, 2016). Climate variability and change pose a significant challenge to food production, particularly in developing countries where rural farming households are the major producers who depend on rain fed agriculture. In Nigeria, most farmers are dependent on rain-fed agriculture, and sources of sufficient water for agriculture have become a great concern to small-scale farmers. The impact of a changing climate is reorganising the regional and global hydrological cycle. Climate change is associated with alterations in seasonal rainfall patterns, fluctuations in levels of groundwater, and increased problems affecting the effectiveness of local water management practices like wells, irrigation, and boreholes. The increasing global temperature escalates evaporation, which brings about an intensified hydrological cycle and consequently results in more frequent and heavy rainfall in some regions and heightened and prolonged droughts in other regions (NASA, 2025). Studies around the West Africa region have shown a shorter rainy season by up to 27 days in some zones, with general delays in onset and earlier cessation; such shifts threaten agricultural productivity and rain-fed farming (Adefisan, 2022). Rainfall is predicted to be more intense, even though an overall decline in rainfall is expected. This occurrence will result in more destructive flooding events interweaving with prolonged dry periods, harming crop cycles and indigenous water availability and supply (PreventionWeb, 2021). Heavy Rainfall events with decreased frequency of rainfall are expected to improve the recharging of groundwater in some environments; however, because of irregular seasonal distribution, recharging of this groundwater will not be reliable (UNESCO ,2022).

A good approach to agricultural production needs to be adopted to overcome the problem of limited scarce resources (Kalu & Mbanasor, 2023). The Food and Agriculture Organisation (FAO) define CSA as agricultural practices that facilitate production, sustainably enhancing resilience and mitigating the attainment of national food security and development goals (FAO, 2010). CSA is based on three main pillars: sustainably increasing agricultural productivity and incomes, reducing and/or removing GHG emissions, and adapting and building resilience to climate change (FAO, 2014; Lipper *et al*, 2014). This method acknowledges that synergies and trade-offs between the three pillars should be considered in the planning and implementation of agricultural strategies (Lipper *et al*, 2014), and it lays the foundation for orienting agricultural technological, policy, and investment conditions to meet future food demands and climate change (Long *et al*, 2016). The practices comprise integrated crop management, mulching, intercropping, crop rotation, water harvesting, irrigation, pest and nutrient management, agroforestry and conservation tillage, soil management, as well as smart agricultural technologies, including robotic systems, drones, remote sensing, satellites and the Internet blend, application of this processes are expected to increase agricultural production (Campbell *et al* 2014; Lipper *et al*, 2014; Agidi *et al*, 2025), but this can be achieved through a cautious blend of different CSA activities, rather than a single CSA activity (Ellis, & Tschakert, 2019). The CSA technology is equipped to help alleviate the problem of hunger and increase productivity and despite the potential benefits of CSA, its implementation in less developed nations is not reaching its full potential due to a low level of uptake (Westermann *et al*, 2018). This study identifies some of the challenges these farmers are experiencing towards the adoption of climate-smart agricultural techniques

Literature Review

Climate Smart Agricultural Technique: Its Implication on agri-Agri-Farmers

Climate-smart agriculture (CSA) is a strategic practice that supports farming, improves food production, and promotes sustainable agriculture. The impact of climate change threatens sustainable food production and is affecting the economies of nations worldwide. Climate-Smart Agriculture (CSA) encompasses a collection of agricultural practices and technologies that concurrently increase productivity, improve resilience, and reduce greenhouse gas emissions. This concept is grounded in established farm knowledge and technologies, as well as sustainability principles, which explains the presence of certain traditional practices within CSA. (Izuogu, *et al* 2025). The CSA technology is unique; it addresses how the agri-food sector is affected by climate change, it takes into account the trade-offs and synergies between mitigation, adaptation, and productivity, and includes a variety of methods and technologies that are adapted to certain socioeconomic and agro-ecological circumstances. including the adoption of climate-resilient crop varieties, conservation agriculture techniques, agroforestry, precision farming, water management strategies, and improved livestock management. (World Bank, 2024)

The practice and adoption of the CSA practice by farmers has been used in some parts of the country. In the southeast, the cooperative societies and extension workers are the primary sources of CSA awareness and adoption in the region., while risk-averse farmers are less likely to adopt CSA practices. (Mbanasor, *et al*, 2024). While in the south western region, farmers implemented various approaches, especially the implementation of indigenous knowledge, which includes adjusting the planting dates and the use of natural pest control methods. (Izuogu, *et al* 2025) other CSA practices adopted by farmers in other regions, include crop rotation, application of organic and inorganic fertilisers, and multiple cropping (Basiru, *et al*, 2025). Farmers documented a rise in productivity and income attributed to enhanced soil health resulting from their adoption of Climate-Smart Agriculture (CSA). The primary predictors of the adoption of Climate-Smart Agriculture (CSA) included access to credit, engagement with extension service providers, years of farming experience, and educational attainment, while farmers affiliated with various cooperatives significantly contributed to its adoption and implementation. To establish a sustainable agricultural system utilising Climate-Smart Agriculture (CSA) techniques and facilitate the transformation of the agri-food system, it is imperative for the government to enhance funding for CSA initiatives, raise awareness, and develop farmers' capacities through training in CSA competencies. Additionally, providing incentives to support farmers will significantly augment agricultural production and sustainability.

The role of climate change adaptation policy in agricultural production.

Climate change adaptation is increasingly being mainstreamed into Nigeria's water and agricultural policies.

The National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN) prioritizes integrated water resource management, climate-smart agriculture, and the protection of critical ecosystems. This strategy calls for greater use of traditional ecological knowledge—such as indigenous water-harvesting techniques—combined with modern innovations like drip irrigation and solar-powered water pumps to enhance resilience at the community level (Oyeleke, 2021). For Nigeria to achieve long-term water and food security, policies must go beyond paper commitments and ensure effective local-level implementation. This requires consistent funding, participatory decision-making that includes smallholder farmers and women, and strong alignment between federal directives and community-based initiatives (FAO, 2021).

MATERIALS AND METHODS

Study area

Nigeria is located in West Africa, between latitudes 40 to 140 North, and longitudes 2021 and 140301 East. To the North, the country is bounded by the Niger Republic (1497km) and Chad (853km) to the West by the Benin Republic (773km) to the East by the Cameroon Republic (1690km) and to the South by the Atlantic Ocean. Nigeria has a population of over 200 million people (NPC, 2020) with a wide range of biophysical traits, socio-economic circumstances, agroecological zones, and ethnic groups (more than 250). About half of the working population is employed in agriculture, with the majority of them being smallholder farmers, making farming the most common occupation. Nigeria's main food and cereal crops include rice, millet, yams, sweet potatoes, sorghum, cassava, and maize (Diagi *et al.*, 2025). Some of the environmental problems facing the country are soil erosion, desertification, excessive flooding, and rapid deforestation.

Sampling technique

A cross-sectional research design using a multistage sampling technique was implemented using questioner, interview and one to one discussion. A structured questionnaire was designed on the Google Docs website (doc.google.com) to gather information from small-scale farmers. Respondents were selected from the farmers' association across South East, South South, and South West Nigeria. The link was active for three months and was strictly monitored. The link was disabled after receiving 400 responses

Analytical techniques

To access objectives (i) to examine the socio-economic characteristics of the respondents and objectives(ii), to identify challenges to adopting climate-smart agricultural techniques adopted in the study area were analyzed with descriptive statistics such as frequencies, means, percentages, and graphs.

RESULTS AND DISCUSSION

Socio–Economic Characteristics of the Agribusiness Farmers

The result of the socio-economic characteristics of the farmers in the study area is presented in Table 1. The findings indicate that the percentage of male and female farmers in the research area is 59.5% and 40.1%, respectively. The results also indicate that 17.8% of farmers are over 55, while 46.6% of farmers are between the ages of 26 and 45. This indicates that young people are also participating more in farming. The farming experience level is quite high, 51.7% of the respondents have been farmers for more than ten years, and well educated, the results shows that, 73.3% have graduate or post-graduate degrees

Different farming methods practiced in Nigeria

The study identified some farming methods practised by the farmers over decades for livelihood and to meet their food security needs. The various farming techniques are represented in Figure 1, and the majority practised different farming methods. The result in Figure 1 shows that 50,7% are involved in crop production, forestry 1%, livestock farming 29.5% and 48% were involved in mixed farming. the majority of farmers diversified their production by engaging in mixed farming because this will help the farmers to distribute the risks and difficulties brought on by climate variability and change.

Challenges influencing farmers' decision to Adopt Climate Smart Agricultural Technologies in the Area of Study

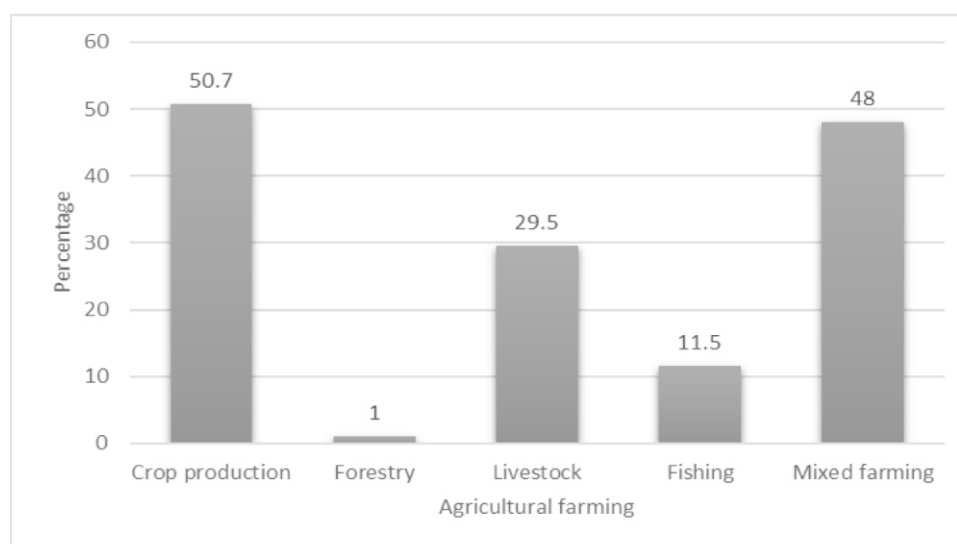
The study identified some challenges during the survey, some of the major challenges that farmers face

include access to credit, appropriate farm equipment and tools, farm size, expensive and insufficient farm inputs and materials, flooding that results in soil infertility, and the lack of information, knowledge, and skills relevant to climate-smart agriculture. The survey also revealed that farmers face a wide range of difficulties when implementing CSA techniques. If the government, non-governmental organisations, and international alliances provide significant support, more than 90% of the respondents are willing to implement the new CAS techniques.

Table 1: Distribution of respondents on socioeconomic characteristics of Farmers (N=400)

Variables	Frequency	Percentage
Gender		
Male	238	59.5
Female	164	40.5
Age		
26-35	48.9	12.1
36-45	137.8	34.5
46-55	142.2	35.6
Above 55	71.1	17.8
Educational Level		
Primary	3	0.8
Secondary	104	26
BSc/ HND/ OND	241	60.2
Post graduate	52	13
Farming experience		
1-5	75	18.8
5-10	120	30
Above 10 years	205	51.2

Source: Field survey 2025



Source: Field Survey, 2025

Figure 1: Farming methods practiced among Farmers in Nigeria

CONCLUSION

The study identified the socio-economic factors that influence the adoption and implementation of the CSA technologies by the small-scale farmers in South East, South South, and South West Nigeria, and identified that most of the farmers practise mixed farming which is supported by climate smart agriculture, it also identified some major challenges to the adoption of CSA which includes access to credit, appropriate farm equipment and tools, farm size, expensive and insufficient farm inputs and materials, flooding that results in soil infertility, and the unavailability of information, knowledge, and skills relevant to climate-smart agriculture. This study recommends that governments and financial institutions improve credit accessibility

for farmers, regulate the costs of agricultural inputs and materials, and implement educational campaigns to raise awareness about climate-smart agricultural practices. Additionally, it suggests providing improved seedlings for planting and promoting policy formation that will strengthen the agricultural sector, enhance food production, and promote sustainability.

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EFFECT OF SELF-HELP GROUP ACTIVITIES ON PERI-URBAN DWELLERS' EMPOWERMENT STATUS IN AKURE SOUTH AND IFEDORE LOCAL GOVERNMENT AREAS, ONDO STATE, NIGERIA

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ABSTRACT

This study examined the effect of Self-Help Group (SHG) activities on the empowerment status of peri-urban residents in Akure South and Ifedore Local Government Areas of Ondo State, Nigeria. Using a multistage sampling technique, 120 respondents were surveyed with structured questionnaires, and the data were analyzed using descriptive statistics, correlations, and multiple regression. Results indicated that key SHG activities included sharing knowledge (15.8%), accessing markets (15.3%), and community development (14.7%), demonstrating that members actively participate in learning, networking, and community improvement. The level of SHG participation and empowerment was generally high, with average scores above 4.0; notably, 90% of respondents reported high levels of knowledge sharing, while 78.3% achieved high empowerment status (Mean=4.21). Correlation analysis revealed a strong, positive relationship between all SHG activities and empowerment status ($r=0.659-0.774$, $p<0.01$). Regression results further showed that SHG activities collectively explained 69% of the variation in empowerment status ($R=0.831$, $R^2=0.690$, $F=35.57$, $p<0.001$). Among the predictors, financial services ($\beta=0.390$, $p<0.001$), capacity building ($\beta=0.187$, $p<0.05$), and market access ($\beta=0.217$, $p\approx 0.058$) had the strongest effects on empowerment status. The study concludes that SHGs significantly promote economic and social empowerment through improved access to credit, skills, and markets. It recommends that the government and NGOs strengthen SHG-based financial programs, capacity-building initiatives, and market linkages to sustain empowerment and improve livelihoods in peri-urban communities.

Keywords: Self-Help Groups; Empowerment; Peri-Urban Dwellers; Financial Services; Capacity Building

INTRODUCTION

Empowerment has become a key concept in development efforts, especially in initiatives aimed at enhancing the socio-economic well-being of vulnerable and marginalized groups (Hanif, 2025). Peri-urban areas—regions situated between rural and urban communities—are often characterized by rapid population growth, informal economic activities, limited infrastructure, and inadequate access to social amenities (Adewoyin *et al.*, 2024). In Nigeria, the peri-urban regions of Akure South and Ifedore Local Government Areas in Ondo State have undergone significant socio-economic changes due to urban expansion from the Akure metropolis (Lawal *et al.*, 2024). However, despite this growth, many peri-urban residents still face ongoing challenges such as poverty, unemployment, limited access to financial services, and low participation in decision-making processes (Torres-Lima *et al.*, 2022).

Self-Help Groups (SHGs) have emerged as a key community-based strategy for enhancing empowerment through collective action, capacity building, and improved access to resources (Kumar & Kumar, 2024). These groups often organized around savings, credit, skills acquisition, and income-generating activities, provide platforms for individuals to enhance their socio-economic performance, participate in community development, and influence decisions affecting their lives (Kyeyune & Ntayi, 2025). In Nigeria, SHGs are progressively being integrated into development interventions aimed at improving livelihoods, particularly in peri-urban settings where formal support systems may be weak or inaccessible (Okosun, 2022). Given the increasing recognition of SHGs as catalysts for empowerment, it becomes important to evaluate the extent to which their activities contribute to improving the empowerment status of peri-urban dwellers in specific local contexts.

Understanding how such groups function and the benefits derived from participation can provide evidence-based guidance for stakeholders, including government agencies, development partners, and grassroots organizations. This study, therefore, investigates the effect of Self-Help Group activities on the empowerment status of peri-urban dwellers in Akure South and Ifedore LGAs of Ondo State, Nigeria. Despite numerous development programmes implemented at different levels of government, a significant

number of peri-urban dwellers in Akure South and Ifedore LGAs still struggle with socio-economic challenges such as unemployment, low income, limited access to credit facilities, poor skill acquisition opportunities, and minimal participation in community decision-making (Oluwadare *et al.*, 2021). These constraints often hinder their ability to achieve sustainable livelihood improvements and contribute to broader community development (Jaya, 2024). Self-Help Groups have been promoted as an alternative mechanism to enhance empowerment through collective resource mobilization, improved access to financial services, and skills development (Survase & Gohil, 2024).

However, there is a limited empirical understanding of how effective these groups are in addressing the empowerment needs of peri-urban populations in the study area. While some SHGs operate actively, the nature of their activities, the level of participation of members, and the tangible outcomes in terms of improved socio-economic status remain unclear (Chakraborty & Dasgupta, 2024). Moreover, existing studies on SHGs in Nigeria have predominantly focused on rural communities, with little attention given to peri-urban contexts where the dynamics of livelihoods differ significantly due to urban influence and market interactions (Buxton, 2022). The gap in location-specific research creates uncertainty regarding the contribution of SHGs to empowerment outcomes among peri-urban dwellers in Akure South and Ifedore LGAs. If this knowledge gap persists, development actors may be unable to properly design or scale up SHG interventions that effectively address local empowerment challenges. Therefore, this study seeks to assess the effect of Self-Help Group activities on the empowerment status of peri-urban dwellers in the study area. Specifically, the objectives to be achieved are as follows:

1. identify the major activities of self-help groups among peri-urban dwellers in the study area.
2. determine the level of self-help group activities and empowerment status among peri-urban dwellers in the study area.
3. examine the relationship between self-help group activities and the empowerment status of peri-urban dwellers in the study area.
4. evaluate the extent to which self-help group activities influence farmer empowerment status in the study area.

Research Hypothesis

H₀₁: There is no significant relationship between self-help group activities and the empowerment status of peri-urban dwellers in the study area.

H₀₂: There is no significant influence on self-help group activities and the empowerment status of peri-urban dwellers in the study areas.

MATERIALS AND METHODS

The study was conducted in Akure South and Ifedore Local Government Areas, Ondo State, Nigeria, and the population of the study consisted of all peri-urban dwellers who are members of SHGs in Akure South and Ifedore Local Government Areas of Ondo State, Nigeria. A multi-stage sampling technique was used to select the total number (120) of respondents for the study. Stage one involved the purposive selection of the study areas because of their high concentration of peri-urban dwellers participating in self-help group activities. At stage two, ten major communities were randomly selected from each Local Government Area through the list of registered self-help groups obtained from agricultural extension offices, cooperative societies, and Ondo State Agricultural Commodities Association. Finally, the random sampling techniques were used to select 12 respondents from each of the 5 selected communities who were active members of the selected self-help groups, giving a total of 120 respondents. Primary data was used for the study; a structured questionnaire and interview guide were used to obtain relevant information from the respondents (peri-urban dwellers). The data from the survey were analysed using descriptive and inferential statistics. The data collected were analysed with descriptive statistics such as frequency, percentage, mean, and standard deviation. Also, the inferential statistics made use of correlation analysis to determine the relationship between the activities of SHGs and the empowerment of peri-urban dwellers. The regression analysis was used to assess the influence of SHG activities on the peri-urban dwellers.

RESULTS AND DISCUSSION

Major Self-Help Activities Involved by the Peri-urban Dwellers

The results in Table 1 show that peri-urban dwellers are actively involved in a wide range of self-help groups (SHGs) that help improve their lives and communities. The most common activities are sharing of knowledge (15.8%), market access (15.3%), and community development (14.7%), meaning that people mostly come together to exchange ideas, learn new skills, and work jointly to solve community problems or improve their businesses. Collective bargaining (14.4%) and social networking (14.2%) also play important roles, helping members to speak with one voice and build strong relationships that can provide emotional and social support. Capacity building (13.6%) and financial services (12.0%), though slightly lower, remain vital because they involve training and access to small loans that help members grow their livelihoods. These findings show that peri-urban dwellers rely on SHGs not just for money but also for learning, cooperation, and improving their communities. This agrees with Kumar and Kumar (2024) and Nichols (2021), who found that SHGs promote empowerment by encouraging collaboration, knowledge sharing, and collective participation in community and economic development. The implication is that strengthening these activities, especially financial access and training, can further boost the self-reliance and well-being of peri-urban populations.

Table 1. Major Self-Help Activities Involved by the Peri-urban Dwellers

Identification	Frequency	Percentage (%)
Capacity Building	96	13.6
Financial Service	85	12.0
Community Development	104	14.7
Social Networking	100	14.2
Sharing of Knowledge	112	15.8
Collective bargaining	102	14.4
Market Access	108	15.3

Level of Self-Help Group Activities and Empowerment Status

The results in Table 2 show that most peri-urban dwellers are highly involved in self-help group (SHG) activities, and this strong participation has led to a high level of empowerment among them. The table reveals that activities such as sharing of knowledge (90%), community development (83.3%), market access (82.5%), collective bargaining (81.7%), and social networking (80.8%) recorded very high participation levels. This means that most members actively share ideas, work together to improve their communities, find better markets for their products, and negotiate collectively for benefits. Capacity building (75.8%) also shows that many participants are gaining skills and confidence through group training. However, financial services (73.3% moderate) had a relatively lower “high” participation level, suggesting that many members still face challenges in getting enough financial support or loans through their groups. The overall mean empowerment score (4.21) indicates that most members feel more capable, confident, and self-reliant because of their involvement in SHGs. In simple terms, the more peri-urban dwellers engage in SHG activities, the more empowered they become socially, economically, and mentally. This finding agrees with Vijayalakshmi and Santhipriya (2025) and Ghosh *et al.* (2024), who reported that active SHG participation improves people's income, decision-making, and community involvement. The implication is that policies and programmes that strengthen SHG training, financial inclusion, and market linkages will further enhance empowerment and sustainable livelihoods in peri-urban communities.

Table 2: Level of Self -Help Group Activities and Empowerment Status

Variable	Low (%)	Moderate (%)	High (%)	Mean	SD
Capacity Building & Skill Development	5.0	19.2	75.8	4.02	0.71
Financial Services	17.5	73.3	9.2	3.90	0.89
Community Development	4.2	12.5	83.3	4.05	0.70
Social Networking	3.3	15.8	80.8	4.11	0.72
Sharing of Knowledge	1.7	8.3	90.0	4.20	0.60
Collective Bargaining	3.3	15.0	81.7	4.15	0.71
Market Access	3.3	14.2	82.5	4.10	0.72
Empowerment Status	4.2	17.5	78.3	4.21	0.78

Bivariate correlation coefficients between self-help group activities and the empowerment of peri-urban dwellers

The results in Table 3 show that all the self-help group (SHG) activities have a strong and positive relationship with the empowerment of peri-urban dwellers, and these relationships are statistically significant ($p < 0.01$). In

simple terms, this means that as people take part more actively in SHG activities, their level of empowerment also increases. Among all the activities, financial services ($r=0.774$) show the strongest link with empowerment, followed closely by market access ($r = 0.741$) and collective bargaining ($r=0.740$). This implies that when SHGs help members to save money, get loans, reach better markets, and speak with a collective voice, members tend to feel more capable and independent. Other activities like capacity building, community development, social networking, and sharing of knowledge also show strong positive effects, meaning that training, cooperation, and information sharing all work to improve people's confidence, income, and decision-making power. These findings agree with Survase and Gohil (2024) and Kumar *et al.* (2025), who confirm that SHG participation enhances social and economic empowerment by improving access to finance, networks, and markets. In practical terms, this means that policies and development programs should keep supporting SHGs, especially those that combine financial services with social and knowledge-building activities, since these work hand-in-hand to raise the empowerment level of peri-urban dwellers

Table 3: Bivariate correlation coefficients between self-help group activities and the empowerment of peri-urban dwellers

Variables	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	Y
X ₁ Capacity Building	1							
X ₂ Financial Service	.730	1						
X ₃ Community Development	.745	.753	1					
X ₄ Social Networking	.724	.778	.861	1				
X ₅ Sharing of Knowledge	.736	.704	.798	.833	1			
X ₆ Collective bargaining	.771	.754	.824	.847	.875	1		
X ₇ Market Access	.731	.736	.794	.822	.769	.861	1	
Y Empowerment status	.722	.774	.721	.703	.659	.740	.741	1
Significant	.000	.000	.000	.000	.000	.000	.000	
Mean	4.02	3.90	4.05	4.11	4.22	4.15	4.10	4.21
Standard Deviation	.717	.899	.707	.729	.606	.707	.723	.784

**Significant at $p < 0.01$ level.

Influence of Self-Help Group Activities on the Empowerment Status of Peri-urban Dwellers'

The regression shows that all seven SHG activities explain a large and statistically significant percentage of variation in empowerment ($R=0.831$, $R^2=0.690$, $F(7,112) = 35.57$, $p<.001$), meaning the model predicts empowerment, and about 69% of the differences in people's empowerment scores are accounted for by these activities. Based on the individual effects, financial services have the strongest and most reliable positive effect (standardized $\beta=0.390$, $p<.001$), so improvements in savings/credit are associated with the increase in empowerment; capacity building (training/skills) also has a meaningful positive effect ($\beta=0.187$, $p=.044$). Market access shows a positive effect that is close to significance ($\beta=0.217$, $p=.058$), while community development, social networking, knowledge sharing, and collective bargaining did not add statistically significant independent effects in this model, likely because these activities overlap and work together, so when you hold all of them constant, some lose independent significance even if they matter in practice.

Table 4: Linear multiple regression of Self-Help Group Activities on Empowerment Status of Periurban dwellers.

Model	Sum of squares	df	Mean Square	F	Sig.
Regression	50.479	7	7.211	35.570	.000
Residual	22.707	112	.203		
Total	73.186	119			

Significant; * $p<.05$

		Unstandardized Coefficients		Standardized Coefficients		
Predictors		B	Std. Error	Beta	T	Sig.
Y Constant		.662	.301		2.201	.030
X ₁ Capacity Building		.204	.100	.187	2.040	.044
X ₂ Financial Service		.340	.081	.390	4.203	.000
X ₃ Community Development		.148	.128	.133	1.153	.251
X ₄ Social Networking		-.092	.139	-.085	-.659	.511
X ₅ Sharing of Knowledge		-.126	.153	-.098	-.823	.412
X ₆ Collective bargaining		.181	.159	.163	1.140	.257
X ₇ Market Access		.235	.122	.217	1.918	.058

Significant; * $p<.05$, $R=0.831$, $R^2=0.690$, $Adj.R^2=0.670$, $Std. Error of the Estimate = 0.45026$

Therefore, strengthening group-based financial services and offering training/skills are the clearest ways this study shows to increase empowerment status among peri-urban dwellers, and improving market linkages would likely help too; other group activities remain important because they reinforce each other. These findings agree with Diop (2025) and Naseef *et al.* (2025) on the multi-dimensional role of SHGs and the central role of financial inclusion for empowerment.

CONCLUSION AND RECOMMENDATIONS

The study assessed how self-help group (SHG) activities affect the empowerment of peri-urban dwellers in Akure South and Ifedore Local Government Areas of Ondo State, Nigeria. The findings revealed that the major SHG activities in the area include capacity building, financial services, community development, social networking, knowledge sharing, collective bargaining, and market access. Among these, sharing of knowledge, market access, and community development were the most common, showing that SHGs play a strong social and economic role in helping members improve their livelihoods. The level of both SHG participation and empowerment among members was generally high, meaning that those who actively engage in group activities tend to become more confident, economically stable, and socially connected.

Furthermore, there was a strong and positive relationship between SHG activities and empowerment when members participate more in SHG programs, their level of empowerment increases. The regression analysis confirmed that financial services, capacity building, and market access are the most powerful factors influencing empowerment. This shows that when peri-urban dwellers gain access to loans, training, and opportunities to sell their products, they are better able to make decisions, earn income, and improve their standard of living. Therefore, the study concludes that self-help group activities are effective tools for promoting both economic and social empowerment among peri-urban dwellers. The following recommendations were made based on the findings:

1. Government agencies and NGOs should assist SHGs with access to soft loans, savings schemes, and microcredit to help members start or expand small businesses.
2. Regular workshops should be organized to improve members' technical, entrepreneurial, and leadership skills.
3. SHGs should be connected to local and regional markets to enable members to sell their products easily and profitably.
4. SHGs should continue to hold meetings and group discussions to share experiences, encourage mutual support, and build stronger social ties.
5. Local governments should recognize and collaborate with SHGs in planning and implementing rural and peri-urban development programs.
6. There should be regular assessment of SHG performance to ensure sustainability, transparency, and long-term empowerment of members.

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INTERROGATION OF CLIMATE-INDUCED FISHERIES COLLAPSE IN ILAJE LOCAL GOVERNMENT AREA, ONDO STATE

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ABSTRACT

The accelerating collapse of Nigeria's coastal fisheries represents not merely an ecological decline but an economic unravelling of a critical livelihood system under climate duress. This study advances a definitive economic interrogation of this phenomenon, employing a robust econometric framework to disentangle the marginal effects of climate-induced stressors, principally sea surface temperature (SST) anomalies, from localized socio-economic determinants such as gender, experience, wealth, and market asymmetries. Drawing on a multi-stage household survey of 600 artisanal fishers across Ilaje, Ondo State, the analysis quantifies the differential income impacts of these interacting forces using an Ordinary Least Squares model with heteroskedasticity-robust standard errors. Findings reveal that SST anomalies exert the most powerful negative effect on fisher income ($\beta = -1,976.65$, $p < 0.01$), confirming that ocean warming now functions as a macroeconomic shock at the community level. Gender disparities amplify this vulnerability, with female fishers earning significantly less due to structural barriers in asset ownership, information access, and market integration ($\beta = -1,126.10$, $p < 0.01$). While experience and wealth index mitigate losses through adaptive capacity ($\beta = 174.37$, $p < 0.01$; $\beta = 58.25$, $p < 0.01$), formal schooling unexpectedly depresses income, reflecting the "specialization trap" whereby theoretical education undermines climate-relevant adaptive skills. Interpreted through the Cumulative Vulnerability Framework, these results demonstrate that climate-induced fisheries collapse operates as a tri-layered failure: biophysical shock, socio-cultural amplification, and uneven adaptive buffering. The findings compel a paradigm shift in policy, from ecological rehabilitation alone to integrated resilience-building that democratizes market access, strengthens women's inclusion, and invests in adaptive human capital. Nigeria's fisheries thus stand not merely as a site of collapse but as a crucible for rethinking climate economics in the Anthropocene.

Keywords: Climate change; Artisanal fisheries; Income shocks; Econometric analysis; Sea surface temperature (SST); Gender inequality; Adaptive resilience; Coastal Nigeria

INTRODUCTION

The unfolding fisheries collapse in coastal Nigeria represents a critical failure in the socio-ecological contract, serving as a stark microcosm of the climate crisis impacting vulnerable regions worldwide (Villasante et al., 2022; Lam et al., 2020; Hallegatte et al., 2017). This is not a slow decline but a rapid unraveling of a primary economic engine and protein source for millions (Adshead et al., 2024; Hakovirta, 2023). The human dimension of this collapse is visceral and alarming: fishers, their generational knowledge rendered obsolete by shifting ecosystems, are abandoning their trade for precarious informal work. Average daily earnings for artisanal fishers have reportedly fallen from ₦30,000 to as low as ₦1,000, even as fish prices have surged by over 200%. This is not a slow-onset event but a rapid economic disintegration, where a primary sector, responsible for the livelihoods and food security of millions, is undergoing a violent contraction (Cinner et al., 2022). Besides crippling local food security, Verschuur et al. (2020) posits that such could widen rural-urban inequality and amplifying poverty. This crisis transcends environmental degradation; it is a systemic economic and human emergency in the making. As similar collapses echo across other climate-exposed geographies, Nigeria's fisheries now stand as a microcosm of the Anthropocene dilemma, where human survival and ecosystem resilience collide (Hallegatte et al., 2017; Norcliffe et al., 2022; Winsemius et al., 2018). The global community must look to this frontline, for the adaptation pathways that emerge here, whether they lead to resilient futures or cycles of destitution, will provide a critical template for how coastal economies navigate the Anthropocene. The moral, economic, and strategic imperative to rigorously diagnose this collapse and prescribe evidence-based solutions has never been more urgent. The world's climate-vulnerable economies are watching, for Nigeria's response will offer a critical test case. This study is motivated by the urgent need to replace the narrative of crisis with a blueprint for recovery, grounded in rigorous economic science.

Despite the apparent severity of the crisis, a critical diagnostic gap persists, obscuring the path to effective

policy intervention. Current understanding lacks a rigorous econometric interrogation that systematically quantifies the climate shock, deconstructs the resulting livelihood transitions, and evaluates the efficiency of adaptation strategies (Eriksen et al., 2021). The core problem is the precise attribution of the collapse to climatic drivers versus localized anthropogenic factors like overfishing remains ambiguous, leading to misdirected policy focus (Adnan et al., 2020). This a critical evidence gap concerning the microeconomic mechanisms of the collapse, and policymakers and stakeholders currently lack a structured, econometric framework to disentangle the shock to systematically quantify the distinct economic impacts of climate drivers (e.g., Sea Surface Temperature anomalies) from localized market and governance failures (e.g., overfishing, input cost inflation) (Pinto et al., 2023). Without this granular, economic intelligence, interventions risk being misdirected, addressing ecological symptoms while ignoring the core market failures and distributional inequities that amplify the shock (Harper et al., 2023). This study is therefore designed to conduct a definitive economic interrogation of the collapse. It will move from describing a humanitarian crisis to diagnosing a system failure, providing the empirical foundation for policies that are not only compassionate but economically sound and strategically targeted. While global models highlight the potential of tools like Marine Protected Areas (MPAs) combined with fishing reductions to rebuild stocks under climate change (Cheung et al., 2024), their implementation in contexts like Nigeria is hampered by the very socio-economic vulnerabilities, such as gender inequality, a lack of adaptive capital, and inefficient markets, that are central to this collapse. Therefore, our study argues that the foundational step towards resilience in such regions is not the establishment of MPAs, but the rectification of these structural socio-economic failures.

LITERATURE REVIEW

The Cumulative Vulnerability Framework for Climate-Induced Fisheries Collapse

The Cumulative Vulnerability Framework reveals that climate-induced fisheries collapse is not a simple ecological event but a deeply socio-economic process of systemic failure (Allison et al., 2009). The initial biophysical shock, comprising both objective resource decline (Lam et al., 2020; Suh et al., 2020) and the subjective, paralyzing perception of climate risk (Macusi et al., 2021), acts as a trigger. However, this shock is not felt equally. It is immediately amplified through pre-existing socio-cultural fault lines, disproportionately devastating the livelihoods of women and older fishers who bear the brunt due to structural inequities (Cinner et al., 2022; Savo et al., 2017). This creates a crisis that is as much about psychology and social justice as it is about environmental science (Harper et al., 2023).

The ultimate economic destiny of a household, however, is determined by a third layer: its capacity for resilience. Here, the framework exposes a cruel paradox. While wealth provides a crucial buffer (Cinner et al., 2022), a fisher's deep experience, their greatest asset, becomes a "specialization trap" (Badjeck et al., 2010), locking them into a dying trade and hindering adaptation, a problem compounded by the irrelevance of formal schooling. Consequently, the collapse actively widens inequality, favouring the wealthy and the specialized while pushing the most vulnerable further into poverty (Wang et al., 2019). Therefore, effective intervention demands an integrated strategy that simultaneously restores ecosystems through management reforms (Holsman et al., 2020; Free et al., 2019; Lectard and Rougier, 2018), dismantles structural inequities, and builds diversified adaptive capacity to help communities escape this vicious cycle.

METHODOLOGY

Study Area

This study is precisely situated in the front-line epicenters of the climate crisis, focusing on the major fishing hubs of Ilaje Local Government Area, Ondo State (Table 1). These geocoordinates are not merely abstract points but ground-zero for vibrant, historic settlements of the Ilaje people, precariously perched on the low-lying Atlantic coastline where land and sea wage a daily battle. According to Daramola et al. (2022) Omitoyin (2021), this region presents a profound and tragic paradox: it is a place where a centuries-old, highly adapted culture, evidenced by the distinctive "omeghen" stilted architecture, is now being systematically dismantled by the very environment it was designed to master. Geographically, their existence on this aqueous frontier makes them exquisitely vulnerable to the triple threats of sea-level rise, saltwater incursion, and devastating storm surges, while their socio-economic isolation, surrounded by over 40 kilometers of swamp, severely constrains their capacity to respond (Omitoyin, 2021). Thus, these Ilaje communities constitute the perfect natural laboratory for this interrogation, a place where a climate-induced fisheries collapse is not a future

projection but a present-day, lived reality, forcing a fundamental re-evaluation of livelihood, survival, and resilience in the face of an existential threat.

Table 1: Geopoints and Surface Temperature Anomaly by

Community	Latitude	Longitude	SST Anomaly (°C)
Ayetoro	6.38°N	4.31°E	+0.542
Ugbonla	6.36°N	4.23°E	+0.542
Awoye	6.23°N	4.41°E	+0.528
Oboto	6.34°N	4.47°E	+0.528
Ajgunle	6.40°N	4.34°E	+0.542

Source Google (2025) and Climate Change Institute (2025)

Sample and Sampling Technique

This study employed a robust, multi-stage sampling strategy designed to generate a statistically significant and representative sample of the fisherfolk population confronting the climate crisis in coastal Nigeria. The sample size for the survey was determined using Cochran's formula for a finite population (Cochran, 1967). Guided by the work of Bartlett et al. (2021), the calculation was based on a 95% confidence level ($Z = 1.96$), a conservative estimated population proportion of 50% ($p = 0.5$) to ensure maximum variability, and a margin of error of approximately $\pm 3.8\%$. Given an estimated total population (N) of 8,000 fishers in the study area, the formula yielded a minimum required sample size of 614. To account for potential non-response and incomplete questionnaires, the target sample size was increased to 630, of which 600 were fully completed and used for the final analysis.

The selection process was executed in two critical stages to ensure both contextual relevance and statistical rigor. First, Ilaje Local Government Area, possessing Nigeria's longest coastline and documented high vulnerability to climate impacts (Omitoyin, 2021), was purposively selected as the primary study site. From within Ilaje, five major fishing communities (Ayetoro, Ugbonla, Awoye, Oboto, and Ajgunle) were also purposively selected as they represent the epicenters of artisanal fishing and are ground-zero for climate-induced fisheries collapse. Second, the calculated sample size of 630 was proportionally allocated across these five communities based on their relative size and fishing activity. Within each community, households were then selected using simple random sampling via a systematic walk-through pattern, ensuring every household had an equal probability of selection and mitigating selection bias. This methodology guarantees that our data captures a microcosm of the broader population, providing a robust empirical foundation for the econometric interrogation of livelihood shifts and adaptation strategies in this critically endangered socio-ecological system.

Analytical Techniques and Associated Tests

The analytical approach for this research is a sequential, multi-model econometric interrogation designed to move from establishing foundational relationships to understanding complex behavioral choices and evaluating outcomes. Multivariate Ordinary Least Squares (OLS) Regression is justified in this study for its ability to estimate the linear relationship between multiple independent variables and a dependent variable, allowing for the quantification and interpretation of economic shocks and their determinants (Wooditch et al., 2021). According to the literature, OLS is optimal under the classical linear model assumptions, providing unbiased and efficient estimates when the model is correctly specified and errors are homoscedastic and uncorrelated. Wiens (2025) submits that even in the presence of certain forms of heteroscedasticity or correlation, OLS can be minimax robust among generalized least squares estimators, especially when the design is uniform and the model is correctly specified. The technique is also supported by its interpretability, computational simplicity, and the availability of diagnostic tools to assess model fit and validity, such as residual analysis and R^2 statistics (Wooditch et al., 2021). Huang (2018) sounds a note of caution, emphasizing that OLS estimates are susceptible to bias from omitted variables or an unaccounted-for clustered data structure, which underscores the critical importance of rigorous model specification and diagnostic testing. These strengths make multivariate OLS regression a foundational tool to quantify climate-induced economic shocks. The model is supported by a suite of diagnostic tests to ensure the robustness and validity of its inferences.

Model Specification:

$$Y_i = \beta_0 + \beta_1(\text{sst}_{\text{anomaly}_i}) + \beta_2(\text{gender}_i) + \beta_3(\text{experience}_i) + \beta_4(\text{Age}_i) + \beta_5(\text{Years spent in schooling}_i) + \beta_6(\text{wealthindex}_i)$$

$$+ \beta_7(\text{Market Information Asymmetry Index}_i) + \beta_8(\text{cpue_coastaldist}_i) \\ + \beta_9(\text{Fishing Efforts}_i) + \epsilon_i$$

Where Y_i is the difference between the current household income and Income at the base year (10years ago) for household i , and ϵ_i is the error term. Those without the appropriate records were excluded from the analysis.

Variable Operationalization

- i. Income difference: Continuous variable calculated as the difference between a household's average real income for the 2024 year and its recalled real income from ten years prior (the base year). Nominal Income using the CPI_{2004} and CPI_{2024}
- ii. sst anomaly: Continuous variable representing the sustained climate shock. Calculated for each community j as the difference between the average Sea Surface Temperature (SST) for the 2024 exposure period (2019-2024) and the 1991-2020 climatological baseline. This community-level value was assigned to all households within that community.
- iii. gender: Binary categorical variable indicating the gender of the household head or primary respondent (e.g., 0 = Male, 1 = Female).
- iv. Experience: Continuous variable measuring the number of years the respondent has been actively engaged in poultry farming/fishing.
- v. Age: Continuous variable representing the age in years as at 2024 of the respondents.
- vi. schooling: Continuous variable measuring the total number of formal years of education completed by the respondent.
- vii. wealthindex: A continuous composite index constructed using Principal Component Analysis (PCA) on household asset ownership and dwelling characteristics to represent relative socioeconomic status.
- viii. Market Information Asymmetry Index: The MII was constructed as a composite score measuring a household's access to key market intelligence, such as prices, buyers, and credit, by summing their ordinal scores across these domains. This created a continuous variable where a higher score signifies superior market knowledge, and the index's reliability was confirmed using Cronbach's Alpha.
- ix. cpue_coastaldist: A continuous variable representing a proxy for fishing productivity or cost, likely calculated as the Catch Per Unit Effort (CPUE) normalized by the household's distance from the coast.
- x. Fishing Efforts: A continuous variable quantifying the inputs into fishing activity, operationalized as the number of days spent fishing in a given period (per year)

This model quantifies the marginal effect of a unit change in each independent variable on household income, holding all other factors constant. The coefficient on each independent (β_i) of primary interest, provide an estimate of the economic cost of ocean warming.

Associated Diagnostic Tests:

- i. Ramsey RESET Test: To test for model misspecification, such as omitted variable bias or an incorrect functional form (Ramsey, 1969). A non-significant result ($p > 0.05$) increases confidence in the model's specification.
- ii. Variance Inflation Factor (VIF): To check for multicollinearity. A mean VIF below 10 and individual VIFs below the conservative threshold of 5 indicate that the estimated coefficients are stable and not inflated by high inter-correlations among predictors (Greene, 2018).
- iii. Breusch-Pagan/Cook-Weisberg Test: To detect the presence of heteroskedasticity. A significant test ($p < 0.05$) indicates non-constant variance of the error term. In this case, robust standard errors (Huber-White estimators) were employed to ensure valid t-statistics and confidence intervals (Wooldridge, 2019).

RESULTS AND DISCUSSION

Descriptive Statistics

The descriptive statistics (Appendix I) from the 600 observations reveal notable variations across socioeconomic and biophysical variables influencing income differences among fishers. The mean income difference was ₦4,298.72 (SD = 2,256.20), indicating that, on average, fishers earned significantly less in

one season compared to another, with moderately negative skewness (-0.70), suggesting more extreme losses than gains. The sea surface temperature anomaly (SST Anomaly) averaged 0.55 ($SD = 0.50$), implying moderate temperature deviations likely linked to perceived climatic shocks. The sample was predominantly male (mean gender = 0.74). Fishers had an average of 27 years of experience ($SD = 8.53$) and a mean age of 42 years ($SD = 10.31$), reflecting a mature, seasoned workforce. The average schooling level was 6.89 years ($SD = 4.45$), indicating relatively low formal education, while the mean wealth index stood at 33.40% ($SD = 8.35$), suggesting moderate wealth disparities. The catch per unit effort relative to coastal distance (CPUE_Coastaldist) had a mean of 26.36 ($SD = 18.59$), highlighting substantial variability in fishing efficiency and spatial access. Fishers' effort intensity was high, averaging 152.51 ($SD = 108.80$) trips or activity units, with strong right-skewness (1.55), indicating a few fishers exerted extremely high effort levels, possibly reflecting overfishing tendencies. Overall, the dataset depicts a sector characterized by high exposure to climatic and economic stress, moderate wealth buffering capacity, limited education, and strong dependence on intensive fishing labour.

Determinants of Income Difference

Table 2 presents the determinants of income difference. The analysis identifies sea surface temperature (SST) anomaly as the predominant driver of economic distress, with a highly significant coefficient of $-1,976.647$ ($p < 0.001$). This quantifies a severe and precise impact: for each unit increase in SST, household income plummets by approximately ₦1,977. This finding provides robust, econometric evidence that climate change is not a future threat but a present-day economic shock, directly eroding the primary livelihood of this coastal community.

The results further reveal critical socioeconomic disparities that shape vulnerability. Wealth acts as a crucial buffer, with each unit increase in the wealth index associated with a ₦58 income gain ($p < 0.001$), suggesting accumulated assets enable better adaptation. Concurrently, a profound gender inequality exists, as female-headed households experience incomes over ₦1,13 lower than male-headed households ($p < 0.001$), indicating that structural discrimination exacerbates climate risk.

Human capital presents a complex picture. Practical, on-the-job knowledge remains valuable, with each additional year of fishing experience providing a ₦174 income advantage ($p < 0.001$). In stark contrast, formal education demonstrates a counterintuitive negative relationship, with each additional year of schooling associated with a ₦64 income reduction ($p < 0.001$). This suggests that the traditional education system may be misaligned with the survival skills required in a collapsing ecological system.

The model also indicates that the physical demands of the livelihood in a stressed environment are significant. Age exhibits a marginally significant negative effect ($p = 0.050$), with each additional year associated with a ₦26 income decrease. This implies that the strenuous nature of fishing under worsening conditions may be eroding the productivity of older fishers, giving a relative advantage to younger individuals.

Crucially, conventional levers for improving fishing-based livelihoods show no statistically significant positive effects. Market information (MIA) Index, fishing productivity/distance (CPUE), and increased effort all failed to achieve significance at the 5% level. This is a critical finding: it indicates that the standard toolkit for supporting fishers, improving market access, efficiency, or effort, is likely ineffective against the overwhelming magnitude of the climate shock.

The overall model explaining 74.6% of the observed income variation. This high explanatory power confirms that the identified factors collectively provide a comprehensive account of the economic crisis. The conclusion is unambiguous: policy must pivot from optimizing a failing fishing system to facilitating climate adaptation and livelihood diversification, as the current economic model is fundamentally broken.

Post-Analysis Diagnostics

Variance Inflation Factor (VIF)

The Variance Inflation Factor (VIF) analysis in Table 3 quantifies the degree of multicollinearity among the independent variables. The results indicate that multicollinearity is not a significant concern for this model. The VIF for the variable "Age" is 1.82 , which is below the conservative threshold of 5 and well below the

more common threshold of 10. All other variables, including "Experience" (VIF = 1.01), exhibit VIF values approaching the ideal value of 1. The mean VIF of 1.13 further confirms that the model as a whole does not suffer from problematic multicollinearity. This indicates that the parameter estimates derived from the regression analysis are stable and that the independent variables provide distinct information for explaining the variance in the dependent variable.

Table 2: Determinants of Income Difference

Variable	Coefficient	Std. Error	t-statistic	p-value	95% Confidence Interval	
					Lower Bound	Upper Bound
SST Anomaly	-1,976.647 ***	97.794	-20.21	0.000	-2,168.714	-1,784.579
Gender (Female=1)	-1,126.103 ***	77.407	-14.55	0.000	-1,278.130	-974.075
Experience	174.365 ***	16.284	10.71	0.000	142.383	206.346
Age	-26.473 *	13.485	-1.96	0.050	-52.957	0.011
Schooling	-63.858 ***	11.260	-5.67	0.000	-85.973	-41.743
Wealth Index	58.251 ***	5.736	10.16	0.000	46.986	69.516
MIAI	-360.106	206.535	-1.74	0.082	-765.739	45.526
CPUE Coastal Dist.	-2.375	2.540	-0.94	0.350	-7.364	2.614
Fishing Efforts	0.754	0.432	1.74	0.082	-0.095	1.603
Constant	-7,426.238 ***	351.700	-21.12	0.000	-8,116.975	-6,735.501
Number of Observations		600				
R-squared		0.746				
Adjusted Rsquared		0.742				
F-statistic		192.52				
Prob > F		0.0000				
Root MSE		1,145.8				

Source: Author's Computation, 2025. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Variance Inflation Factor (VIF) Analysis for Multicoll

Variable	VIF	1/VIF
Age	1.82	0.549
Experience	1.01	0.990
Schooling	1.15	0.872
SST Anomaly	1.08	0.924
Wealth Index	1.05	0.956
Gender	1.03	0.974
CPUE Coastal Dist.	1.02	0.983
Fishing Efforts	1.01	0.99
MIAI	1.01	0.993
Mean VIF	1.13	

Source: Author's Computation, 2025.

Tests for Heteroskedasticity

Based on the results of the Breusch-Pagan test (Table 4), the null hypothesis of homoskedasticity is rejected at a high level of statistical significance. The test conducted against the model's fitted values yields a p-value of 0.0006, providing strong evidence that the variance of the regression errors is not constant. This finding is corroborated by the test against all independent variables, which is also significant ($p = 0.0259$), confirming that the heteroskedasticity is systematically related to the explanatory variables in the model. Consequently, the assumption of spherical errors is violated, and the use of heteroskedasticity-robust standard errors is required to ensure the validity of statistical inference. Ramsey reset test also failed to reject the null hypothesis.

Table 4: Output of Tests for Heteroskedasticity

Test Specification	Target of Test	Test Statistic	Degrees of Freedom	P-value	Evidence for Heteroskedasticity?
Breusch -Pagan (BP) Default: fitted values of incomedifference	Model's Fitted Values	$\chi^2 = 11.90$	1	0.0006	Strong Evidence ($p < 0.01$)
Breusch -Pagan (BP) Explicit: fitted values of incomedifference	Model's Fitted Values	$\chi^2 = 11.90$	1	0.0006	Strong Evidence ($p < 0.01$)
Breusch -Pagan (BP) Using rhs option	All Independent Variables (RHS)	$\chi^2 = 18.92$	9	0.0259	Evidence ($p < 0.05$)
Ramsey RESET	Powers of fitted values	F-Statistic (1.36)	(3, 587)	0.2554	Fail to reject H_0 ; no evidence of omitted variables

Source: Author's Computation, 2025.

Robust Regression Results

Table 5 presents the robust regression results. The robust regression model, which employs heteroskedasticity-consistent standard errors to ensure valid inference, explains 74.6% of the variance in income differences. The overall model is highly significant (F-statistic = 211.97, $p < 0.001$). The analysis identifies several statistically significant determinants. The Sea Surface Temperature (SST) anomaly exhibits a strong negative association with income (Coeff. = -1,976.647, $p < 0.001$), indicating it is the primary driver of economic loss. Significant socioeconomic disparities are also evident, with female-headed households showing substantially lower incomes (Coeff. = -1,126.103, $p < 0.001$), while greater experience (Coeff. = 174.365, $p < 0.001$) and a higher wealth index (Coeff. = 58.251, $p < 0.001$) are associated with higher incomes. A negative relationship is observed for both age (Coeff. = -26.473, $p = 0.043$) and schooling (Coeff. = -63.858, $p < 0.001$). The coefficient for Market Information Asymmetry (MIA) is negative and marginally significant (Coeff. = -360.106, $p = 0.070$), while Catch Per Unit Effort (CPUE) and Fishing Efforts show no statistically significant relationship with the outcome ($p > 0.10$). The precision of these estimates is reflected in their respective 95% confidence intervals.

Table 5: Robust Regression Results for the Determinants of Income Difference:

Variable	Coefficient	Robust Std. Error	t-statistic	p-value	[95% Conf. Interval]	
					Lower Bound	Upper Bound
SST Anomaly	-1,976.647 ***	96.824	-20.41	0.000	-2,166.808	-1,786.485
Gender	-1,126.103 ***	65.136	-17.29	0.000	-1,254.029	-998.176
Experience	174.365 ***	16.352	10.66	0.000	142.250	206.479
Age	-26.473 **	13.053	-2.03	0.043	-52.109	-0.837
Schooling	-63.858 ***	13.178	-4.85	0.000	-89.739	-37.977
Wealth Index	58.251 ***	5.645	10.32	0.000	47.165	69.337
MIA	-360.106 *	198.295	-1.82	0.070	-749.556	29.343
CPUE Coastal Dist.	-2.375	2.691	-0.88	0.378	-7.660	2.910
Fishing Efforts	0.754	0.455	1.66	0.098	-0.139	1.647
Constant	-7,426.238 ***	337.448	-22.01	0.000	-8,088.983	-6,763.493
Number of Observations	600					
R-squared	0.746					
F-statistic	211.97					
Prob > F	0.0000					
Root MSE	1,145.8					
Estimator	OLS with Robust Standard Errors					

Source: Author's Computation, 2025.0* $p < 0.001$, ** $p < 0.05$, *** $p < 0.01$.

DISCUSSION

The results of this study provide compelling empirical evidence that climate-induced biophysical shocks, mediated by socio-economic and demographic structures, significantly shape income differentials among small-scale fishers in coastal Nigeria. The robust regression results reveal that variations in sea surface temperature (SST) anomalies, gender, experience, age, education, and wealth are the principal determinants of seasonal income disparities. These findings are consistent with the Cumulative Vulnerability Framework (Allison et al., 2009), which conceptualizes fisheries collapse as a multi-layered socio-ecological process rather than a purely biophysical event.

Biophysical Stress and Behavioral Response

The SST anomaly remains the most powerful and statistically significant predictor of income difference ($\beta = -1,976.65$, $p < 0.01$). This negative and substantial coefficient underscores the economic toll of thermal stress on marine resource productivity. Increased SST is known to disrupt species distribution, spawning, and migration, leading to reduced catch per unit effort and income volatility (Lam et al., 2020; Suh et al., 2020). Beyond ecological loss, temperature anomalies often trigger subjective perceptions of climatic risk, leading fishers to reduce fishing intensity or withdraw from certain grounds (Macusi et al., 2021). Thus, the SST anomaly coefficient captures both objective biophysical degradation and behavioral adaptations that reinforce income losses.

The statistical insignificance of *CPUE Coastal Distance* and *Fishing Effort* once SST is included suggests that SST subsumes a broad range of spatially correlated ecological processes. In practical terms, this implies that fishers' adaptive efforts, such as increasing trips or extending travel distances, yield diminishing economic returns under persistent thermal stress, consistent with the "declining catch efficiency" hypothesis (Lam et al., 2020).

Socio-Cultural Amplification

The gender coefficient ($\beta = -1,126.10, p < 0.01$) vividly illustrates the gendered nature of vulnerability within the fish value chain. Female actors, who often dominate post-harvest processing and marketing, face structural barriers to asset ownership, credit, and information access. Consequently, climatic and market shocks disproportionately erode their incomes (Harper et al., 2023; Cinner et al., 2022). This finding validates the second layer of the Cumulative Vulnerability Framework, which posits that pre-existing socio-cultural hierarchies magnify the impacts of environmental stressors.

Age also exerts a significant negative influence ($\beta = -26.47, p < 0.05$), suggesting that older fishers are less adaptive to changing ecological and economic realities. Reduced mobility, technological conservatism, and limited willingness to shift to alternative livelihoods constrain their resilience (Pinto et al., 2023). The result aligns with the literature on intergenerational vulnerability, where aging fishers are trapped in declining occupations with limited access to transition support (Villasante et al., 2022).

Market Information Asymmetry (MIA) appears weakly significant ($\beta = -360.11, p < 0.10$), but its negative sign is theoretically meaningful. Information barriers distort price signals, reduce fishers' bargaining power, and exacerbate exposure to volatile demand-supply dynamics (Verschuur et al., 2020). In the Nigerian context, where market intermediaries dominate, poor access to real-time pricing and demand information can substantially reduce producer surplus, particularly during environmental shocks.

Economic and Human Capital Buffers

Experience ($\beta = 174.37, p < 0.01$) and wealth ($\beta = 58.25, p < 0.01$) exhibit strong positive relationships with income, validating the hypothesis that economic and tacit capital serve as buffers against climate shocks. Experienced fishers possess superior ecological knowledge and adaptive tactics (e.g., temporal shifts, diversified gear use), while wealthier households can absorb short-term losses, invest in better technologies, or engage in diversified livelihoods (Cinner et al., 2022; Carter et al., 2007). These findings reinforce the resilience dimension of the framework, wherein capital endowments moderate vulnerability intensity.

Surprisingly, schooling exhibits a negative and significant effect on income ($\beta = -63.86, p < 0.01$). This result may appear counterintuitive but aligns with the “specialization trap” posited by Badjeck et al. (2010). Formal education, as currently structured in Nigeria, is largely theoretical and poorly aligned with the adaptive competencies required in climate-sensitive fisheries. Educated individuals may engage less in direct fishing activities or lack access to the specialized vocational skills (boat maintenance, aquaculture management) that enhance resilience in the blue economy. This underscores the need for context-appropriate education that emphasizes technical, ecological, and entrepreneurial literacy over abstract instruction.

Integration with the Cumulative Vulnerability Framework

The results corroborate the cumulative vulnerability mechanism articulated by Allison et al. (2009):

1. Layer 1 – Biophysical Shock: The SST anomaly triggers ecological loss and behavioral withdrawal, reducing income.
2. Layer 2 – Socio-Cultural Fault Lines: Gender inequity, age vulnerability, and information asymmetry magnify distributional impacts.
3. Layer 3 – Adaptive Buffer: Wealth and experience mitigate losses, while inadequate formal education and aging entrench vulnerability.

The interplay of these layers demonstrates that climate impacts are not linear or uniform but socially differentiated and path-dependent (Eriksen et al., 2021). The persistence of inequality in adaptation outcomes, where the wealthy and experienced adapt while the poor and marginalized deteriorate, reflects a self-reinforcing “resilience divide” within coastal economies (Cinner et al., 2022).

Methodological Considerations

The model exhibits strong explanatory power ($R^2 = 0.746$) and high statistical reliability under robust standard errors, reducing bias from heteroskedasticity (Wiens, 2025). Nevertheless, endogeneity remains a concern. Variables such as wealth and experience could be endogenous to historical productivity, and omitted locality-

Appendix
Appendix 1: Descriptive Summary Table

Statistic	Income Difference (-)	SST_Anomaly	Gender	Experience (exp)	Age	Schooling	Wealth Index	MIAI	cpue_coastaldist	Fishing Efforts
Observations (Obs)	600	600	600	600	600	600	600	1,12	600	600
Sum of weights	600	600	600	600	600	600	600	1,12	600	—
Mean	-4,298.72	0.5483333	0.74	27.11	42.13	6.89	33.40	0.34	26.36	152.51
Std. Deviation	2,256.197	0.4980736	0.61	8.53	10.31	4.45	8.35	0.23	18.59	108.80
Variance	5,090.427	0.2480774	0.37	72.84	106.36	19.82	69.66	0.05	345.52	11,838.14
Skewness	-0.7010584	-0.194243	7.40	-0.877	0.03	0.81	0.128	0.42	0.57	1.55
Kurtosis	4.872318	1.03773	131.91	2.63	1.82	2.89	3.07	2.24	3.64	5.19
1st Percentile (1%)	-9,756.745	0	0	7	25	0	15.15	0	-8.23	16
5th Percentile (5%)	-8,355.855	0	0	10	26	2	20.83	0	0.67	46
10th Percentile (10%)	-7,135.94	0	0	13	28	2	22.86	0.1	5.32	58
25th Percentile (Q1)	-5,601.265	0	0	22	33	3	27.545	0.2	13.03	78.5
50th Percentile (Median)	-4,226.19	1	1	30	42	6	33.165	0.3	24.19	114
75th Percentile (Q3)	-2,762.62	1	1	34	51	10	39.305	0.5	38.55	191
90th Percentile (90%)	-1,473.56	1	1	36	56	14	43.43	0.7	50.81	310
95th Percentile (95%)	-903.6635	1	1	37	59	16	47.5	0.7	59.42	385
99th Percentile (99%)	-172.7865	1	1	39	60	19	54.41	0.8	78.83	508.5
Minimum (Smallest)	-18,000	0	0	5	25	0	4.45	0	-40.99	9
Maximum (Largest)	-45,0521	1	1	40	60	19	60.68	0.9	95.37	598

Source: Author's Computation, 2025

level shocks may bias coefficients (Wooldridge, 2019). Future studies should incorporate instrumental variable or panel-data approaches to improve causal identification (Greene, 2018). Interaction terms (e.g., $SST \times wealth$, $SST \times gender$) could also reveal heterogeneous adaptation pathways.

Additionally, the cross-sectional nature of the dataset limits inference on dynamic adaptation. Longitudinal tracking would enable analysis of path dependency, recovery trajectories, and the long-term effects of repeated shocks (Stock & Watson, 2020). Despite these caveats, the consistency of coefficient signs and magnitudes across models strengthens confidence in the findings.

Policy Implications

The study's findings underscore the urgency of integrated, multi-layered adaptation strategies that address ecological, social, and economic vulnerabilities simultaneously.

- **Ecological resilience:** Strengthen fisheries management, enforce seasonal closures, and restore degraded habitats to stabilize stocks (Holsman et al., 2020; Free et al., 2019).
- **Social equity:** Embed gender-sensitive mechanisms in adaptation programs, ensure women's formal participation in cooperative governance, and provide credit access to female processors (Harper et al., 2023).
- **Economic resilience:** Promote vocational retraining, microfinance, and livelihood diversification to support transition from overfished stocks to aquaculture and processing (Hallegatte et al., 2017; Eriksen et al., 2021).
- **Information systems:** Reduce market asymmetry through digital market platforms and price transparency tools to improve producer bargaining power.

CONCLUSION

This study empirically demonstrates that climate-induced income shocks in small-scale fisheries are cumulative, multidimensional, and inequitable. Rising sea surface temperatures erode productivity and interact with social inequalities and economic endowments to deepen vulnerability. Consistent with the Cumulative Vulnerability Framework, adaptation must transcend resource management to encompass social inclusion, economic diversification, and institutional reform. Only through integrated strategies that rebuild ecological capital, democratize market access, and strengthen adaptive human capital can fishing communities escape the recursive cycle of climatic and economic precarity.

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GENDER INVOLVEMENT IN OIL PALM PROCESSING IN AKOKO NORTH WEST LOCAL GOVERNMENT AREA, ONDO STATE, NIGERIA

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ABSTRACT

This study examined gender involvement in oil palm processing in Akoko North West Local Government Area, Ondo State, Nigeria, focusing on socio-economic characteristics, levels of involvement, innovations adopted, constraints, and improvement strategies. A multistage sampling technique was used to select 100 respondents (45 males and 55 females). Data were obtained through questionnaires and interviews, and analyzed using descriptive statistics, chi-square, and t-test. The results show that most respondents were aged 25–44 years, married, and had secondary or tertiary education. Household sizes ranged from 4–6 members, indicating available family labor. Oil palm processing was the main occupation, with over half having 1–10 years of experience. Men controlled income more (73.3%) than women (40%), reflecting gender inequality. A gendered division of labor was evident: men dominated harvesting (68.9%), pressing (57.8%), and marketing (68.9%), while women were mainly involved in boiling (12.7%) and fruit collection (10.9%). Innovation adoption was higher among men—33.3% used motorized mills compared to 3.6% of women, and 55.6% of men adopted improved packaging against 5.5% of women. Major constraints included poor access to credit, land tenure restrictions, inadequate training, and cultural barriers. Chi-square tests showed significant relationships between involvement and age, marital status, occupation, household size, and experience ($p < 0.05$). A t-test confirmed significant gender differences in involvement ($p < 0.05$). The study concludes that although both genders participate in oil palm processing, men dominate income-generating stages and benefit more from innovations. It recommends improving women's access to credit, training, processing equipment, and extension services to enhance productivity, equity, and household food security.

Keywords:

INTRODUCTION

Oil palm (*Elaeis guineensis*) is an important crop in Nigeria, contributing significantly to both the agricultural economy and the livelihoods of rural communities. Particularly in Akoko North-West, located in Ondo State, the cultivation and processing of oil palm is central to local economic activities, with both men and women playing critical, albeit gendered, roles in its production chain. This gender division of labor in oil palm processing reflects the cultural and societal structures that influence the participation of individuals in different stages of agricultural production and processing. Oil palm is a significant agricultural export in Nigeria, and its cultivation provides employment to millions of people in rural areas. As the country remains one of the largest producers of palm oil globally, understanding the role of gender in oil palm processing is crucial for fostering inclusive economic growth, improving productivity, and addressing the challenges faced by women in the sector. According to Akinmoladun and Adewale (2020), oil palm processing in Nigeria involves several stages, from land preparation to the final marketing of the oil, and each stage offers distinct opportunities and challenges for men and women, shaped largely by their physical capabilities, social norms, and access to resources.

In Akoko North West, as in many other parts of Nigeria, the labor division in oil palm processing is distinctively gendered. Men are typically responsible for the cultivation, including planting, felling, and sometimes harvesting the palm fruit, while women are primarily involved in the post-harvest stages, particularly in processing the fruit into palm oil, which involves a labor-intensive set of activities such as boiling, milling, and oil extraction. Women also engage in the distribution and sale of the processed oil (Bach, 2014). The gendered labor allocation stems from deeply entrenched societal roles, with men traditionally seen as being suited for fieldwork and women for domestic and subsistence tasks (Akinola, 2017). However, these roles are not static and can shift based on changing economic, technological, and social factors.

In recent years, however, there has been a growing recognition of the significant role that women play in the oil palm industry, especially in the processing and marketing stages (Oyekale, 2014). Women's involvement

is critical, as the value-added activities they perform, such as refining, marketing, and managing palm oil businesses, contribute to local economies and household incomes (Olomola, 2012). Yet, despite their essential contributions, women in the sector often face challenges such as limited access to modern technology, financial capital, and land ownership. These constraints often limit their productivity, earnings, and ability to scale up their operations (FAO, 2020).

The gendered division of labor in the oil palm value chain reflects broader patterns of social inequality in agricultural systems, where women's work is undervalued in comparison to men's, despite their critical contributions to the overall productivity of the sector (Doss, 2011). In many cases, women's labor is relegated to the informal sector, where they receive fewer benefits and protections compared to their male counterparts. Moreover, the lack of access to modern processing equipment means that women often use outdated, less efficient methods, which not only reduces their productivity but also affects the quality of the final product. This issue of gender inequality is further compounded by the fact that women often lack formal training in modern agricultural techniques, thereby limiting their ability to innovate within the industry (Alaba, 2014).

However, gender roles in the oil palm sector are not immutable. As technological advancements, rural development policies, and women's empowerment initiatives gain momentum, women are gradually taking on more roles traditionally reserved for men, such as land ownership, leadership in cooperative farming groups, and even involvement in the harvesting process (Adebayo, 2008). The transformation of these gender roles is crucial for improving the overall productivity and sustainability of the oil palm sector, especially as Nigeria seeks to strengthen its position as a major player in the sector. This study investigates gender involvement in oil palm processing in Akoko North West, Ondo State. Specifically, it examined the actors socioeconomic characteristics, determined gender involvement and level of innovation, assessed factors influencing gender involvement and identified constraints to gender involvement in oil palm processing.

Test of Hypotheses

Ho₁: There is no significant relationship between socioeconomic characteristics and involvement in oil palm processing in the study area

Ho₂: There is no significant difference between male and female involvement in oil palm processing

MATERIALS AND METHOD

The study was conducted in Akoko North-West Local Government Area (LGA) of Ondo state Nigeria. The Akokos are a large Yoruba cultural sub-group in the northeastern part of Yoruba land. They make up 20.3% of the population of Ondo state and mainly domiciled in four out of 18 LGAs in the state (Olutumise, 2024). Two-stage sampling procedure was used to select respondents for the study. In the first stage, five communities were purposively selected out of the towns in Akoko North-West LGA namely Arigidi, Okeagbe, Ogbagi, Ikaram and Ibaram due to their high involvement in oil palm processing. In the second stage, 20 oil palm farmers were randomly selected from these communities bringing the total number of respondents to 100. Data was collected using a well-structured questionnaire and analysed using frequency distributions, percentages and mean scores while Chi square and correlation analyses was used to test the relationships among the variables.

Socioeconomic characteristics such age, gender, education level, farming experience, etc., were measured at nominal levels. Level of involvement in oil palm processing was measured as High (2) and low (1). Factors influencing gender involvement in oil palm processing was measured using a three-point Likert-type scale - major factor (3), minor factor (2) and not a factor (1). Constraints to gender involvement in oil palm processing was measured by asking respondents to tick from a list of constraints using a four-point Likert-type scale: agree (1), disagree (2), strongly disagree (3) and strongly agree (4). Gender involvement in oil palm processing was measured using a three-point Likert-type scale: mostly involved (2), rarely involved (1), and not involved (0).

RESULTS AND DISCUSSION

Socioeconomic characteristics

Table 1 presents the socio-economic characteristics of oil palm processors in Akoko South East LGA. Out of the 100 respondents, 45 were male and 55 were female. Most respondents were between 18–34 years, indicating a relatively young farming population. A majority were married, with men more likely to control household decisions. Education levels varied, but many had at least secondary education, reflecting the growing awareness of formal education's role in agricultural productivity (Adebayo & Okunlola, 2013). Household sizes were moderate, suggesting the availability of family labor for processing, which is a common feature in rural agrarian communities (Ojo et al., 2020). Farming and oil palm processing were the dominant occupations, consistent with findings that rural livelihoods in southern Nigeria are largely agriculture-based (Akinbile et al., 2019). Most respondents had 1–10 years of experience, and more than half spend 4–6 hours daily on processing. Income sources were mostly from palm oil sales, with males having more control over earnings, highlighting gender disparities in resource control within farming households (Nnadi & Akwiwu, 2008).

Table 1: Socioeconomic characteristics

Variables	Male, n = 45		Female, n = 55	
	Freq	%	Freq.	%
Age	4	8.90	9	16.4
18 – 24	16	35.6	12	21.8
25 – 34	11	24.4	11	20.0
35 – 44	9	20.0	15	27.3
45 – 54	5	11.1	8	14.5
55 and above				
Marital Status				
Single	10	22.2	16	29.1
Married	24	53.3	21	38.2
Widowed	9	20.0	11	20.0
Divorced	2	4.40	7	12.7
Highest Level of Education				
No formal education	6	13.3	11	20.0
Primary school	10	22.2	9	16.4
Secondary school	15	33.3	13	23.6
Tertiary education (University/Polytechnic)	9	20.0	17	30.9
Others	5	11.1	5	9.1
Household Size				
1-3 members	6	13.3	7	12.7
4-6 members	28	62.2	32	58.2
7-9 members	9	20.0	9	16.4
10 or more members	3	6.70	7	12.7
Primary Occupation				
Oil Palm Processing	9	20.00	17	30.9
Farming (Oil Palm Cultivation)	20	44.4	19	34.5
Trading	10	22.2	11	20.0
Civil Service	3	6.70	6	10.9
Student	3	6.70	2	3.6
Other				
Experience in oil palm processing				
Less than 1 year	4	8.90	9	16.4
1-5 years	24	53.3	17	30.9
6-10 years	11	24.4	20	36.4
More than 10 years	6	13.3	9	16.4
No. of hours per day spend on oil palm processing activities				
Less than 4 hours	12	26.7	13	23.6
4-6 hours	26	57.8	30	54.5
7-9 hours	7	15.6	12	21.8
More than 9 hours				
Who makes household decisions in oil palm				

Involvement in oil palm processing

Table 2 indicated that respondents were more involved in harvesting and pressing, while females dominated boiling and packaging. These differences reflect traditional gender roles and the physical demands of certain tasks, with men typically engaging in more labor-intensive activities and women more involved in processing and value addition stages (Perelli et al., 2024).

Table 2: Involvement in Oil Palm Processing

Variables	Male, n = 45		Female, n= 55	
	Freq	%	Freq.	%
Harvesting	31	68.9	6	10.9
Collection of palm fruits	23	51.1	6	10.9
Boiling palm fruits	21	46.7	7	12.7
Pressing oil	26	57.8	7	12.7
Packaging and selling the oil	31	68.9	4	7.3

Source: Field Survey, 2025.

Innovations adopted by the respondents

Table 3 reported higher use of motorized mills and mechanized harvesting, particularly among male respondents. Females, on the other hand, were more likely to adopt improved boiling techniques. These gendered patterns of adoption reflect both the physical demands of certain technologies and existing gender norms that influence access to tools and roles within the value chain (Adegbite & Olorunfemi, 2019). Adoption rates suggest that while both genders engage with innovations, disparities in access to equipment, extension services, and training opportunities may limit full utilization, especially for women (Kamara et al., 2025).

Respondents rated their knowledge of modern oil palm processing techniques as moderate, with females reporting slightly higher awareness levels. This indicates a general awareness of improved practices but underscores the need for regular and inclusive capacity-building programs to enhance technical skills and bridge knowledge gaps (Akinpelu et al., 2021).

Table 3: Innovations adopted by respondents

Variables	Male, n = 45		Female, n= 55	
	Freq	%	Freq.	%
Use of motorized mills	15	33.3	2	3.6
Improved boiling methods	30	66.7	5	9.1
Improved packaging methods	25	55.6	3	5.5
Introduction of mechanized harvesting	17	37.8	8	14.5
Rating of your level of knowledge on modern techniques	16	35.6	15	27.3

Source: Field Survey, 2025.

Factors influencing involvement in oil palm processing

Table 4 showed that family tradition, availability of labor, and access to markets were key factors influencing involvement in oil palm processing. These factors align with findings that family inheritance and community-based labor systems strongly shape agricultural livelihoods in rural Nigeria (Ibitunde et al., 2023). Female respondents placed more importance on government support, indicating its perceived role in empowering women and enhancing their access to resources and opportunities. This reflects broader evidence that targeted government interventions can significantly improve women's participation and productivity in agricultural value chains (Adegbesan and Shittu, 2025).

Table 4: Factors influencing involvement in oil palm processing

Factors	Male		Female	
	Mean	Std. Dev.	Mean	Std. Dev.
Family tradition	1.89	0.88	2.00	0.77
Access to capital or financial resources	1.62	0.68	1.87	0.77
Availability of labor (family support)	1.76	0.71	1.73	0.68
Knowledge of oil palm processing	1.71	0.76	1.84	0.83
Government policies and support programs	1.80	0.81	2.05	0.97
Availability of markets for the products	1.42	0.66	1.80	1.01

Source: Field Survey, 2025. *Mean $\geq$ 2.0 = High

Constraints faced by oil processors

Table 5 indicated that limited access to land, training, and capital were major constraints in oil palm processing. Female respondents faced additional societal constraints, including gender-based restrictions on land ownership and decision-making power, which limited their access to resources and opportunities (Nnadi&Akwiwu, 2008). Poor infrastructure, including inadequate road networks, unreliable power supply, and insufficient processing facilities, was a common concern among all respondents. This reflects broader systemic challenges faced by rural agricultural sectors in Nigeria, which hamper productivity and hinder the adoption of modern technologies (World Bank, 2020; Okunoye&Sanusi, 2018).

Table 5: Constraints faced by oil processors

Constraints	Male		Female	
	Mean	Std. Dev.	Mean	Std. Dev.
Limited access to capital	1.93	0.96	2.00	1.05
Limited access to land	2.09	1.16	1.98	0.97
Lack of training opportunities	2.18	1.07	2.20	1.18
Cultural and societal norms	1.78	1.02	2.33	1.09
Limited access to modern technology	1.96	1.11	1.75	0.97
Lack of decision-making power	1.49	0.97	1.47	0.86
Poor infrastructure (e.g., roads, mills)	1.29	0.51	1.49	0.74

Source: Field Survey, 2025. *Mean $\geq$ 3.0 = Significance.

Overcoming challenges of oil palm processing

Table 6 highlighted that access to credit, training, and modern equipment were perceived as helpful resources for improving oil palm processing; however, they were notably underutilized. This underutilization may stem from structural barriers such as bureaucratic loan procedures, inadequate training outreach, and limited awareness or affordability of modern equipment (Agbam, 2011). Female respondents showed slightly more support for these interventions, reflecting their greater willingness to embrace opportunities that could enhance their productivity and economic empowerment—despite the systemic gender-based limitations they often face in accessing such resources (Adepoju&Oso, 2020).

Table 6: Overcoming challenges of oil palm processing

Overcoming challenges	Male		Female	
	Mean	Std. Dev.	Mean	Std. Dev.
Access to microcredit or loans	1.42	0.54	1.47	0.54
Government training programs	1.51	0.82	1.42	0.53
Provision of modern processing equipment	1.44	0.78	1.44	0.60
Equal land access and ownership rights	1.40	0.54	1.44	0.50
Improved infrastructure (e.g., roads, power supply)	1.53	0.55	1.38	0.56

Source: Field Survey, 2025. *Mean $\geq$ 3.0 = Significance3.5

Hypotheses Tests results

Table 7 showed as insignificant associations between involvement in oil palm processing and variables such as age, marital status, occupation, years of processing experience, household size, and decision-making authority. However, education level was not significantly associated with involvement. This implies that demographic and experiential factors—rather than formal education—are stronger determinants of participation in oil palm processing activities. Similar findings have been reported in studies highlighting how traditional knowledge, social roles, and household dynamics often outweigh formal education in influencing participation in rural agro-processing enterprises (Agwu&Anyanwu, 2019; Yusuf et al., 2020).

Table 7: Chi square results of relationship between socioeconomic characteristics and involvement in oil processing

	Chi-Square	df	Sig
Age	10.444 ^a	4	0.034
Marital Status	22.644 ^a	3	0.001
Education	6.889	3	0.142
Household size	55.333 ^b	4	0.001
Occupation	21.556	4	0.001
Experience	21.578	3	0.001
Hours spend in processing	12.933 ^a	3	0.002
Who make decision	38.222 ^b	3	0.001

Source: Field survey. 2025.

Table 8 reveals that females are significantly more involved in oil palm processing than males. This highlights women's central role in the sector, especially in post-harvest activities.

Table 8: Test of difference between male and female involvements in oil palm processing

	Mean	Std. Deviation	t	df	Sig	Mean Difference
Male	27.71	4.66	-14.703*	98	0.000	-14.76
Female	42.47	5.25				

Source: Field Survey, 2025.

In summary, males dominate physically demanding tasks and control most income, while females lead in processing stages. Women face greater barriers, but their involvement is higher overall. Addressing gender-specific constraints will be key to improving productivity and equity.

CONCLUSION

The study concludes that both male and female farmers play active roles in oil palm processing, but their involvement is shaped by different socio-economic and cultural factors. While men dominate in tasks requiring physical strength, women contribute more significantly to processing and value addition. Despite their central role, women continue to face challenges related to access to land, capital, and decision-making power. Addressing these gender-specific barriers is essential for enhancing productivity, promoting equity, and achieving inclusive agricultural development.

It is recommended that gender-sensitive agricultural programs should be promoted to address specific constraints faced by women in the oil palm processing sector. Furthermore, the Government and NGOs should facilitate training programs and access to modern equipment for both genders, particularly for women. Moreover, access to credit facilities targeted to female processors should be enhanced to boost their oil palm processing investments. Similarly, policy reforms to support women's autonomy in agriculture through land access and ownership rights should be implemented, while improving infrastructure such as roads and power supply in rural communities to support oil palm processing activities. Finally, extension services and

community-based information dissemination that could effectively reach both men and women should be strengthened.

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BRIDGING THE KNOWLEDGE–PRACTICE GAP: WOMEN'S PARTICIPATION IN SUSTAINABLE ARABLE FARMING IN ONDO STATE, NIGERIA

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ABSTRACTS

Women play a crucial yet under recognized role in agriculture globally, especially in developing regions where they contribute significantly to farm labor and food production. This study set out to examine the involvement of women arable crop farmers in sustainable agricultural practices (SAPs) in Ondo State, Nigeria, with a focus on their socio-economic characteristics, knowledge levels, extent of involvement, and the constraints hindering adoption. A multi-stage sampling technique was employed to select respondents and 128 women arable crop farmers were randomly selected from these communities. Data were collected through structured questionnaires administered via interviews and analyzed using descriptive statistics (frequencies, percentages, means, and rankings) and inferential statistics (linear regression). The findings showed that the majority of women arable crop farmers were within the productive age bracket of 31–49 years and 72.7% were married. Most had a moderate household size (5–9 persons), and over half (53.9%) possessed a tertiary education. Although 69.5% had farming experience of 10 years or less, their medium-sized farm holdings (2–5 hectares) provided a viable platform for sustainable practice experimentation. Labour sources were mainly mixed (39.1%) or hired (40.6%), and 65.6% earned ₦300,000 and above annually. All respondents accessed credit and training through the LIFE-ND program, with cooperatives and thrift groups serving as additional financial channels. Furthermore, 100% were members of LIFE-ND associations, with significant participation in Women in Agriculture (60.2%) and multipurpose associations (53.9%). Contact with extension agents was irregular, with only 24.2% reporting frequent (six times/year) engagement. The overall cumulative knowledge index revealed that a majority of respondents fell below the threshold of high knowledge (mean < 33.69). Involvement in sustainable farming practices was generally low to moderate. Only two practices, intercropping (mean = 3.15) and manure use (mean = 3.12) surpassed the threshold for high involvement. The overall involvement index revealed that most respondents were not consistently engaged across a broad spectrum of sustainable practices (mean < 28.52), reinforcing the gap between knowledge and practice.

Keywords: Involvement in sustainable agricultural practices; Sustainable practices; Arable crop; Women arable crop farmers.

INTRODUCTION

Globally, women's involvement in agriculture has been reported as unrecognized. In most countries of the world, particularly in agrarian dependent nations, women do a disproportionate amount of work in agriculture but are rarely credited for their efforts. Present-day statistics, however, show that farming jobs are increasingly occupied by women. In the US, 36% of producers are female. This value is 63% in sub-Saharan Africa. Over two-thirds of economically active women in South Asia work agricultural jobs (Kelly, 2024). Also, Women constitute 75% of the agricultural workforce in Nigeria, yet suffer marginalization in accessing information and resources (Ifeanyi-obi, 2023).

Agriculture is a highly diversified enterprise worldwide, especially in the area of crop production, such as arable crop production. This diversity typically means more work, activities and manpower demand, this variation in crop production activities is attributed to the soil and climatic conditions as well as the wide variety of crops cultivated across the different regions to meet nutritional needs which has come about through efforts to tackle increasing global hunger, food demand, low grain reserves and climate change (Renard & Tilman, 2019). According to Ahmad (2022), arable farming is various crop production activities engaged in by peasant farmers throughout the cropping season every year under different categories. Over a decade, attention and efforts have been on sustainable development in all spheres of life, and most importantly in agriculture as rural livelihood anchors on land. Sustainable efforts recognize societal requirements and limitations in meeting the present and future socio-economic needs of the people (International Institute of Sustainable Development, 2012). Sustainable agricultural practices have to do with the purpose of using land resources to meet the present demand without compromising the interests of future generations in using the resources. The use of sustainable farming practices, therefore, is mixed cropping, minimum tillage, cover cropping, mulching, integrated pest control, agro-forestry, improved variety, organic

manure, crop rotation, green manure, alley cropping, and water harvesting. These practices have the capacity to make the farm produce continuously, enhance farm productivity, and long-term availability of input (Medugu, 2006)

It is also known that sustainable farming has three dimensions, which are: environment, profitable farming, and progressing farming groups (Omonona & Babatunde, 2012). However, despite the participation of women and the emphasis on them in LIFE-ND, little is known about how their beneficiaries integrate sustainable practices into their farms and enterprises. Hence, the study was conducted to examine the extent, determinants, and challenges of women arable crop farmers' involvement in sustainable agricultural practices (SAPs) and LIFE-ND beneficiaries in Ondo State, Nigeria, with a view to promoting gender-responsive strategies for sustainable rural development. Specifically, the study describe the socio-economic characteristics of women arable crop farmers participating in LIFE-ND programme in Ondo State., assess the level of access to agricultural information and extension services among women arable crop farmers and identify the major communication platforms used for disseminating sustainable farming knowledge, evaluate women farmers' knowledge of sustainable agricultural practices, determine the extent of women farmers' involvement in sustainable agricultural practices and identify the most commonly adopted methods, and identify the major constraints hindering women's adoption of sustainable agricultural practices in the study area.

METHODOLOGY

The study was conducted in Ondo State, Nigeria. The state has 18 Local Government Areas, with the capital in Akure City, and the Agricultural Development Programme (ADP) delineated it into three zones to align with the political senatorial districts. The state is prominently known for arable crop production, and farmers are known for their involvement in arable crop production and processing. The data for the study were obtained from LIFE-ND women arable crop farmers using a structured questionnaire to quantify women arable crop farmers' involvement in sustainable agriculture. The design captures various sustainable agricultural practices and associated factors and supports both descriptive profiling and multivariate inference.

The population comprised all registered women arable crop farmers who registered and participated in the IFAD LIFE-ND programme in the state who cultivate arable crops. Eligibility criteria were: (i) >30 years; (ii) cultivated an arable crop; (iii) provided informed consent.

A multi-stage sampling technique was employed to select respondents. First, three Local Government Areas (Okitipupa, Akure North, and Owo) were purposively selected to represent the state's three senatorial districts. Then, two communities were randomly chosen from each LGA, and finally, 128 women arable crop farmers were randomly selected from these communities.

Primary data were collected through structured questionnaires administered via interviews. The questionnaire included both open- and closed-ended items to capture information on farmers' socio-economic characteristics, knowledge of sustainable practices, level of involvement, and constraints faced. The study achieved a response rate of 98.5%, ensuring a high level of data reliability. A structured questionnaire (English) covered socio –economic profile (age, marital status, education qualification in years, household size, experience, farm size in hectares, sources of labour, credit, training, extension contact); access to information (television, radio, WhatsApp, Instagram twitter, extension agent, fellow processors, local leader, seminars, friends and family); knowledge (crop rotation, intercropping, improved varieties, precision farming, minimal tillage system, increased crop diversity, integrated pest management, agroforestry use of cover crops, use of manure); constraints (funds, market prices, storage facilities, cost of input, bad road).

The dependent variable for this study is the level of involvement of sustainable farming practices. It is a composite score built from standardized items on the use of sustainable farming practices (crop rotation, intercropping, improved varieties, precision farming). The independent variables are the demographics like age (years), marital status, education (years), household size, farm size (ha), experience (years), sources of labour, sources of credit, extension contact, and sources of training coded as dummies. Data collected from

questionnaires were subjected to descriptive statistics analysis, such as frequency distribution, standard deviation, percentage, and mean score, while binary logistic regression analysis and regression analysis were used to analyse relationships between the variables.

RESULTS AND DISCUSSION

Sources and Access to Information on Sustainable Farming Practices

The Result in Table 1 shows the overwhelming use of Instagram (99.2%), Twitter (92.2%), and Facebook (82.8%) indicating that social media has emerged as a powerful tool for agricultural knowledge dissemination among rural women. This finding reflects a broader trend in Sub-Saharan Africa, where mobile phone penetration and internet access are transforming how farmers interact with information systems (Aker *et al.*, 2016). Despite the growing role of digital tools, radio (53.9%) and television (38.3%) remain crucial channels, especially for less digitally literate farmers. These findings align with Asenso-Okyere and Mekonnen (2012), who observed that radio remains the most accessible and trusted agricultural information source for many African farmers, particularly women and older adults. Newspapers also maintain significant reach (83.6%), perhaps due to content targeted at cooperative groups or literate farmers.

More than 70% of the respondents receive information through local leaders or community heads (73.4%) and friends and family (70.3%), highlighting the social embeddedness of agricultural communication. These informal sources are often more trusted, context-sensitive, and culturally relevant (Obidike, 2011). Cooperatives (53.1%) and fellow processors (35.2%) also serve as peer learning platforms that facilitate information exchange, experience sharing, and reinforcement of sustainable practices. The relatively low access rate through extension agents (39.8%), seminars (33.6%), and even workshops (64.8%) is concerning, considering that these are formal platforms for in-depth and structured training. This underutilization reflects broader systemic issues in Nigeria's extension services, such as low staffing, inadequate funding, and gender-insensitive delivery (Agwu & Chah, 2014). Women, in particular, face mobility constraints, time poverty, and language barriers that reduce their participation in such events (Manfre *et al.*, 2013).

The role of extension agents (Mean = 2.86; SD = 0.96) emerged as highly significant. Despite moderate usage frequency (39.8%), extension services were rated as one of the most accessible and impactful sources of information on sustainable farming. This finding is consistent with the work of Ozor and Nnaji (2011), who argue that Agricultural Development Programmes (ADPs) remain a central pillar in rural agricultural transformation across Nigeria and Sub-Saharan Africa.

Beyond institutional and digital platforms, traditional communication networks such as local leaders (Mean = 2.48) and friends and family (70.3% frequency) play a critical role in the dissemination of agricultural knowledge. While the accessibility of these informal sources varies, their influence is rooted in trust, cultural capital, and proximity. Ajani (2008) and FAO (2018) emphasize that indigenous communication pathways often hold more persuasive power in rural settings than top-down communication from external agencies. Seminars (Mean = 2.95) and workshops (Mean = 1.52) illustrate a compelling paradox: while seminars are highly impactful among those who attend, their overall participation rate (33.6%) is relatively low. Workshops, despite being more attended (64.8%), scored lower in accessibility, possibly due to their limited depth, time constraints, or generalized content.

Table 1: Sources and access to information on sustainable farming practices

Information	Sources		Accessibility	
	Freq.	%	Mean	Std. Dev.
Television	49	38.3	2.54*	1.01
Radio	69	53.9	1.55	0.98
WhatsApp	64	50	1.70	0.91
Facebook	106	82.8	1.40	0.87
Instagram	127	99.2	1.20	0.64
Twitter	118	92.2	1.23	0.69
Extension agents (ADP/ LRD)	51	39.8	2.86*	0.96
Fellow processors	45	35.2	1.89	0.73
Local leaders or community heads	94	73.4	2.48*	0.88
Newspapers	107	83.6	1.26	0.76
Workshops	83	64.8	1.52	0.80
Seminars	43	33.6	2.95*	0.99
Telephone	50	39.1	2.54*	0.88
Friends and family	90	70.3	1.77	0.92
Cooperatives	68	53.1	1.67	0.32

Source: Field Survey, 2025.

*Mean ≥ 2.5 = High access

Knowledge of sustainable farming practices

Table 2 presents data on respondents' level of knowledge regarding various sustainable agricultural practices. The data reveal that women arable farmers demonstrate high knowledge in practices that are visible, traditionally rooted, or widely promoted through extension campaigns and community initiatives. For example, "TME 419 cassava is an example of improved cassava variety" recorded the highest mean score of 3.85 (SD = 1.00), The natural fertilizer derived from animal waste also received a high mean score of 3.45 (SD = 1.06), and The practice of intercropping, framed as "growing two or more crops in proximity," recorded a mean of 3.15 (SD = 1.01), further emphasizing that women are conversant with traditional and visible ecological practices. Other practices, such as "Agroforestry involves planting crops among trees" (M = 3.15, SD = 0.99) and "Cover crops can suppress weeds and soil-borne pests" (M = 3.17, SD = 0.93) suggest familiarity with integrated ecological systems that combine trees, crops, and organic inputs. Additionally, respondents demonstrated high conceptual awareness of crop rotation as "the practice of growing different crops across seasons", scoring 3.05 (SD = 1.04).

These findings reflect the cumulative impact of community knowledge, extension services, and government programs such as the LIFE-ND initiative and Agricultural Development Projects (ADPs) that promote climate-resilient and sustainable methods (Akinbile et al., 2021; FAO, 2018). This means that women farmers are well-informed on basic and visible sustainable techniques, particularly where interventions have emphasized clarity, demonstration, and community involvement. It was also reported that a considerable number of practices recorded mean scores below 2.5, reflecting limited understanding or the presence of knowledge gaps and misconceptions. For instance, the belief that "Intercropping increases labour and reduces yield" had a low mean of 1.74 (SD = 0.79), indicating a misunderstanding of its agronomic benefits. It was reported that precision farming received the lowest overall knowledge scores among all the listed practices.

Table2: Knowledge of sustainable farming practices

Practices	Mean	Std. Dev.
Crop rotation		
The Practice of growing a series of different types of crops in the same area sequence of growing seasons is crop rotation	3.05	1.04
Crop rotation increases soil fertility and prevents soil erosion	2.36	0.95
Intercropping		
Intercropping increases labour and tends to reduce yields	1.74	0.79
Intercropping involves growing 2 or more crops in proximity	3.15	1.01
Improved varieties		
Use of improved varieties includes higher yield and resistance to diseases	3.10	0.96
TME 419 cassava is an example of an improved cassava variety	3.85	1.00
Precision farming, among others.		
Precision farming may result in increased use of inputs, labour and costs	2.08	0.84
Precision farming makes it possible to achieve higher productivity and reduce environmental risks	2.33	1.16
Minimal tillage system		
Minimal tillage involves limited soil disturbance, especially outside the plant	2.08	0.94
Minimal tillage always requires herbicides for weed control	2.21	0.84
Increased crop diversity		
Crop diversity helps in controlling weeds and pests specific to particular crop	2.15	0.88
Crops of the same family should not be cultivated in regular succession	1.96	0.87
Integrated pest management (IPM)		
IPM involves applying the same pesticides at the same time each year to maintain consistency	2.09	0.80
Applying a pre-emergence herbicide is an example of cultural control	2.02	1.00
Agroforestry		
Agroforestry involves planting crops among trees	3.15	0.99
Agroforestry competes with cropland, thus they do not contribute to food security	1.99	0.91
Use of cover crops		
Cover crops can suppress weeds and soil-borne pests	3.17	0.93
Cover crops decrease water holding capacity in soil	2.13	0.96
Use of manure		
Animal manure is not a effective source for fertilizing crops	2.08	0.90
The natural fertilizer derived from animal waste is manure	3.45	1.06

Source: Field survey, 2025; *Mean $\geq$ 3.0 = High Knowledge

The perception that “Precision farming may result in increased use of inputs and costs” had a mean of 2.08 (SD = 0.84). Conversely, its potential benefit as “reducing environmental risks and increasing productivity” was only moderately recognized, with a mean of 2.33 (SD = 1.16). This shows that women are either unfamiliar or skeptical of precision farming as a modern digital practice that requires ICT tools, data analytics, or GPS-based interventions. As observed in Aker et al. (2016), digital agriculture remains underutilized by rural women due to poor access, low literacy, and a lack of female-focused training models.

Interpretation Summary: Precision farming remains an emerging, elite-associated practice whose value is not yet appreciated at the grassroots level among women arable farmers. Interestingly, several sustainable practices had mixed ratings depending on how the information was framed. Crop rotation as a concept had a high score (3.05), yet its benefit in “increasing soil fertility and reducing erosion” scored a lower 2.36 (SD = 0.95). Similarly, use of manure was highly recognized (3.45), yet perceived as not cost-effective (2.08), despite its affordability compared to chemical fertilizers. These findings confirm the cognitive dissonance between theoretical knowledge and practical economic judgment, particularly in resource-constrained farming systems. According to Ragasa (2012), knowledge transfer that is not grounded in local realities or participatory demonstrations often leads to superficial comprehension. Understanding is often fragmented; women may be able to describe a practice but not explain its benefits, limitations, or full economic implications.

Knowledge Level of Sustainable Agricultural Practices

Figure 1 presents the distribution of women arable crop farmers' knowledge levels on sustainable agricultural practices. Knowledge scores were computed from multiple indicators and practices discussed earlier in Table 4, and grouped into two categories using a cut-off mean score of 33.69. The categories are high knowledge for those who had $X \geq 33.69$ knowledge scores and low knowledge for those with $X \leq 33.69$ knowledge scores. Although the precise values are not displayed here, the graphical representation indicates a disproportionate number of respondents falling within the low knowledge bracket, suggesting that the majority of women arable farmers possess limited cumulative knowledge of sustainable farming practices.

The findings show that engagement in sustainable practices is not merely a function of exposure but depends heavily on knowledge defined here as a combination of cognitive, procedural, and ecological understanding (World Bank, 2020; Ragasa, 2012). The results from Figure 1 imply that women farmers are partially involved in sustainable practices, but their involvement is often limited to traditional knowledge or donor-driven practices that may not be sustained in the long term. This situation is consistent with Ragasa (2012), who found that women's adoption of sustainable innovations across Sub-Saharan Africa often lacks depth due to systemic exclusion from knowledge networks and male-dominated extension models. Aligning this finding with theories, and from a theoretical standpoint, the result affirms the argument that knowledge is a mediating variable between exposure and adoption. Sustainable agriculture, particularly among vulnerable or marginalized groups like rural women, is fundamentally a knowledge-intensive enterprise. From a practical perspective, this result provides a baseline for targeted intervention. Development agencies, NGOs, and government bodies aiming to boost climate resilience and food security must prioritize women's knowledge buildi

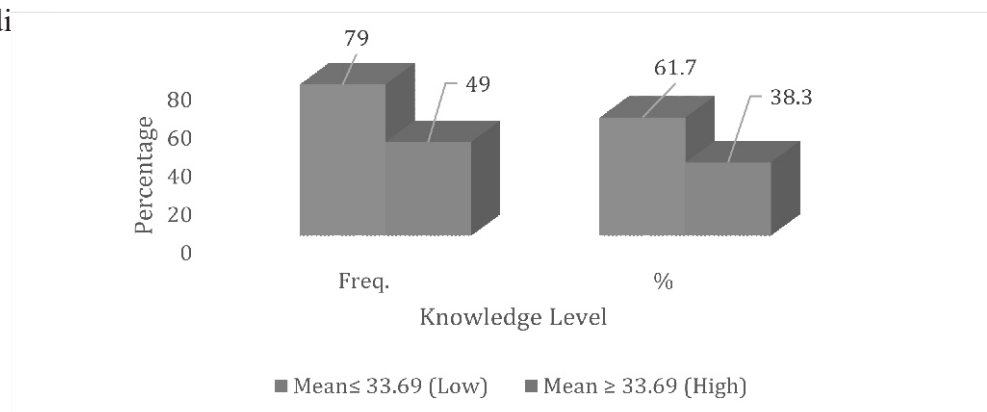


Figure 1: Level of knowledge in sustainable

Source: Field survey, 2025; Mean ≥ 33.69 = High knowledge; ≤ 33.69 = Low knowledge

Involvement in sustainable practices

Among the ten sustainable practices listed, only two recorded high involvement (mean ≥ 3.0). Intercropping (Mean=3.15), and Use of manure – Mean: 3.12. The remaining eight practices recorded mean scores below 3.0, including. Crop rotation – Mean: 2.96, improved varieties – Mean: 2.90, Precision farming – Mean: 2.77, integrated pest management (IPM) – Mean: 2.89, Minimal tillage system – Mean: 2.59, and Agroforestry – Mean: 2.48. This suggests that while there is some awareness and trial use of most practices, only a few are consistently practiced and embedded in the routine farming behaviour of women arable crop farmers.

The relatively high involvement in intercropping ($M = 3.15$) reflects its deep roots in indigenous farming systems across Nigeria and Sub-Saharan Africa. Intercropping is traditionally recognized for its benefits in maximizing land use, reducing pest attacks, and enhancing yield stability (Adedoyin *et al.*, 2020). It also aligns with gendered labor patterns, as women are often responsible for multiple household crops grown simultaneously. Similarly, manure use ($M = 3.12$) enjoys high adoption due to its local availability, affordability, and cultural acceptance as a source of soil enrichment. Studies by Adeogun *et al.* (2016) and FAO (2018) confirm that women farmers often favor organic materials like manure due to limited access to chemical fertilizers, economic constraints, and ecological knowledge passed down through generations. These two practices require minimal external inputs, are locally controlled, and rely heavily on experiential knowledge—making them accessible and practical for resource-limited women farmers.

For the moderate level of involvement, results show that practices like crop rotation ($M = 2.96$), improved varieties ($M = 2.90$), and IPM ($M = 2.89$) recorded near-average involvement levels. These results suggest that although farmers may be aware of these methods (as seen in earlier knowledge tables), their adoption is still limited or inconsistent. For example, improved varieties such as TME 419 cassava are known and distributed through government and NGO channels (IITA, 2017), but consistent use may be hindered by inadequate seed distribution networks, cost and availability constraints, and low understanding of long-term yield performance.

Regarding the low level of knowledge, results show that agroforestry – Mean: 2.48, minimal tillage system – Mean: 2.59, and precision farming – Mean: 2.77. These findings point to several key barriers. Agroforestry, though beneficial for erosion control and microclimate stabilization, is often seen by farmers as land-intensive and slow-yielding, conflicting with immediate food security goals (Aregu *et al.*, 2019). Minimal tillage requires technical guidance and often herbicide use, which can be financially or culturally prohibitive. Precision farming, with its dependence on ICT, mapping tools, and capital investment, is largely inaccessible to women due to technological illiteracy, land ownership issues, and lack of institutional support (Adenle *et al.*, 2020; Aker *et al.*, 2016). These practices demand capital, technical skill, and long-term planning areas where rural women are most constrained due to socio-economic and gender-based inequalities.

Table 3: Involvement in sustainable practices

Involvement in Sustainable Practices	Mean	Std. Dev.
Crop rotation	2.96	1.13
Intercropping	3.15*	1.07
Improved varieties	2.90	1.08
precision farming, among others.	2.77	1.05
Minimal tillage system	2.59	0.99
Increased crop diversity	2.90	1.19
Integrated pest management (IPM)	2.89	1.31
Agroforestry	2.48	1.18
Use of cover crops,	2.78	1.02
Manure	3.12*	1.21

Source: Field survey, 2025.

*Mean ≥ 3.0 = High Involvement

Level of involvement

Figure 2 presents the aggregated level of involvement of women arable crop farmers in sustainable agricultural practices. The figure categorizes respondents' total involvement scores using a cut-off mean of 28.52. High involvement with a mean score ≥ 28.52 , and low involvement with a mean score ≤ 28.52 . The graphical result indicates that a significant proportion of women farmers fall below the high-involvement threshold, suggesting that overall involvement is generally low to moderate. This cumulative result corroborates earlier findings in Table 5, where only two practices—intercropping ($M = 3.15$) and manure use ($M = 3.12$)—surpassed the high-involvement threshold. The remaining practices had mean scores between 2.48 and 2.96, indicating modest to low adoption rates. The implication of Figure 2 is that while women are aware of and even trial some sustainable practices, their consistent, habitual, and integrated implementation across multiple practices remains limited.

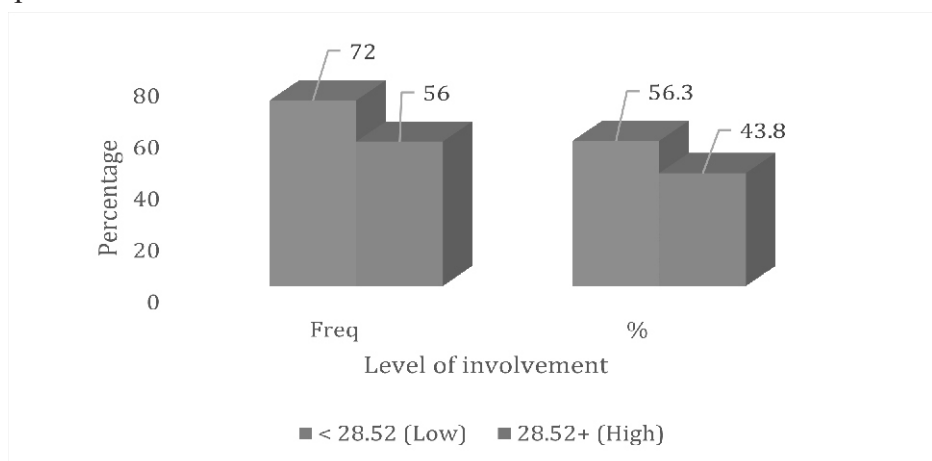


Figure 2: Level of involvement in sustainable

Source: Field survey, 2025.

Mean ≥ 28.52 = High involvement; ≤ 28.52 = Low involvement

Constraints to involvement in sustainable farming practices

The high cost of labour (Mean = 3.10) emerged as the most significant constraint. The cost and inaccessibility of farm inputs ($M = 2.72$ and $M = 2.34$, respectively) reinforce a longstanding barrier to sustainable farming, where organic compost, improved seeds, and IPM kits are either unavailable or unaffordable (Ayanlade *et al.*, 2020). Also, insufficient funds ($M = 2.89$) and market price fluctuation ($M = 2.70$) further explain women's cautious engagement with sustainable agriculture. Seasonal price crashes for crops disincentive investment in practices that require long-term soil and pest management strategies (Adepoju & Oyewole, 2014). The bureaucracy of loan access ($M = 2.41$) and lack of functional markets ($M = 2.23$) further exclude women from economic tools needed to invest in inputs, hire labor, or transport produce. This means that women's limited access to finance constrains their ability to shift from subsistence farming to environmentally sound intensification.

Furthermore, low interaction with extension agents ($M = 2.48$) and inadequate technical knowledge ($M = 2.32$) point to systemic deficiencies in capacity-building. Insecurity ($M = 2.53$) and theft ($M = 2.53$) reflect the broader impact of Nigeria's rural conflict environment on agricultural participation. In the northern and central regions, armed conflict and land disputes have displaced farmers and discouraged farm investment. Poor road infrastructure ($M = 2.48$) further compounds the challenge by making it harder to access markets, training centers, and farm input suppliers. This implies that women in insecure or remote areas are least able to implement sustainable practices due to mobility restrictions and risks of farm loss.

On the other hand, poor government policy ($M = 2.50$) indicates dissatisfaction with agricultural governance and weak policy incentives for sustainability. When government programs do not address gender-specific realities or fail to enforce climate-smart support services, rural women bear the brunt of policy failure (Sulo *et al.*, 2012). This implies that gender-insensitive policies and weak implementation mechanisms continue to undermine national and international sustainability goals. This finding provides concrete evidence that

structural poverty, gendered institutional exclusion, weak rural infrastructure, and policy failure form the major barriers to women's involvement in sustainable farming. This validates the findings of Ragasa (2012) and FAO (2018) that constraints in women's farming are multi-dimensional and, therefore, require multi-sectoral interventions.

Table 4: Constraints to sustainable farming practices

Constraints	Mean	Std. Dev.
Insufficient fund	2.89	1.13
Fluctuation in market prices	2.70	0.94
Lack of storage facilities	2.43	0.97
High cost of inputs	2.72	0.99
Inaccessibility of inputs	2.34	1.03
Inadequate technical knowledge	2.32	0.98
High cost of labour	3.10	1.34
Inadequate labour	2.33	0.89
Bad road network	2.48	1.13
Poor government policy	2.50	1.03
Insecurity	2.53	1.08
Low contact with extension agents	2.48	1.06
Theft	2.53	0.98
Unpredictable climate change	2.48	1.00
Lack of market	2.23	1.01
Bureaucracy in the processing of accessing a loan	2.41	1.02

Source: Field survey, 2025.

Hypothesis Testing

Socio-economic characteristics of women, arable crop farmers and level of involvement in sustainable farming practices

Binary logistic regression analysis was conducted to determine the extent to which selected socio-economic variables predict the likelihood of women arable farmers' involvement in sustainable agricultural practices. The dependent variable was the level of involvement (coded as high or low), and nine independent variables were tested. The model shows good explanatory power, with Nagelkerke $R^2 = 0.717$, indicating that the model explains 71.7% of the variation in involvement, -2 Log Likelihood = 168.037, and the overall classification accuracy = 63.3%

Specifically, household size ($\text{Exp}(B) = 0.802$, $p = 0.0000$) had a negative and significant effect on women's involvement. This suggests that as household size increases, the likelihood of involvement in sustainable practices decreases. Large household responsibilities may limit the time, mobility, and resources that women can allocate to acquiring knowledge or experimenting with new techniques (Lambrecht et al., 2016). Women in large households often prioritize short-term food security over long-term sustainability. Education ($\text{Exp}(B) = 0.529$, $p = 0.0050$) significantly reduces the odds of non-involvement. Women with higher education are more likely to engage in sustainable farming due to improved access to information, better comprehension of training content, and openness to innovation (Morris et al., 2017).

A negative but significant coefficient implies that as years of experience increase, the probability of involvement in sustainable practices slightly decreases. This counterintuitive result may reflect entrenched traditional habits or reluctance to change among more experienced women farmers (Teklewold *et al.*, 2013). Farm size ($\text{Exp}(B) = 1.878$, $p = 0.0350$) positively influences involvement. Women with larger farms are 1.88 times more likely to practice sustainable farming than those with smaller holdings. Larger land holdings provide the space and flexibility for trial of innovations, soil conservation, and diversification (Arslan et al., 2014).

Average Income Per Annum ($\text{Exp}(B) = 38.475$, $p = 0.0000$) was the strongest predictor. Women with higher annual incomes were 38 times more likely to be involved in sustainable agriculture. Income enhances purchasing power for inputs like compost, improved seeds, cover crops, and even precision tools (Ali et al., 2020).

Income from Other Sources ($\text{Exp}(B) = 18.394$, $p = 0.0000$) and this means that women with alternative

income streams were 18.39 times more likely to be involved. Off-farm income reduces economic vulnerability and enables reinvestment into the farm. Studies by Kassie et al. (2015) show that women with remittances or micro-enterprise earnings are more likely to invest in soil health, pest control, and climate adaptation.

Table 5: Relationship between socio-economic characteristics and level of involvement in sustainable practices

	B	S.E.	Wald	Sig.	Exp(B)
Age in years	-0.02	0.02	0.70	0.4020	0.984
Marital status	0.21	0.37	0.33	0.5690	1.234
Household size	-0.22	0.08	7.63**	0.0000	0.802
Educational qualification	-0.64	0.26	6.22**	0.0050	0.529
Years of farming experience	-0.12	0.03	20.94**	0.0000	0.888
Farm size	0.63	0.23	3.84*	0.0350	1.878
Sources of labour	0.04	0.20	0.04	0.8380	1.041
Average income per annum in naira	3.65	1.29	7.99**	0.0000	38.475
Income from other sources	2.91	0.89	10.73**	0.0000	18.394
Constant	1.30	1.53	0.72	0.3970	3.666

Source: Field survey, 2025.

-2 Log likelihood = 168.037; Nagelkerke R Square = 0.717

Overall Percentage = 63.3

*Significant at 0.05; **Sign at 0.01 level of significance

Influence of Knowledge and involvement in sustainable practices

Table 6 presents the result of a simple linear regression analysis examining the relationship between women's knowledge of sustainable agricultural practices and their level of involvement in those practices. The analysis tested the hypothesis that knowledge significantly predicts the extent to which women arable farmers engage in sustainable methods. The R-value of 0.554, and this shows that there is a moderate positive correlation between knowledge and involvement, while the R² value of 0.3069 indicates that approximately 30.7% of the variance in involvement is explained by knowledge levels. The model is statistically significant at the 1% level, but the negative sign of the regression coefficient is counterintuitive, as it indicates an inverse relationship: as knowledge increases, involvement tends to decrease slightly.

The finding reflects a critical disconnect between cognitive understanding and practical engagement, which is supported by several recent studies in African agricultural systems. Several plausible explanations can be drawn:

Women may know *what* sustainable practices are, but lack the means (e.g., labour, credit, land) to apply them. This finding aligns with Mudege *et al.* (2017), who showed that women farmers in Malawi had high knowledge of soil conservation but low adoption due to gendered control over resources. Many women associate sustainable techniques with increased labour or uncertain outcomes, especially when these practices are unfamiliar or not widely demonstrated. According to Meijer *et al.* (2015), knowledge of agroforestry did not increase uptake among women in East Africa due to perceived labour costs and delayed returns. High knowledge without follow-up support, such as extension visits, input subsidies, or peer support groups, often leads to non-adoption. Wossen *et al.* (2015) found that even where women were knowledgeable, poor access to credit and markets undermined their willingness to implement sustainable innovations.

In patriarchal rural systems, women may know about improved practices but be excluded from decision-making or implementation, especially where land or mechanized inputs are controlled by men. Doss (2013) emphasizes that women's knowledge does not always equate to agency in agricultural decision-making. This result signals a fundamental need to rethink sustainability programming for rural women. Knowledge transfer is essential but not sufficient without enabling conditions that allow women to act on what they know.

Table 6: Relationship between the knowledge of sustainable farming practices and their level of involvement in the practices among women

	Unstandardized Coefficients	Standardized Coefficients			
Variable	B	Std. Error	Beta	T	Sig.
(Constant)	30.357	3.09		9.824**	0.0000
Knowledge scores	-0.225	0.041	-0.054	-5.488**	0.0000

Source: Field survey, 2025.

R = 0.554; R-squared = 0.3069

*Significant at 0.05; **Sign at 0.01 level of significance

CONCLUSION

The study found that women arable crop farmers in Ondo State have moderate knowledge of sustainable agricultural practices but limited involvement in their actual application. While traditional practices like intercropping and manure use are widely adopted, modern techniques such as precision farming and agroforestry remain underused due to economic, technical, and institutional barriers. Education, income, and farm size positively influence adoption, whereas large household size and limited extension contact reduce participation. The findings emphasize that knowledge alone is insufficient without access to credit, resources, and gender-sensitive support systems. Strengthening agricultural extension, improving infrastructure, and creating inclusive financial and training opportunities are essential to bridge the knowledge–practice gap. Empowering women farmers through these measures is key to advancing food security and achieving sustainable agricultural development in Nigeria.

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GENDER DYNAMICS OF POVERTY COPING STRATEGIES AMONG FARMING HOUSEHOLDS IN AKOKO SOUTH-WEST ONDO STATE, NIGERIA

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ABSTRACT

This study examines gender-based differences in poverty coping strategies among rural farming households in Akoko South Local Government Area, Ondo State, Nigeria. A multi-stage sampling technique was used to select 120 respondents, comprising equal numbers of male- and female-headed households from six randomly chosen communities. Primary data were collected through structured questionnaires and analyzed using descriptive statistics, the Foster–Greer–Thorbecke (FGT) poverty index, and logistic regression models. Findings reveal significant gender disparities in household characteristics, economic activities, and poverty levels. The average age of female-headed households was 44.7 years, compared to 53.4 years for male-headed households. Educational attainment was relatively high, with 56.7% of female and 46.6% of male household heads having tertiary education. Male-headed households recorded higher average incomes (₦56,664,100) and a lower poverty incidence (30%) than female-headed households (53.4%). The FGT index further indicated a greater poverty depth among female-headed households (0.534). Livelihood activities differed, with 70% of male-headed households engaged in farm labour and an equal proportion of female-headed households involved in the sale of agricultural products. Logistic regression identified marital status, income level, and participation in crop processing as significant determinants of poverty status. Reducing the number of daily meals was the most common coping strategy. The study highlights the need for gender-responsive rural development policies that promote equitable access to credit, productive resources, and training. Targeted empowerment programmes for female-headed households can strengthen resilience and support sustainable poverty reduction in rural communities.

Key words: Gender, Dynamics, Poverty, Coping, Strategies, Households.

INTRODUCTION

A household refers to individuals—related or unrelated—who share a dwelling unit, meals, and housekeeping arrangements (World Bank, 2001). Membership is based on co-residence rather than kinship; some members may be absent for extended periods (Posel et al., 2006). Typically, a household has a designated head responsible for income generation and decision-making. While household heads are usually male, female heads often emerge in the absence of a male member, resulting in female-headed households (Ngwenya, 2008).

Men and women experience poverty differently due to their distinct social roles, constraints, and priorities. Women often face socio-cultural barriers limiting their access to land, capital, services, decision-making authority, and representation in economic and political spheres (Ministry of Finance and Economic Development, 2008; Mofed, 2008). Poverty is a central marker of underdevelopment, reflecting inadequate access to resources and dysfunctional economic, ecological, and governance systems (Central Bank of Nigeria, 1999; Onibokun and Kumuyi, 1996). It deprives individuals of the ability to achieve their full potential and contributes to the "vicious cycle" wherein poverty perpetuates intergenerational disadvantage.

In Nigeria today, poverty remains acute. As of April 2025, 75.5% of rural dwellers live below the poverty line, compared to 41.3% in urban areas (World Bank, 2025). Overall, over 54% of Nigerians are estimated to be impoverished (World Bank, 2025). Additionally, 63% of the population is multidimensionally poor—72% in rural zones versus 42% in urban areas—according to the 2022 National MPI (National Bureau of Statistics, 2023). Poverty is closely tied to malnutrition and poor health outcomes. Nigeria's under-five mortality rate was 105 deaths per 1,000 live births in 2023 (WHO, 2024), and 27% of African children under five are affected by severe food poverty, with many from Nigeria (AP, 2024). Infant mortality remains high at 53.7 per 1,000 live births in 2024 (Macrotrends, 2025). Nigeria's rural poor—commonly farmers and informal traders—continue to bear the brunt of poverty. National social investment programs (e.g., N-Power, Conditional Cash Transfer, Government Enterprise and Empowerment Program, Home-Grown School

Feeding) initiated since 2015 have reached millions (National Social Investment Office, 2024). However, poverty persists and deepens across the country.

Problem statement

Despite numerous government interventions and poverty alleviation programs, poverty remains a significant and persistent challenge among farming households in rural Nigeria. The agricultural sector, which is the mainstay of rural livelihoods, continues to experience low productivity and limited profitability, contributing to the high incidence of poverty. Recent data indicate that approximately 38.9% of Nigerians live below the national poverty line, with rural populations disproportionately affected (World Bank, 2025). Additionally, 63% of Nigerians are multidimensionally poor, with deprivation most severe in health, education, and living standards—conditions that are particularly acute in rural farming communities (National Bureau of Statistics, 2023; OPHI, 2022).

Gender disparities further compound the poverty challenge. Female-headed households often face systemic barriers to accessing resources, credit, land, and extension services, which limit their ability to adopt effective coping strategies or improve their economic conditions. Yet, most existing poverty-related studies focus primarily on macro-level indicators and production-side constraints, with limited attention paid to how male and female farming households differentially experience and respond to poverty at the grassroots level. Understanding the gendered dimensions of poverty and the coping mechanisms adopted by rural farmers is essential for designing inclusive and effective poverty reduction strategies. This study therefore seeks to examine the gender-specific coping strategies employed by farming households in Akoko South-West Local Government Area, Ondo State, Nigeria. It addresses the critical gap in empirical evidence regarding how gender influences poverty experiences, access to support, and adaptive capacity among rural agricultural households. This study seeks to investigate gender-based poverty coping mechanisms among farming households in Akoko South-West Local Government Area of Ondo State, Nigeria, by addressing the following key research questions:

1. What are the socio-economic characteristics of male- and female-headed farming households in the study area?
2. What income-generating activities are predominantly undertaken by male and female in in the study area?
3. What are the main determinants of poverty status among rural farming households in the study area?
4. Which socio-economic and demographic factors significantly influence the poverty status of respondents?
5. What coping strategies are adopted by farming households to mitigate the effects of poverty, and how do these differ by gender?

Objectives of the Study

The primary objective of this study is to examine the poverty coping strategies employed by farming households in Akoko South-West Local Government Area of Ondo State, Nigeria, with a focus on gender-based differentials. The study specifically aims to:

1. Describe the socio-economic characteristics of male and female farming households in the study area;
2. Identify and analyze the various income-generating activities undertaken by male and female respondents;
3. Assess the poverty status among rural farming households disaggregated by gender;
4. Investigate the socio-economic and demographic factors influencing poverty status among farming households;
5. Ascertain the poverty coping strategies adopted by male- and female-headed households in the study area.

Justification of the Study

Nigeria continues to grapple with high levels of poverty, particularly among its rural population, despite years of government and donor-led interventions. Recent statistics reveal that poverty is not only widespread but also multidimensional in nature, with rural farming households being among the most affected (World Bank, 2025; National Bureau of Statistics, 2023). While many studies have explored the causes and manifestations

of poverty, there is a significant gap in literature regarding the gender-differentiated coping mechanisms used by rural farmers to navigate poverty.

This study is justified on several grounds:

- **Policy Relevance:** It will provide empirical evidence to guide the formulation of gender-sensitive poverty alleviation strategies and programs.
- **Literature Gap:** The study addresses the dearth of localized and gender-disaggregated data on coping strategies among farming households.
- **Development Planning:** Understanding how gender shapes poverty experiences and responses is vital for effective rural development planning and resource allocation.
- **Sustainable Livelihoods:** The insights gained will be valuable in designing interventions that enhance the resilience of vulnerable groups, especially female-headed households, thereby promoting inclusive agricultural development and food security.

In sum, this study is crucial for policymakers, development practitioners, and researchers interested in targeted poverty reduction, gender equity, and sustainable rural development in Nigeria.

METHODOLOGY

The Study Area

This study was conducted in Akoko South-West Local Government Area (LGA) of Ondo State, Nigeria. The administrative headquarters is located in Oka-Akoko, and the LGA comprises fifteen communities: Akungba, Supare, Oka, Ayegunle, Oba, Ikun, Okia, Korowa, Ikese, Iwonrin, Ebo, Owalusin, Ayepe, Okela, and Bolorunduro. Geographically, the LGA covers an estimated area of 226 square kilometers and recorded a population of 229,486 during the 2006 national census (National Population Commission [NPC], 2006). Akoko South-West LGA is bordered to the north by Akoko North-East LGA, to the south by Ose and Owo LGAs, and to the west by Ekiti State. The area is predominantly agrarian, with agriculture serving as the primary economic activity. Farmers engage in the cultivation of both food and cash crops, including cassava, rice, yam, plantain, cocoa, cashew, palm produce, citrus, coffee, soybeans, cowpea, timber, and kolanut. Among these, cocoa remains the leading cash crop and a major source of non-oil export earnings for Nigeria. Notably, Ondo State contributes approximately 60% of Nigeria's total cocoa output, highlighting the state's pivotal role in the national cocoa value chain (International Institute of Tropical Agriculture [IITA], 2007).

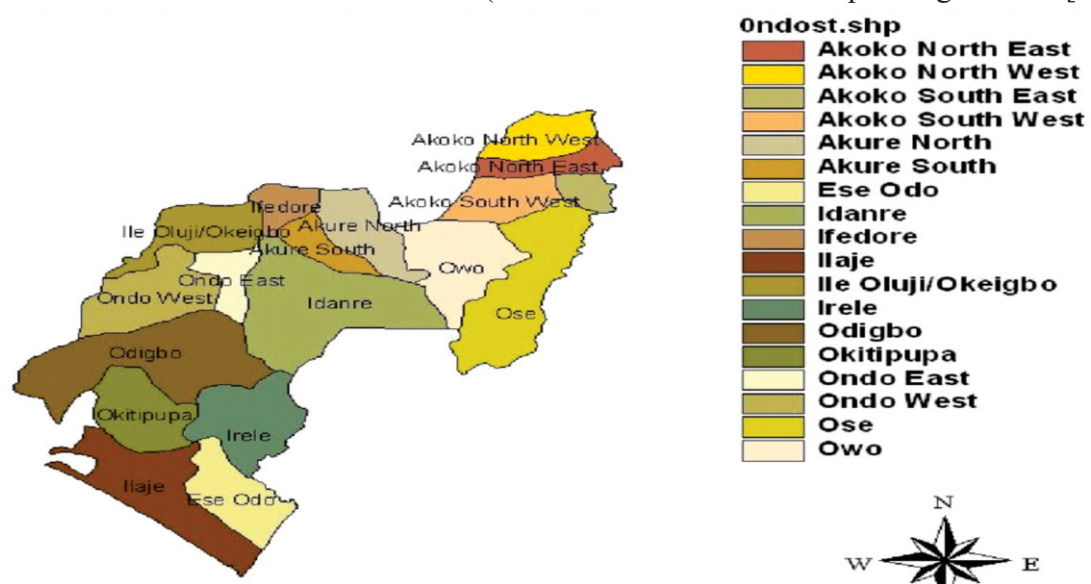


Figure-1. Map showing the location of Akoko South-west Local Government Area within Ondo State.
Source: (Ojo, O.S. 2025)

Sampling Technique

A multi-stage sampling technique was employed for this study. In the first stage, six communities were randomly selected from the fifteen (15) communities within Akoko South-West Local Government Area. In the second stage, a total of twenty (20) respondents were randomly selected from each of the chosen communities, comprising ten (10) female-headed and ten (10) male-headed households. This yielded a total sample size of 120 respondents—60 female household heads and 60 male household heads—for the study.

Data Analysis

Data for analysis were generated primarily using interview scheduled and structured questionnaires administered to one hundred and twenty (120) respondents selected for the study. Data analysis was achieved through the use of descriptive statistics, the Foster-Greer-Thorbecke (FGT) model and Logistic regression model.

Analytical Technique

Data for the study were analyzed using both descriptive and inferential statistics. Objectives (i), (ii) and (v) were analyzed using descriptive statistics such as mean, percentages and frequency distribution. Objective (iii) was analyzed using Foster-Greer-Thorbecke (FGT) model while Objective (iv) was analyzed using Logistic regression model

Model Specifications

Foster-Greer-Thorbecke (FGT) Poverty Index

To assess the poverty status of rural farming households in the study area, the Foster-Greer-Thorbecke (FGT) poverty index was employed. This model is widely used in poverty analysis due to its capacity to capture not only the incidence of poverty but also its depth and severity. The general form of the FGT poverty measure is given as:

$$P_{\alpha}(y, z) = \frac{1}{2} \sum_{i=1}^n \left(\frac{z - y_i}{z} \right)^{\alpha}$$

Where: n = total number of households in population, q = the number of poor household's Z = the poverty line for the household, y_i = household income, α = poverty aversion parameter and takes on value 0, 1, 2

$\left(\frac{z - y_i}{z} \right)$ = proportion short fall in income

Below the poverty line

Determining the poverty index When $\alpha = 0$ in FGT, the expression becomes:

$$P_0 \left(\frac{1}{n} \right) q = \frac{1}{n} \dots \dots \dots (2)$$

This is called the Incidence of poverty or headcount index, which measures the proportion of the population that is poor i.e. falls below the poverty line.

When $\alpha = 1$ in FGT, the expression becomes:

$$P_1 = \frac{1}{2} \sum_{i=1}^n \left(\frac{z - y_i}{z} \right) \dots \dots \dots (3)$$

This is called Poverty depth or Poverty gap index, which measures the extent to which individuals fall below the poverty line as a proportion of the poverty line. When $\alpha = 2$ in FGT, the expression becomes:

$$P_2 = \frac{1}{3} \sum_{i=1}^n \left(\frac{z - y_i}{z} \right)^2 \dots \dots \dots (4)$$

This is the *poverty severity index*, which gives more weight to the poorest among the poor by squaring the poverty gap, thereby accounting for inequality among the poor.

Poverty Line and Classification

This study adopts the World Bank's international poverty line of USD \$1.90 per capita per day (post-2020 benchmark) as the absolute poverty threshold. Using the prevailing exchange rate at the time of the study (₦1,400 per USD), this corresponds to approximately **₦2,660 per capita per day**. Per capita daily household expenditure was computed based on total household expenditure. Households with per capita daily expenditure below ₦2,660 were classified as poor, while those at or above this threshold were considered non-poor.

Logit Regression Model

To identify the determinants of poverty among rural farming households, the logistic regression model was employed. This model is appropriate when the dependent variable is binary—in this case, indicating whether a household is poor or not.

Let the dependent variable Y_i represents the poverty status of the i^{th} household, such that:

$Y_i=1$ if the household is classified as poor

$Y_i=0$ if the household is classified as non-poor

The probability of being poor depends on a set of variables listed below and denoted as x so that:

$$\text{Prob} = (Y_i = 1) = F(\beta'x) \quad \text{----- (1)}$$

$$\text{Prob} = (Y_i = 0) = 1 - F(\beta'x) \quad \text{----- (2)}$$

Using the logistic distribution, we have:

$$Z_i = \ln \left(\frac{p_i}{1-p_i} \right) + \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \epsilon_i \quad \text{----- (3)}$$

Where, Z_i is the log odds of the i^{th} household, α is constant, $\beta_1, \beta_2, \beta_3$, are coefficients of independent variables X_{1i}, X_{2i}, X_{3i} , and ϵ_i is an error term for the i^{th} household.

The explanatory variables specified as determinants of poverty are:

X_1 = Age of the household head in years;

X_2 = Marital status of the household head ($D = 1$ If married, 0 if other wise);

X_3 = Educational level of headed households in years;

X_4 = Household size;

X_5 = Year of experience

X_6 = Size of farm

X_7 = Access to health (1=access, 0= do not have access)

X_8 = Cooperative association (= 1 if yes, 0 if no).

X_9 = Access to credit (= 1 if yes, 0 if no).;

X_{10} = Crop processing (= 1 if yes, 0 if no);

X_{11} = Income (N)

Poverty Coping Strategies Use Index (PCSUI)

The Poverty Coping Strategies Use Index (PCSUI) was used to assess the extent of utilization of coping strategies by rural farming households in the study area. This index is crucial for understanding the mechanisms that households employed to cope with poverty and for identifying potential intervention points for policy makers and stakeholders. To compute the PCSUI, coping strategies were first ranked based on their frequency of use. Each strategy was scored on a four-point scale as follows: frequently used (3), occasionally used (2), rarely used (1), and not used (0). This approach was adopted from Oluwatayo, (2008) and subsequently modified to suit the context of the study.

The formula for calculating the PCSUI is presented as follows:

$$\text{PCSUI} = (N_1 \times 3) + (N_2 \times 2) + (N_3 \times 1) + (N_4 \times 0)$$

Where:

PCSUI = Poverty Coping Strategies Use Index

N_1 = Number of households frequently employing a particular coping strategy

N_2 = Number of households occasionally employing a particular coping strategy

N_3 = Number of households rarely employing a particular coping strategy

N_4 = Number of households not employing the coping strategy at all

The PCSUI scores were subsequently ranked to reflect their relative significance, thereby offering a clear view of the most frequently used coping strategies among the surveyed households in the study area.

RESULT AND DISCUSSION

Socio-economic characteristics

The socio-economic characteristics of the respondents considered in this study include age, marital status, household size, educational attainment, years of marketing experience, business size, access to credit, and sources of credit. The study revealed that female household heads had a mean age of 44.7 years, while their male counterparts averaged 53.4 years, indicating that both groups remain within economically active age brackets. This suggests a strong capacity for participation in income-generating activities. Recent studies support this, highlighting continued productivity among rural men and women in similar age ranges across Nigeria (Awoyemi et al., 2023; Otekunrin et al., 2023; Bigwa and Ibrahim, 2024 ; Ojo, 2024). These findings underscore the age-related potential of farming households to engage actively in poverty reduction efforts.

An analysis of the marital status of respondents revealed that 56.6% of female-headed households and 90.0% of male-headed households were married. Marital status, particularly being in a union, has been shown to influence household labour dynamics positively. In agricultural households, married couples often engage in joint labour contributions, which enhances productivity and reduces dependence on external labour sources. This observation aligns with recent findings by Adedokun et al., (2021), who reported that household structure and marital stability significantly improve labour efficiency and resource management among farming households in rural Nigeria.

The result of household size revealed that 46.7% of male-headed households comprised between 6 and 10 members, while 50.0% of female-headed households had between 1 and 5 members. This pattern indicates the potential availability of family labour within many households, which could reduce reliance on hired labour and subsequently minimize production costs. This finding is consistent with recent research suggesting that moderately sized households contribute significantly to smallholder farming systems by providing necessary labour, thereby boosting productivity and supporting the adoption of improved agricultural practices (Oyinbo et al., 2022; Adeniyi and Ogundipe, 2021). However, larger household sizes may also place greater pressure on household resources by increasing consumption needs and dependency ratios, which can aggravate poverty and food insecurity—particularly in economically vulnerable settings (Adepoju and Oyewole, 2023). Therefore, while household size may present opportunities for economic efficiency through labour contributions, its net effect on household welfare is influenced by broader socio-economic conditions.

The results indicated that 56.7% of female respondents and 46.7% of male respondents had attained tertiary education. This suggests that a substantial proportion of the farming household heads in the study area are literate, which enhances their ability to access, comprehend, and adopt agricultural innovations. Higher educational attainment is also associated with better health awareness and informed decision-making, which can contribute to reduced illness incidence and, ultimately, lower levels of poverty.

These findings are consistent with those of Olutumise and Apata (2021), who observed that a significant proportion of food crop farmers in southwest Nigeria had formal education, facilitating their engagement with agricultural development programs. Additionally, contemporary research confirms that increased years of schooling positively correlate with improved household income, wealth accumulation, and resilience to economic shocks (Ogunniyi et al., 2022; Ajayi & Oyetade, 2023).

The results revealed a clear gender-based disparity in farm size among the respondents. Male-headed households reported an average farm size of 4.8 hectares, whereas female-headed households operated smaller holdings, averaging 3.2 hectares. This variation suggests that men have comparatively greater access to land resources, which may influence agricultural output and income levels. Despite this difference, both groups fall within the smallholder category, commonly defined as farmers cultivating between 0.1 and 5.9 hectares (Adepoju et al., 2021). This finding corroborates the study by Oparinde et al., (2022), which noted that the majority of cassava and maize producers in Southwestern Nigeria are small-scale farmers. Notably, approximately 1% of respondents indicated that their farms were situated directly adjacent to their residences, underscoring the limited scale of agricultural activity in the area. The dominance of smallholder farming in the region may be a contributing factor to the persistence of poverty, as land constraints can limit economies of scale, hinder investment in technology, and ultimately suppress productivity and income (Ogunniyi and Olagunju, 2023).

The findings reveal that 73.3% of female-headed households and 66.7% of male-headed households in the study area do not belong to any cooperative association. This low level of cooperative participation may significantly limit farmers' access to essential resources such as agricultural credit, training programs, and market information—factors critical to enhancing productivity and reducing poverty. Cooperative societies serve as platforms for collective bargaining, capacity building, and information sharing, which are essential for improving farm-level decision-making and resilience to economic shocks (Awotide et al., 2022); Ololade and Olagunju, 2021). The limited involvement of farmers in such institutions suggests the need for targeted sensitization and policy interventions to enhance rural household participation in collective organizations, thereby strengthening their socioeconomic outcomes.

A substantial proportion of female-headed households (95.0%) and male-headed households (86.7%) reported having no access to credit. This limited financial access poses a critical barrier to poverty alleviation, as it impedes farmers' ability to invest in productive inputs, expand income-generating activities, and respond effectively to health and livelihood shocks. Access to credit is strongly correlated with improved welfare outcomes, enhanced decision-making capacity, and increased resilience among rural households. Omar and Inaba (2020) underscores that financial inclusion is a key driver of poverty reduction and income equality, particularly in underserved rural communities. The observed credit constraints among respondents may therefore exacerbate their vulnerability to poverty and reduce their capacity to transition into more sustainable livelihoods.

Table 1: Socio-economic characteristics of the respondents

Characteristics	Category	Female-Headed Freq.	Female-Headed %	Female-Headed Mean	Male-Headed Freq.	Male-Headed %	Male-Headed Mean
Age (Years)	20 – 30	9	15		6	10	
	31 – 40	6	10		14	23.3	
	41 – 50	31	51.7		32	53.3	
	51 – 60	10	16.7		8	13.4	
	61 – 70	4	6.6	44			53.4
Marital Status	Married	34	56.6		54	90	
	Single	24	40		6	10	
	Divorced	2	3.4		0	0	
Household Size	1–5 Persons	30	50		14	23.3	
	6–10 Persons	28	46.7	5.7	28	46.7	5.8
	11–15 Persons	2	3.3		18	30	
Education Status	Primary	6	10		10	16.7	
	Secondary	6	10		22	36.7	
	Tertiary	34	56.7		28	46.6	
Farm Size(Ha.)	2-5	35	58.3		31	51.7	
	6-9	25	41.7		20	33.3	
	10-13	0	0		3	5	
	13-17	0	0	3.2	6	10	
Cooperative	Yes	16	26.7		20	33.3	
	No	44	73.3		40	66.7	
Credit Access	Yes	3	5		8	13.3	
	No	57	95		52	86.7	
Income(₦)	<50,000	15	24.6		14	23.3	
	51,000-100,000	10	16.4		27	45	
	101,000-150,000	25	41		10	16.6	
	151,000-200,000	8	13.1		7	11.7	
	>200,000	3	4.9	87,000	2	3.3	59,664
Health care	Yes	48	80		28	46.7	
	No	12	20		32	53.3	

As presented in Table 9, the income analysis reveals that female-headed households reported a higher average of mean income (₦87,000) compared to their male-headed counterparts (₦59,644). This finding suggests that female household heads in the study area may be more engaged in a broader range of income-generating activities, possibly including both farm-based and non-farm enterprises. It also indicates a shifting dynamic in rural economic participation, where women increasingly contribute to household income beyond subsistence roles. This observation is consistent with recent literature emphasizing the growing economic agency of women in sub-Saharan Africa. For instance, Edeh et al. (2022) and the Food and Agriculture Organization (FAO, 2021) report that women account for a substantial share of agricultural labor and are increasingly involved in diversified livelihood strategies that enhance household income and resilience.

The findings reveal a notable gender disparity in access to healthcare services among farming households in the study area. Specifically, 80% of female-headed households reported access to healthcare, compared to only 46.7% of their male-headed counterparts. This disparity has significant implications for household welfare, as access to healthcare services is intrinsically linked to labor productivity and economic stability. Health challenges can constrain farmers' capacity to work efficiently, thereby reducing agricultural output and increasing the risk of poverty. The relatively higher healthcare access among women may be attributed to their active role in household health decision-making, which often prioritizes medical needs and preventive care. Recent studies affirm that women are more likely to influence healthcare spending and utilize services when empowered to do so (Afolabi and Ajani, 2022; OECD, 2021). These findings underscore the importance of promoting equitable access to healthcare as a critical poverty reduction strategy in rural communities.

Income-Generating Activities of Respondents in the study Area.

A gender-disaggregated analysis of respondents' income-generating activities (Table 2) reveals notable variations between male- and female-headed households. Approximately 80.0% of female-headed households were engaged in crop processing compared to 73.3% of male-headed households, suggesting that women play a more significant role in value addition. This pattern aligns with recent findings that women dominate post-harvest processing and marketing within the cassava value chain, largely due to cultural roles and limited access to production resources (Ndjouenkeu et al., 2021; Alabuja et al., 2023). In the study area, cassava was predominantly processed into *fufu* to enhance shelf life, improve value, and diversify income streams.

Participation in farm labor exhibited a contrasting trend, with 70.0% of male-headed households and 60.0% of female-headed households involved. This reflects the physically demanding nature of field operations, which men are more likely to undertake (Ogunleye et al., 2021). Conversely, marketing of agricultural products showed female predominance, as 70.0% of female-headed households sold agricultural produce compared to 50.0% of male-headed households, a finding consistent with gendered roles in rural markets across sub-Saharan Africa (Adepoju et al., 2022).

To mitigate poverty risks, respondents diversified into alternative income-generating activities. Trading, which included the sale of yam, cassava, maize, and *fufu*, was reported by 73.0% of male-headed households and 70.0% of female-headed households. Handicraft production was more prevalent among female-headed households (83.3%) than their male counterparts (16.7%), reinforcing the notion that women often adopt flexible income options compatible with household responsibilities (Adebayo et al., 2021). Employment in civil service roles, such as teaching in public schools was reported equally by both household types (46.7% each), while engagement in private businesses such as driving and artisanal work was higher among male-headed households (63.3%) than female-headed households (50.0%).

These findings underscore the critical role of gender in shaping livelihood diversification strategies among rural households. They corroborate earlier evidence that women rely more on processing, petty trading, and craft-making as coping strategies, while men gravitate toward physically intensive and higher-capital activities such as commercial driving and artisanal work (Alabuja et al., 2023; Ndjouenkeu et al., 2021). Such gendered patterns have significant implications for poverty reduction programs, emphasizing the need for targeted interventions that enhance women's access to processing technologies, market infrastructure, and credit facilities.

Table 2. Distribution of Respondents Based on Gender income generating activities

S/No	Agricultural activities		Yes	No	Total
1	Crop processing	Male	73.3	26.7	100
		Female	80.0	20.0	
2	Farm labour	Male	70.0	30.0	100
		Female	60.0	40.0	
3	Selling of agricultural products	Male	50.0	50.0	100
		Female	70.0	30.0	
Non agriculture activities					
5	Trading	Male	73.3	26.7	100
		Female	70.0	30.0	
6	Handicraft	Male	16.7	83.3	100
		Female	30.0	70.0	
7	Civil servants	Male	46.7	53.3	100
		Female	46.7	53.3	
8	Private business	Male	63.3	36.7	100
		Female	50.0	50.0	

Source: Field Survey, 2025

Determinants of Poverty Status among Respondents in the Study Area

Table 3 presents the poverty status of male- and female-headed farming households. Based on the international poverty line of USD 11.90 per day, 53.3 % of female-headed households were classified as poor, whereas 46.6 % were non-poor. By contrast, 70.0 % of male-headed households were non-poor and 30.0 % were poor. These results indicate that interventions aimed at improving farmers' incomes as a poverty-reduction strategy are beginning to yield measurable outcomes. However, they also reveal persistent gender disparities. Recent evidence shows that female-headed cassava farming households in Nigeria continue to experience higher levels of poverty, largely due to limited access to productive resources and markets (Alabuja et al., 2023). Similarly, Odozi and Oyelere (2024) demonstrate that unequal access to land remains a key driver of poverty among agricultural households.

The relatively better poverty status of male-headed households in the study area may reflect their greater control over land and other productive resources. This is consistent with Adekunle et al. (2024), who attribute women's disadvantage to patriarchal inheritance systems that limit their bargaining power and ownership of land. These findings underscore the need for gender-responsive land access policies and agricultural support programmes to further reduce rural poverty.

Table 3: Distribution Based on Poverty Status of the Respondents

Female headed	Household		Male headed	Household	
	Frequency	Percentage		Frequency	Percentage
Poverty status					
Non poor	28	46.6	42	70	
Poor	32	53.3	18	30	
Total	60		60		

Source: Field Survey, 2025

Determinants of Poverty Status of the Respondents Using (FGT)

The Foster–Greer–Thorbecke (FGT) poverty indices reveal marked gender disparities in poverty among farming households in the study area. As presented in Table 4, female-headed households recorded a poverty incidence (headcount) of 0.533, considerably higher than the 0.30 observed for male-headed households. The poverty gap (depth) was also greater for women (0.69) than for men (0.43), while the poverty severity (squared gap) was highest among female-headed households (0.96) compared with male-headed households (0.42). These findings differ from those of Ajewole et al. (2006) on rice-farming households, where male-headed households exhibited higher poverty incidence (0.47 vs. 0.37), greater depth (0.18 vs. 0.09) and

severity (0.10 vs. 0.05) than their female counterparts. More recent evidence underscores the persistence of gendered poverty in Nigerian agriculture. Ameh, Okoye, et.al., (2021) applied the FGT measure to rice-farming households in Kogi State and reported that 58.7% of female farmers were poor compared with 43.2% of males, with higher depth and severity indices for women. Similarly, Obi-Egbedi, et.al.(2021) show that although women in Southwest Nigeria diversify more into non-farm activities, they continue to experience greater poverty burdens than men. Oladele, et.al. (2022) report persistent welfare inequalities between male- and female-headed agricultural households despite livelihood diversification. Alabuja, et.al.,(2023) further demonstrate that limited access to land, credit and other productive resources exacerbates poverty among female-headed cassava farming households. The pattern observed in the present study aligns with these recent findings and suggests that structural constraints—especially restricted access to land and productive resources under patriarchal inheritance systems—remain key drivers of female poverty in rural Nigeria. Policies aimed at improving women's access to farmland, credit facilities, and value-adding opportunities could therefore accelerate poverty reduction among female-headed farming households.

Table 4: Distribution Based on Poverty Incidence, Depth and Severity of Poverty among male and female households

Gender					
Household head	Sample Size	No of Poor	Incidence	Depth	Severity
Female	60	32	0.533	0.69	0.96
Male	60	18	0.30	0.43	0.42

Source: Field Survey, 2025.

To identify the determinants of poverty among farmers in the study area, a logit regression model was estimated using selected socio-economic variables. The explanatory power of the model was confirmed by the likelihood ratio (chi-square) statistics of 62.5 for female-headed households and 53.8 for male-headed households, both significant at $p < 0.001$, indicating a strong overall fit. In this model, a positive coefficient indicates that an increase in the explanatory variable raises the likelihood of a household being poor, whereas a negative coefficient implies that an increase in the variable lowers the likelihood of poverty. Three variables were statistically significant for female-headed households are family size, access to health care services, and income, while for male-headed households, marital status, crop processing, and income were significant. For female-headed households, family size was negatively significant at the 10% level, suggesting that a one-unit increase in family size reduces the likelihood of being poor by about 3.71%. This may be because children or other household members contribute to family income, as also noted by Krishnaji (1980). Similar evidence of household composition influencing poverty risk among Nigerian farmers is reported by Olarinde et al. (2020), who found that larger family sizes sometimes dilute per capita poverty through increased labour supply. Access to health care services was positively significant at the 5% level for female-headed households, implying that a one-unit increase in health care access increases the likelihood of being poor by about 2.71%. This is consistent with OECD (2003) and with findings by Adewoyin et al. (2022), which show that, although access to health and financial services benefits women in the long run, the short-term costs of uptake can increase measured poverty. Income was negatively significant for both female- and male-headed households, indicating that higher household income reduces the probability of being poor, a result supported by Oyewunmi and Obayelu (2023), who observed that improved earnings from non-farm activities significantly lower the odds of being poor among rural households in Nigeria. For male-headed households, marital status was negatively significant at the 1% level, suggesting that marriage reduces poverty likelihood by approximately 2.5%. This aligns with Liu et al. (2006), who reported that marital disruption can increase unemployment and poverty risk, and with Oyewunmi and Obayelu (2023), who noted that stable households exhibit lower poverty incidence. Finally, crop processing was significant at the 5% level for male-headed households, indicating that increased engagement in processing activities contributes to poverty reduction. This corroborates Olarinde et al. (2020), who found that value-adding activities such as cassava processing reduce multidimensional poverty among smallholder farmers.

Gender-Based Coping Strategies Adopted by Respondents

To identify poverty-coping mechanisms by gender, a four-point Likert scale was employed (Table 5). Multiple responses were permitted, as most respondents relied on several strategies simultaneously. Fourteen principal strategies were identified. Across both male- and female-headed households, the most frequently

Table 5: Results of logistic regression showing the factors affecting Gender poverty status

Logistic regression		Female			Male		
No of observations		60			No of observations		
Log likelihood		-62.5			Log likelihood		
Variables	Coe fficient	Std error	Sig.	Coe efficient	Std error	Sig	
Constant	-6.423	3.177	.043	-2.889	3.036	.341	
Age	.028	.034	.405	.001	.046	.979	
Marital status	-1.276	.888	.151	2.587	1.001	.010***	
Education	2.082	1.469	.156	.131	.800	.870	
Family size	-.371	.213	.082*	-.263	.164	.109	
Year of experience	.032	.053	.541	-.053	.076	.489	
Size of farm	.440	.382	.249	.032	.171	.851	
Access to health care	2.711	1.285	.035**	-.074	1.142	.948	
Cooperative association	.837	1.064	.432	-1.192	1.174	.310	
Access to credit	.307	.905	.735	1.168	1.111	.293	
Crop processing	.067	.811	.934	2.315	1.162	.046**	
Income	-.000	.000	.003***	.000	-.000	.003***	

Note: **** * indicated significant levels at 1%, 5% and 10% respectively

Dependent variable (Non Poor = 0 and poor = 1).

***< 0.01-1%; ** 0.01-0.05= 5%; *0.051-0.099=10%

Source: Field Survey, 2025

employed coping mechanisms were reducing the number of daily meals and consuming less preferred foods, ranked first and second respectively. These behaviours are consistent with recent evidence from rural Nigeria, where food rationing and dietary substitution are common responses to income shocks (Okoli, 2024). Fasting and prayer, ranked fourth among female-headed households but only eighth among males, reflecting the higher salience of religious coping for women. Field observations showed that many households had already reduced meal frequency from three meals to two or even one per day—often breakfast and dinner or dinner alone—rarely with preferred foods. Purchasing food on credit was ranked fifth for female-headed households and sixth for male-headed ones, suggesting women's higher propensity to obtain foodstuffs on credit and repay after selling farm produce. Conversely, selling farm implements or other productive assets ranked fourth for male-headed households and seventh for female-headed households, indicating men's greater likelihood to liquidate assets to meet urgent needs. Social-network strategies also differed by gender. Seeking help from relatives and friends ranked sixth among female-headed households but only thirteenth among male-headed ones. Education-related adjustments, such as withdrawing children from private to public schools, ranked eighth for female-headed households and seventh for male-headed ones, whereas full withdrawal from school ranked twelfth for both groups—indicating that this is a less common, last-resort strategy. Other low-frequency strategies included sending children to social events to collect leftover food, engaging in non-farm activities (e.g., artisanal work, petty trading, driving), begging for alms, child hawking, family planning or contraceptive use, and borrowing from cooperatives, though the ranking of these varied considerably between male- and female-headed households. Overall, the results show that women rely more on consumption-smoothing and informal credit strategies, whereas men are more likely to sell assets or borrow formally. This gendered differentiation is consistent with recent studies showing that female-headed households in Nigeria adopt more diversified, consumption-oriented coping strategies in response to poverty and food insecurity (Igene et al., 2025; Okoli, 2024).

Table 6: results of poverty coping strategies based on frequency of use

Coping strategies	Female headed household poverty coping strategies							Male headed household poverty coping strategy						
	FU(3)	OU (2)	RU (1)	NU 0	PCSU 1	%	R	FU(3)	OU (2)	RU (1)	NU 0	PCS UI	%	R
Eating of less preferred food	22	18	10	10	112	10	1	14	32	4	10	110	8.6	3
Reducing the frequency of eating per day	22	14	14	10	108	9.7	2	36	12	4	8	136	10.6	1
Consumption of stored produce meant for planting	26	10	10	14	108	9.7	2	24	14	12	10	112	8.8	2
Result to fasting and prayer	16	24	4	16	100	9	4	14	14	8	24	78	6.1	10
Purchase food on credit	22	10	10	18	96	8.6	5	18	12	12	18	90	7	6
Seeking help from friends/relatives	10	24	14	12	92	8.2	6	2	24	6	28	60	4.7	13
Selling off farm implement/selling assets	10	20	6	24	76	6.8	7	16	20	8	16	96	7.5	4
Withdrawing children from private to public school	10	10	16	24	66	5.9	8	18	14	4	24	86	6.7	7
Sending your children to party to pack left over meal /food	14	8	6	32	64	5.7	9	4	20	2	34	54	4.2	14
Engaged in non-farming activities	6	16	12	26	62	5.6	10	14	8	14	24	72	5.6	11
Begging for alms	10	4	14	32	52	4.7	11	4	14	6	36	46	3.6	15
Withdrawing children from school	8	8	10	34	50	4.5	12	10	16	6	28	68	5.3	12
Children hawking	0	16	14	30	46	4.1	13	18	14	4	24	86	6.7	7
Family planning/use of inceptives	0	16	12	32	44	3.9	14	6	28	8	18	82	6.4	9
Borrowing money from cooperatives	0	12	16	32	40	3.6	15	16	18	12	14	96	7.5	4
Total					1,116	100						1,272	100	

Source: Field survey, 2025.

FU (3) stands for frequently used.**OU (2) stands for occasionally used****RU (1) stands for rarely used.****NU (0) stands for not used.****PCSU-Poverty Coping Strategy Based on Frequency**

CONCLUSION AND RECOMMENDATION

This study examined poverty coping strategies among male- and female-headed farming households in Akoko South-West Local Government Area of Ondo State, Nigeria. The findings revealed that both male and female household heads were within the economically active age range and possessed moderate to high levels of education, indicating strong potential for productivity and innovation in farming. However, gender disparities persist across key livelihood dimensions such as access to land, credit facilities, and income-

generating opportunities. Female-headed households were more engaged in crop processing and agricultural product marketing, while male-headed households cultivated larger farm sizes and were more involved in farm labor. Despite these contributions, female-headed households experienced higher poverty incidence (53.3%) compared to male-headed households (30%), reflecting persistent gender inequality in resource access and control. The Foster-Greer-Thorbecke (FGT) poverty index and logit regression results highlighted income, family size, and access to healthcare as significant determinants of poverty among female-headed households, while income, marital status, and crop processing were major determinants among male-headed households. These results underscore the complex interplay between gender, socioeconomic factors, and poverty outcomes in rural Nigeria (Adeleke et al., 2021; Etim et al., 2022; Ojo et al., 2023). In sum, addressing gender-based disparities, promoting financial inclusion, and supporting livelihood diversification are critical for enhancing the resilience and welfare of rural farming households. Based on the above findings, the following aligned policy recommendations are proposed: promote inclusive access to credit and financial services, strengthen gender-specific empowerment and capacity building, ensure equitable distribution of agricultural inputs and support programmes, promote diversification into off-farm and non-farm enterprises and enhance access to healthcare and family welfare services.

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EFFECT OF SMART TRAINING ON THE DISSEMINATION OF AGRICULTURAL INNOVATIONS AMONG EXTENSION WORKERS IN ONDO STATE

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ABSTRACT

The study examined the effect of SMART training on the dissemination of agricultural innovations among extension workers in Ondo State. The study has its focus on determining the socio-economic characteristics of the extension workers, identifying the types of training the extension workers need to undergo, determining the effect of exposure and determining the constraint to dissemination of SMART. Complete enumeration was applied to select 54 extension workers actively involved in SMART innovation dissemination. Data were collected using well-structured questionnaires and administered to extension workers. The data collected were analyzed using frequency, percentages and correlation analysis. The study revealed that extension workers in Ondo State were nearly gender-balanced (51.9% male, 48.1% female) and predominantly middle-aged (mean = 49 years) with high educational attainment (61.1% M.Sc). Most respondents are married (88.9%) and experienced (mean = 17 years), with moderate household size (mean = 8) and income (₦213,703). Village-level workers dominate (79.6%). SMART training needs were highest for Remote Sensing (Mean = 2.69) and Drone Technology (Mean = 2.50). Training positively influenced innovation delivery (Mean = 4.33). Key constraints included funding, digital literacy, infrastructure, and cultural resistance (100%). A significant positive correlation ($r = 0.276$, $p = 0.044$) linked tailored training to enhanced innovation delivery. The study concluded that extension workers in Ondo State show strong readiness to adopt SMART technologies, especially in remote sensing and drone use. High training demand reflects their recognition of digital tools' potential. It was then recommended that government and developmental agencies should allocate more financial resources to support SMART agricultural training programs, digital tools, and operational needs of extension workers. There should be deliberate investment in rural infrastructure, especially reliable electricity and internet connectivity, to enable the practical application of digital extension technologies. Also regular and targeted training workshops should be organized to equip extension workers with hands-on skills in remote sensing, drone operation, mobile applications, and other SMART technologies.

Keywords: smart, training, information, dissemination, digital tools

INTRODUCTION

The agricultural sector is a cornerstone of the global economy, supplying food, fiber, and essential resources to a growing world population. Projections indicate the global population will reach 9.7 billion by 2050, exerting significant pressure on agriculture to increase food production to meet rising demand (FAO, 2020). However, the sector faces complex challenges, including climate change, resource scarcity, and the urgent need for sustainable practices, all threatening the long-term sustainability of agricultural production (Tilman & Clark, 2022). Extension workers, as agricultural professionals, work closely with farmers, providing them with the knowledge, skills, and resources necessary to enhance farming practices and improve productivity (Rivera & Qamar, 2021). They serve as a vital link between research institutions and farmers, translating scientific advancements into practical, actionable solutions for field implementation (Klerkx, Begemann & Schut, 2023). The role of extension services in promoting smart agricultural practices is critical for sustainable agricultural development.

Smart agriculture refers to the use of advanced technologies and data-driven approaches to optimize agricultural production, reduce environmental impact, and improve the overall efficiency of farming systems (Basso & Antle, 2020). This includes the use of precision farming techniques, such as GPS-guided tractors, variable-rate fertilizer application, and remote sensing technologies, as well as the integration of digital platforms, mobile apps, and other digital tools to support decision-making and resource management (Walter, Huber & Buchmann, 2021). However, the dissemination and adoption of smart agricultural practices have been uneven, with many farmers, particularly in developing countries, lacking access to the necessary resources, knowledge, and skills to effectively implement these technologies (Baumüller, 2021). This is where the role of extension workers becomes critical, as they can provide targeted training and support to help

farmers overcome these barriers and adopt smart agricultural practices (Klerkx et al., 2022). One of the key challenges in this regard is the need to ensure that extension workers themselves are equipped with the necessary knowledge and skills to effectively disseminate smart agricultural practices. Extension workers must not only be familiar with the latest technologies and best practices but also be able to effectively communicate this information to farmers in a way that is accessible and relevant to their specific needs (Yigezu, El-Shater, Boughlala, Bishaw & Niane, 2020).

Objectives of the Study

The main aim of this study is to examine the role of extension workers training and dissemination of smart agricultural practices. The specific objectives are to:

1. determine the socio-economic characteristics of the extension workers;
2. identify the types of training the extension workers need to undergo;
3. determine the effect of exposure;
4. determine the constraint to dissemination of SMART.

METHODOLOGY

Description of the Study Area

The study was conducted in Ondo State, located in the southwestern region of Nigeria. Ondo State is known for its agricultural activities, with major crops including cocoa, cassava, maize, and yam. The state consists of both rural and semi-urban areas, making it an ideal location for assessing the dissemination of smart agricultural practices by ADP extension workers.

Population of the Study

The target population comprised of all the agricultural extension workers operating under the Ondo State Agricultural Development Program (ADP): Village extension officer, Block extension officer, zonal extension officer, deputy director and subject matter specialist

Sampling Techniques

The study employed a complete enumeration. Complete enumeration was applied to selection of 54 extension workers actively involved in SAP dissemination.

Source of Data Collection

The research instrument for this study was a well-structured questionnaire which was a research instrument consisting of series of questions and other prompts for the purpose of gathering information from respondents. A well-structured questionnaire was administered to extension workers with the assistance of trained research assistants.

Method of Data Collections

Data were collected through the use of primary data source. The primary source was a well-structured questionnaire. The questionnaire was administered to the extension workers.

Validation/Reliability Test

The instrument was conducted through face validating during the interview on related knowledge services, the instrument was subjected through face interview.

Reliability was tested using t-test method by giving to the respondent.

Measurement of Variables

Independent Variables:

- **Socio-economic Characteristics:** Age, gender, education level and years of work experience.
- **SMART Agricultural Practices Awareness:** Measured on a binary scale (Yes = 1, No = 0).
- **Level of Training Received:** Assessed using a 5-point scale from "No training" to "Extensive training."
- **Perception of SMART Practices' Benefits:** Measured using a 5-point Likert scale from "Strongly disagree" to "Strongly agree."

- **Access to Training Resources:** Evaluated on a 4-point scale from "Very low" to "Very high."
- **Technological Competence:** Measured using a 5-point scale from "Not competent" to "Highly competent."

Dependent Variable:

- **Dissemination of Agricultural Innovations:** Measured on a 5-point scale from "Very low dissemination" to "Very high dissemination."

Method of Data Analysis

Data from the questionnaires were analyzed using descriptive and inferential statistics. Descriptive statistics, including frequency count, percentages, means, and standard deviations, were used to summarize the responses. Inferential statistics, such as chi-square tests and regression analysis, were employed to examine the relationship between extension worker training and SAP dissemination.

RESULT AND DISCUSSIONS

Table 1: Socio-Economic Characteristics of Respondents

The socio-economic profile shows that 51.9% of respondents were male, while 48.1% were female, indicating a nearly equal gender representation among extension workers. This balance suggests that both men and women are actively engaged in agricultural extension roles. The majority (49.1%) were between 41–46 years, implying that most respondents are middle-aged and likely experienced professionals. This aligns with Aina (2021) who observed that age is a determinant of productivity and adaptability to new agricultural innovations.

Table 1: Distribution of Respondents Based on their Socio-Economic Characteristics

Variable	freq	%	$\bar{x}$	Std.Dev
Sex				
Male	28	51.9		
Female	26	48.1		
Age				
41–46	7	13		
47–51	38	70.4	49	3.135
52 and above	9	16.7		
Marital status				
Single	2	3.7		
Married	48	88.9		
Separated	1	1.9		
Divorced	3	5.6		
Religion				
Christianity	33	61.1		
Islam	21	38.9		
Educational status				
adult literacy	1	1.9		
HND	2	3.7		
B.Sc	18	33.3		
M.Sc	33	61.1		
Year of experience				
≤16	16	29.6		
16–20	28	51.9	17	2.652
>20	10	18.5		
Household size				
≤5	28	51.9		
6–10	22	40.7	8	1.85
>10	4	7.4		
Monthly income				
150000–200000	24	44.4		
210000–269999	25	46.3	213703	33942.12
270000 and above	5	9.3		
Status				
Village extension	43	79.6		
zonal extension officer	4	7.4		
block extension supervisor	5	9.3		
subject matter specialist	2	3.7		

Source: Field Survey, 2025

In terms of marital status, 88.9% were married, suggesting stability and possibly greater social responsibility, which may influence their commitment to extension duties. Most respondents practiced Christianity (61.1%), while 38.9% were Muslims, reflecting the religious composition typical of southwestern Nigeria.

Educationally, 61.1% held M.Sc. degrees, while 33.3% had B.Sc., showing that most extension workers were highly educated. This supports the findings of Ogunlade and Adebayo (2020) that higher educational attainment enhances the ability to adopt and disseminate agricultural innovations.

Regarding years of experience, 51.9% had 16–20 years of service, and 29.6% had less than 16 years, indicating a well-experienced workforce. The average household size (mean = 8.1) suggests a moderately large family size typical of rural Nigeria. Monthly income data revealed that 46.3% earned between ₦210,000–₦269,999, showing that extension work provides moderate income. The majority (79.6%) were village extension agents, indicating that the respondents are primarily frontline workers who interact directly with farmers.

Table 2: Type of SMART Training Needed by Extension Workers

The mean responses ranged from 2.09 to 2.69, with a grand mean of 2.28, suggesting a moderate to high level of perceived training need across digital agricultural technologies. The highest-rated need was for Remote Sensing for Crop Health Monitoring ($\bar{x} = 2.69$), followed by Drone Technology ($\bar{x} = 2.50$) and Digital Tools for Data Collection ($\bar{x} = 2.37$). These findings imply that extension workers recognize the importance of digital and precision agriculture in modern extension practice.

This aligns with Adejo and Haruna (2019) who reported that Nigerian extension workers increasingly require ICT-based skills to enhance the efficiency of agricultural advisory services. Similarly, FAO (2022) emphasized that capacity building in emerging smart technologies such as drones, GIS, and mobile applications is essential for achieving sustainable agricultural development goals.

Table 2: Showing the type of SMART Training Needed by Extension Workers

Variables	Yes	Occasionally	Often	Always	$\bar{x}$
I believe training in Remote Sensing for Crop Health Monitoring would be beneficial.	54	3	11	40	2.69
I believe training in Drone Technology for Crop and Livestock Monitoring would be beneficial.	53	4	19	31	2.50
I believe training in Digital Tools for Data Collection would be beneficial.	54	4	26	24	2.37
I believe training in Big Data Analytics for Agricultural Decision Making would be beneficial.	54	5	24	25	2.37
I believe training in Social Media and WebBased Training Platforms would be beneficial.	54	10	18	26	2.30
I believe training in Technology Integration for Sustainable Agriculture Practices would be beneficial.	54	7	24	23	2.30
I believe training in the use of Mobile Applications for Agriculture Extension would be beneficial.	54	9	24	21	2.22
I believe training in E-learning Content Development and Delivery would be beneficial.	50	12	19	23	2.20
I believe training in Geographic Information System: (GIS) for Agricultural Planning would be beneficial.	54	14	15	25	2.20
I believe training in Precision Agriculture Technologies would be beneficial.	54	11	22	21	2.19
I believe training in Artificial Intelligence Applications in Agriculture would be beneficial.	54	9	27	18	2.17
I believe training in Online Communication and Outreach Strategies would be beneficial.	54	6	33	15	2.17
I believe training in IoT Devices for Farm Management would be beneficial.	54	12	22	20	2.15
I believe training in ClimateSmart Agriculture Technologies would be beneficial.	54	13	23	18	2.09
Grand Mean					2.28

Source: Field Survey, 2025

Table 3: Effect of SMART Training on Innovation Delivery

The data show that respondents strongly agreed that SMART training improved their capacity for innovation delivery ($\bar{x} = 4.33$) and competence in extension work ($\bar{x} = 4.28$). Other high means include improved understanding of innovative agricultural practices ($\bar{x} = 4.20$) and increased confidence in delivering innovations ($\bar{x} = 4.19$).

However, moderate agreement was observed for improved team collaboration ($\bar{x} = 3.81$) and adoption of new practices among farmers ($\bar{x} = 3.80$). Negative statements recorded lower mean scores (1.70–2.28), indicating strong disagreement — confirming that SMART training positively influenced innovation delivery.

This is consistent with Mbo'o-Tchouawou and Colverson (2020), who noted that ICT-enabled capacity-building programs enhance agricultural extension workers' performance and farmer outreach. Likewise, Adisa et al. (2023) found that digital extension interventions significantly improve innovation diffusion and adoption rates among Nigerian farmers.

Table 3: Effect of SMART Training on Innovation Delivery

	Strongly Agree Freq (%)	Agree Freq (%)	Undecided Freq (%)	Disagree Freq (%)	Strongly Disagree Freq (%)	$\bar{x}$	Std. Dev
SMART training has significantly improved my ability to deliver innovations to farmers.	24 (44.4)	24 (44.4)	6 (11.1)	–	–	4.33	0.673
SMART training has contributed to enhancing my competence in carrying out extension work by equipping me with modern tools, practical knowledge that improves my effectiveness in the field.	22 (40.7)	25 (46.3)	7 (13.0)	–	–	4.28	0.685
The SMART training provided a clear understanding of innovative agricultural practices to me.	14 (25.9)	37 (68.9)	3 (5.6)	–	–	4.20	0.528
After receiving SMART training, I feel more confident in delivering innovative agricultural practices to farmers.	18 (33.3)	28 (51.9)	8 (14.8)	–	–	4.19	0.675
SMART training has enhanced team collaboration in innovation projects.	6 (11.1)	32 (59.3)	16 (29.6)	–	–	3.81	0.617
I have observed significant improvements in the adoption of new agricultural practices among farmers after receiving SMART training.	10 (18.5)	23 (42.6)	21 (38.9)	–	–	3.80	0.737
After receiving SMART training, I do not feel more confident in delivering innovative agricultural practices to farmers.	4 (7.4)	29 (53.7)	20 (37.0)	1 (1.9)	–	3.67	0.644
I have not observed any significant improvements in the adoption of new agricultural practices among farmers after receiving SMART training.	7 (13.0)	20 (37.0)	21 (38.9)	2 (3.7)	4 (7.4)	3.44	1.022
The SMART training has not provided a clear understanding of innovative agricultural practices to me.	–	4 (7.4)	14 (25.9)	29 (53.7)	7 (13.0)	2.28	0.787
SMART training has not contributed to enhancing my competence in carrying out my extension work effectively.	–	3 (5.6)	9 (16.7)	28 (51.9)	14 (25.9)	2.02	0.812
SMART training has not significantly improved my ability to deliver innovations to farmers.	–	3 (5.6)	4 (7.4)	32 (59.3)	15 (27.8)	1.91	0.759
SMART training has not enhanced team collaboration in innovation projects.	–	–	4 (7.4)	30 (55.6)	20 (37.0)	1.70	0.603

Source: Field Survey, 2025

Table 4: Constraints to Dissemination of SMART Training

The table shows that all respondents (100%) identified major constraints such as lack of resources, inadequate infrastructure, low motivation, insufficient trained facilitators, resistance to technology, and low digital literacy. The grand mean of 2.00 and uniform ranking imply that these challenges are severe and widespread among extension officers.

This agrees with Agwu and Chah (2021), who found that inadequate funding, poor ICT infrastructure, and low digital literacy remain critical barriers to effective dissemination of modern extension services in Nigeria. Similarly, World Bank (2022) noted that digital transformation in African agriculture requires not just training but enabling infrastructure and policy support.

Table 4: Showing the Constraints to Dissemination of SMART Training

Constraints Variable	A Constraint		Not a Constraint		$\bar{x}$	Rank
	Freq	%	Freq	%		
Lack of resources (funding, tools, etc.)	54	100			2	1
Limited access to technology or internet connectivity	53	98.1	1	1.9	1.98	2
Low motivation or interest	54	100			2	1
The lack of trained facilitators or experts	54	100			2	1
Resistance to adopting new technologies	54	100			2	1
Poor infrastructure (e.g., internet, electricity)	54	100			2	1
Low Digital Literacy among Farmers	54	100			2	1
Low Incentives for Adoption	54	100			2	1
Cultural Resistance and Traditional Beliefs	54	100			2	1
Language and Communication Barriers	53	98.1	1	1.9	1.98	2
Grand Mean=	2.00					

Source: Field Survey, 2025

HYPOTHESIS TESTING**Table 5: Relationship Between Type of SMART Training Needed and Effect on Innovation Delivery**

The correlation analysis ($R = 0.276$, $p = 0.044$) indicates a significant positive relationship between the type of SMART training needed by extension workers and its effect on innovation delivery. This implies that targeted SMART training programs directly enhance innovation capacity among extension personnel.

This finding corroborates Okoro et al. (2020), who emphasized that the relevance and specificity of digital training determine how effectively extension workers can apply knowledge to real-world innovation delivery. It also supports the Rogers' Diffusion of Innovation Theory (2003), which posits that knowledge acquisition through appropriate training accelerates the adoption and diffusion of innovations.

Table 5: Ho: Relationship between Type of SMART Training Needed by Extension Workers and effect of smart training on innovation delivery

Variables	B-value	Standard deviation	R-value	T-value	P-value	Decision
Type of smart training needed by extension worker and effect of the smart training on innovation delivery	0.125	0.060	0.276	2.069	0.044	Significant

Source: Field Survey, 2025

CONCLUSION AND RECOMMENDATIONS

The study examined the effect of SMART training on dissemination of agricultural innovations among extension workers in Ondo State. Results showed a positive relationship between SMART training and innovation delivery. The major constraints identified include poor funding, digital illiteracy, and inadequate infrastructure.

Conclusion

SMART training enhances extension workers' competence, confidence, and innovation dissemination capacity. The more tailored and practical the training, the higher the likelihood of improving agricultural productivity and sustainability.

Recommendations:

1. Government should allocate more funding for SMART agricultural training programs.
2. Regular workshops should be organized to improve skills in remote sensing, drones, and digital tools.
3. Rural infrastructure such as electricity and internet connectivity should be upgraded.
4. Public-private partnerships should be encouraged to sustain training programs.
5. Digital literacy initiatives should be integrated into extension curricula.

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IMPACT ASSESSMENT OF PROCESSING EQUIPMENT DISTRIBUTION IN ONDO COMMUNITIES ON BENEFICIARIES' POVERTY STATUS

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ABSTRACT

Ondo state benefited from the Federal Government recipient of credit, and through FADAMA provides support to beneficiaries with food processing and equipment. This study tends to assess the impact of the benefits of the processing equipment supplies to the beneficiaries on the poverty reduction level. The population of the study consist of 42 groups of farmers with a total of 450 beneficiaries Multi stage sampling procedure was adopted. Based on the preponderance of processors, purposive sampling was used to sample 11 out of 18 Local government areas across the three senatorial districts within the state. Random sampling technique was used to select 30.2% of the beneficiaries from each group of participants to give a sample size of 136, structured questionnaire was administered to the respondents by the trained enumerators. Data obtained were analyzed using descriptive (means, frequency and percentage) and inferential statistics t-test. Major findings revealed that majority of the respondents were male with average age 46.9 years, having secondary education, mean household of 5 person. It was also observed that majority of them had no source to credit, and primarily had food processing as their major occupation. Findings also revealed an Improve poverty reduction from the lives of the beneficiaries. The study concluded that the assistant received by the beneficiaries in form of processing equipment, has significantly reduced the poverty level of the recipients, and had positively impacted on the outputs and income and as well as substantial improvement on their lives. The study recommended among others that more awareness programs and enlightenment campaign should be mounted to sensitize the populace on the needs to be empowered economically and be self-employed especially in the present economic situation where there is scarcity of white-collar jobs.

Keywords; processing equipment, beneficiary, poverty reduction, government intervention, income

INTRODUCTION

The provision of processing equipment to beneficiaries has been widely recognized as a strategy for poverty reduction in various contexts. Poverty remains a pervasive challenge in Nigeria, with various government interventions aimed at reducing its prevalence. Poverty is a complex and multifaceted issue in Nigeria, with various factors contributing to its persistence. Government interventions, such as cash transfers, skill acquisition programs, and livelihood support, have been implemented to address poverty. However, the impact of these interventions on poverty reduction remains a subject of investigation.

This paper presents an impact assessment of government intervention on reduction of poverty levels in the lives of beneficiaries, specifically in Ondo State, Nigeria. The study evaluates the effectiveness of these interventions in improving the socio-economic well-being of beneficiaries and reducing poverty. This study aims to contribute to the existing body of knowledge on the impact of government interventions on poverty reduction. The findings are expected to inform policy decisions and improve the effectiveness of poverty reduction strategies in Ondo State and beyond. The objectives of this paper are to; assess the impact of government intervention on poverty reduction among beneficiaries of the programs in Ondo State and determine the extent to which government interventions improved the socio-economic well-being of beneficiaries?

This study aims to contribute to the existing body of knowledge on the impact of government interventions on poverty reduction. The findings are expected to inform policy decisions and improve the effectiveness of poverty reduction strategies in Ondo State and beyond.

RESEARCH METHODOLOGY

This study was conducted in Ondo state, created on February 3rd, 1976 is bounded in the North by Ekiti and Kogi state; in the East by Edo State: In the West by Osun and Ogun state and in the south by the Atlantic Ocean. The state was a land area of 14, 788.7259km, with population 3,460.877 comprising 1,745.057 males and 1,715,820 females as at 2006 (NPC, 2006), with a projection of about 2.7% annual population growth rate. The State enjoys in luxuriant vegetation, a high forest zone in the south western Nigeria. The climate is tropical with two distinct seasons: - the raining season (April – October) and the dry season (November-

March) the temperature throughout the year ranges from 210C to 290C while humidity is relatively high. The annual rainfall varies from 2,000mm in the southern parts, to 1,150mm in the northern area. The rainfall decreases in amount and distribution from the crest to hinterland. Ondo State is endowed with extensive land suitable for agriculture capable of producing cash crops such as cocoa, rubber, cashew as well as staple crops such as cassava, yam, rice, and maize, while animals include sheep, goats, rabbit and cattle are reared

Table 1: Summary of sampling procedures and sample size

S/N	Senatorial District	LGA	Name of processing group	Population	Sample size (30.22%)
1	Ondo North	Akoko North West	Ounjeloreawo	10	3
			Bolorunduro	10	3
			Brighter	10	3
			Agbeserere	10	3
			Agbelagba	10	3
2	Ondo Central	Idanre	Ilako	8	2
			Odewu	10	3
			Gbalegi	10	3
			Apefon	11	3
			Awo	10	3
		Ifedore	Aanuoluwapo	13	4
			Irepodun	13	4
			Gboluwaga	12	4
			Ilerioluwa	10	3
			Erogbem	7	2
		Ileoluji	Iremide	10	3
			Aramson	10	3
			Asejere	10	3
		Akure North	Olaoluwa I	10	3
			Olaoluwa II	10	3
			Irawo	10	3
			Yemade	10	3
			Joy	10	3
		Akure South	Progressive	13	4
			Godswill	7	2
			Agbewumi	10	3
			Obelawo	12	4
			Mojere	13	4
			Asejere	15	5
			Ogo Oluwa	15	5
			Ajumose	10	3
			Arokobodunde	10	3
			Progressive II	10	3
			Itgesiwaju	9	3
3	Ondo South	Ilaje	Agbajeokun	10	3
			Irele	10	3
			Irewolede	10	3
		Irele	Ounjeloga	11	3
			Ifesowapo II	10	3
			Adanlawo	10	3
			Goodluck	10	3
		Okitipupa	Aswojere	11	3
			Agbedara	10	3

Summary: Ondo South = 15, Ondo Central =94 & Ondo North = 15. Total = 136

Source: field survey ,(2025)

This study employs a mixed-methods approach, combining quantitative and qualitative data collection and analysis methods. The study utilized primary data collected through surveys, interviews, and focus group discussions with beneficiaries of government interventions in Ondo State, it examines the impact of processing equipment on poverty reduction among beneficiaries of the government programs in Ondo state. By analyzing the effects of processing equipment on income generation, food security, and livelihoods, of the beneficiaries. The population for this impact assessment consists of 42 groups of farmers numbering 450 who benefited from the empowerment Programme (processing equipment support) Multi-stage sampling procedure was adopted. Based on the preponderance of processors, purposive sampling was used to sample 11 out of 18 Local Government Areas of Ondo State namely: Akure South, Akure North, Akoko North West, Ile-oluji, Irele, Okitipupa, Owo, Ilaje, Ose, Ifedore and Idanre Local Government Areas spreading across the three Senatorial Districts in the State. Random sampling technique was used to select 30.2% of beneficiaries from each of the groups of participants to give a sample size of 136.

Coding, data entry and data cleaning were carried out. Data obtained were analyzed using descriptive statistics such as mean, percentages, frequency distribution, bar charts and line graph. Inferential statistics (T-test) was used to determine statistical difference in outputs of beneficiaries before and after the program's intervention by means of processing equipment support to the participant. Average quantity of output was measured in Kg/month/year, while average income realized was measured in Naira/month/year

Quality of the training and equipment were measured on 3-point Likert type rating scale
(Good=3, Fair=2 or Poor=1)

Changes in output and input over the last 5 years was measured on 5 -point Likert rating scale. Significant increase in output and income

= 5 points Increase in output and income

= 4 points No change in output and income

= 3 points decrease in output and income

= 2 points significant decrease in output and income

= 1 point

RESULTS AND DISCUSSION.

Findings shows that majority of the respondents were males (64.7%), mostly between the ages of 40-49 years with average age of 46.9years. The implication is that males were more involved in agro-processing in the State and are mostly in their economic active age to support processing activities. Again, most of the respondents had formal education (91.9%) with over one-half of them having secondary education and above (53.7%). This implies that the respondents might be able to acquire knowledge about equipment maintenance and access to relevant information on improved methods of agro-processing. The household size of the respondents is also a crucial variable in the determination of their expenditures, incomes and labor availability. With a mean household size of 5 people, the respondents might have more mouths to feed and at the same time having advantage of family labor to complement the operation of the processing equipment which is a form of Labor-Saving Device, LSD especially for the women who are considered to be weaker vessels and vulnerable in their access to production resources. It is pertinent to note that based on the findings, the respondents were involved in different occupations such as farming, trading and being an artisan but majority of them were into agro processing as their primary occupation (91.9%). This might be due to the processing equipment support intervention by government. Also, the respondents had experience of an average of 7.3years as processors which could have given them greater opportunities to participate in the Programme. Furthermore, the findings revealed that majority of the respondents were members of Agricultural Cooperative Societies (79.4%) and had participated in government programs for an average of 3.2years but majority of them had no source of credit facilities (94.1%). This might be due to lack of collateral securities on their parts or the fear of recouping back credit facilities by the lending institutions. However, their contacts with Facilitators under government, at reasonable frequency by majority of them (89.4%), afforded the respondents different opportunities in their processing activities

Table 2: Socio-economic characteristics of respondents in the study Area.

Variables	Frequency	Percentage (%)	Mean/Mode
Sex			Male
Male	48	64.7	
Female	88	35.3	
Age (yrs)			46.3 years
20 – 29	3	2.2	
30 – 39	25	18.4	
40 – 49	67	49.3	
50 – 59	27	19.9	
≥ 60	14	10.3	
Highest educational Level			Primary education
None	4	2.9	
Koranic Education	4	2.9	
Adult Education	3	2.2	
Primary Education	52	38.2	
Secondary Education	50	36.8	
Tertiary Education	23	16.9	
Household Size (members)			5 persons
1 – 3	24	17.6	
4 – 6	88	64.7	
7 - 10	21	15.4	
More than 10	3	2.2	
Primary Occupation			Processing
Processing	125	91.9	
Others	11	8.1	
Secondary Occupation			Farming
Farming	73	53.7	
Trading	48	35.3	
Artisan	15	11.00	
Years in Agricultural Processing			7.3 years
1 - 3	42	30.9	
4 - 6	53	39.0	
7 - 9	9	6.6	
10 years and above	32	23.5	
Cooperative Membership			Yes
Yes	108	79.4	
No	28	20.6	
Years in government Programme			3.2 years
None	2	1.5	
1 - 2	88	64.7	
3 - 4	43	31.6	
Above 4 years	3	2.2	
Access to Credit Facilities			No access
Yes	11	8.1	
No	125	91.9	
Sources of Credits			None
None	128	94.1	
Cooperative			
Bank	8	5.9	
Friends/Family			
NGOs			
Average Credit Collected (₦)			
None	128	94.1	
50,000 – 99,999	1	0.7	
100,000 – 149,000	1	0.7	
150,000 – 199,000	2	1.5	
200,000 and above	4	2.9	
Contact with Facilitator			Contacted
Yes	132	97.1	
No	4	2.9	
Frequency of Contact (if Yes)			Always in contact
Always	67	49.3	
Occasionally	55	40.4	
Rarely	10	7.3	
Never	4	2.9	

Source ; Field survey ,2025

Impact of government intervention of processing equipment support Programme on output and income of beneficiary

The study considered output and income status of respondents before and after government intervention in the determination of the impact of the Programme. Findings on Table 9 showed an increase in output for each of the processed products after intervention. Moreover, *Pupuru* processing had the highest increase in output after the intervention, followed by food processing and *Garri* among others. Further analysis based on paired samples T-Test result for output before and after Intervention revealed a positive and significant difference before and after government intervention ($T = 9.33$, $P < 0.05$). Generally, majority of the respondents (92.7%) indicated significant / increase in their outputs after intervention. Furthermore, the results on Table 9 showed an increase in incomes from all processed products after the intervention and that the respondents realized the highest income from food processing than any other products, while rice processing, cassava flour, tomato/pepper processing, yam flour, *pupuru* and *gaari* followed in decreasing order. Maize flour recorded the lowest income. The implication is that market outlets and marketing may influence pricing of the products and income realized. Generally, majority of the respondents (92.6%) indicated significant / increase in their incomes.

Table 3: Mean output and income realized before and after government intervention and the percentage (%) changes

Product	Mean output before intervention (Kg/month)	Mean output after intervention (Kg/month)	Mean income before intervention (Naira/month)	Mean income after intervention (Naira/month)
Cassava products				
- <i>Garri</i>	232,580.00	364,085 (56.5%)	3,922,200	8,847,700 (125.6%)
- <i>Pupuru</i>	461,500.00	613,490 (32.9%)	4,349,000	7,988,000 (83.7%)
-Cassava flour	28,445.00	45,593 (60.3%)	480,738	979,842 (103.8%)
Rice	6,850.00	(15.5%)	11,280,000	(19.1%)
Food Processing	36,835.00	526,214.30 (13.3%)	11,391,200	24,498,000 (115.1%)
Yam flour	260.00	500.0 (92.3%)	52,000	120,000 (130.8%)
Maize Flour	435.00	734.0 (68.7%)	23,000	45,000 (95.7%)
Tomato/pepper	734.00	1,385.0 (88.7%)	1,175,000	2,270,700 (93.2%)
Fish Processing	NA	NA -	NA	NA

Source: Field Survey, 2025

*Figures in parentheses represent the percentage (%) increase after intervention

Table 4: Respondents' ratings of output and income realized after equipment support through government Programme

	Output F (%)	Income F (%)
Significant increase in output	82 (60.3)	80 (58.8)
Increase in output	44 (32.4)	46 (33.8)
No change in output	3 (2.2)	3 (2.2)
Decrease in output	5 (3.7)	5 (3.7)
Significant decrease in output	2 (1.5)	2 (1.5)
TOTAL	136 (100.0)	136 (100.0)

Source: Field Survey, 2025.

CONCLUSION

In conclusion, it can be stated categorically, that food processing equipment support to some beneficiaries of Ondo Community, resulted to a significant reduction in poverty level and had positively, significantly and successfully impacted on the outputs and incomes as well as substantial improvement in the livelihood status of the beneficiaries.

RECOMMENDATION

Based on the findings, it is recommended that:

1. More women should be incorporated into this type of Programme with a view to increasing their economic capabilities in improving their household economies
2. More awareness Programme and enlightenment campaign should be mounted to sensitize the populace on the needs to be empowered economically and be self-employed, especially in the present economic situations where there is scarcity of white-collar jobs.
3. The coordinating Ministry should sustain the positive impact of government Programme by working with the beneficiaries to strengthen the various groups with the aim of being registered as Agricultural Cooperative. This will boost their access to credit facilities which can assist them to buy more processing equipment in the nearest future.
4. Also, government Programme should collaborate with relevant industries to identify off-takers for bulk purchase of processed products from the beneficiaries. This will eliminate the problem of middlemen and enhance the incomes of the beneficiaries.
5. In addition, government Programme should also liaise with relevant Organizations and Research Institutes on the needs to provide or develop better storage facilities that can increase the shelf-life of the processed products. This should include improved methods of packaging during transportation.
6. The Parent Ministry in charge of the Programme, that is, the Ministry of Agriculture, should liaise with the Ministry of Works and relevant authorities to repair the rural roads linking the processing areas with a view to reducing the problems of transporting processing inputs and outputs as well as the associated costs

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ASSESSMENT OF FARMERS' ACCESSIBILITY AND UTILIZATION OF WEATHER FORECAST INFORMATION ON CLIMATE CHANGE ADAPTATION IN EKITI STATE, NIGERIA

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ABSTRACT

Climate change is one of the most pressing issues of our time, with far-reaching consequences for agriculture, food security, and sustainable development. The study assessed farmers' accessibility and utilisation of weather forecast information on climate change adaptation in Ekiti State, Nigeria. A multi-stage sampling method was used to select 120 respondents. Descriptive statistics, Probit and Multiple Regression models were the econometric tools used to analyze the obtained data for the study. Result from the socio-economic characteristics of the farmers showed that 89.2% of the farmers were aware of climate change, but they (34.2%) had little access to weather station. The result further identified government agencies (65%), weather forecast websites (53%) and mobile applications (57%) as the major sources of weather forecast information. From the study, it was shown that level of education, membership of farm organization, mobile phone ownership, internet access and access to weather station were the statistically significant variables influencing farmers' access to weather forecast whereas, having access to weather forecast information improved farmers' productivity as evidenced from the result obtained where frequency of use of weather forecast information; type of weather forecast information, accuracy of weather information, access to weather information and climate zone were all statistically significant at different levels. The study concluded that better access to and use of weather forecast information play a significant role in ensuring increased productivity, and it is recommended that individual farmers and the government agencies should ensure that weather information is accessible, not minding the cost.

Keywords: Farmers, accessibility, utilization, weather information, climate change

Introduction

Climate change is one of the most pressing issues of our time, with far-reaching consequences for agriculture, food security, and sustainable development (IPCC, 2021). In Nigeria, agriculture is a critical sector that employs a significant proportion of the workforce and contributes to the country's GDP (CBN, 2020). However, the sector is highly vulnerable to climate variability and change, which can impact crop yields, livestock productivity, and farmers' livelihoods (Ayanlade *et al.*, 2020). Farmers in Nigeria, like many other parts of the world, are already experiencing the impacts of climate change, including increased temperatures, changing rainfall patterns, and more frequent extreme weather events (Adefolalu, 2020). To adapt to these changes, farmers need access to reliable and accurate weather forecast information that can help them make informed decisions about planting, harvesting, and managing their crops (Ogunjimi *et al.*, 2020).

Weather forecast information is critical for farmers to plan and manage their agricultural activities effectively (Orlove *et al.*, 2020). With accurate weather forecasts, farmers can take proactive measures to reduce the risks associated with climate variability and change, such as planting drought-resistant crops or adjusting their irrigation schedules (Ayanlade *et al.*, 2020). However, many farmers in Nigeria lack access to reliable weather forecast information, which can limit their ability to adapt to climate change (Ogunjimi *et al.*, 2020). The use of weather forecast information is also influenced by various factors, including the type of crops being grown, the farming system, and the level of education and experience of the farmer (Orlove *et al.*, 2020). For example, farmers who grow crops that are sensitive to weather conditions, such as maize or soybeans, may be more likely to use weather forecast information to inform their planting and harvesting decisions (Ayanlade *et al.*, 2020).

In Nigeria, there is a growing recognition of the importance of climate information services, including weather forecasting, for agriculture and sustainable development (FMARD, 2020). The government has initiated various programs and projects aimed at improving farmers' access to climate information services, including weather forecasting (Adefolalu, 2020). However, more needs to be done to ensure that farmers have access to reliable and accurate weather forecast information that can help them adapt to climate change. The

impact of climate change on agriculture in Nigeria is significant, with potential losses in crop yields and livestock productivity projected to increase in the coming years (Ayanlade *et al.*, 2020). To mitigate these impacts, farmers need to adopt climate-resilient agricultural practices, including the use of weather forecast information (Ogunjimi *et al.*, 2020). By providing farmers with access to reliable weather forecast information, policymakers and agricultural extension agents can help farmers make informed decisions about their agricultural activities and reduce the risks associated with climate variability and change.

The use of weather forecast information can also have broader benefits for agriculture and sustainable development in Nigeria (Orlove *et al.*, 2020). For example, by reducing the risks associated with climate variability and change, farmers can increase their productivity and income, which can contribute to poverty reduction and improved food security (Ayanlade *et al.*, 2020). Additionally, the use of weather forecast information can help farmers adopt more sustainable agricultural practices, such as conservation agriculture, which can reduce the environmental impacts of agriculture (FMARD, 2020). Despite the importance of weather forecast information for climate change adaptation, there is limited research on farmers' access to and use of weather forecast information in Nigeria (Ogunjimi *et al.*, 2020). This study aims to fill this knowledge gap by examining farmers' access to and use of weather forecast information for climate change adaptation in Nigeria. By understanding the factors that influence farmers' access to and use of weather forecast information, policymakers and agricultural extension agents can develop targeted interventions to support farmers' adaptation to climate change.

The study will draw on existing literature on climate change adaptation, agriculture, and weather forecasting (IPCC, 2021; Ayanlade *et al.*, 2020; Orlove *et al.*, 2020). It will also build on previous research on farmers' access to and use of climate information services, including weather forecasting (Ogunjimi *et al.*, 2020; Adefolalu, 2020). By examining the specific context of Nigeria, the study will provide insights into the challenges and opportunities for improving farmers' access to and use of weather forecast information for climate change adaptation. The findings of this study will have implications for policymakers, agricultural extension agents, and farmers in Nigeria (FMARD, 2020). By understanding the factors that influence farmers' access to and use of weather forecast information, policymakers can develop targeted interventions to support farmers' adaptation to climate change (Ayanlade *et al.*, 2020). Agricultural extension agents can also use the findings of this study to develop more effective strategies for disseminating weather forecast information.

METHODOLOGY

The Study Area

This study was conducted in Ekiti State, Nigeria. The State is one of the States in the South Western Region of Nigeria. The state is within the tropics. The state was created on the 1st of October, 1996 and comprises of 16 Local Government Area (LGAs). Ekiti State occupies land mass of approximately 6,6028km² and a population of 2,432,321 (NPC 2006). Ekiti state is predominantly an agricultural area whose main cash crops are cocoa, timbers, oil-palm and kolanuts. The food crops grown are cassava, yam, cocoyam and grain crops such as maize and rice. The state has two main seasons i.e. the rainy season and dry season.

The area is predominantly agrarian, with agriculture being the main source of their livelihood in the area. Tree crops cultivated includes cocoa, mango, cashew, citrus, oil palm and arable crops cultivated includes maize, yam, cassava, cocoyam, tomatoes, and vegetables among others. The state has 16 Local Government Areas and three Agro Ecological Zones (AEZs) namely rain forest, derived savannah, and savannah zones.

Method of Data Collection

Primary data were used for the study. The data were collected using a well-structured questionnaire and were analyzed using descriptive statistics and inferential statistics. Descriptive statistics is concerned with the efficient methods of organizing, summarizing and presentation of statistical data, such as frequency counts, and percentages will be used.

Sampling Technique

A multi-stage sampling method was employed in this study. In the first stage, three Local Government Areas [LGAs] were purposely selected. These are; Moba, Gbonyin and Ekiti West. At the second stage, four communities were randomly selected from each of the 3 LGAs. Finally, at the community level, 10 respondents were randomly chosen, making ninety (120) respondents for the study.

Analytical Techniques

The data collected was analyzed using descriptive statistics, Probit regression model and Multiple regression analysis.

Descriptive statistics

Objectives one, two and five were analyzed using descriptive statistics while objective three and four were analyzed using Probit regression model and Multiple regression analysis respectively. Descriptive statistics is concerned with the efficient methods of organising, summarising and presentation of statistical data. The descriptive statistics tool that was used will include the mean, frequency distribution, variances, percentages and standard deviation.

Probit regression analysis: To examine the factors influencing farmers' access to weather forecast information in the study area, Probit regression model was used. The Probit is used to model dichotomous or binary outcome variables. In the Probit model, the inverse standard normal distribution of the probability is modeled as a linear combination of the predictors. The Probit model [15] employed was of the form;

$$P^i = \beta X_i + \mu_i \dots \dots \dots \text{equation 1}$$

that is $P^i = f(\text{Age, level of education etc.})$

Algebraically expressed as

$$P^i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \dots \dots \dots \beta_n X_n + \mu_i \dots \dots \dots \text{equation 2}$$

Where P^i = probability function

$P^i (Y=1)$ = Access to weather forecast information (yes = 1 otherwise = 0)

Where:

$X_1, X_2 \dots X_n$ = independent variables

β_0 = intercept or constant term

$\beta_1, \beta_2 \dots \beta_n$ = coefficients of the independent variables

ϵ = error term

While the independent variables are hereby listed

X_1 = Age (years)

X_2 = Farming experience (years)

X_3 = Level of education (no formal education = 0, primary education = 1, secondary education = 2, tertiary education = 3)

X_4 = Household size (number)

X_5 = Level of income (Naira)

X_6 = Membership in farm organization (yes = 1 otherwise = 0)

X_7 = Crop type grown (cash crop = 1, food crop = 2)

X_8 = Access to credit (yes = 1 otherwise = 0)

X_9 = Mobile phone ownership (yes = 1 otherwise = 0)

X_{10} = Radio/television ownership (yes = 1 otherwise = 0)

X_{11} = Internet access (yes = 1 otherwise = 0)

X_{12} = Access to extension service (yes = 1 otherwise = 0)

X_{13} = Climate zone (arid = 1, semi-arid = 2, humid = 3)

X_{14} = Awareness of climate change (yes = 1 otherwise = 0)

X_{15} = Access to weather station (yes = 1 otherwise = 0)

Multiple regression analysis

To examine the effect of weather forecast information on farmers' productivity, multiple regression analysis was used. Multiple Regression Analysis is a statistical method used to estimate the relationship between a

dependent variable and one or more independent variables. It aims to minimize the sum of the squared errors between observed and predicted values.

The OLS equation can be written as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon \dots \dots \dots \text{equation 3}$$

Where:

Y is the dependent variable i.e. Output value (Naira)

X₁, X₂... X_n are the independent variables (predictor variables)

β₀ is the intercept or constant term

β₁, β₂... β_n are the coefficients of the independent variables

ε is the error term (residual)

While the independent variables are;

X₁ = Age (years)

X₂ = Farming experience (years)

X₃ = Level of education (no formal education = 0, primary education = 1, secondary education = 2, tertiary education = 3)

X₄ = Crop type grown (cash crop = 1, food crop = 2)

X₅ = Livestock ownership (yes = 1, otherwise = 0)

X₆ = Access to extension services (yes = 1, otherwise = 0)

X₇ = Farm size = (Ha)

X₈ = Access to weather forecast information (yes = 1, otherwise = 0)

X₉ = Frequency of use of weather forecast information (weekly = 1, monthly = 2, quarterly basis = 3, every six months = 4)

X₁₀ = Type of weather forecast information used (short term = 1, long term = 2)

X₁₁ = Accuracy of weather information (yes = 1, otherwise = 0)

X₁₂ = Access to information (Naira)

X₁₃ = Climate zone (arid = 1, semi-arid = 2, humid = 3)

Limitations of the study

The study has several limitations. These include potential biases in the sampling method, which may not fully represent all farmers in Ekiti State, and the reliance on self-reported data, which can lead to inaccuracies. The study's geographic focus on Ekiti State may also limit the generalizability of the findings to other regions. Additionally, the availability and quality of weather forecast information could impact the results.

Potential areas for further research

Further research could explore comparative studies in other regions or countries to compare findings and identify best practices. Developing training programs to enhance farmers' understanding and utilization of weather forecast information, analyzing policies and regulations supporting or hindering farmers' access to weather forecast information, and investigating the potential of emerging technologies to improve weather forecasting and dissemination are also potential areas for further research.

RESULTS AND DISCUSSION

Socio-economic Characteristics of the Respondents

This table provides insight into the socio-economic background of the farmers in Ekiti State, helping to fulfill the **first and fifth objectives** of the study: to describe the characteristics of farmers and identify barriers to accessing weather forecast information. The results show that **81% of the respondents were male**, reflecting the male-dominated nature of agriculture in the area. This suggests potential gender disparities in access to weather information and decision-making. While gender itself was not a significant factor in later analyses, extension services must be gender-inclusive. In terms of **education**, a significant number (34.2%) of respondents had secondary education, while 21.6% had tertiary education. Only 15% had no formal education. The average education level was moderately high, which is promising for information uptake and comprehension. Since education was later found to significantly affect access to weather forecast

information, this variable is crucial for targeted interventions. **Mobile phone ownership** was high, with 78.3% of respondents owning phones. This aligns with global trends in mobile penetration in rural Africa and positions mobile platforms as effective tools for disseminating forecasts. However, **only 51.7% had internet access**, indicating a digital divide that could affect the reach of online weather services and apps. **Membership in farm organizations** was notable at 61.7%. These groups often facilitate training, group extension services, and shared information. The high participation rate makes them valuable channels for outreach. A key barrier identified was **limited access to weather stations**, only 34.2% of farmers reported having access. This infrastructural challenge directly hinders the flow of localized and timely weather data. Additionally, **access to credit was low** (only 39.2%), which could affect farmers' ability to act on weather forecast information by investing in necessary inputs or changing practices. Lastly, **awareness of climate change was high** (89.2%), showing that farmers recognize environmental changes but may lack the tools to respond effectively. Despite this awareness, actual access to forecast infrastructure and services remains inadequate.

Table 1: Descriptive Statistics of SocioEconomic Characteristics of Respondents (N = 120)

Variable	Frequency	Percentage	Mean
Gender			
Male	97	81	
Female	23	19	
Age			45.2
21–30	12	10	
31–40	28	23.3	
41–50	40	33.3	
51–60	25	20.8	
>60	15	12.5	
Educational Level			
No formal Education	18	15	
Primary education	35	29.2	
Secondary education	41	34.2	
Tertiary Education	26	21.6	
Farming Experience			13.8
1–5	16	13.3	
6–10	22	18.3	
11–15	34	28.3	
16–20	27	22.5	
>20	21	17.5	
Household size			6.3
1–3	18	15	
4–6	49	40.8	
7–9	38	31.7	
≥10	15	12.5	
Mobile Phone Ownership			
Yes	94	78.3	
No	26	21.7	
Internet Access			
Yes	62	51.7	
No	58	48.3	
Membership of Farm Organization			
Yes	74	61.7	
No	46	38.3	
Access to Credit			
Yes	47	39.2	
No	73	60.8	
Access to Weather Station			
Yes	41	34.2	
No	79	65.8	
Weather Zone			
Rainforest		37	30.8
Derived savannah	35	29.2	
Savannah	48	40	
Awareness of Climate Change			
Yes	107	89.2	
No	13	10.8	

Computed data from field survey, 2025

Primary sources of weather forecast information for farmers in Ekiti State, Nigeria

The data in Table 2 highlights the primary sources of weather forecast information for farmers in Ekiti State, Nigeria, and underscores the importance of understanding these channels for effective climate change adaptation. Government agencies are the most prominent source, cited by 65% of farmers, emphasizing their critical role in disseminating climate information. This is likely due to their broad reach and perceived credibility. However, relying solely on government channels may limit the timeliness and localization of weather forecasts, particularly in remote areas. Digital platforms, including mobile applications (57%) and weather forecast websites (53%), are increasingly important for climate communication, reflecting the growing trend of mobile phone ownership and internet usage in rural Africa. These tools provide real-time and customizable weather information, enabling farmers to manage short-term climate risks more effectively.

Traditional media platforms, such as radio and television, remain relevant, with 45% of farmers citing them as sources of weather information. Radio is particularly valuable for its accessibility, cost-effectiveness, and ability to broadcast in local languages, making it an inclusive tool for information dissemination. Farm organizations are identified by 39% of respondents as important sources of weather forecasts, highlighting their potential as knowledge networks and vehicles for climate information dissemination. However, their relatively lower percentage suggests that their capacity could be strengthened to deliver more actionable and context-specific weather advice.

Notably, only 34.2% of respondents reported access to weather stations, revealing a significant infrastructural gap. The limited availability of weather stations poses a major barrier to effective adaptation planning, as farmers may have to rely on generalized forecasts that lack relevance to their specific microclimates. This shortfall undermines the reliability and usefulness of forecast data, even when information channels are functioning effectively.

Table 2: Descriptive results of primary sources of weather forecast information for farmers in Ekiti State

Primary Source of Weather	Frequency (n=120)	Percentage
Forecast Information		
Government Agencies	78	65
Mobile Applications	68	57
Weather Forecast Websites	64	53
Radio/Television	54	45
Farm Organizations	47	39
Weather Stations	41	34.2

Computed data from field survey, 2025

Factors influencing farmers' access to weather forecast information in Ekiti State

The probit regression model presented in the table is a good fit, as indicated by the LR Chi-square value of 43.04, which suggests that the model is statistically significant. The log likelihood function value of 73.80 also indicates a good fit of the model to the data. These statistics suggest that the variables included in the model are relevant and contribute significantly to explaining the factors influencing access to weather forecast information. The results show that education level has a positive and significant effect on access to weather forecast information, with a coefficient of 0.182. This suggests that farmers with higher levels of education are more likely to have access to weather forecast information. This finding is consistent with previous studies that have shown that education plays a crucial role in accessing and utilizing climate information [9]. Membership in farm organizations also has a positive and significant effect on access to weather forecast information, with a coefficient of 0.130. This suggests that farmers who are members of farm organizations are more likely to have access to weather forecast information, possibly due to the sharing of information and resources within these organizations [10].

Mobile phone ownership and internet access also have positive and significant effects on access to weather forecast information, with coefficients of 0.611 and 0.413, respectively. These findings suggest that farmers who own mobile phones and have access to the internet are more likely to access weather forecast information, possibly due to the ease of access to information and communication technologies (ICTs) [11]. Access to weather stations also has a positive and significant effect on access to weather forecast information,

with a coefficient of 0.578. This suggests that farmers who have access to weather stations are more likely to receive accurate and reliable weather forecast information, which can inform their agricultural decisions.

Table 3: Probit Regression Results of the Factors Influencing Access to Weather Forecast Information

Variable	Coefficient	Std. Error	p-value
Education Level	0.182**	6.50	0.028
Membership in farm organization	0.130**	11.8	0.011
Mobile phone ownership	0.611**	9.54	0.064
Internet access	0.413**	12.9	0.032
Access to weather station	0.578**	4.810	0.120
Age	-6.77e-109.86e-10	0.945	
Farming experience	-4.77e-105.01e-10	0.34	
Income	0.0002*	0.055	0.071
Household size	-2.89e-092.54e-09	0.259	
Access to extension services	-2.99e-102.05e-09	0.885	
Awareness of climate change	-2.74e-097.22e-09	0.705	
Access to credit	-6.56e-101.58e-09	0.678	
Crop type	-1.77e-143.15e-14	0.574	
Radio/Television ownership	-4.77e-145.01e-10	0.344	
Climate zone	-6.77e-119.86e-10	0.945	
LR Chi-square	43.04		
Log likelihood function	73.80		

Computed data from field survey, 2025

Significance codes: ***p < 0.01, **p < 0.05, *p < 0.1

Effect of Weather Forecast on Farmers' Productivity

The multiple regression model presented in the table is a good fit, as indicated by the R-squared value of 79.7% and the adjusted R-squared value of 54.4%. The significant variables in the model are farm size, access to forecast information, frequency of use, type of forecast information, forecast accuracy, mobile phone ownership, income, and livestock ownership, and climate zones.

The results show that access to forecast information has a positive and significant effect on farmers' productivity, with a coefficient of 0.514. This suggests that farmers who have access to weather forecast information are better equipped to make informed decisions about planting, harvesting, and crop management, leading to increased productivity. The positive relationship between access to forecast information and productivity can be attributed to the fact that accurate and timely weather forecasts enable farmers to take proactive measures to mitigate the impacts of adverse weather conditions, such as droughts or floods, on their crops [12]. For instance, farmers can use forecast information to adjust their planting schedules, irrigation management, and pest control measures, ultimately reducing crop losses and improving yields [13]. Moreover, access to forecast information can also help farmers to optimize their resource allocation, reduce waste, and improve their overall productivity [14].

Table 4: Multiple Regression Results of the Effect of Weather Forecast on Farmers' Productivity

Variables	Coefficient	Std. Error	t-value
Farm Size	0.064**	0.0193	3.32
Access to Forecast Information	0.514**	0.1876	2.74
Frequency of Use	-0.231**	0.0979	-2.36
Type of Forecast Info	0.411**	0.1885	2.18
Forecast Accuracy	0.379**	0.1504	2.52
Mobile Phone Ownership	0.004	0.0017	2.30
Income	0.053	0.0262	2.02
Education Level	0.071	0.0538	1.32
Age	0.002	0.0040	0.50
Livestock Ownership	0.123*	0.0703	1.75
Extension Services	0.066	0.0471	1.40
Climate Zones	0.147*	0.0840	1.75
Crop Type	0.061	0.0459	1.33

R² = 79.7

Adjusted R square = 54.4

Computed data from field survey, 2025

Significance codes: ***p < 0.01, **p < 0.05, *p < 0.1

The type of forecast information also has a positive and significant effect on productivity, with a coefficient of 0.411. This suggests that the type of forecast information received by farmers, such as short-term or long-term forecasts, can influence their productivity. Forecast accuracy is another important factor, with a coefficient of 0.379, indicating that more accurate forecasts lead to higher productivity levels. Farm size also has a positive and significant effect on productivity, with a coefficient of 0.064, suggesting that larger farms tend to be more productive due to economies of scale. Livestock ownership and climate zones are also significant, indicating that diversification and adaptation to local climate conditions are important for agricultural productivity.

CONCLUSION

The study concludes that weather forecast information is a vital tool for climate change adaptation and has a measurable impact on agricultural productivity in Ekiti State, Nigeria. Farmers with better access to accurate and relevant weather forecasts are more likely to make informed decisions that enhance crop yield and reduce losses caused by climate variability. However, access to this crucial information remains unequal due to barriers such as limited education, poor digital connectivity, lack of weather station infrastructure, and low economic capacity. While awareness of climate change is widespread among farmers, the tools and systems necessary to respond effectively are not yet fully in place. To improve productivity and resilience among rural farmers, especially in regions vulnerable to climate change, it is imperative that weather forecast information be made more accessible, understandable, and actionable. This requires a combination of technological investment, capacity building, and policy support at both governmental and community levels.

Recommendations

Based on the findings of the study, the following recommendations are made:

1. Government and private stakeholders should invest in expanding the reach of weather stations, internet services, and communication technologies in rural areas.
2. Training programs should be implemented to help farmers interpret and apply weather forecast information effectively, especially through mobile and internet platforms.
3. Strengthening farm organizations can serve as a powerful means of disseminating weather forecast information and building collective knowledge on climate-smart agriculture.
4. Meteorological agencies should improve the accuracy and localization of forecasts to make them more relevant and trustworthy for farmers.
5. Extension workers should be trained and equipped to deliver weather forecast information as part of their regular services to farmers.

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INVESTIGATING THE ADAPTIVE STRATEGIES OF ARABLE CROP FARMERS TO SEASONAL VARIATIONS IN EKITI STATE, NIGERIA.

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ABSTRACT

The country's agricultural production is heavily influenced by climate variability, particularly seasonal variations in rainfall and temperature. The study examined the adaptive strategies of arable crop farmers to seasonal variations in Ekiti State, Nigeria. A multi-stage sampling method was used to select 90 respondents, and primary data was collected using a well-structured questionnaire. The data collected were analyzed with the aid of descriptive statistics, binary logistic and ordered logit models based on the set objectives of the study. Result from the socio-economic characteristics of the arable crop farmers revealed that the farmers relied solely on friends and relations for climate information (64.4%) and moderately aware of adaptive strategies (45.6%). The result further showed that planting dates adjustment (72.2%) and crop diversification (70%) were the common adaptive strategies used by the arable crop farmers in the study area while level of education, household income, participation in training, farming experience, farm size, awareness of adaptive strategies, membership in farmers' organization, access to extension services and access to credit were the significant factors influencing the adoption of adaptive strategies to seasonal variations in the study area. The result further established statistically significant relationship between food security and planting dates adjustments; crop diversification, drought resistant variety, participation in training, soil conservation and seasonal forecasting. It is therefore suggested that consistent practice of different adaptive strategies to seasonal variations should be prioritized among the arable crop farmers. This study empirically links adaptive strategy adoption to food security outcomes in Southwestern Nigeria using a dual-model approach.

Keywords: Adaptive strategies, arable crop farmers, seasonal variations

INTRODUCTION

Arable crop farming is a vital component of Nigeria's agricultural sector, providing food, income, and employment for millions of people. However, the region's agricultural production is heavily influenced by climate variability, particularly seasonal variations in rainfall and temperature. According to Adejuwon (2018), seasonal variations in climate can have significant impacts on crop yields, food security, and the livelihoods of farmers in West Africa. In Nigeria, for example, arable crop farmers face significant challenges due to seasonal variations in climate. According to Olanrewaju *et al.* (2020), farmers in the Guinea savanna zone of Nigeria experience varying levels of rainfall and temperature during different seasons, which can affect the growth and yield of crops such as maize, sorghum, and cassava. To cope with these challenges, farmers need to adopt adaptive strategies that enable them to manage seasonal variations in climate effectively.

Adaptive strategies refer to the practices, technologies, and policies that farmers use to adapt to changing climate conditions. According to Ayanlade *et al.* (2017), adaptive strategies can help farmers reduce the risks associated with climate variability and improve their resilience to climate-related shocks. In West Africa, farmers have developed various adaptive strategies to cope with seasonal variations in climate, including changes in planting dates, crop selection, and soil management practices. One of the key adaptive strategies used by arable crop farmers in West Africa is the use of climate-smart agriculture (CSA) practices. According to Ojo, *et al.* (2020), CSA practices such as conservation agriculture, agroforestry, and integrated soil fertility management can help farmers improve crop yields, reduce greenhouse gas emissions, and enhance their resilience to climate variability. In Nigeria, for example, farmers are adopting CSA practices such as mulching, crop rotation, and minimum tillage to improve soil health and reduce erosion.

Another adaptive strategy used by arable crop farmers in West Africa is the use of climate information and early warning systems. According to Tarhule, *et al.* (2019), climate information and early warning systems can help farmers make informed decisions about planting, harvesting, and crop management, reducing the risks associated with climate variability. In Ghana, for example, farmers are using climate information and early warning systems to plan their farming activities and reduce the impacts of climate-related shocks. In

addition to these strategies, arable crop farmers in West Africa are also using other adaptive strategies such as crop diversification, irrigation, and soil conservation practices. According to Adejuwon, J. O., *et al.* (2020), crop diversification can help farmers reduce their dependence on a single crop and improve their resilience to climate-related shocks. Irrigation can also help farmers improve crop yields and reduce the risks associated with drought.

Soil conservation practices are also an important adaptive strategy used by arable crop farmers in West Africa. According to Ologeanu, *et al.* (2018), soil conservation practices such as terracing, contour farming, and cover cropping can help farmers reduce soil erosion, improve soil health, and enhance their resilience to climate variability. In Côte d'Ivoire, for example, farmers are using soil conservation practices such as contour farming and terracing to reduce soil erosion and improve crop yields.

Despite the importance of adaptive strategies in managing seasonal variations in climate, many arable crop farmers in West Africa face significant challenges in adopting these strategies. According to Ayanlade, *et al.* (2020), these challenges include limited access to climate information, lack of financial resources, and inadequate institutional support. Therefore, there is a need for policymakers and development agencies to support farmers in adopting adaptive strategies that can help them manage seasonal variations in climate effectively.

This study aims to investigate the adaptive strategies used by arable crop farmers in Nigeria to cope with seasonal variations in climate. Specifically, the study will examine the factors that influence the adoption of adaptive strategies, the types of adaptive strategies used by farmers, and the effect of these strategies on crop yields and farmers' livelihoods. The findings of this study will contribute to the development of policies and programs that support farmers in adopting adaptive strategies to manage seasonal variations in climate effectively. According to Ojo, *et al.* (2020), policymakers and development agencies can play a crucial role in supporting farmers' adaptation efforts by providing access to climate information, financial resources, and institutional support.

METHODOLOGY

The Study Area

This study will be conducted in Ekiti State, Nigeria. The state is one of the states in the South Western Region of Nigeria. The state is within the tropics. The state was created on the 1st of October, 1996 and comprises of 16 Local Government Area (LGAs). Ekiti State occupies land mass of approximately 6,6028km² and a population of 2,432,321 (NPC 2006). Ekiti state is predominantly an agricultural area whose main cash crops are cocoa, timbers, oil-palm and kolanuts. The food crops grown are cassava, yam, cocoyam and grain crops such as maize and rice. The state has two main seasons i.e. the rainy season and dry season.

It has a population of 3,423,535 (National Population Census, 2006). The area is predominantly agrarian, with agriculture being the main source of their livelihood in the area. Tree crops cultivated includes cocoa, mango, cashew, citrus, oil palm and arable crops cultivated includes maize, yam, cassava, cocoyam, tomatoes, and vegetables among others. The state has 16 Local Government Areas and three Agro Ecological Zones (AEZs) namely rain forest, derived savannah, and savannah zones.

Method of Data Collection

Primary data was used for the study. The data was collected using a well-structured questionnaire and analyzed, using descriptive statistics and inferential statistics. Descriptive statistics is concerned with the efficient methods of organizing, summarizing and presentation of statistical data, such as frequency counts, and percentages were used.

Sampling Technique

A multi-stage sampling method was employed in this study. In the first stage, three Local Government Areas [LGAs] were randomly selected. These are; Ido-Osi, Irepodun/ Ifelodun and Ikere based on the fact that they are among the Local Government Areas that are deeply involved in arable crop production in Ekiti State. At the second stage, 3 communities were selected from of the LGAs. Finally, 10 arable crop farmers were randomly selected at the community level, making the total of ninety (90) respondents for the study.

Analytical Techniques

The data collected will be analyzed using descriptive statistics and probit regression analysis.

Descriptive statistics

Objectives one and two were analyzed using descriptive statistics. Descriptive statistics is concerned with the efficient methods of organising, summarising and presentation of statistical data. The descriptive statistics tool that was used would include the mean, frequency distribution, variances, percentages and standard deviation.

Binary Logistic Regression Model: This was used to analyze objective three i.e. factors influencing the adoption of adaptive strategies among arable crop farmers in the study area. A binary logistic regression model is a statistical technique used to analyze the relationship between a binary dependent variable and one or more independent variables. The dependent variable is binary, meaning it has only two possible outcomes (e.g., 0 and 1, yes and no).

Model Equation

$$\log(p/(1-p)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n$$

Where:

- p is the probability of the event occurring (e.g., adoption = 1)
- $p/(1-p)$ is the odds ratio
- β_0 is the intercept or constant term
- $\beta_1, \beta_2, \dots, \beta_n$ are the coefficients of the independent variables
- $X_1, X_2, \dots, X_n$ are the independent variables

Probability Equation

$$p = 1 / (1 + e^{(-z)})$$

Where:

- $z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n$
- e is the base of the natural logarithm

This model estimates the probability of an event occurring based on the values of the independent variables. The coefficients (β) represent the change in the log-odds of the event occurring for a one-unit change in the independent variable.

X_1 = Age (years)

X_2 = Sex (male = 1, female = 0)

X_3 = Level of education (no formal education = 0, primary education = 1, secondary education = 2, tertiary education = 3)

X_4 = Household income (₦.....)

X_5 = Participation in training programme (yes = 1 otherwise = 0)

X_6 = Farming experience (years)

X_7 = Farm size (Ha)

X_8 = Awareness of adaptive strategies (yes = 1 otherwise = 0)

X_9 = Membership of organization (yes = 1 otherwise = 0)

X_{10} = Source of climate information (friends/ relatives = 1, internet = 2, radio/ television = 3)

X_{11} = Access to extension service (yes = 1, otherwise = 0)

X_{12} = Access to credit (yes = 1, otherwise = 0)

Ordered Logit Model

In order to investigate whether the adaptive strategies used by arable crop farmers in Ekiti State have effects on their food security or not, Ordered Logit Model was used. Ordered Logit Model is a statistical technique used to analyze ordinal dependent variables. It estimates the probability of an outcome falling into one of several ordered categories.

The ordered logit model can be written as:

$$P(Y \leq j) = 1 / (1 + e^{-(\alpha_j + \beta X)})$$

Where:

- $P(Y \leq j)$ is the cumulative probability of the outcome being in category j or lower i.e Food security (food secured = 1, otherwise = 0)
- α_j is the threshold or cut-point for category j

- β is the coefficient vector for the independent variables
- X is the vector of independent variables
- e is the base of the natural logarithm

The independent variables are hereby stated;

- X_1 = Crop insurance (yes = 1 otherwise = 0)
- X_2 = Use of drought-resistant (yes = 1 otherwise = 0)
- X_3 = Crop diversification (yes = 1 otherwise = 0)
- X_4 = Irrigation (yes = 1 otherwise = 0)
- X_5 = Participation in training programme (yes = 1 otherwise = 0)
- X_6 = Soil conservation (yes = 1 otherwise = 0)
- X_7 = Planting dates adjustment (yes = 1 otherwise = 0)
- X_8 = Water harvesting (yes = 1 otherwise = 0)
- X_9 = Use of early maturing varieties (yes = 1 otherwise = 0)
- X_{10} = Agroforestry (yes = 1, otherwise = 0)
- X_{11} = Seasonal forecasting (yes = 1, otherwise = 0)
- X_{12} = Storage preservation (yes = 1, otherwise = 0)

RESULTS AND DISCUSSION

Socio-Economic Characteristics of Arable Crop Farmers

The findings reveal that the arable crop farmers in Ekiti State are predominantly male (75.6%) and relatively aged, with a mean age of 52.1 years. Over half of the respondents were above 50 years old, indicating that the farming population is ageing. This demographic trend raises concerns about the long-term sustainability of agriculture in the region, as younger generations may be less inclined to engage in farming. Additionally, while 83.3% of respondents had at least a primary education, only 16.7% attained tertiary education. This moderate level of literacy could facilitate some level of understanding of new technologies and climate information, although there remains a gap in advanced technical capacity. Income levels among the respondents were relatively low, with an average monthly income of ₦45,700 and a significant proportion (44.4%) earning below ₦40,000. Low income may pose a significant barrier to the adoption of advanced adaptive strategies that require capital investments, such as irrigation systems or improved storage facilities. Most respondents were smallholder farmers operating on an average farm size of 1.9 hectares, with over 57% cultivating less than 2 hectares. This further compounds the income challenge and limits scalability of agricultural innovations. Experience in farming was generally high, with an average of 21.3 years. Such long-term engagement likely equips farmers with valuable traditional knowledge of climate patterns and coping mechanisms. However, only 43.3% had participated in formal training programs related to agriculture or climate adaptation, which restricts the infusion of new techniques and modern practices. Furthermore, while 60% belonged to farmer organizations and 64.4% were aware of adaptive strategies, access to credit (41.1%) and extension services (53.3%) remained limited. Alarmingly, nearly half of the farmers relied on informal sources—friends and relatives—for climate information, while just 34.4% accessed it through radio or television. This highlights a critical information gap that undermines informed decision-making.

Adaptive strategies used by farmers

The study identified several adaptive strategies utilized by farmers in the face of seasonal variations. The most prevalent and effective ones included adjustment of planting dates (72.2%), crop diversification (70%), planting of early maturing varieties (50%), use of drought-resistant varieties (65.6%), soil conservation practices (57.8%), and reliance on seasonal forecasting (53.3%). These strategies align with the low-resource nature of most respondents and demonstrate the ability of smallholder farmers to adapt using context-specific and relatively affordable measures. The use of early maturing and drought-resistant varieties allows farmers to avoid losses caused by shortened rainy seasons and erratic rainfall patterns. Crop diversification helps spread risk, ensuring that the failure of one crop does not result in total livelihood collapse. Adjusting planting dates enables farmers to better align their crop cycles with changing rainfall patterns. The widespread use of these practices suggests a level of responsiveness and resilience among farmers, despite the constraints they face.

Table 1: Descriptive Statistics of Socio-Economic Characteristics of Arable Crop Farmers (N = 90)

Variable	Frequency	Percentage (%)	Mean
Gender			
Male	68	75.6	
Female	22	24.4	
Age			52.1
<30	6	6.7	
30-39	12	13.3	
40-49	24	26.2	
50-59	29	32.2	
≥60	19	21.1	
Level of Education			
No formal Education	20	22.2	1.81
Primary education	28	31.1	
Secondary Education	27	30	
Tertiary education	15	16.7	
Household Income (₦/month)			45,700
≤₦20,000	15	16.7	
₦20001 - 40000	26	28.9	
₦40,001 - #60,000	30	33.3	
₦60,001 - #80,000	13	14.4	
>₦80,000	6	6.7	
Farming Experience (Years)			21.3
<10 years	8	8.9	
10 - 19 years	21	23.3	
20 - 29 years	31	34.4	
30 - 39 years	20	22.2	
≥40	10	11.1	
Farm size (Ha)			1.9
<1	22	24.4	
1 - 1.9	30	33.3	
2 - 2.9	23	25.6	
3 - 3.9	10	11.1	
≥4	5	5.6	
Participation in Training			
Yes	39	43.3	
No	51	56.7	
Membership in Organization			
Yes	54	60	
No	36	40	
Awareness of Adaptive Strategies			
Yes	58	64.4	
No	32	35.6	
Access to Extension Service			
Yes	48	53.3	
No	42	46.7	
Access to Credit			
Yes	37	41.1	
No	53	58.9	
Source of Climate Information			
Friends/Relatives	41	45.6	
Internet	18	20	
Radio/Television	31	34.4	

Computed data from field survey, 2025

Table 2: Distribution of the farmers according to the adaptive strategies used

S/N	Adaptive strategies	Frequency	Percentage
1	Planting dates adjustment	65	72.2
2	Crop diversification	63	70.0
3	Use of resistant varieties	59	65.6
4	Soil conservation practices	52	57.8
5	Reliance on seasonal forecasting	48	53.3
6	Planting of early maturing varieties	45	50.0

Computed data from field survey, 2025

Determinants of strategies adoption

The binary logit model results suggest that the model is a good fit, as indicated by the LR Chi-square value of 37.07, which implies that the explanatory variables jointly have a significant effect on the dependent variable (adoption of adaptive strategies). The log likelihood function value of 63.40 further supports the model's explanatory power. The statistically significant variables in the model are level of education (p-value = 0.019), household income (p-value = 0.005), participation in training (p-value = 0.014), awareness of adaptive strategies (p-value = 0.010), membership in farmers' organization (p-value = 0.022), and access to extension services (p-value = 0.028).

The positive coefficient of level of education ($\beta = 0.427$) suggests that farmers with higher levels of education are more likely to adopt adaptive strategies. This finding is consistent with previous research, such as a study by [10], which found that educated farmers are more likely to adopt climate-resilient agricultural practices due to their increased awareness and understanding of climate change impacts. The positive coefficient of household income ($\beta = 0.0006$) indicates that farmers with higher household incomes are more likely to adopt adaptive strategies. This finding is supported by research from [11], which highlighted that financial stability enables farmers to invest in adaptive measures, such as new technologies and training.

Participation in training ($\beta = 0.891$) is also positively associated with the adoption of adaptive strategies, suggesting that farmers who receive training are better equipped to understand and implement these strategies. A study by [12] similarly found that training programs significantly enhance farmers' knowledge and adoption of climate-smart practices. Awareness of adaptive strategies ($\beta = 1.092$) has a strong positive effect on adoption, indicating that farmers who are aware of these strategies are more likely to adopt them. This finding aligns with research by [13], which emphasized the importance of awareness and knowledge in the adoption of sustainable agricultural practices.

Membership in farmers' organizations ($\beta = 0.768$) is positively associated with adoption, suggesting that farmers who are part of these organizations have better access to information, resources, and support for adopting adaptive strategies. This finding is consistent with studies by [14], which found that social networks and farmer groups play a crucial role in facilitating the adoption of new practices. Finally, access to extension services ($\beta = 0.645$) is positively associated with adoption, indicating that farmers who have access to extension services are more likely to adopt adaptive strategies. This finding is supported by research from [15], which highlighted the critical role of extension services in providing farmers with the knowledge and support needed to adopt climate-resilient practices.

Table 3: Binary logistic regression result on factors influencing adoption of adaptive strategies

Variables	Coefficient (β)	Std. Error	p-value
Constant	-1.832*	0.942	0.051
Age	0.021	0.014	0.134
Sex	0.315	0.327	0.335
Level of education	0.427**	0.182	0.019
Household income	0.006***	0.002	0.005
Participation in training	0.891**	0.362	0.014
Farming experience	0.038*	0.021	0.070
Farm size	0.112*	0.064	0.080
Awareness of adaptive strategies	1.092**	0.425	0.010
Membership in farmers' organization	0.768**	0.334	0.022
Source of climate information	0.218	0.284	0.443
Access to extension services	0.645**	0.294	0.028
Access to credit	0.598*	0.310	0.054

LR Chi-square 37.07, Log likelihood function 63.40

Significance codes: ***p < 0.01, **p < 0.05, *p < 0.1

Computed data from field survey, 2025

Effect of adaptive strategies used on food security

The logit model results presented in the table suggest that the adaptive strategies employed by farmers have a significant impact on food security. The model appears to be a good fit, as indicated by the LR Chi-square value of 42.02, which suggests that the explanatory variables jointly have a significant effect on the dependent variable. Furthermore, the log likelihood function value of 71.09 indicates that the model has a good explanatory power. The statistically significant variables in the model are drought-resistant variety (p-value = 0.026), crop diversification (p-value = 0.004), participation in training (p-value = 0.010), soil conservation (p-

value = 0.063), planting dates adjustment (p-value = 0.003), early maturing variety (p-value = 0.010), and seasonal forecasting (p-value = 0.018).

The positive coefficient of drought-resistant variety ($\beta = 0.586$) suggests that farmers who adopt this strategy are more likely to achieve food security. This finding is consistent with previous research by [15] which found that adopting climate change adaptation strategies, such as drought-resistant varieties, significantly improves food security among smallholder farmers. Drought-resistant varieties can withstand water stress, reducing crop losses and ensuring a stable yield. In the same vein, the positive coefficient of crop diversification ($\beta = 0.894$) indicates that farmers who diversify their crops are more likely to achieve food security. Crop diversification can reduce reliance on a single crop, increasing the resilience of farming systems to shocks and stressors.

Participation in training ($\beta = 0.721$) is also positively associated with food security, suggesting that farmers who receive training are better equipped to manage risks and improve their productivity. This finding is consistent with previous research emphasizing the importance of training and capacity building for farmers in climate-resilient agriculture. The positive coefficient of soil conservation ($\beta = 0.489$) indicates that farmers who adopt soil conservation practices are more likely to achieve food security. Soil conservation can improve soil health, reducing erosion and increasing fertility, which is essential for maintaining agricultural productivity and ensuring food security. Planting dates adjustment ($\beta = 0.953$) is also positively associated with food security, suggesting that farmers who adjust their planting dates in response to weather patterns are better able to manage risks and ensure a stable yield. This finding highlights the importance of climate information and forecasting in informing farmers' decision-making.

The positive coefficient of early maturing variety ($\beta = 0.801$) indicates that farmers who adopt early maturing varieties are more likely to achieve food security. Early maturing varieties can escape drought and other stressors, reducing crop losses and ensuring a stable yield. Finally, seasonal forecasting ($\beta = 0.634$) is positively associated with food security, suggesting that farmers who use seasonal forecasts are better able to plan and manage their farming activities, reducing risks and improving productivity. This finding is consistent with previous research emphasizing the importance of climate information and forecasting in supporting farmers' decision-making.

Table 4: Ordered logistic regression result on the effect of the adaptive strategies on food security

Variable	Coefficient (β)	Std. Error	p-value
Crop Insurance	0.243	0.316	0.442
Drought-resistant variety	0.586**	0.264	0.026
Crop diversification	0.894***	0.309	0.004
Irrigation	0.132	0.247	0.593
Participation in training	0.721**	0.281	0.010
Soil conservation	0.489*	0.263	0.063
Planting dates adjustment	0.953***	0.321	0.003
Water harvesting	0.105	0.250	0.674
Early maturing variety	0.801**	0.311	0.010
Agroforestry	0.318	0.279	0.254
Seasonal forecasting	0.634**	0.269	0.018
Storage Preservation	0.288	0.258	0.265

LR Chi-square 42.02, Log likelihood function 71.09

Computed data from field survey, 2025

Significance codes: * $p < 0.01$ ** $p < 0.05$ *** $p < 0.1$

CONCLUSION

The study concludes that arable crop farmers in Ekiti State have developed and implemented several adaptive strategies to respond to seasonal climatic variations. While these efforts have led to noticeable improvements in food security, the ability of farmers to adapt effectively is constrained by several socio-economic and institutional factors. Education, income, farm size, training, and access to information and credit were key drivers of strategies' adoption. However, significant gaps remain in terms of institutional support, access to modern adaptation technologies, and dissemination of climate information. These gaps need to be addressed to further strengthen the adaptive capacity of smallholder farmers.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Government and NGOs should enhance the capacity of extension officers to provide timely, accurate, and climate-specific advisory services. These services should include training on adaptive practices and climate-smart agriculture.
2. Efforts should be made to improve farmers' access to reliable weather forecasts through radio, mobile alerts, or community climate information centers, especially in rural areas.
3. Microcredit schemes and input subsidy programs should be designed to enable smallholder farmers to invest in adaptive innovations such as improved seed varieties, irrigation, and storage technologies.
4. Regular workshops, field schools, and seminars should be organized to build the technical capacity of farmers to adopt and effectively implement adaptive strategies.
5. Farmer groups should be supported and empowered as platforms for information exchange, joint investment in adaptive infrastructure, and collective access to credit and inputs.

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EXPLORATION OF AGROCHEMICAL USE HAZARDS EXPERIENCED BY COCOA PRODUCERS IN ONDO STATE NIGERIA

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ABSTRACT

Cocoa farming in Nigeria depends heavily on agrochemicals to combat pests and diseases, especially during the maturation of pods. However, improper use poses health and environmental risks. This study in Ondo State assessed agrochemical use health hazard experiences of interviewed 120 cocoa producers, selected through a multi-stage sampling process. Most respondents were male (75.8%), married (88.3%), formally educated (76.7%), with an average age of 51 years and over 15 years of farming experience (75%). The study found that none of the reported health issues recorded very high occurrence (mean ≥ 2.0), with excessive sweating ($\bar{x} = 1.66$), skin rashes ($\bar{x} = 1.50$), and body weakness ($\bar{x} = 1.31$) being the most common side effects experienced. Similarly, no health hazard reported very high severity, though forgetfulness ($\bar{x} = 1.64$), loss of libido ($\bar{x} = 1.57$), dizziness ($\bar{x} = 1.57$), and diarrhea ($\bar{x} = 1.56$) were notable. Regression analysis revealed significant relationships between farmers' socio-economic characteristics; age, household size, years of experience, farm size, and annual yield, and the health hazards experienced. While health concerns exist, they remain below critical thresholds, and training and equipment usage are widespread and effective.

Keywords: Cocoa farming, agrochemical usage, health risks, inorganic agriculture, chemical safety

INTRODUCTION

The use of agrochemicals in cocoa production is essential for managing pests, diseases, and environmental sensitivities, especially in Nigeria where cocoa farming holds significant economic value. From the nursery stage to fruiting, cocoa plants face numerous threats, with mature pods particularly vulnerable to black pod disease. As a result, extensive agrochemical application is necessary to protect yields. However, improper handling of pesticides, herbicides, and fertilizers poses serious health risks to farmers and environmental hazards. Despite regulatory efforts by international bodies, misuse and lack of safety awareness remain widespread, leading to skin and eye irritation, respiratory issues, chronic conditions, and in severe cases, death or permanent disability (Oyekale, 2022; Tham-Agyekum *et al.*, 2024; Oyekale, 2017; Ndaghu, Bunu & Dire, 2017).

To ensure sustainable cocoa production and safeguard human and environmental health, farmers must be equipped with proper training in agrochemical application and safety practices. Many African cocoa producers lack access to protective equipment and knowledge of safety protocols, increasing their vulnerability to occupational hazards. Addressing these gaps requires global collaboration and targeted education (Ranabhat *et al.*, 2021; Tham-Agyekum *et al.*, 2024). This study, therefore, seeks to assess farmers' experiences with agrochemical-related health hazards in Ondo State, focusing on their socio-economic characteristics, frequency and severity of health issues.

Hypotheses: There is no significant relationship between socio-economic characteristics of the farmers and the frequency of health hazards experienced by the respondents.

MATERIALS METHODS

Sampling Procedure and Sample Size

The study was conducted in Ondo State using a two-stage multistage sampling method. First, Odigbo LGA, a major cocoa-producing area, was purposively selected. Then, 120 cocoa producers were randomly chosen from the cocoa farmers' association membership records. Data were collected through structured interviews with both open and closed-ended questions.

RESULTS AND DISCUSSION

Socio-economic characteristics of the respondents

The socio-economic characteristics of cocoa farmers, as presented in Table 1, reveal a profile dominated by

older, experienced individuals, with 60% aged above 50 and 75% having more than 15 years of farming experience. This aging population, while rich in experience, is often more vulnerable to health risks associated with agrochemical exposure due to declining physical resilience and entrenched practices. The gender distribution shows a male majority (75.8%), reflecting the traditional structure of cocoa farming in Nigeria, where men typically manage cocoa farm operations. Marital status data indicates that 88.3% of respondents are married, suggesting a family-based labour system, although 72.5% still rely on hired labour, highlighting the commercial scale of operations and the potential for increased exposure among labourers who may lack safety training. These findings are consistent with Adeogun *et al.* (2020), who observed that aging and male-dominated cocoa farming communities in Ondo State face heightened health risks due to prolonged exposure to agrochemicals and limited adoption of safety measures. Similarly, Adebisi and Okunade (2021) noted that the reliance on hired labour in cocoa production often leads to inconsistent safety practices, as labourers may not receive adequate training on chemical handling, thereby increasing the risk of exposure for both workers and farm owners.

A critical socio-economic characteristic in this context is the level of formal education. Notably, 76.7% of respondents have received formal education, ranging from primary to tertiary levels which significantly enhances their capacity to access and apply technical knowledge on safe agrochemical practices. Educated farmers are more likely to read and understand chemical safety labels, adopt personal protective equipment (PPE), and follow recommended safety protocols. This is supported by Adebayo *et al.* (2023), who found that cocoa farmers in Ondo and Osun States with formal education demonstrated higher compliance with agrochemical safety standards. Furthermore, Oladeji and Oyesola (2022) reported that educated farmers were less prone to pesticide-related health issues due to better awareness and training uptake. The mode of land acquisition is another socio-economic factor that influences investment in safety. Farmers with secure tenure are more likely to adopt long-term health and environmental safeguards. In essence, the combination of formal education, farming experience, and land security plays a pivotal role in mitigating the severity of agrochemical hazards among cocoa farmers in Nigeria.

Table 1: selected respondents' socioeconomic characteristics

Age (in years)	Freq	%	Mean	Std. Dev.
<30	3	2.5	51.50	10.04
30 – 39	5	4.2		
40 – 49	40	33.3		
>50	72	60		
Sex				
Male	91	75.8		
Female	29	24.2		
Marital Status				
Single	3	2.5		
Married	106	88.3		
Widowed/widower	7	5.8		
Separated/Divorced	4	3.3		
Educational level				
No formal Education	28	23.3		
Primary	29	24.2		
Secondary	43	35.8		
Tertiary	20	16.7		
Cocoa farming experience				
<5	3	2.5		
5 – 14	27	22.5		
>15	90	75	19.98	8.28
Source (s) of labour				
Family members	27	22.5		
Hired labour	87	72.5		
Communal labour/partnership	6	5.0		

Source: Field survey 2024

The frequency of the health hazard experience of the respondents: As shown in Table 2, the frequency of the health hazard experience of the respondents remains below the high threshold (mean ≥ 2.0). Common issues include excessive sweating ($\bar{x} = 1.66$), skin rashes ($\bar{x} = 1.50$), and body weakness ($\bar{x} = 1.31$), followed by fatigue ($\bar{x} = 1.30$), headache ($\bar{x} = 1.28$), and itching/skin irritation ($\bar{x} = 1.11$). These findings align with Aminu (2020), who documented similar health risks from pesticide exposure. Although not highly frequent, these symptoms indicate a need for improved safety practices.

Table 2: The frequency of the health hazard experience of the respondents

Health hazards	Mean	Std. Dev.
Excessive sweating	1.66	0.61
Skin rashes	1.50	0.65
Body weakness	1.31	0.56
Fatigue	1.30	0.59
Headache	1.28	0.54
Watering / peppery eyes	1.15	0.46
Diarrhea	1.12	0.42
Itching / skin irritation	1.11	0.41
Loss of libido	1.10	0.40

Source: Field survey, 2024; Mean ≥ 2.0 = High frequen

Severity of health hazards experienced: severity scores in Table 3 also fall below the critical mean of 1.5, with forgetfulness ($\bar{x} = 1.64$), loss of libido ($\bar{x} = 1.57$), dizziness ($\bar{x} = 1.57$), and diarrhea ($\bar{x} = 1.56$) being the most reported. Olaoye & Ojebiyi (2020) similarly observed that occupational health hazards in agriculture may not always be severe but still warrant preventive measures.

Table 3: Severity of the health hazard experience of the respondents

Health hazards	Mean	Std. Dev
Forgetfulness	1.64	0.93
Loss of libido	1.57	0.94
Dizziness	1.57	0.94
Diarrhea	1.56	0.89
Vomiting	1.15	0.38
Headache	1.14	0.35
Skin rashes	1.05	0.22
Shortness of breath	1.00	0.00
Itching / skin irritation	1.00	0.00
Stomach ache/cramps	1.00	0.00

Source: Field survey, 2024; Mean ≥ 1.5 = High sev

There is no significant relationship between socio-economic characteristics of the farmers and the frequency of health hazards experienced.

Regression analysis in Table 6 reveals a significant relationship between farmers' socio-economic characteristics and the frequency of health hazards experienced. Variables such as age, household size, years of farming, farm size, and annual yield all had p-values below 0.05, indicating their influence. These results align with Obiora *et al.* (2024) and Danladi *et al.* (2021), who found that socio-economic factors significantly affect health outcomes and farming practices.

Table 4: There is no significant relationship between socioeconomic characteristics of the farmers and the frequency of health hazards experienced by the respondents.

	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
(Constant)	78.574	1.114		70.544	0.0000
Age	-0.321	0.027	-0.098	-11.889	0.0000
Household size	0.361	0.121	0.086	2.983	0.0500
Years of cocoa farming experience	0.528	0.031	0.109	17.032	0.0000
Total farm size (Ha)	0.166	0.052	0.058	3.192	0.0050
Annual yield of cocoa in kg	-13.001	0.511	-0.141	-25.442	0.0000

Source: Field Survey, 2024; R = 0.456; R-square = 0.207

CONCLUSION AND RECOMMENDATIONS

The study concludes that cocoa farmers in Ondo State are largely experienced, aging, and male, with most operating small farms acquired through purchase. Encouragingly, 76.7% have formal education, suggesting strong potential for adopting safe agrochemical practices. Although health issues like excessive sweating and dizziness are present, they are not highly frequent or severe. Training methods combining lectures and visual aids are effective, and modern spraying equipment is widely used. Socio-economic factors significantly influence health hazard experiences, underscoring the need for tailored interventions.

Recommendations include leveraging farmers' literacy for enhanced training, promoting health awareness, and improving access to protective equipment and land. Additionally, attracting younger generations to cocoa farming is vital to address the aging workforce and ensure sustainability.

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USE OF SOCIAL MEDIA PLATFORMS IN EDUCATING FARMERS ON SUSTAINABLE AGRICULTURAL PRACTICES AMONG EXTENSION OFFICERS IN ONDO STATE, NIGERIA

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ABSTRACT

Agriculture remains a major livelihood in Nigeria, yet farmers face persistent challenges in accessing timely information for improved productivity and sustainability. With the advancement of digital technology, social media platforms have become critical tools for agricultural education and extension service delivery. This study examined the impact of social media on agricultural information sharing among farmers in Akoko South-West Local Government Area and its influence on extension workers' competence in promoting sustainable agricultural practices. A multistage sampling technique was used to select 64 respondents. Data were collected using standardized questionnaires and analyzed with descriptive statistics, Chi-square, and regression analyses. Results showed that 62.5% of respondents were male, with an average age of 42 years and mean farming experience of 11 years. The most frequently used platforms were WhatsApp (85.0%), Facebook (72.5%), and YouTube (61.7%). Social media facilitated the adoption of sustainable practices such as soil fertility management (68.3%), climate-smart agriculture (55.8%), and integrated pest control (52.5%). Major constraints included poor internet connectivity (74.2%), high data costs (68.3%), and low technical competence (55.0%). Chi-square analysis revealed significant relationships between age ($p < 0.05$), education ($p < 0.01$), and farming experience ($p < 0.05$) with social media competence. Regression results indicated a significant positive influence ($\beta = 0.417$, $p < 0.01$) of social media use on extension workers' competency. The study concludes that social media is vital for agricultural knowledge dissemination and recommends improved rural internet infrastructure, affordable data access, and capacity-building programs for farmers and extension personnel.

Keywords: Social Media Platforms, Sustainable Agricultural Practices, Extension Officers, Agricultural Extension, Digital Literacy

INTRODUCTION

Agricultural extension services are meant to empower farmers with the knowledge and inputs that help them increase productivity and adopt conservation practices for the environment (Sennuga, 2019). Throughout the years, it has been implemented through one-to-one meetings, group training, and traditional media such as newspapers and radio. Despite their popularity, these tactics have downsides, including time limits, high pricing, and a confined reach (Turow, 2019). Information sharing in a range of areas, including agriculture, has been altered by social media. Using platforms such as YouTube, Facebook, and WhatsApp allows us a whole new method to participate in a range of debates, receive fast responses, and have dynamic communication (Uwalaka & Nwala, 2023). According to Reddy, Kumari, and Singh (2020), these are effective and low-cost ways of reaching target groups, promoting collaboration, and knowledge sharing. There is great potential that accompanies the integration of social media into extension services, with millions of people in Nigeria remaining highly dependent on agriculture.

Recent studies show that social media platforms are becoming popular among extension officers as tools for educating farmers, sharing sustainable agricultural practices, and addressing specific challenges farming communities face (Okoro, Agwu, & Igbokwe, 2018). While social media has become increasingly popular, we have not figured out how effective it is at utilizing social media to utilize sustainable farming practices in Ondo State, nor what the impact of social media will be on the practice itself. This study investigates the role of social media platforms. This study, therefore, investigates, with a focus on extension agents in Ondo State, how social media platforms could be used to inform farmers about sustainable farming methods. The study will provide practical recommendations that could guide the improvement in the integration of social media in the delivery of agricultural extension services through assessing usage trends, effectiveness, and challenges.

Social media assimilation into extension services has great potential to enhance communication, knowledge acceptance, impact on agricultural sustainability, and dissemination (Lv & Li, 2024). Some of the interactive, reasonably priced, and easily available channels farmers can utilize to share best agriculture practices involve

Facebook, WhatsApp, and YouTube (Schoemaker, Talhouk, Kamanu, McDonough, McDonough, Casey, & Donner, 2022). Despite these benefits, not much research has ever been done regarding the uptake and utilization of social media in farmers' training in Ondo State, Nigeria. These, and many other issues, hinder the effective use of social media by farmers and extension agents in the area. Generally, digital literacy among farmers is very poor; this hinders them from appreciating and utilizing information shared on social media (Phiri, Chipeta & Chawinga, 2019). In addition, access to technology and reliable internet services in most rural areas remains limited, affecting the reach and access to social media as an educational tool (Ferri, Grifoni, & Guzzo, 2020).

Concerns over the credibility and accuracy of agricultural information shared on social media further complicate its adoption and impact (Okoro et al., 2018). Among other challenges, these indeed need targeted strategies to enhance the role of social media in agricultural extension. More importantly, discovering certain barriers to education with regard to farmers and extension officers will be very fundamental in designing intervention tactics that tap into social media opportunities toward improving education on sustainable agricultural practices (Reddy, Kumari, & Singh, 2020). Overcoming such gaps will not only enhance agricultural sustainability but also lead to economic growth and food security in Ondo State and beyond. The study objectives are to:

1. describe the socio-economic characteristics of extension officers in the study area;
2. identify the social media platforms most commonly utilized for agricultural education in the study area;
3. assess the frequency of social media usage by extension officers in educating farmers on sustainable agricultural practices in the study area;
4. evaluate the level of knowledge and competency of extension officers in the use of social media platforms for farmer education in the study area;
5. analyse the effect of social media platforms on farmers' adoption of sustainable agricultural practices in the study area;
6. identify the constraints faced by extension officers when using social media to educate farmers in the study area.

Hypothesis

- There is no significant relationship between extension officers' socio-economic characteristics and their competence in using social media to educate farmers on sustainable agricultural practices in the study area.
- Social media use has no significant influence on the competence of extension workers in educating farmers on sustainable agricultural practices in the study area.

MATERIALS AND METHODS

Study area

The field work will be conducted in Nigeria in Ondo State, with a political and administrative orientation towards Akure. Akure, located between latitude 7°15'N and 5°11'E, is a commercial hub for the state and a location for significant government buildings, including the Ondo State Ministry of Agriculture. As a focal point for agricultural development programs, extension service, and technology dissemination to farmers, the Ministry forms a nucleus for agricultural development in Nigeria. The state of Ondo in southwest Nigeria is a flagship agricultural state, with a strong record for producing significant cash crops, including cocoa, rubber, and oil palm, and food crops, including yams, cassava, and maize. Due to its agricultural diversity, it is an ideal site for investigating social media use in sensitizing farmers about sustainable agricultural practices.

For efficient delivery of agricultural service, four regions have been earmarked for the Agricultural Development Program (ADP), and these have been specifically selected for investigation. Ikare zone, in its upper part, with its arable farm produce and cocoa, and Owo zone, known for its extensive cropping of foods and cattle breeding, a key region for cocoa growing and farm work, with a mix, and finally, Okitipupa zone, which exists in southern coastal regions, is renowned for its fisheries and production of oil palm. They form the operational framework for agricultural extension in the Ondo State Agricultural Development Project (ODSADEP).

Population of the Study

This targets the population involved in agricultural extension officers within Ondo State. Since extension officers pass on agricultural information and technologies to farmers, their views become important in this research.

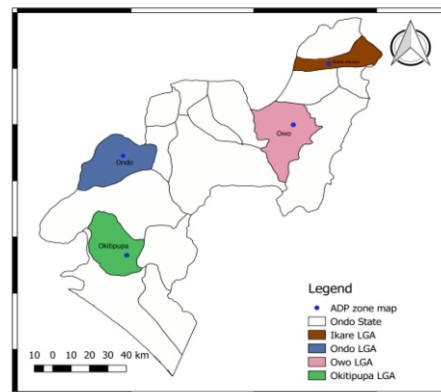


Figure 1: Study Area Map

Sample Size and Sampling Procedure

The study population included 64 extension officers representing the four agricultural development programme (ADP) regions in Ondo State, Nigeria. The four regions, namely, Okitipupa (16 field workers), Owo (16 field workers), Ondo (16 field workers), and Ikare (16 field workers), were specifically chosen for agricultural importance and for having an active presence of extension workers providing educational information to farmers. The sample in such a case was considered satisfactory enough to produce a representative base for analysis of social media use trends in different agricultural regions of the state.

Method of Data Collection

Primary data was collected through the use of a questionnaire consisting of well-structured open and closed-ended questions supported by interviews. Secondary data were obtained through a thorough document review, encompassing agricultural reports, community profiles, and existing studies on agricultural information dissemination in the region.

Instrument Validity and Reliability

The researcher will contact experts in the field of agricultural extension for validation of the instrument. The expert will be chosen based on the area of expertise that satisfies the area of this research. Major questions about the research topic will be asked and supported with variables that will give valid answers to the questions asked. The question to be asked will be in line with the research objectives, and it will answer the research question.

Method of Data Analysis

The data collected were analysed using both descriptive and inferential statistics. Descriptive statistics involves the use of frequency distribution, mean, and percentages. Inferential statistics, like chi-square analysis, were used to test the hypothesis.

RESULTS AND DISCUSSION

Socio-economic Characteristics of Respondents

This comprises the attributes of the respondents, which include variables such as their sex, age, marital Status, religion, educational qualification, years of experience as an extension worker, area of degree specialization, monthly income/salary, primary source of income, own a personal smartphone, and access to the internet.

The gender distribution, with 53.1% male and 46.9% female, demonstrates a small male dominance but still displays significant female engagement. The near parity in gender reflects a progressive approach to gender inclusion in agricultural extension services, which accords with recent literature advocating for gender-sensitive outreach in agricultural development (Ajayi & Oladipo, 2022; Muoneke & Njoku, 2020). This close gender distribution shows the increased awareness of women's roles in agriculture, defying old gender stereotypes and ensuring both men and women are active in promoting sustainable farming methods. The

major age group of extension officers is between 45-54 years (70.3%). This shows a highly seasoned team, with many having over 20 years of engagement in extension activities. While this experience is vital, elder officers may have difficulty adopting new technology such as social media. However, their substantial knowledge base gives them an advantage in terms of content production for social media that is grounded in actual, real-world experience. For persons in this age bracket, targeted training in social media usage could assist in bridging any gaps between their agricultural experience and the digital tools available to them (Bationo et al., 2021; Mudzonga & Mudenda, 2022).

With 76.6% of the extension officers holding an HND/B.Sc. degree and 15.6% holding M.Sc./Ph.D. degrees, the educational history of these officers implies a highly competent workforce. This is critical in the context of digital agriculture, as higher levels of education are often correlated with better digital literacy, enabling extension officers to effectively utilize social media platforms for complex agricultural content creation and dissemination (Bationo et al., 2021; Ajayi & Oladipo, 2022). The educational attainment of these officials positions them to critically engage with the large amount of information available online, making them good conduits for delivering knowledge to farmers. A big part of the officers (57.8%) has more than 20 years of experience. This vast professional background equips them with a profound awareness of agricultural methods, making them well-suited to be trainers and content creators on social media platforms. Their ability to integrate traditional extension knowledge with innovative digital tactics is a crucial strength. However, as the workforce matures, they may need specialised training on digital technologies to preserve their effectiveness in reaching younger, more tech-savvy farmers (Muoneke & Njoku, 2020). Most extension officers earn between ₦151,000-₦200,000 per month, which is reasonably consistent.

This salary range presumably gives the financial means needed to access smartphones and the internet, crucial tools for engaging in social media-based extension work. With larger disposable incomes, these officers are more likely to hold the required resources to acquire data plans or upgrade their devices, guaranteeing they can participate fully in digital outreach activities (Ajayi & Oladipo, 2022; Nwankwo et al., 2020). The fact that all respondents own smartphones and have an internet connection (100%) is quite significant. It ensures that all extension officers are equipped with the necessary tools to interact effectively on social media sites. This widespread access shows that technological limitations will not hinder their participation in online agriculture education. The relevance of this cannot be emphasised, as digital literacy and access are essential determinants in the effectiveness of online extension services (Munyua & Ouma, 2021).

Social Media Platforms Most Commonly Utilized for Agricultural Education by Respondents

The distribution of respondents according to the social media platforms most commonly used for agricultural education is shown in Table 2. The results revealed that 18.20% of the Extension Officers stated that Facebook is the most widely used social media platform for agricultural education among farmers, followed by 17.30% who use WhatsApp for agricultural education. Additionally, about 16.80% are using Messenger. The findings further indicated that 13.60% and 12.50% are using YouTube and TikTok, respectively, for agricultural education. Finally, 9.70%, 8.20%, 2.80%, 0.60%, and 0.30% are using Telegram, Instagram, Twitter/X, LinkedIn, and Pinterest, respectively. Social media plays a key role in educating farmers about sustainable practices. This table displays which platforms extension officers are using most frequently. In a related study, Udoeye and Okoro (2024) reported Facebook and WhatsApp as the most widely used social media platforms for extension service delivery.

Frequency of Use of Social Media for Agricultural Education

The distribution of respondents in Table 3 provides information on how often extension officers use various social media platforms to engage farmers educationally. Extension officers frequently use social media to respond to farmers' inquiries (Mean=3.76) and also analyse social media engagement metrics like likes, comments, and shares (Mean=3.75). They mentioned sharing government or NGO-supported agricultural content via social media (mean=3.67) and using WhatsApp groups to discuss sustainable farming practices with farmers (mean=3.50). The table further shows that extension officers participate in social media live sessions or webinars to educate farmers (mean=3.47), and they also use Facebook and Instagram to share extension information, images, and short videos on sustainable farming (both with a mean of 3.41).

Additionally, the table indicates that they use YouTube to upload or recommend videos on sustainable agriculture (mean=3.37) and Telegram to send educational materials and farming updates (mean=3.36). The inference is that farmers' view of transport systems presents significant problems by hindering their smooth marketing system and income. The result is consistent with Ghosh *et al.* (2021), indicating that social media, particularly platforms like WhatsApp and Facebook, are widely used by agricultural extension professionals for service delivery, including responding to farmer queries and providing information.

Table 1 Socioeconomic characteristics of the respondents

Variables	Frequency (n=64)	Percentage (%)
Sex		
Female	30	46.9
Male	34	53.1
Age		
Below 25	-	-
25-34		
35-44	12	18.8
45-54	45	70.3
55 and above	7	10.9
Marital Status		
single	1	1.6
married	54	84.4
divorced	6	9.4
widowed	3	4.7
Religion:		
Christian	44	68.8
Muslim	20	31.3
Educational Qualification		
OND/NCE	5	7.8
HND/B.Sc.	49	76.6
M.Sc./PhD	10	15.6
Years of Experience as an Extension Worker		
16-20 years	27	42.2
Above 20 years	37	57.8
Area of degree specialization:		
General Agriculture	12	18.8
Agricultural Extension	11	17.2
Agricultural Economics	6	9.4
Agronomy	13	20.3
Animal Science	14	21.9
Fisheries & Aquaculture	4	6.3
Forestry & Wildlife Management	1	1.6
Other (Specify)	3	4.7
Monthly Income/Salary (₦)		
101,000- 150,000	1	1.6
151,000- 200,000	38	59.4
Above 200,000	25	39.1
Primary Source of Income:		
Salary from employment	61	95.3
Farming	1	1.6
Other (Specify)	2	3.1
Own a personal smartphone?	64	100.0
Access to the internet?	64	100.0

Source: Field Survey, 2025.

Table 2: Social media platforms most commonly utilized for agricultural education

Social media platform most commonly used	Frequency	Percentage (%)
Facebook	64	18.20
LinkedIn	2	0.60
WhatsApp	61	17.30
Telegram	34	9.70
Messenger	59	16.80
YouTube	48	13.60
TikTok	44	12.50
Twitter/X	10	2.80
Threads	0	0.00
Instagram	29	8.20
Pinterest	1	0.30

**Multiple responses,

Source: Field Survey, 2025

Table 3: Frequency of Social Media Usage for Agricultural Education

Frequency of Social Media Usage	Mean	Std. Dev.
Respond to farmers' inquiries through social media platforms.	3.76	0.84
Social media analytics (likes, comments, shares) to assess farmers' engagement.	3.75	0.94
Share government or NGO -supported agricultural extension content via social media.	3.67	0.94
WhatsApp groups to discuss sustainable farming practices with farmers.	3.50	0.84
Participate in social media live sessions or webinars to educate farmers.	3.47	1.02
Use of Facebook to share extension information	3.41	0.89
Instagram to share images and short videos on sustainable farming methods.	3.41	0.89
YouTube to upload or recommend videos on sustainable agriculture.	3.37	0.89
Twitter/X to share quick updates on agricultural practices.	3.36	1.03
Telegram to send educational materials and updates on farming.	3.36	1.01

Source: Field Survey, 2025

Knowledge in Using Social Media for Farmer Education

The distribution of responses regarding extension officers' knowledge in using social media for farmer education is shown in Table 4.. Extension Officers indicated they are knowledgeable about social media analytics to assess farmer engagement (mean=3.97) and best practices for effective agricultural extension (mean=3.94). Extension Officers said they have knowledge on privacy, security, and ethical concerns in social media usage (mean=3.87) and evaluate engagement metrics (likes, shares, comments) (mean=3.84). The Table also revealed that Extension Officers have knowledge that different social media platforms are used for agricultural education (mean=3.83), and content creation (videos, images, text) for farmer engagement (mean=3.81). Furthermore, they expressed that they know general use of social media for communication (mean=3.80).

Table 4 below shows data from this table, suggest that extension officers have a thorough understanding of how to use social media to engage farmers in sustainable practices. With mean scores of roughly 3.8 or higher for numerous social media activities, the officers look skilled in developing material, organising groups, and assessing social media interaction. The officers' understanding of social media best practices (mean=3.94) is excellent, demonstrating their ability to use these platforms successfully for instructional objectives. This is vital for ensuring that the content presented is both effective and engaging (Suwartono & Furqon, 2021). Their capacity to assess social media analytics (mean=3.97) implies a forward-thinking strategy, with extension officers harnessing engagement data to improve the quality of their outreach and customise material to farmers' needs (Eduafu *et al.*, 2024).

Table 4: Knowledge in using social media for farmer education

Knowledge in using social media for farmer education	Mean	Std. Dev.
Social media analytics to assess farmer engagement.	3.97	0.76
Social media best practices for effective agricultural extension.	3.94	0.66
Privacy, security, and ethical concerns in social media usage.	3.87	0.79
Evaluate engagement metrics (likes, shares, comments).	3.84	0.80
Different social media platforms are used for agricultural education.	3.83	0.68
Content creation (videos, images, text) for farmer engagement.	3.81	0.66
General use of social media for communication.	3.8	0.69
Create and manage social media pages/groups for farmers.	3.8	0.76

Source: Field Survey, 2025

Level of ability in using social media for agricultural education

Table 5 presents the level of competency of extension workers in using various social media platforms for agricultural education, measured on a scale ranging from Not Competent to Highly Competent. The results indicate that all the mean values were above the benchmark of 3.0, implying that extension workers generally demonstrated a high level of competence across different social media platforms.

The highest competency was recorded in the use of social media for agricultural events and training programmes (M=3.97), followed closely by managing agricultural videos on YouTube (M=3.94), and WhatsApp for real-time farmer engagement and group discussions (M=3.92). These results highlight that extension workers are highly skilled in using interactive and multimedia-based tools that promote effective knowledge sharing and farmer participation. The high mean scores for YouTube and WhatsApp also affirm their growing popularity as agricultural learning platforms due to their simplicity, low cost, and wide

accessibility (Alhassan et al., 2023). Competency was also rated high in the use of live social media sessions/webinars (M=3.91), handling farmers' inquiries via social media (M=3.88), and Twitter/X for agricultural tips and updates (M=3.86).

Similarly, high competency was observed in using Instagram for sharing images and short videos on sustainable farming (M=3.84) and Facebook groups/pages for farmers (M=3.83). These platforms are particularly useful for reaching younger and digitally active farmers who prefer visual and short-form content. Their relatively high usage shows adaptability among extension workers to tailor content to diverse audiences. The lowest, though still within the "high competency" range, was in the use of social media to share educational materials such as PDFs, Word documents, and infographics (M=3.78). This suggests that extension workers are comparatively less competent in leveraging platforms for document-based dissemination, possibly because farmers show stronger preferences for audiovisual content that is easier to comprehend than text-heavy documents (Kpodo & Nejadhashemi, 2025).

Table 5: Level of Competency in using social media

Level of competency in using social media	Mean	Std. Dev.
Agricultural events and training programs on social media.	3.97	0.84
Managing agricultural videos on YouTube.	3.94	0.56
WhatsApp for real-time farmer engagement and group discussions.	3.92	0.80
Live social media sessions/webinars.	3.91	0.83
Farmers' inquiries via social media platforms.	3.88	0.85
Agricultural tips and updates on Twitter/X.	3.86	0.87
Instagram is used to share images and short videos on sustainable farming.	3.84	0.98
Facebook group/page for farmers.	3.83	0.75
Social media to share educational materials (e.g., PDFs, Word, infographics).	3.78	0.92

Source: Field Survey, 2025.

Mean ≥ 3.0 = High competency

Effect of social media on the adoption of sustainable agricultural practices

Table 6 presents the effects of social media on the adoption of sustainable agricultural practices among farmers. Using the benchmark of mean ≥ 3.0 as high effectiveness, the results indicate that social media platforms have had a generally positive influence on farmers' decisions and practices related to sustainability.

The findings reveal that social media was most effective in encouraging farmers to adopt biological pest control methods (M=3.75), improved irrigation techniques (M=3.64), and agroforestry/afforestation practices (M=3.67). These results suggest that farmers are responsive to practical and cost-effective techniques shared via social media, particularly those that improve productivity and environmental sustainability. This corroborates the work of (Hamza *et al.*, 2025), who noted that social media facilitates knowledge transfer on environmentally friendly practices by providing access to diverse and innovative agricultural solutions. Similarly, a high mean value was recorded for the adoption of organic fertilizers over synthetic fertilizers (M=3.47), indicating that farmers are influenced by the health and soil-conservation benefits of organic practices promoted through online platforms. This finding is consistent with Wang and Long (2025), who emphasized that digital platforms play a vital role in shifting farmers' attitudes toward environmentally friendly farming inputs.

On the other hand, moderate effects were observed in influencing farmers' decisions to adopt sustainable practices generally (M=3.17) and in the implementation of organic farming techniques (M=3.11). Although these values are above the threshold of effectiveness, they are relatively lower compared to other practices. This implies that while social media contributes positively, other factors such as the cost of adoption, the availability of inputs, and farmers' risk perception may affect the full implementation of organic farming methods. Furthermore, crop rotation and diversification (M=3.39) also emerged as a moderately effective practice adopted through social media influence. This indicates that while farmers are aware of the benefits of diversification for soil fertility and pest control, its implementation may require additional resources and technical guidance beyond online information. This observation supports the findings of (Voss *et al.* 2016), who highlighted that ICT tools enhance awareness but often need to be complemented with practical extension services for adoption to be sustained.

Table 6: Effect of social media on the adoption of sustainable agricultural practice

Social media and the adoption of sustainable agricultural practice	Mean	Std. Dev.
Biological pest control methods after learning.	3.75	0.87
Encouraged me to engage in agroforestry or afforestation.	3.67	0.86
Adopted better irrigation techniques due to the information shared.	3.64	0.82
Encouraged me to use organic fertilizers instead of synthetic ones	3.47	0.78
Crop rotation and diversification based on information	3.39	1.02
Influenced my decision to adopt sustainable farming practices.	3.17	1.08
implemented organic farming techniques after learning	3.11	1.09

Source: Field Survey, 2025.

*Mean $\leq$ 3.0 = Less Effective*Mean $\geq$ 3.0 = High Effective

Constraints Faced in Using Social Media for Agricultural Education

Table 7 presents the constraints faced by extension workers in the use of social media for agricultural education. Using a decision rule of mean $\geq$ 3.0, indicating high constraint, the findings reveal that all the listed factors were considered major barriers, although with varying degrees of severity. The most critical constraints identified were limited access to smartphones or digital devices among farmers (M=4.13), high cost of internet data (M=4.11), and poor internet connectivity in rural areas (M=4.06). These findings suggest that infrastructural and economic limitations significantly hinder the adoption of social media for agricultural education. This aligns with earlier studies (Bindawa, 2024; Ik-Ugwoezuonu, 2024), which reported that inadequate access to ICT tools and high data costs remain persistent challenges in rural agricultural extension systems across sub-Saharan Africa.

Similarly, frequent power outages (M=4.05) emerged as another notable impediment. Constraints related to technical capacity and institutional support also featured prominently. For instance, lack of training on social media use for farmer education (M=3.90), limited technical support (M=3.87), and absence of clear policies on social media in extension services (M=3.89) were all reported as high constraints. Furthermore, challenges associated with content creation and dissemination were also highlighted. Respondents indicated difficulties in verifying the credibility of agricultural information (M=3.80), creating simple and understandable content (M=3.81), and low skills in developing engaging content (M=3.59). On the socio-cultural side, farmers' preference for face-to-face interaction (M=3.69), low digital literacy (M=3.52), and language barriers (M=3.58) also constrained adoption. These findings suggest that while social media offers opportunities for broader outreach, traditional communication methods still dominate farmers' learning preferences. This is in line with the work of Adedoyin (2020), who noted that farmers in rural areas often perceive interpersonal communication as more trustworthy and accessible than digital alternatives.

Chi-Square Relationship Between Socio-Economic Characteristics and competence of extension workers in educating farmers on sustainable agricultural practices

Table 8 presents the Chi-square analysis showing the association between socio-economic characteristics and the competence of extension workers in educating farmers on sustainable agricultural practices. The results reveal that while some socio-economic characteristics significantly influenced competence, others did not. The result indicates that sex was not significantly associated with competence in educating farmers ($\chi^2=0.250$, $p=0.617$). This suggests that both male and female extension workers displayed similar levels of competence in farmer education. Gender, therefore, does not appear to determine the effectiveness of extension delivery. This finding aligns with the observations of Umar *et al.* (2017), who reported that professional competence in extension work is more closely related to training and skills than to gender.

Age, on the other hand, showed a highly significant association with competence ($\chi^2=39.969$, $p<0.01$). This indicates that competence varies with age, with older extension officers likely benefiting from maturity, greater exposure, and accumulated knowledge. Farmers may also perceive older agents as more credible, which enhances their effectiveness in farmer education. This finding agrees with Olorunfemi *et al.* (2018), who found that age positively influences extension service competence. Also, Marital status was significantly associated with competence ($\chi^2=118.27$, $p<0.01$). Married extension workers may have higher levels of social responsibility, stability, and commitment, all of which could enhance their effectiveness in educating farmers.

This finding supports Fawole and Ogunbowale (2016), who emphasized that family responsibilities often influence the level of dedication to professional duties.

The result further shows that religion was significantly associated with competence ($\chi^2=9.000$, $p<0.01$). This suggests that religious orientation may shape values, discipline, and work ethics, which in turn influence competence. Religious identification may also strengthen extension workers' acceptance within farming communities. This corroborates the findings of Chu *et al.* (2025), who reported that shared religious values can enhance trust between extension agents and rural communities. Educational qualification had a strong, significant association with competence ($\chi^2=54.406$, $p<0.01$). This underscores the role of formal education in equipping extension workers with the technical knowledge, analytical skills, and communication abilities needed for farmer education on sustainable practices. This finding is in line with Olorunfemi *et al.* (2018), who observed that higher educational attainment positively affects competence in extension delivery.

However, years of experience as an extension worker did not show a significant association with competence ($\chi^2=1.563$, $p=0.211$). This suggests that longer years of service do not necessarily guarantee greater competence. Competence may be more dependent on continuous professional development, refresher training, and exposure to modern agricultural innovations than on mere length of service. This is consistent with Umar *et al.* (2017), who noted that professional competence requires ongoing capacity building. In addition, the area of degree specialization was significantly related to competence ($\chi^2=22.500$, $p<0.01$). Extension workers whose specialization is agriculture or related fields were more competent in educating farmers compared to those from unrelated disciplines. This finding corroborates Anthonia *et al.* (2024), who reported that the field relevance of academic training enhances competence in extension service delivery.

Finally, Monthly income/salary also showed a significant association with competence ($\chi^2=33.031$, $p<0.01$). This indicates that adequate remuneration plays a role in motivating extension workers to perform effectively. Workers with higher or more stable salaries are likely to devote greater commitment and energy to their responsibilities. This finding is consistent with Saepudin *et al.* (2023), who highlighted that financial motivation strongly influences employee competence. Primary source of income was significantly associated with competence ($\chi^2=110.656$, $p<0.01$). Extension workers who rely primarily on their extension jobs for livelihood are more competent in educating farmers, compared to those who rely on secondary sources of income. This suggests that economic dependence on extension work fosters greater commitment and professional delivery. This supports Uka and Prendi (2021), who found that job dedication improves when workers rely mainly on their primary occupation.

Table 8: Relationship of Chi-square showing the association between Socio-economic characteristics and competence of extension workers in educating farmers on sustainable agricultural practices.

Variable	X ² Value	df	Sig.
Sex	0.250	1	0.617
Age (in years)	39.969	2	0.000
Marital Status	118.27	3	0.000
Religion	9.000	1	0.003
Educational Qualification	54.406	2	0.000
Years of Experience as an Extension Worker	1.563	1	0.211
Area of degree specialization	22.500	7	0.002
Monthly Income/Salary	33.031	2	0.000
Primary Source of Income	110.656	2	0.000

Source: Field Survey, 2025

Social media use and the competence of extension workers in educating farmers on sustainable agricultural practices.

The results in Table 9 reveal that WhatsApp use ($\beta=0.285$, $p=0.055$) showed a positive effect on competence and approached statistical significance at the 10% level, indicating that extension workers who actively use WhatsApp may demonstrate slightly higher competence in educating farmers. This can be attributed to WhatsApp's interactive features, including group messaging, voice notes, video sharing, and document dissemination, which facilitate effective communication and knowledge transfer. Similar observations were reported by Balaji and Kavaskar (2024), who noted that WhatsApp is widely used in agricultural extension to maintain real-time contact with farmers. Other platforms, such as LinkedIn ($\beta = 0.205$, $p = 0.160$) and TikTok

($\beta=0.187$, $p=0.220$), showed positive but non-significant relationships, suggesting a potential contribution to competence that is not statistically confirmed. LinkedIn may enhance professional networking and information exchange, while TikTok offers a platform for short, visual educational content.

Several platforms showed negative or negligible relationships with competence, including Messenger ($\beta=-0.052$, $p=0.712$), Twitter/X ($\beta=-0.213$, $p=0.178$), Instagram ($\beta=-0.136$, $p=0.408$), Telegram ($\beta=0.009$, $p=0.957$), YouTube ($\beta=0.042$, $p=0.796$), and Pinterest ($\beta=0.119$, $p=0.368$). These results suggest that these platforms currently do not significantly influence competence, possibly because they are used more for social interaction than professional extension purposes, or due to limited adoption by extension workers in the study area. The regression model yielded an R value of 0.428 and an R^2 of 0.183, indicating that approximately 18.3% of the variation in competence can be explained by the combined use of social media platforms. This suggests that while social media contributes to competence, a large portion (81.7%) of variance is explained by other factors, such as experience, training, or socio-economic characteristics. Based on the results, the null hypothesis stating that “social media use has no significant influence on the competence of extension workers in educating farmers on sustainable agricultural practices” is accepted at the 5% significance level. Although WhatsApp shows a marginal effect, the overall influence of social media use on competence is not statistically significant in this study.

Table 9: The influence of social media use on the competence of extension in educating farmers on sustainable agricultural practices

Variable	Std. Error	Beta		t	Sig
(Constant)	-0.157	0.48		-0.327	0.745
LinkedIn	0.567	0.397	0.205	1.427	0.160
WhatsApp	0.79	0.402	0.285	1.966	0.055
Telegram	0.009	0.163	0.009	0.054	0.957
Messenger	-0.094	0.253	-0.052	-0.371	0.712
YouTube	0.048	0.183	0.042	0.26	0.796
TikTok	0.198	0.159	0.187	1.242	0.220
Twitter/X	-0.282	0.207	-0.213	-1.367	0.178
Instagram	-0.132	0.158	-0.136	-0.834	0.408
Pinterest	0.461	0.508	0.119	0.908	0.368

Significant; * $p<.05$, $R = 0.428$, $R^2 = 0.183$, Adj. $R^2 = 0.23$, Std. Error of the Estimate = 0.831

CONCLUSION

The incorporation of social media into agricultural extension services in Ondo State has demonstrated promising outcomes in boosting the spread of sustainable farming practices. The platforms not only enable real-time communication but also facilitate peer-to-peer learning and community development, which are vital in rural areas where traditional extension approaches are limited. The ability of extension officers to harness social media for both educational and engagement objectives is a crucial advance in boosting agricultural productivity and environmental sustainability. However, the usefulness of social media in educating farmers is hampered by various problems, including digital gaps, low technical skills among extension agents, and the need for more reliable and validated agricultural content. Addressing these hurdles is vital to fully harness the promise of social media in agricultural education.

Recommendations

Programmes should be designed to promote the digital literacy of both farmers and extension officers. This involves training in fundamental digital skills and more advanced social media tactics to guarantee that both groups can effectively participate on the platforms.

- There is a need for increased internet connectivity in rural regions to ensure that farmers have reliable access to social media platforms. Partnerships with telecommunications firms and government agencies could assist in addressing these infrastructural gaps.
- Given the importance of visual content in boosting learning, extension services should focus on generating more video-based educational resources. These resources should cover a variety of sustainable farming approaches and should be provided in local languages for better accessibility.
- To counteract disinformation, methods should be put in place to verify the reliability of agricultural information posted on social media. Extension personnel could play a vital role in selecting accurate knowledge and ensuring that it is shared with farmers.

- Social media efforts should be designed to target different groups of farmers, with specific techniques for younger, tech-savvy farmers who engage more readily with platforms like Instagram and Twitter. Additionally, the involvement of farmers in content production and knowledge sharing can boost the sense of ownership and encourage increased participation.
- Policymakers should examine the incorporation of social media as a formal tool in agricultural extension initiatives. This could involve defining standards and protocols for the use of digital platforms in agriculture education, as well as giving financial support for the spread of social media activities.

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EFFECTS OF QUARRYING ACTIVITIES ON SOIL MINERAL NUTRIENTS AND HEAVY METALS.

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ABSTRACT

Quarrying and stone crushing activities like the other anthropogenic activities are globally considered as economically essential because of the daily uses of the crushed stones in building of houses, construction of roads and bridges. This study was carried out to examine the effects of quarrying activities on soil mineral composition and heavy metals of soil from quarry site and non-quarry site. Soil samples were randomly collected at a depth of 0-15cm, 15-30cm and 30-45cm and replicated three times. The results of the study indicated that quarrying activity causes considerable degradation of soil fertility characteristics. It was observed that macro nutrients (N, K, Ca and Mg) of the soil samples obtained from the quarry site were significantly ($P < 0.05$) higher than that of the control site although phosphorus was significantly low in the quarry site than the control site. In addition, concentrations of heavy metals such as cadmium (Cd), lead (Pb), arsenic (As), and chromium (Cr) were significantly elevated in quarry soils across all sampled depths. These findings suggest that quarrying activities enhance nutrient accumulation but also introduce potentially harmful levels of heavy metals, indicating both beneficial and detrimental impacts on surrounding soil environments.

Keywords: Quarrying, Soil fertility, Heavy metals, Soil nutrients, Environmental impact

INTRODUCTION

A quarry is a place where natural stone, gravel or sand is extracted for use in construction or other decorative building purposes (such as gravel paths or decorative garden aggregates). Quarries produce a wide variety of natural stone materials, including limestone, gypsum, marble, sandstone, slate and granite. Most quarries are man-made, so the process starts with geologists finding a place with a large supply of rocks beneath the earth's surface. Environmental hazards resulting from quarrying activities dates back to 1890's (Yu, 2007). The main issues of concern include visual impairments, damage to landscapes, traffic, smoke, noise, dust, damage to caves, loss of land and deterioration in water quality (John *et al.*, 2007). Quarrying activities causes significant impact on the environment. In particular, it is often necessary to blast rocks with explosives in order to extract material for processing but this method of extraction gives rise to noise pollution, air pollution, damage to biodiversity and habitat destruction (Okafor, 2006).

Soil is the most important component of the environment, but it is the most undervalued, misused and abused one of the earth's resources (Gokulakrishnan and Balamurugan, 2010). Soil contamination has become a serious problem in all industrialized areas of the country. Heavy metals are generally referred to as those metals which possess a specific density of more than 5 g/cm³ and adversely affect the environment and living organisms (Järup, 2003). They, without doubt, are important constituents for plants and humans, when present only in small amount. Some micronutrient elements may also be toxic to both animals and plants at high concentrations. For instance, copper (Cu), chromium (Cr), fluorine (F), molybdenum (Mo), nickel (Ni), selenium (Se) or zinc (Zn). Other trace elements such as arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb) are toxic even at small concentrations (Divrikli *et al.*, 2006). Heavy metals, being persistent and non-biodegradable, can neither be removed by normal cropping nor easily leached by rain water (Khadeeja *et al.*, 2013). They might be transported from soil to ground waters or may be taken up by plants, including agricultural crops. For this reason, the knowledge of metal plant interactions is also important for the safety of the environment (Divrikli *et al.*, 2006).

Materials and Methods

Study Area

The study was conducted in a quarry site located at Supare Akoko in Ondo State in Akoko South West, situated at Latitude 7° 48'N and Longitude 5° 75'E while the control site is located Adekunle Ajasin University, Akungba-Akoko research farm situated in Akungba Akoko, AAUA research farm is situated at

Latitude 70 23N and Longitude 50 00E. The soil samples collected from the quarry site was compared to soil samples collected from the non-quarry site.

Soil Sample Collection

Soil samples were collected from two locations: a quarry site at Supare Akoko East and a control site at the AAUA Research Farm. Sampling was conducted at three depths: 0–15 cm, 15–30 cm, and 30–45 cm, following standard soil sampling procedures. The collected samples were air-dried, homogenized, and passed through a 2 mm mesh sieve to obtain fine earth fractions. Processed samples were then stored in neatly labeled polythene bags for subsequent laboratory analysis.

Determination of heavy metals

1 g of soil sample was digested with aqua regia and 10% of Nitric acid was added and make up to 100ml with distil water. Weighing a 2.5 g of each soil sample pretreated was placed into 100 mL of beaker glass. A 5 mL of 0.1 M HCl in 0.025 M H₂SO₄ was added to the beaker and shaken on a shaker for 25 minutes. After shaking, the solutions were passed through a blue band filter paper and then the filtrates were taken into 10 mL of volumetric flasks by completing to the mark with distilled water. The determination of metals which are soluble in dilute acid mixture was performed by FAAS. A 15 mL aliquot of 1 M ammonium acetate solution (pH 7) was added to 1.5 g of soil sample in a 100 mL of beaker glass and then the mixture obtained was shake for 15 minutes. The suspension was filtered through a blue band filter paper and the filtrate was taken into a volume of 15 mL with some distilled water. The determinations of the exchangeable cations in a medium of 1 M CH₃COONH₄ were made by FAAS. A 10 mL of aqua regia was added to 1 g of soil sample in a beaker glass. The soil sample solution was evaporated to incipient dryness on a sand bath at 80°C. After adding a 5 mL of concentrated HClO₄ to each one, the solutions were heated again at 50°C. A second 10 mL of aqua regia was added to the samples and the solutions were evaporated near to dryness. The residue was dissolved with some dilute nitric acid and passed through the filter, and then completed with distilled water to 10 mL. The metal contents of these solutions were determined by FAAS. For the determinations of the elements Fe, Cu, Pb, Mn, Cd, Ar and Cr 100,400,1000 and 2000-fold dilutions were made, when required.

Statistical analysis

Data collected were subjected to one-way Analysis of Variance (ANOVA) at P<0.05 and significant means were separated using Tukey test.

RESULTS

Table 1 shows the effects of control and quarry mining site on soil macronutrients (Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg)) from the samples collected from the control and quarry site. It was observed that N from the quarry site was significantly (P<0.05) higher than that of the control in which P and Mg were significantly (P<0.05) lower in the quarry than the control. Meanwhile K and Ca were also observed to be significantly higher in the quarry site than the control

Table 1: Effects of control and quarry mining site on soil macronutrients

Site	N	P	K	Ca	Mg
Quarry	0.47a	14.63 b	1.21a	1.54a	1.10a
Control	0.23b	15.10a	1.14b	1.50 b	1.50 b

Table 2 presents the effect of soil depth on macronutrient concentrations. Nitrogen, calcium, and potassium were significantly higher (P<0.05) in the 0-15 cm depth, while magnesium and phosphorus were significantly lower at the 30-45 cm depth.

Table2: Effectsof depthon soil macronutrientlevels in control siti

Depth(cm)	N	P	K	Ca	Mg
0-15	0.38a	14.87 ab	1.22a	1.56a	0.82a
15-30	0.30a	14.62 ab	1.16ab	1.51ab	0.82a
30-45	0.27ab	15.08a	1.05b	1.41 b	0.75 b

Effects of Mining on Soil Micronutrients

Table 3 presents the influence of quarrying activities on soil micronutrient concentrations, comparing samples from the quarry and control sites. Results indicated that iron (Fe) and manganese (Mn) were

significantly higher ($P < 0.05$) in soils from the control site, whereas copper (Cu) was significantly elevated ($P < 0.05$) in soils from the quarry site.

Table 3: Effects of quarry mining on soil micronutrients

ite	Iron (Fe)	Copper (Cu)	Manganese (Mn)
Quarry	204.58b	41.36a	12.20b
Control	237.40a	13.57b	12.47a

Effects of Soil Depth on Quarry Site Soil Micronutrients

The effects of soil depth on micronutrient concentrations are shown in Table 4. It was observed that iron (Fe) and manganese (Mn) were significantly higher ($P < 0.05$) at the 0–15 cm depth, while copper (Cu) recorded significantly higher values ($P < 0.05$) at the 15–30 cm depth.

Table 4: Effects of depth on quarry site soil micronutrients

Depth (cm)	Iron (Fe)	Copper (Cu)	Manganese (Mn)
0 – 15	225.50a	27.47b	12.49a
15 – 30	213.50b	29.70a	12.23ab
30 – 45	223.95ab	25.24ab	12.29b

Interaction Effects of Site and Depth on Soil Heavy Metals

Table 5 presents the interaction effects of site and soil depth on heavy metal concentrations. Cadmium (Cd), lead (Pb), arsenic (As), and chromium (Cr) were significantly higher ($P < 0.05$) in soils from the quarry site at the 0–15 cm depth compared to those from the control site.

Table 5: Interaction effects of site and depth on soil heavy metals

ite	Depth (cm)	Cadmium (Cd)	Lead (Pb)	Arsenic (Ar)	Chromium (Cr)
Quarry	0-15	1.09a	20.95a	0.72a	1.75a
Control	0-15	0.80c	8.62b	0.38c	1.33bc
Quarry	15-30	1.06ab	17.40ab	0.63ab	1.61ab
Control	15-30	0.80c	7.53c	0.37c	1.29c
Quarry	30-45	1.04b	16.57b	0.52b	1.55b
Control	30-45	0.40d	7.53c	0.27d	1.25d

DISCUSSION

The laboratory analysis conducted during the present investigation indicated that quarrying activity causes considerable degradation of soil fertility characteristics. The soil around the quarry area in several cases are found to be affected considerably because of dust emission and deposition which affects soil texture and the pore size (Rani *et al.*, 2017). The damages caused due to surface mining are not confined to the immediate site only, but also spread over a vast area around the operation sites (Naik *et al.*, 2006).

Similarly, this study revealed higher macronutrient concentrations in soils collected from control sites compared to the quarry, indicating that quarrying has a significant effect ($P < 0.05$) on soil nutrient composition. The influence of quarry operations on soil quality can be attributed to residues from explosives and the deposition of crushed rock materials, which alter soil organic carbon and other physicochemical attributes (Naik *et al.*, 2006).

CONCLUSION

The findings of this study reveal low to moderate levels of micronutrient contamination across the ample locations, with iron (Fe) and manganese (Mn) being the most prominent contributors. Micronutrient concentrations declined with increasing distance from the quarry site. Similarly, this study confirmed that micronutrient levels in soils from quarry sites were significantly ($P < 0.05$) lower than those in control soils. These results demonstrate that quarrying activities exert a considerable influence on the availability and distribution of soil micronutrients.

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EFFECT OF SOIL TILLAGE AND IRRIGATION ON SOIL HYDRO-PHYSICAL PROPERTIES OF AN ALFISOL GROWN TO UPLAND RICE (*ORYZA SATIVA*) IN A TROPICAL CLIMATE

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ABSTRACT

Rice (*Oryza sativa* L.) is a staple food for a large share of the world's populace. This study evaluates the effect of tillage and drip irrigation frequency on soil hydro-physical properties of an Alfisol grown to upland rice. The experiment was a 2 x 3 factorial in a randomized complete block design, with arrangements in three replicates. The irrigation factor consisted of three levels of drip irrigation frequency: (I4) Irrigation four times a week, (I3) Irrigation three times a week, (I2) Irrigation two times a week, while the tillage factor was Conventional Tillage (CT) and No Tillage (NT). The effect of tillage was not significant on any of the soil hydro-physical properties in the 0-30 cm soil layers. Also, irrigation regimes had no significant effect on the soil physical properties at 0-10 cm and 10-20 cm soil layer, but had a significant effect 5% on the total porosity at the 20-30. The interaction effect between irrigation and tillage was significant only on bulk density at the 0-10cm soil layer, while there was a significant effect on the particle density at 10-20 cm and 20-30 cm soil layers. Conventional tillage recorded significantly higher bulk density. Tillage had no effect on the soil water content (SWC) of the two soil layers on both sampling dates, while drip irrigation frequency significantly influenced SWC in the 10 - 20 cm layer. Generally, SWC increased with depth, and treatment combination I3NT had the highest SWC in all cases. Soil particle density (Pd) had a positive and significant correlation with panicle length, while the correlation was negative and significant with water use efficiency (WUE).

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for a large share of the world's populace. Rice has become an increasingly important crop in many countries in the world, and extensively in tropical Africa. Nigeria is leading in the West Africa sub-region in terms of production and importation of rice and is the second largest importer of rice in the World after China. It was estimated that Nigeria imports rice of about 356 billion naira annually (Agwu, 2021). Rice growing ecologies in Nigeria include mangrove swamp, which contributes 4% to rice production in Nigeria, deep water (5%), irrigated lowland (16%), rainfed lowland (inland valleys; 48%), and rainfed upland (Mafo, 2022; Garbanzo *et al.*, 2024). Lamichhane *et al.* (2021) stated that the success or failure of any crop production system is a function of the seedbed environment. In rice-producing areas of southwest Nigeria, upland rice cultivation has been under slash-and-burn soil management without tillage. However, the continuous monocropping, alternate wetting and drying cycles, raindrop impacts, and uncontrolled human traffic have caused degradation of soil structure by compaction of the surface layer (Kassam *et al.*, 2014; Osman, 2018).

Several factors are hindering rice production/processing in Nigeria, which fail to meet the demand of the general public. In recent years, upland rice production in southwest Nigeria has been on a decrease as a result of inadequate rainfall, which is highly essential in rice production due to climate change. Rice production during the dry season is from lowland and valley bottoms, but production is very low due to limited land area. The continuous use of untilled, slash-and-burn land does not favour root growth and development, resulting in low production. Therefore, the combination of drip irrigation frequency and tillage could favour rice production. The general objective is to evaluate the effects of soil tillage and irrigation on soil hydro-physical properties of an Alfisol grown to upland rice (*Oryza sativa*) in a tropical climate in southwest Nigeria. The specific objectives are to evaluate; the effect of tillage on some soil hydro-physical properties of an alfisol grown to upland rice; the effect of drip irrigation frequency on some soil hydro-physical properties of an alfisol grown to upland rice; interaction effect of tillage and drip irrigation frequency on soil hydro-physical properties of an alfisol grown to upland rice and correlation between soil physical properties and rice yield under the different drip irrigation frequency and tillage.

MATERIALS AND METHODS

The field experiment was conducted at the Teaching and Research Farm of Ekiti State University, Ado-Ekiti,

Nigeria, situated in a humid tropical climate with an average annual rainfall of 1367 mm and a mean temperature ranging between 27–28°C. The soil at the site, classified as Kandipludalf, has a sandy-loam to clay texture and has been previously cultivated with crops like cassava, maize, yams, and cucumbers. The experiment was structured as a two-factor randomized complete block design (RCBD) with three replications. Treatments involved two tillage practices—Conventional Tillage (CT) and No Tillage (NT)—and three irrigation regimes of twice, thrice, and four times weekly, resulting in 18 treatment combinations. Each plot measured 3 m × 2 m, with poultry waste applied at 10 t/ha to CT plots, and a drip irrigation system delivering 4 L/hr was installed for water management. Rice (FARO 57 upland variety) was planted at 20 cm × 20 cm spacing with five to seven seeds per hill, and fertilizers (NPK, KNO₃, and foliar supplements) were applied at recommended rates. Weed control was done manually, and soil samples (disturbed and undisturbed) were collected from 0–30 cm depth for laboratory analysis of physical and chemical properties. Key soil evaluations included bulk density, particle density, total porosity, soil moisture, temperature monitoring, and saturated hydraulic conductivity using standard methods. Data obtained were analyzed using descriptive statistics and analysis of variance (ANOVA), with treatment means separated by least significant difference (LSD) at the 5% significance level in SAS (version 8.0).

RESULT AND DISCUSSION

During drip-irrigated rice cultivation, rainfall was insufficient to meet the evaporative demand of the atmosphere (ET_o) between December and March, exposing rice to potential water stress without supplemental irrigation. Similar observations were made by Farooq et al. (2011), who noted that inadequate rainfall and high evapotranspiration rates in tropical environments necessitate irrigation to sustain rice

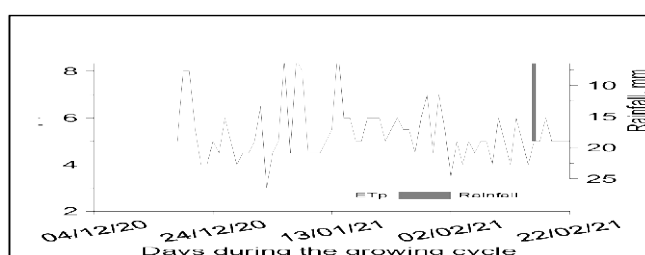


Figure 1: Temporal distribution of pan evaporation and rainfall during the rice growing cycle.

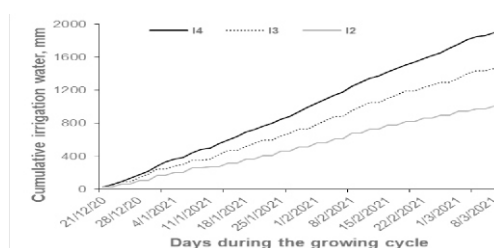


Figure 2. Cumulative irrigation water applied to the rice field under the different drip irrigation frequency

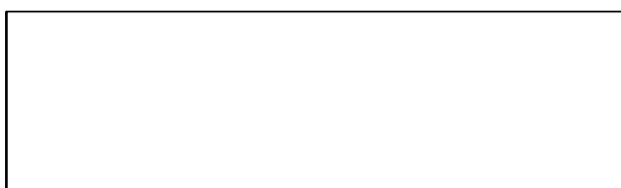


Figure 3: Temporal distribution of soil temperature of the 0-10 cm and 10-20cm

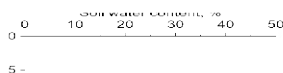


Figure 4: Interaction effect of drip irrigation frequency and tillage on soil water content of the 0-20 cm depth of the rice field.

Table 1: Effect of tillage and drip irrigation frequency of some soil physical properties of the 0 - 10 cm soil surface layer in the rice field at harvest

Tillage	Irrigation	PD -----g/cm ³ -----	BD -----g/cm ³ -----	Pt cm ³ /cm ³	Ksat -----cm/h-----	LOGKsat
CT	I4	2.41	1.43	0.41	52.40	1.71
	I3	2.34	1.40	0.40	56.05	1.67
	I2	2.25	1.36	0.39	36.30	1.55
CT _{Mean}		2.33	1.40	0.40	48.25	1.64
NT	I4	2.39	1.21	0.49	57.37	1.75
	I3	2.35	1.58	0.33	47.00	1.63
	I2	2.40	1.34	0.44	36.30	1.55
NT _{Mean}		2.38	1.38	0.42	46.89	1.64
Overall Mean		2.36	1.39	0.41	47.57	1.64
CV, %		2.2	7.4	11.1	16.8	4.3
Tillage Effect (p<0.05)		NS	NS	NS	NS	NS
Irrigation Effect (p<0.05)		NS	NS	NS	NS	NS
Irrigation x Tillage (p<0.05)		NS	S	NS	NS	NS

PD: particle density; BD: bulk density; Pt: total porosity; Ksat: saturated hydraulic conductivity; LOGKsat: logarithm transformed saturated hydraulic conductivity

Table 2: Effect of tillage and drip irrigation frequency on some soil physical properties of the 20 - 40 cm soil layer in the rice field at harvest.

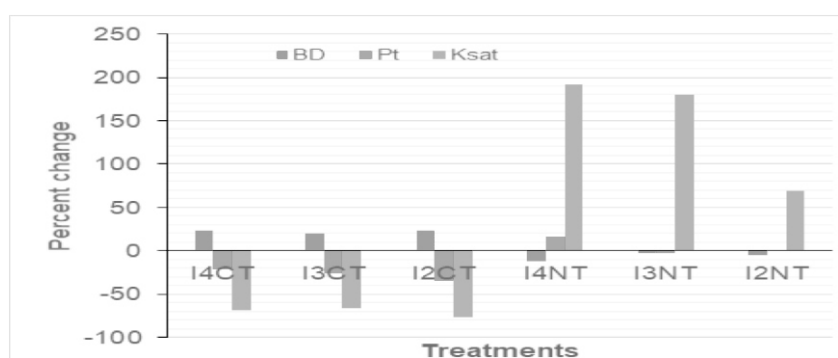
Tillage	Irrigation	PD -----g/cm ³ -----	BD -----g/cm ³ -----	Pt cm ³ /cm ³	Ksat -----cm/h-----	LOGKsat
CT	I4	2.67	1.59	0.40	30.47	1.48
	I3	2.41	1.45	0.39	37.63	1.46
	I2	2.19	1.58	0.28	31.93	1.48
CT _{Mean}		2.42	1.54	0.36	33.34	1.47
NT	I4	2.39	1.36	0.43	45.13	1.64
	I3	2.40	1.44	0.40	46.05	1.60
	I2	2.42	1.48	0.38	20.63	1.30
NT _{Mean}		2.40	1.43	0.40	37.27	1.51
Overall Mean		2.41	1.48	0.38	35.31	1.49
CV, %		5.4	5.4	11.9	23.3	6.8
Tillage Effect (p<0.05)		NS	NS	NS	NS	NS
Irrigation Effect (p<0.05)		NS	NS	NS	NS	NS
Irrigation x Tillage (p<0.05)		S	NS	NS	NS	NS

PD: particle density; BD: bulk density; Pt: total porosity; Ksat: saturated hydraulic conductivity; LOGKsat: logarithm transformed saturated hydraulic conductivity; I4: four irrigations per week; I3: three irrigations per week; I2: two irrigations per week; CT: conventional tillage; NT: no tillage; S: significant; NS: not significant at 5% level of probability by Duncan Multiple Range Test; CV: coefficient of variation

Table 3: Effect of tillage and drip irrigation frequency of some soil physical property of the 20- 30 cm soil layer in the rice field at harvest.

Tillage	Irrigation	PD -----g/cm ³ -----	BD -----g/cm ³ -----	Pt cm ³ /cm ³	Ksat -----cm/h-----	LOGKsat
CT	I4	2.45	1.44	0.41	38.23	1.55
	I3	2.30	1.47	0.36	39.63	1.56
	I2	2.31	1.51	0.34	21.67	1.33
CT _{Mean}		2.35	1.47	0.37	33.18	1.48
NT	I4	2.55	1.44	0.43	29.33	1.42
	I3	2.40	1.44	0.40	33.85	1.37
	I2	2.34	1.52	0.35	19.57	1.27
NT _{Mean}		2.43	1.47	0.39	27.58	1.35
Overall Mean		2.39	1.47	0.38	30.38	1.42
CV, %		3.5	2.1	8.2	23.9	7.5
Tillage Effect (p<0.05)		NS	NS	NS	NS	NS
Irrigation Effect (p<0.05)		NS	NS	S	NS	NS
Irrigation x Tillage (p<0.05)		S	NS	NS	NS	NS

PD: particle density; BD: bulk density; Pt: total porosity; Ksat: saturated hydraulic conductivity; LOGKsat: logarithm transformed saturated hydraulic conductivity I4: four irrigations per week; I3: three irrigations per week; I2: two irrigations per week; CT: conventional tillage; NT: no tillage. S: significant; NS: not significant at 5% level probability by Duncan Multiple Range Test. CV: coefficient of variation

**Figure 5. Changes in soil bulk density (BD), total porosity (Pt), and saturated hydraulic****Table 4. Pearson correlation of soil physical properties versus rice yield, yield components, and water use efficiency.**

	Pd	BD	Pt	Ksat	P. Lngth	P. Wt	1000-Grain	Yield	WUE
Pd	1	-0.034	0.555 **	0.150	0.331 *	0.213	-0.067	-0.233	-0.510 **
BD		1.000	-0.847 **	-0.248	0.042	0.228	0.109	0.156	0.188
Pt			1.000	0.282 *	0.178	-0.037	-0.123	-0.270 *	-0.445 **
Ksat				1.000	0.187	0.067	0.127	0.046	-0.127
P. Lngth					1.000	-0.803 **	0.137	0.134	-0.162
P. Wt						1.000	0.235	-0.073	-0.217
1000-wt							1.000	0.278 *	0.060
Yield								1.000	0.813 **
WUE									1.000
N	54	54	54	54	54	54	54	54	54

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

productivity. Irrigation application varied with frequency, with four irrigations per week reaching about 2,000 mm, and the lowest being 850 mm at two irrigations per week. These values were lower than sprinkler irrigation requirements reported in previous studies but higher than average water needs in Malaysia, indicating substantial water demand under local conditions. Bouman and Tuong (2001) reported that water use in upland rice systems varies significantly with climatic and soil conditions. Soil temperature dynamics revealed no significant differences among treatments during the first 25 days after planting (DAP).

However, no-tillage plots generally maintained higher temperatures than conventional tillage in both the 0–10 cm and 10–20 cm layers, in the evening. Beyond 28 DAP, temperature patterns stabilized, but reduced irrigation depth was associated with higher soil temperatures. Lampurlanés and Cantero-Martínez (2003) found that soil temperature under no-till conditions tends to be higher due to reduced soil disturbance. Soil water content (SWC) was unaffected by tillage but was significantly influenced by irrigation frequency, particularly at 10–20 cm depth, with I3NT (thrice-weekly irrigation under no-tillage) maintaining the highest SWC. Soil physical properties showed limited response to tillage and irrigation frequency within the short study period. Bulk density (BD) was generally higher in tilled plots, while porosity (Pt) and saturated hydraulic conductivity (Ksat) were greater in no-till treatments. Over time, tilled soils tended to reconsolidate, increasing BD and reducing porosity, whereas no-till treatments improved pore continuity and Ksat. These findings corroborate Lal (1993), who reported that no-tillage enhances soil structure, hydraulic conductivity, and water retention compared to conventional tillage. At harvest, BD increased in tilled plots, while Pt and Ksat improved under no-tillage, highlighting the resilience of undisturbed soil. Correlation analysis revealed that soil particle density positively influenced panicle length but reduced water use efficiency (WUE), while porosity negatively correlated with both yield and WUE. Zhang et al. (2009) observed that soil porosity and particle arrangement influence root growth and yield performance in rice systems. Correlation analysis revealed that soil particle density positively influenced panicle length but reduced water use efficiency (WUE), while porosity negatively correlated with both yield and WUE.

CONCLUSION

The study revealed that tillage had little effect on soil hydro-physical properties, while irrigation frequency significantly influenced total porosity at 20–30 cm. Interaction effects were noted on bulk density at 0–10 cm and particle density at deeper layers. Conventional tillage showed higher bulk density due to porosity. Soil water content (SWC) was unaffected by tillage but increased with irrigation frequency at 10–20 cm and with depth overall. The no-tillage with thrice-weekly irrigation (I3NT) treatment yielded the highest SWC.

Recommendation

It is therefore recommended that rice cultivation in the region during the dry season be carried out under conventional tillage with three irrigation applications per week to optimize soil conditions and water use efficiency.

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IMPACT OF SELECTIVE AND NON-SELECTIVE HERBICIDES ON THE PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF SOILS IN THE RHIZOSPHERE OF MAIZE (*zea mays L.*)

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ABSTRACT

The widespread dependence on agrochemicals for weed management raises critical concerns regarding the health and stability of soil microbiome and its physicochemical properties. This study evaluated the comparative impact of selective and non-selective herbicides on the physical, chemical, and biological properties of soil within the rhizosphere of maize (*Zea mays L.*). A pot experiment was conducted in a screen house using a Completely Randomized Design (CRD) with three treatments replicated three times: T1 (Control/no application), T2 (Selective herbicide - butachlor), and T3 (Non-selective herbicide - paraquat). The herbicide treatments were applied at the recommended rate of application. Soil samples were collected and analyzed at 5, 14, and 21 days after treatment (DAT) to monitor changes in rhizosphere bacteria and fungi population, physical and chemical properties. The results revealed that herbicide application induced changes in soil properties compared to the control. The non-selective herbicide (T3 - Paraquat) exerted more negative effect on soil physical, chemical and biological. Non-selective herbicide (T2 – butachlor) had a positive influence on the growth of soil microorganisms than Non-selective herbicide (T3 – paraquat). The control soil had a steady increase in Bacteria and fungi population. The changes induced by the treatments were not significantly different at ($P < 0.05$). Some of the organisms present in the soil include; *Azospirillum niger*, *Penicillium notetum*, *Mucor mucedo*, *Aspergillus flavus*, *Bacillus subtilis*, *pseudomonas aeruginosa*, *Micrococcus leteus*, *staphylococcus albus*.

Key words: Selective Herbicide, non-selective herbicide, Soil Microbiology, Soil Chemical properties, Maize Rhizosphere.

INTRODUCTION

Maize (*Zea mays L.*) stands as one of the most critical cereal crops globally, serving as a cornerstone for food security, livestock feed, and industrial raw materials. However, the productivity of maize is persistently threatened by pest infestation, with weed infestation being a primary pest in maize production. In Nigeria, Akobudun, (2000) recorded yield loss in maize production ranging from 51% to 90% due to weed competition. Similarly, Chikoye, (2002) reported maize yield loss ranging from 50% to 90% in central and West Africa. To mitigate these losses and ensure food sufficiency, modern agriculture has become increasingly reliant on chemical weed control methods. While effective, the extensive application of herbicides has raised significant environmental concerns regarding their non-target effects on biotic and edaphic environment (Bacmaga, M., 2024), particularly within the maize rhizosphere (the biologically active zone of soil immediately surrounding the roots).

Herbicides are broadly categorized based on their mode of action and selectivity. Selective herbicides, such as atrazine and butachlor, are formulated to target specific weed species while leaving the maize crop unharmed. Non-selective herbicides, including glyphosate and paraquat, are broad-spectrum agents designed to eliminate all vegetation it comes across (Paul, 2024).

The soil physicochemical properties form the structural and nutritional foundation for crop growth. Research indicates that herbicide application can alter soil pH, cation exchange capacity (CEC), and organic matter content. For instance, certain triazine herbicides have been linked to temporary acidification of the rhizosphere, which can subsequently affect the bioavailability of essential macronutrients like nitrogen and phosphorus. Physically, while herbicides reduce tillage needs—thereby preserving soil structure, they may indirectly affect soil temperature and moisture retention by altering the vegetative cover and surface residue dynamics (Eze *et al.*, 2019). The biological properties of soil serve as sensitive indicators of ecosystem health (Bhaduri *et al.*, 2022). The rhizosphere is a hotspot of microbial activity, hosting complex communities of bacteria, fungi, and actinomycetes that drive nutrient cycling and organic matter decomposition. The introduction of synthetic chemicals into this delicate microenvironment can disrupt microbial equilibrium.

Understanding the differential impacts of selective versus non-selective herbicides is crucial for developing sustainable agricultural practices. While immediate weed control is necessary for yield protection, it must not

come at the cost of soil degradation. While there is abundant literature on individual herbicides (e.g., studies solely on Atrazine or solely on Glyphosate), there is a scarcity of research that simultaneously compares the impact of selective and non-selective herbicides under the same experimental conditions (same soil type, same climate, same maize variety). This knowledge gap makes it difficult to definitively say which class of herbicide is "safer" or more detrimental to soil health because they are usually studied in isolation.

MATERIALS AND METHODS

The site for soil sample collection was a maize field located at Ekosodin community near the University of Benin, Benin City Edo State (geographical location lies between latitude 6°24'33" N, longitude 5°37'13" E and latitude 6°23'39" N, longitude 5°38'15" E, with an altitude of 149.4m) with no prior herbicide treatment. The district falls within the humid tropical climate and the rainforest zone of Nigeria with an average annual rainfall of 1900 mm and average annual temperature of 27°C (NIFOR, 2013), the region has two major seasons; dry (November – March) and wet (April to October) (Molindo and Nwachokor, 2010).

Soil samples were collected from the rhizosphere of maize plants. Each plant was carefully uprooted and the soil attached to the root was collected by shaking off the soil from the root into a sampling bag. 10 cm of soil around the uprooted plant was also collected into the sampling bag. This process continued until a soil weight of 45 kg of soil was obtained, which was fed into nine experimental pots containing 5 kg of soil each.

Solution of paraquat was prepared using the manufacturer's recommended application rate of 1.5 liters of the chemical diluted in 50 liters of water for 1 hectare of land, and the solution of butachlor was also prepared using the company recommended application rate of 1 liter of the chemical to 100 liters of water for 0.4 hectare of land. Knowing that 1 hectare of land contains approximately 2,000,000kg of soil (FAO, 2006), the dilution ratio was converted for application unto a 5kg soil pot. The conversion gave a volume of 0.004 ml paraquat which was diluted in 0.12 ml of water, and 0.006 ml of the butachlor which was diluted in 0.6 ml of water.

The diluted solutions of paraquat and butachlor were sprayed into separate research pots containing 5 kg of maize rhizosphere soil and each treatment were replicated three times, whereas, the controlled pots received none of these solutions. This finally led to a total of nine experimental pots that were laid out in a completely randomized design. Before application of herbicide, the physical, chemical and biological properties of the soil were determined. The physical chemical and biological properties of the soil were also determined on the 5th day, 14th day, and 21st day after applying the herbicides to the soil samples. Data were subjected to analysis of variance (ANOVA) and means were separated using Duncan's Multiple Range Test (DMRT) at $P < 0.05$.

RESULTS AND DISCUSSION

Physical and chemical analysis of soil before and after treatment.

The result reveals that the soil texture before treatment had a proportion of sand silt and clay fraction (88.70 %, 5.90 % and 5.40 % respectively). This is classified as a sandy soil using texture triangle. The initial pH of the soil was 6.60 which was near neutral. The rhizosphere soil also had an organic carbon content (2.37 %) that was very low <4% (Lal 2007). The soil had a total nitrogen content of 0.12 %, the cation exchange capacity (CEC) of 1.67cmolkg⁻¹ which indicates a very low cation exchange capacity of the soil due to the soil texture. The available phosphorus in the soil was 8.30 mgkg⁻¹ which suggests that the availability of phosphorus to the crop was low (Youssef and Chino 1988). Whereas in Table 1, the result suggests a more acidic condition for the control as the number of days increased. The pH was observed to gradually reduce from 6.45 in day 5, to 6.41 and 6.27 in day 14 and 21 respectively. However, the results were not significantly different ($P < 0.05$) from those of selective herbicide (T_2 : 6.50 – 6.55) and non-selective herbicide (T_3 : 6.53 – 6.64).

This finding aligns with the work of Bera, (2013). The selective and non-selective herbicides (T_2 and T_3) had positive effects on the amount of organic carbon. It was observed that soil with T_3 had the highest amount of organic carbon, whereas, the amount seem to reduce with time of days in the control (C) and with the application of the selective herbicides (T_2), the high amount of organic carbon in the T_3 could be due to the

Table 1: Effect of treatment on soil Physical, chemical and biological properties.

Treatment	pH (1:1)	%O.C	%T.N	Av.P mgkg ⁻¹	Ca Cmolkg ⁻¹	Mg Cmolkg ⁻¹	Na Cmolkg ⁻¹	K Cmolkg ⁻¹	H ⁺ Cmolkg ⁻¹	Sand gkg ⁻¹	Silt gkg ⁻¹	Clay gkg ⁻¹	Bacteria CFUg ⁻¹	Fungi CFUg ⁻¹
T ₁	6.38a	18.15a	3.70a	8.25a	2.17a	0.48a	0.18a	0.58a	0.06a	884.10a	59.11b	56.00a	25010.00a	6526.67a
T ₂	6.55b	19.35a	3.98a	18.39a	1.90a	0.57a	0.22a	0.84a	0.13a	885.63a	55.89a	58.89a	28633.33a	15333.33b
T ₃	6.63b	29.50a	4.00a	17.49a	2.43a	0.69a	0.28a	0.96a	0.04a	887.53a	54.67a	58.00a	30685.67a	6723.33a

❖ Columns with similar superscripts are not significantly different ($P > 0.1$)
❖ T₁ = control, T₂ = (selective herbicide), T₃ = (non-selective herbicide)

chemicals ability to kill all forms of weed that will hence, result in higher amount of organic material readily available for decomposition and mineralization (Mayeetreyee *et al.*, 2013). Total nitrogen in the soil was not significantly affected by the application of both herbicides (T₂ and T₃). While an increase in the available phosphorus over time was observed. T₂ (selective herbicides) recorded the highest amount of phosphorus 10.44 – 25.17 mgkg⁻¹.

This result is suspected to be due to the selective nature of the chemical which certainly is only targeted towards a particular kind of plant thus allowing for growth of more soil microbe than the non-selective treatment that had a negative effect on the abundance of soil organisms. Hence, limiting the organisms that are responsible for decomposition and mineralization of organic matter. Calcium content in the soil was observed to increase with time of application and T₃ had the highest Ca²⁺ content from 5th – 21st day after treatment (1.29 – 3.02 cmolkg⁻¹). A similar trend was also observed for K (potassium) content which ranged from 0.26 – 0.33 cmolkg⁻¹ in the control, to 0.32 – 1.18 and 0.62 – 1.22 cmolkg⁻¹ in T₂ and T₃ respectively. Although these values were not significantly different at 5 % level of probability, the highest amount was found with the soil treated with the non-selective (T₃) herbicide. On the other hand, the application of T₂ and T₃ had no significant effect on the soil texture. This result agrees with the findings of Bera *et al.*, (2013).

Effect of selective and non-selective herbicides on soil microbial population.

The population of soil microbes (bacteria and fungi) are presented in Fig 1 and 2. The control soil had a gradual growth in fungal population with increase in time, while T₂ and T₃ soils experienced a reduction in the microbial abundance over time. It was observed that the selective herbicide (T₂) had a positive effect on fungal population, with the peak of the population at the 5th day after treatment, while the non-selective herbicide (T₃) had a negative effect on fungal population (Fig 2). This result does not tally with the research of Mayeetreyee *et al* (2013) which revealed that selective and non-selective herbicides had negative effect on soil fungal population. T₂ and T₃ soils experienced an initial increase in bacterial population, but over time (14 days after treatment) the bacterial population experienced a drastic reduction, and then recovered gradually over a longer period of time (21 days after treatment). The sudden decrease in population may be due to the sudden change in the soil environment which had resulted from the application of the herbicides, but as more organic material for decomposition was made available by the action of the herbicide on weed, the bacterial population gradually increased. The change in bacteria population of T₂ and T₃ was not significantly different ($P > 0.05$) from the control. However, this result contradicts the research of Mayeetreyee *et al* (2013), whose investigations revealed that bacterial population are adversely affected by herbicides.

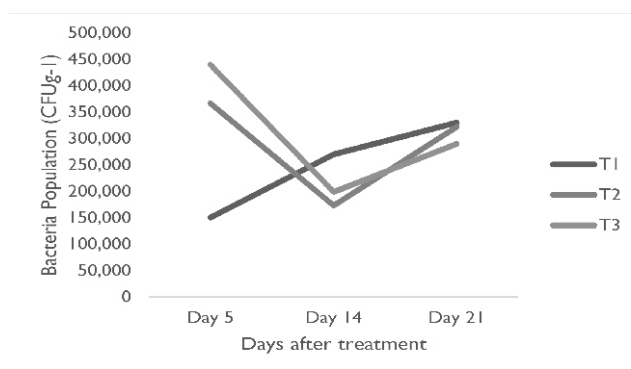


Fig. 1 Bacterial population on different days after treatment
T₁: control, T₂: Selective Herbicide, T₃: Non-Selective Herbicide

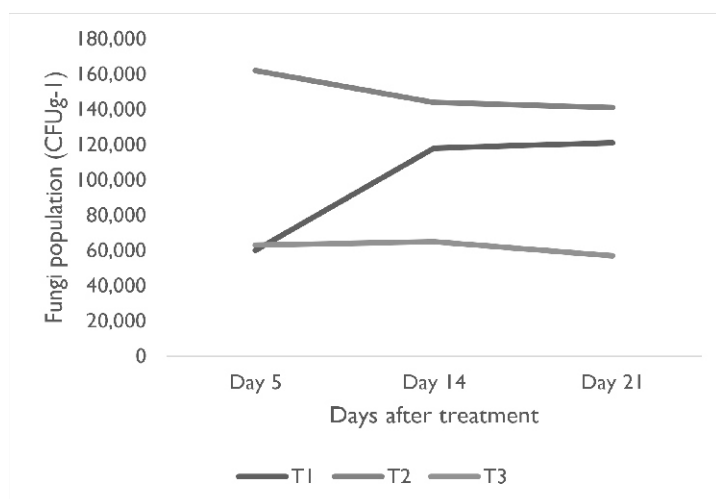


Figure 2 Fungal population on different days after treatment
T1: control, T2: Selective Herbicide, T3: Non-Selective Herbicide

CONCLUSION

The use of synthetic herbicide has been greatly adopted by many farmers for the control of weeds. But these chemicals do not only affect their target organisms, but also alters physical, chemical and biological processes in the soil. This research compared the impact of selective and non-selective herbicide on the physical, chemical and biological properties of soil in the rhizosphere of maize, and revealed that non-selective herbicide has more negative impact on the biological, physical and chemical properties of soil in maize rhizosphere than selective herbicide. Non-selective herbicide significantly increased the fungal population and all other parameters analyzed in this research remained significantly unaffected at 5% level of probability by the treatments applied. For sustainable agricultural practice and soil health, farmers should ensure that they adhere to the manufacturer's recommended rate of herbicide application when using herbicides.

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SHORT-TERM EFFECTS OF COCOA POD HUSK BIOCHAR ON SELECTED SOIL PHYSICAL PROPERTIES, TOMATO PERFORMANCE AND FRUIT NUTRITIONAL QUALITY

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ABSTRACT

A screen house experiment was conducted to evaluate the effects of cocoa pod husk biochar (CPHB) on selected soil physical properties, growth, yield, and fruit nutrient composition of tomato (*Solanum lycopersicum* L.). Five biochar application rates: 0, 10, 20, 30, and 40 t ha⁻¹, were laid out in a completely randomized design (CRD) with three replications. Surface soil (0-15 cm depth) of sandy loam texture was collected from the Teaching and Research Farm of Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria. Each 10 kg soil sample was thoroughly mixed with the designated biochar rate, moistened to field capacity, and incubated for eight weeks in the screen house before transplanting tomato seedlings. Results showed that CPHB significantly improved soil physical properties by reducing bulk density and enhancing porosity, moisture retention, and temperature regulation. Chemical properties were also markedly increased. Tomato growth parameters (plant height, stem girth, leaf number) and fruit weight improved consistently with increasing CPHB rates, with the highest performance recorded at 30 t ha⁻¹. Fruit mineral composition (P, K, Ca, Mg, Fe, Zn, and Cu) was also enhanced at 30 t ha⁻¹ but declined slightly at 40 t ha⁻¹, indicating possible nutrient antagonism or salt stress at higher rates. Overall, the findings demonstrate that CPHB is a promising soil amendment for improving structure, fertility, tomato productivity, and fruit nutritional quality in sandy loam soils. Field validation is recommended to confirm its effectiveness under open-field conditions.

Keywords: Cocoa pod husk biochar, fruit nutrients, soil properties, sandy loam soil, tomato

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is among the most widely cultivated vegetables worldwide, valued for both economic and nutritional importance. It is consumed fresh or processed into pastes, sauces, juices, and soups, and serves as a major dietary source of vitamins A and C, minerals, fiber, and the antioxidant lycopene, which has been linked to reduced risks of chronic diseases such as cancer and cardiovascular disorders (Dorais *et al.*, 2008). In Nigeria, tomato plays a central role in daily diets and local markets, with annual production estimated at over 1.5 million tonnes. However, supply still falls short of demand due to soil fertility decline, pest infestation, and unsustainable fertilizer practices (Lal, 2020). Soils in the forest-savanna transition zone of Nigeria are predominantly sandy loam, acidic, and low in organic matter and nutrients, limiting crop productivity (Agbede and Oyewumi, 2022). Dependence on mineral fertilizers has boosted yields temporarily but has also caused soil degradation, nutrient imbalance, and reduced biological activity (FAO, 2002). These limitations highlight the need for sustainable management practices that restore soil fertility while maintaining high yields and quality produce. Biochar, a carbon-rich material from the pyrolysis of organic residues under limited oxygen, is increasingly recognized as a potential soil amendment. Its high porosity, surface area, alkaline pH, and stable organic carbon provide multiple agronomic benefits.

Studies have shown that biochar reduces soil bulk density, enhances water retention, increases cation exchange capacity, and improves nutrient availability (Lehmann and Joseph, 2015). It also buffers acidity, minimizes nutrient leaching, and supports microbial activity, thereby promoting crop growth (Agegnehu *et al.*, 2017). Feedstock type and application rate largely determine biochar's effectiveness. Cocoa pod husk, an abundant agro-waste in Nigeria's cocoa-producing regions, is particularly rich in potassium, calcium, and magnesium. When converted to biochar, it offers a low-cost, eco-friendly option for soil improvement. Beyond yield effects, biochar may influence the nutritional composition of fruits, which is critical for human health. However, results remain inconsistent, with reports ranging from positive impacts to negligible or negative outcomes depending on soil type and application rate (Biederman and Harpole, 2013). Despite growing research, little is known about the influence of cocoa pod husk biochar on tomato in the forest-savanna transition zone of Nigeria. This study therefore assessed its effects on selected soil physical properties, tomato performance, and fruit nutritional quality under controlled screen house conditions.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted from March to July 2025 in a screen house at the Teaching and Research Farm, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria (7°28'–7°29' N, 5°44'–5°46' E; 317–352 m a.s.l.). The facility had a galvanized frame, UV cover, and insect-proof netting. Soils derive from Precambrian basement rocks (Okpoli, 2015). The area has a humid tropical climate with bimodal rainfall (1200–1400 mm), temperatures of 21–32 °C, and relative humidity of 75–95%. Rainforest vegetation is degraded to derived savannah due human activities.

Sample preparation and experimental design

Composite soil samples were collected from the Research Farm, sieved through a 2-mm mesh, and 10 kg portions were filled into perforated polythene bags. Five cocoa pod husk biochar rates (0, 10, 20, 30, and 40 t ha⁻¹) were applied. Treatments were arranged in a Completely Randomized Design with three replications to ensure unbiased distribution within the screen house.

Biochar preparation

Cocoa pod husks obtained from local farms were air-dried for three weeks and pyrolyzed in a 200-liter metal drum kiln fitted with vents and a chimney to ensure limited oxygen supply. The kiln was pre-heated with wood, and husks were gradually added. Pyrolysis was conducted at 350–500 °C for 3–4 hours, monitored with a probe thermometer. After sealing to cool and prevent oxidation, the biochar was collected, crushed, and sieved through a 2-mm mesh to obtain a uniform particle size suitable for soil application and analysis.

Biochar application

Quantities of 0 g, 50 g, 100 g, 150 g, and 200 g of cocoa pod husk biochar were mixed into 10 kg of soil in the grow bags, corresponding to the equivalent rates of 0, 10, 20, 30, and 40 t ha⁻¹ of cocoa pod husk biochar, respectively. The cocoa pod husk biochar was added into the soil using a hand trowel and allowed to incubate for eight weeks prior to transplanting the tomatoes into the grow bags. Watering commenced immediately and continued every other day until transplanting day.

Nursery and transplanting of tomato

A local tomato variety was sown in seed trays filled with loamy soil and watered daily. After three weeks, seedlings were transplanted into grow bags in the evening to reduce stress, with soil kept around roots to prevent damage. Each bag contained one plant, regularly watered to maintain field capacity. Weeding was done manually as needed. The experiment lasted 100 days, during which healthy growth and maintenance practices were ensured.

Soil analysis

Soil samples were collected with an auger at a depth of 0-15 cm before the experiment. The physico-chemical properties were determined prior to treatment application. At the end of the study, additional samples were taken from each polythene bag for physical and chemical analysis, excluding texture determination. The samples were bulked, air-dried, and sieved through a 2-mm mesh for routine analysis. Particle size was determined by the hydrometer method and textural class by a textural triangle. Bulk density and moisture content were determined with a coring tube (3 cm diameter, 10 cm height), while gravimetric method was used for moisture content. Total porosity was derived from bulk density, using a particle density of 2.65 Mg m⁻³. Soil temperature was determined by soil thermometer. Soil pH was measured in a 1:2 soil-water suspension using a digital pH meter. Organic carbon was determined by the Walkley and Black wet oxidation method. Total nitrogen was analyzed with the micro-Kjeldahl method, and available phosphorus with Bray-1 extraction followed by molybdenum blue colorimetry. Exchangeable K, Ca, and Mg were extracted with 1 N ammonium acetate (pH 7). Potassium was measured with a flame photometer, while Ca and Mg were determined with an atomic absorption spectrophotometer.

Chemical analysis of cocoa pod husk biochar used for the experiment

Approximately 5 g subsamples of cocoa pod husk biochar (CPHB) were analyzed to determine nutrient

composition. The samples were air-dried, ground, and sieved through a 2-mm mesh before analysis. Parameters assessed included bulk density, ash content, pH, electrical conductivity (EC), surface area, organic carbon (OC), total nitrogen (TN), available phosphorus (P), and exchangeable bases (K, Ca, and Mg). Trace elements such as manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn) were also determined following the procedures of Tel and Hagarty (1984).

Determination of growth and yield parameters of tomato plants

Three plants were selected from each treatment group for data collection. Growth measurements, including plant height, stem diameter, and the number of leaves per plant, were taken at the mid-flowering stage (approximately 28 days after transplanting). Plant height was measured from the base of the plant to the shoot tip using a meter rule, while the stem diameter was determined with a vernier caliper. The number of leaves per plant was manually counted. Ripe and mature fruits were harvested, counted, and weighed to determine the tomato yield. The fresh weight of tomato fruits was measured using a weighing balance. Yield measurements continued up to 100 days after transplanting.

Determination of mineral composition of tomato fruits

At harvest, mature tomato fruits of uniform size were selected from each treatment for chemical analysis to determine their mineral content, following the guidelines of AOAC (2012). For each sample, one gram of fruit tissue was digested using a tri-acid mixture consisting of nitric acid (HNO₃), sulfuric acid (H₂SO₄), and perchloric acid (HClO₄) in a volume ratio of 7:2:1. After digestion, the concentrations of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), and zinc (Zn) were determined using atomic absorption spectrophotometry (AAS).

Statistical analysis

The collected data were subjected to analysis of variance (ANOVA). The treatment means were separated using the Duncan's multiple range test (DMRT) at $p < 0.05$ probability level.

RESULTS

Initial soil analysis

The physical and chemical characteristics of the soil prior to planting in 2025 are presented in Table 1. The soil was classified as sandy loam, slightly acidic, with relatively high bulk density and low total porosity. According to the FAO (2002) guidelines for soil analysis interpretation, the organic matter content was low at 1.62%. Total nitrogen was also very low (0.11%), while available phosphorus was low at 8.9 mg kg⁻¹. The exchangeable bases were equally low, with potassium at 0.12 cmol kg⁻¹, calcium at 1.8 cmol kg⁻¹, and magnesium at 0.34 cmol kg⁻¹. These results point to low soil fertility, implying that crop production on this soil would require external nutrient inputs to achieve satisfactory yields.

Table 1. Physical and chemical properties of soil (0 -15 cm depth) before the experiment

Property	Value	Class
Sand (%)	73.1	
Silt (%)	12.7	
Clay (%)	14.2	
Textural class	Sandy loam	
Bulk density (Mg m ⁻³)	1.52	
Total porosity (%)	42.6	
Moisture content (%)	12.8	
pH (water)	5.63	Slightly acidic
Organic matter (%)	1.62	Low
Total N (%)	0.11	Low
Available P (mg kg ⁻¹)	8.9	Low
Exchangeable K (cmol kg ⁻¹)	0.12	Low
Exchangeable Ca (cmol kg ⁻¹)	1.8	Low
Exchangeable Mg (cmol kg ⁻¹)	0.34	Low

Physical and chemical properties of cocoa pod husk biochar used for the experiment

Table 2 presents the properties of the cocoa pod husk biochar. It had a bulk density of 0.39 Mg m^{-3} , 38.42% ash, and a surface area of $15.7 \text{ m}^2 \text{ g}^{-1}$. It was alkaline (pH 9.8) with electrical conductivity (13.0 mS cm^{-1}). Organic carbon and nitrogen contents were 48.5% and 1.43%, giving a C:N ratio of 33.9. Major nutrients included phosphorus (0.73%), potassium (10.52%), calcium (2.41%), magnesium (1.35%), while micronutrients were iron ($5842.3 \text{ mg kg}^{-1}$), manganese ($953.43 \text{ mg kg}^{-1}$), zinc ($186.25 \text{ mg kg}^{-1}$), and copper (62.38 mg kg^{-1}).

Table 2. Physical and chemical properties of cocoa pod husk biochar used for the experiment

Cocoa pod husk biochar property	Value
Bulk density (Mg m^{-3})	0.39
Ash content (%)	38.42
Surface area ($\text{m}^2 \text{ g}^{-1}$)	15.7
Electrical conductivity (mS cm^{-1})	13.0
pH (H_2O)	9.8
Organic C (%)	48.5
Nitrogen (%)	1.43
C:N	33.9
Phosphorus (%)	0.73
Potassium (%)	10.52
Calcium (%)	2.41
Magnesium (%)	1.35
Iron (mg kg^{-1})	5842.3
Manganese (mg kg^{-1})	953.43
Zinc (mg kg^{-1})	186.25
Copper (mg kg^{-1})	62.38

Effects of cocoa pod husk biochar on soil physical properties

Cocoa pod husk biochar significantly improved soil physical properties (Table 3). Bulk density declined from 1.52 Mg m^{-3} in the control to 0.87 Mg m^{-3} at 40 t ha^{-1} , while porosity rose from 42.6% to 67.2%. Moisture content increased from 10.2% to 18.4%, and soil temperature decreased from 34.3°C to 25.1°C . These changes indicate improved soil structure, moisture retention, and moderated temperature.

Table 3. Effects of cocoa pod husk biochar on soil physical properties (0-10 cm depth)

Treatment	Bulk density (Mg m^{-3})	Total porosity (%)	Moisture content (%)	Temperature ($^\circ\text{C}$)
0 t ha^{-1} CPHB	1.52a	42.6e	10.2e	34.3a
10 t ha^{-1} CPHB	1.31b	50.6d	12.5d	31.2b
20 t ha^{-1} CPHB	1.12c	57.7c	14.3c	28.5c
30 t ha^{-1} CPHB	1.01d	61.9b	16.1b	26.2de
40 t ha^{-1} CPHB	0.87e	67.2a	18.4a	25.1e

Mean values followed by the same letter under the same column are not significantly different according to Duncan's multiple range test (DMRT); CPHB = Cocoa pod husk biochar

Effects of cocoa pod husk biochar on mineral composition of tomato fruits

Cocoa pod husk biochar (CPHB) significantly affected tomato fruit mineral composition (Table 4). Phosphorus, potassium, calcium, magnesium, iron, copper, and zinc all increased with biochar, peaking at 30 t ha^{-1} before declining slightly at 40 t ha^{-1} . For example, P rose from $118.3 \text{ mg } 100 \text{ g}^{-1}$ to $214.5 \text{ mg } 100 \text{ g}^{-1}$, K from $182.5 \text{ mg } 100 \text{ g}^{-1}$ to $248.4 \text{ mg } 100 \text{ g}^{-1}$, and Fe from 3.45 to $5.04 \text{ mg } 100 \text{ g}^{-1}$. Overall, 30 t ha^{-1} produced the highest nutrient concentrations, indicating its effectiveness for improving fruit nutritional quality.

Table 4. Effects of cocoa pod husk biochar on mineral composition of tomato fruits

Treatment	P ($\text{mg } 100 \text{ g}^{-1}$)	K ($\text{mg } 100 \text{ g}^{-1}$)	Ca ($\text{mg } 100 \text{ g}^{-1}$)	Mg ($\text{mg } 100 \text{ g}^{-1}$)	Fe ($\text{mg } 100 \text{ g}^{-1}$)	Cu ($\text{mg } 100 \text{ g}^{-1}$)	Zn ($\text{mg } 100 \text{ g}^{-1}$)
0 t ha^{-1} CPHB	118.3e	182.5e	95.75d	49.31e	3.45e	0.21e	1.18e
10 t ha^{-1} CPHB	151.4d	198.2d	112.4c	67.35d	3.81d	0.29d	1.33d
20 t ha^{-1} CPHB	183.2c	223.1c	123.1b	80.39c	4.23c	0.35c	1.48c
30 t ha^{-1} CPHB	214.5a	248.4a	137.2a	94.46a	5.04a	0.44a	1.76a
40 t ha^{-1} CPHB	195.1b	235.2b	132.0a	87.43b	4.67b	0.39b	1.62b

Mean values followed by the same letter under the same column are not significantly different according to Duncan's multiple range test (DMRT); CPHB = Cocoa pod husk biochar

Effects of cocoa pod husk biochar on growth and yield parameters of tomato

Cocoa pod husk biochar (CPHB) significantly improved tomato growth and yield (Table 5). Plant height rose from 32.3 cm (control) to 59.5 cm at 30 t ha⁻¹, similar to 40 t ha⁻¹. Stem girth increased from 1.8 to 3.1 cm, while leaf number rose from 32.0 to 85.3 per plant. Fruit number and weight peaked at 18.5 fruits and 244.3 g at 30 t ha⁻¹, declining slightly at 40 t ha⁻¹. Thus, 30 t ha⁻¹ gave optimum performance.

Table 5. Effects of cocoa pod husk biochar on growth and yield parameters of tomato

Treatment	Plant height (cm)	Stem girth (cm)	Number of leaves/plant	Number of fruit/plant	Fruit weight/plant (g)
0 t ha ⁻¹ CPHB	32.3d	1.8d	32.0d	9.4e	157.7e
10 t ha ⁻¹ CPIIB	37.1c	2.4c	64.2c	12.3d	170.3d
20 t ha ⁻¹ CPHB	42.9b	2.7b	74.5b	14.4c	200.3c
30 t ha ⁻¹ CPHB	59.5a	3.1a	85.3a	18.5a	244.3a
40 t ha ⁻¹ CPIIB	57.8a	3.0a	75.1b	16.2b	221.3b

Mean values followed by the same letter under the same column are not significantly different according to Duncan's multiple range test (DMRT); CPIIB = Cocoa pod husk biochar

DISCUSSION

The initial soil analysis showed sandy loam, acidic conditions, and low fertility, typical of tropical soils that are weathered, leached, and nutrient-deficient (Lal, 2020). Such soils require external amendments to sustain crop production. Application of cocoa pod husk biochar (CPHB) improved soil physical properties by lowering bulk density, increasing porosity, and enhancing water retention. These effects result from the porous, low-density nature of biochar, which lightens the soil matrix, reduces compaction, and improves aeration and infiltration (Lehmann and Joseph, 2015; Abujabhah *et al.*, 2016). Its high surface area and micropores enable water storage and gradual release (Basso *et al.*, 2013). Reduced soil temperature under CPHB agrees with findings that biochar moderates thermal regimes by improving soil moisture and reflectance (Zheng *et al.*, 2013; Xu *et al.*, 2016). Soil chemical properties were also improved (data not shown). Tomato fruit mineral composition was improved, with maximum concentrations of P, K, Ca, Mg, Fe, Zn, and Cu at 30 t ha⁻¹. This reflects enhanced nutrient availability and improved root access supported by higher porosity and microbial activity (El-Naggar *et al.*, 2019). Potassium, calcium, and magnesium are especially important for fruit quality and firmness (Dorais *et al.*, 2008). The decline at 40 t ha⁻¹ suggests nutrient antagonism or salt stress, where high K may suppress Mg and Ca uptake (Obia *et al.*, 2016). Thus, optimum fruit nutritional quality was achieved at 30 t ha⁻¹. Growth and yield parameters also responded positively. Increases in height, stem girth, leaf number, and fruit weight were linked to better soil structure, aeration, and nutrient supply, which promoted root development and photosynthesis (Jeffery *et al.*, 2011; Agegnehu *et al.*, 2017). Declines at 40 t ha⁻¹ may be due to excess alkalinity and high soluble salts (EC = 13.0 mS cm⁻¹), which can cause osmotic stress and nutrient imbalances (Biederman and Harpole, 2013). Overall, CPHB proved effective in improving soil physical properties, yield, and fruit quality, with 30 t ha⁻¹ identified as the most beneficial rate.

CONCLUSION

This study showed that cocoa pod husk biochar (CPHB) is a promising amendment for degraded tropical soils. It improved physical conditions by reducing bulk density, enhancing porosity, retaining water, and stabilizing temperature. Chemically, CPHB corrected nutrient deficiencies, raising soil fertility and supporting higher tomato growth, yield, and fruit quality. Optimum results occurred at 30 t ha⁻¹, while 40 t ha⁻¹ was less effective. A moderate rate is recommended for sandy loam acidic soils. Field validation and long-term studies remain essential.

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COMPARATIVE EFFICACY OF BOTANICAL AND SYNTHETIC PESTICIDES ON GROWTH PERFORMANCE OF *AMARANTHUS VIRIDIS* UNDER SCREENHOUSE CONDITIONS

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ABSTRACT

Sustainable pest management in vegetable production requires balancing plant productivity with the use of environmentally compatible inputs. This study presents a preliminary evaluation of how botanical and synthetic pesticides influence the growth performance of *Amaranthus viridis* L., under screenhouse conditions. Four treatments consisting of neem leaf extract, moringa leaf extract, cypermethrin, and a control were arranged in a completely randomised design (CRD) with nine replications completely. Each treatment was applied as a soil drench at 50 mL per 5-kg pot. The neem and moringa extracts were prepared as 5% (w/v) aqueous working solutions, while cypermethrin (10% EC) was prepared at the label rate of 1.0 mL L⁻¹. Treatments commenced at 14 days after sowing (DAS) and were repeated fortnightly, simulating realistic pesticide exposure under screenhouse conditions. And the chemical and physical properties of the soil, poultry manure, and botanical extracts were analysed to establish baseline fertility and compositional differences. Growth performance was subsequently monitored by measuring plant height, number of leaves, stem girth, and leaf area. Moringa extract consistently promoted superior vegetative growth, producing taller plants with broader leaves and greater vigour compared with neem and control treatments. Neem extract produced moderate improvements, whereas cypermethrin caused a notable decline in shoot development and overall plant performance. By 49 DAS, moringa-treated plants attained 37 leaves, 76.9 cm height, and 4.6 cm stem girth; representing 23%, 15%, and 18% increases, respectively, over the untreated control, and far exceeding cypermethrin-treated plants (21 leaves, 48.2 cm height, 2.9 cm stem girth). These findings indicate that moringa and neem extracts have potential as eco-friendly alternatives to synthetic pesticides. Their positive effects on early vegetative growth provide a foundation for subsequent investigations into microbial population shifts, nutrient uptake efficiency, and overall system sustainability to establish the biological mechanisms underlying these responses.

Keywords: *Amaranthus viridis* L., moringa leaf extract, neem leaf extract, cypermethrin, sustainable pest management

INTRODUCTION

Vegetable production plays a vital role in improving household nutrition and income across tropical and subtropical regions. However, productivity is often constrained by insect pests and foliar diseases that cause severe yield losses, prompting frequent dependence on synthetic pesticides. Although effective for pest suppression, continuous pesticide use has been associated with soil degradation, nutrient imbalance, and contamination of the agroecosystem (Yasir *et al.*, 2025). These concerns have renewed interest in developing environmentally compatible pest management strategies that sustain plant productivity while conserving soil health.

Botanical pesticides derived from plants such as neem (*Azadirachta indica* A. Juss.) and moringa (*Moringa oleifera* Lam.) have gained significant attention for their potential to provide both pest control and growth stimulation. Neem extracts contain azadirachtin and related limonoids that interfere with pest feeding, molting, and reproduction, making them effective and broad-spectrum bioinsecticides (Campos, 2016). In contrast, moringa leaf extracts are rich in phenolic compounds, antioxidants, and micronutrients that enhance plant vigour, chlorophyll formation, and physiological tolerance to environmental stress (Rashid *et al.*, 2021; Vijayalaxmi *et al.*, 2025). These bioactive compounds confer both protective and growth-promoting effects, aligning with the goal of sustainable and low-residue pest management.

Recent studies have demonstrated that moringa-based biostimulants significantly improve vegetative growth, nutrient uptake, and yield performance in several crops. For instance, foliar application of moringa leaf extract improved growth and nutrient accumulation in blackgram (Vijayalaxmi *et al.*, 2025) and enhanced biochemical and physiological attributes of quinoa, particularly under stress conditions (Rashid *et al.*, 2021). Similarly, moringa extract applications have been shown to increase leaf area and chlorophyll content in *Amaranthus hybridus*, a close relative of *Amaranthus viridis* L., under foliar and seed priming

treatments (Keshinro *et al.*, 2024).

Assessing the influence of botanical and synthetic pesticides on commonly cultivated leafy vegetables provides a practical framework for advancing eco-friendly production systems. *Amaranthus viridis* L., (African spinach) is a widely cultivated leafy vegetable in West Africa, valued for its nutritional content, rapid growth, and adaptability to diverse soil conditions. Despite its economic and dietary significance, there is limited evidence on how botanical and synthetic pesticide applications influence its vegetative growth under controlled screenhouse environments where environmental variability can be minimised.

This study therefore presents a preliminary assessment of the effects of organic (neem and moringa leaf extracts) and synthetic (cypermethrin) pesticides on the growth performance of *Amaranthus viridis* L., under screenhouse conditions. The physical and chemical properties of the soil, poultry manure, and botanical extracts were also analysed to establish baseline fertility and compositional differences. Findings from this evaluation will guide subsequent investigations focusing on shoot biomass accumulation, microbial population shifts, nutrient uptake efficiency, and system-level sustainability.

MATERIALS AND METHODS

Experimental Site

The experiment was carried out in the screenhouse of the Department of Soil Resources Management, University of Ibadan, Nigeria (7°26' N, 3°55' E). The location lies within the derived savannah agro-ecological zone, characterized by bimodal rainfall ranging from 1200 to 1500 mm yr⁻¹ and mean daily temperatures of 26–28 °C. The screenhouse provided a controlled environment that minimized external pest interference and rainfall variability, ensuring uniform experimental conditions throughout the study period.

Planting Materials

Topsoil (0–15 cm) was collected from Parry Road, University of Ibadan (7°27'N, 3°53'E; 189 m above sea level), air-dried, and sieved (<2 mm) to remove debris. Five kilograms of soil were weighed into perforated polythene pots and amended with poultry manure at 15 g pot⁻¹, equivalent to approximately 100–120 kg N ha⁻¹ and 25–30 kg P ha⁻¹ (Makinde *et al.*, 2015). The amended soil was allowed to stabilize for two weeks to enhance mineralization and reduce potential ammonia toxicity. Seeds of *Amaranthus viridis* L. were obtained from the National Horticultural Research Institute (NIHORT), Ibadan. Seeds were directly sown into pots, and seedlings were thinned to two per pot at 7 days after emergence to minimize intra-pot competition and ensure uniform stand density.

Treatments

The experiment comprised 36 pots arranged in a completely randomised design (CRD) with four treatments and nine replicates per treatment. Three replicates were designated for each destructive sampling stage. Pots were watered regularly to maintain optimum soil moisture. Treatments applied to the *Amaranthus viridis* L., under the screen house as shown in Table 1.

Table 1. Treatments applied to *Amaranthus viridis* under screenhouse conditions

Treatment code	Treatment description	Dose / Preparation method	Application rate
T ₁	Control (no pesticide)	Untreated plants	—
T ₂	Neem leaf extract	Prepared following Nwankwo <i>et al.</i> (2016): 25 g dried leaf powder soaked in 125 mL distilled water for 12 h, filtered through muslin cloth, and diluted with 375 mL distilled water to obtain 500 mL of 5 % (w/v) working solution	50 mL per pot, applied fortnightly
T ₃	Moringa leaf extract	Prepared following Haq (2024): same extraction protocol as neem; diluted with 375 mL distilled water to obtain 500 mL of 5 % (w/v) working solution	50 mL per pot, applied fortnightly
T ₄	Cypermethrin (10 % EC)	Commercial formulation prepared at label rate of ≈ 1 mL L ⁻¹ (by mixing 0.5 mL product in 500 mL distilled water) (Pomais Agrochemical, 2023)	50 mL per pot, applied fortnightly

Treatments commenced at 14 DAS and were applied fortnightly (14-day RSI), consistent with recommended re-spray intervals for leafy vegetables (FAO/WHO, 2020). Destructive samplings were conducted at 21, 35, and 49 DAS, occurring 7 days after the preceding spray(s), in accordance with pre-harvest interval (PHI) requirements (FAO/WHO, 2025). This schedule enabled the evaluation of treatment effects on early vegetative growth and short-term pesticide responses under conditions that closely reflect typical smallholder management and international food-safety guidelines. At each stage, 12 pots (four treatments $\times$ three replicates) were harvested.

Sampling and Data Collection

At each destructive sampling, plants were gently uprooted and separated into shoot and root components for growth assessment. Measured parameters included plant height, leaf number, stem girth, and leaf area. Plant height was measured from the soil surface to the apical meristem using a graduated ruler, stem girth was determined 3 cm above the collar using a Vernier calliper, and *Amaranthus* leaf area was calculated as length $\times$ width $\times$ 0.75, following the method described by Olaniyi (2022).

Shoots and roots were weighed fresh immediately after harvest to determine fresh biomass. Samples were then oven-dried to constant weight using a thermostatic drying oven to obtain dry biomass data. The shoot dry weight component was retained for further nutrient and biochemical analyses to be conducted in subsequent phases of the research.

Subsequent Laboratory Analyses

Laboratory analyses of post-harvest soil and plant samples will be carried out in subsequent phases to quantify nutrient composition and assess microbial community structure. These follow-up studies aim to clarify how botanical and synthetic pesticide applications influence soil–plant–microbe interactions. The findings will help explain the biological mechanisms underlying the growth responses observed in this preliminary phase and contribute to a broader understanding of soil fertility and microbial functionality in managed vegetable systems.

Statistical Analysis

Data were analysed using one-way ANOVA in GenStat (8th edition). Treatment means were separated using Fisher's LSD at $p \leq 0.05$. Results are expressed as means $\pm$ standard deviation (SD). Pearson's correlation will be used to evaluate relationships among microbial populations, nutrient uptake, and plant growth.

RESULTS

Soil and Input Properties

The experimental soil was classified as loamy sand, slightly acidic (pH 6.19), with modest organic carbon (2.74 g kg^{-1}) but low total nitrogen (0.30 g kg^{-1}) and available phosphorus (5.52 g kg^{-1}). Such characteristics are typical of coarse-textured tropical soils with low cation exchange capacity and poor nutrient retention, often leading to rapid leaching losses (Weil and Brady, 2016; Smith & Kucera, 2018).

Poultry manure, applied as a basal amendment, was alkaline (pH 7.13) and nutrient-rich (OC 30.50 g kg^{-1} , N 3.03 g kg^{-1} , P 1.32 g kg^{-1} , K 1.28 g kg^{-1}), with a narrow C:N ratio ($\sim 10:1$), favouring rapid mineralization and early nutrient release. This supports previous findings that manure enhances soil fertility, structure, and yield through organic matter enrichment (Agbede, 2025).

The botanical pesticide extracts also contributed appreciable nutrients. Moringa extract was notably higher in N (41.3 g kg^{-1}) and Ca (19.6 g kg^{-1}), while neem extract contained more K (16.2 g kg^{-1}) and Mn (60.0 mg kg^{-1}). The elevated Fe concentration in moringa ($420.57 \text{ mg kg}^{-1}$) likely promoted chlorophyll formation and photosynthetic efficiency. These compositional differences created variable but biologically meaningful fertility backgrounds that influenced crop and microbial responses (Tables 2 and 3). Such dual-action organic extracts have been reported to function both as biopesticides and as biofertilizers through their phytohormone and nutrient contents (Yaseen and Hajos, 2020; Ali *et al.*, 2021).

Table 2. Chemical composition of soil, poultry manure, and organic pesticide extracts used in the experiment

Parameter	pH	EC	OC	N	P	C:N	Ca	Mg	K	Na	Mn	Fe	Cu	Zn
	H ₂ O	(μ S/cm)	g kg ⁻¹				cmol kg ⁻¹				mg kg ⁻¹			
Soil	6.19	360	2.74	0.3	5.52	9:01	7.8	0.88	0.22	0.33	60.78	8.42	1.93	7.72
Poultry manure	7.13	1980	30.5	3.03	1.32	10:01	2.5	0.28	1.28	0.34	305.05	505.75	68.7	136.75
Neem extract	4.72	–	–	28.4	2.3	–	11.2	4.1	16.2	5.6	60	230.00	7.2	16.5
Moringa extract	4.60	–	–	41.3	2.1	–	19.6	3.7	13.4	0.1	18	420.57	5.8	28.9

Table 3. Soil physical properties

Physical properties	Texture / Form	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)
Soil	Loamy sand	810	120	70

Growth Performance of *Amaranthus viridis*

Plant growth was significantly influenced by treatments across all stages (21, 35, 49 DAS). *Moringa*-treated plants consistently exhibited superior growth, achieving the highest leaf number, height, stem girth, and leaf area. Neem treatments performed better than the control but were intermediate, whereas cypermethrin suppressed growth. By 49 DAS, *Amaranthus viridis* L., under moringa extract attained 37 leaves, 76.9 cm in height, and 4.6 cm stem girth, exceeding the control (30 leaves, 64.1 cm, 3.9 cm) and cypermethrin-treated plants (21 leaves, 48.2 cm, 2.9 cm). These values represent improvements of 23%, 15%, and 18% over the control, and 76%, 60%, and 59% relative to cypermethrin (Table 4). Neem extract also enhanced growth compared with the control, though slightly below moringa.

Table 4. Growth parameters of *Amaranthus viridis* under different pesticide treatments across 21, 35, and 49 DAS (mean $\pm$ SD, n = 3).

Stage (DAS)	Treatment	No. of Leaves	Plant Height (cm)	Stem Girth (cm)	Leaf Area (cm ²)
21	Control	10 $\pm$ 1 b	12.8 $\pm$ 0.3 c	0.9 $\pm$ 0.1 a	28.8 $\pm$ 1.5 b
	Moringa	12 $\pm$ 1 a	15.1 $\pm$ 0.4 a	1.0 $\pm$ 0.1 a	37.9 $\pm$ 3.0 a
	Cypermethrin	8 $\pm$ 1 c	11.2 $\pm$ 0.2 d	0.7 $\pm$ 0.1 b	21.2 $\pm$ 1.0 c
	Neem	10 $\pm$ 1 b	14.0 $\pm$ 0.2 b	0.9 $\pm$ 0.1 a	32.1 $\pm$ 1.9 b
	LSD (0.05)	1	0.5	0.1	3.8
35	Control	19 $\pm$ 1 c	40.9 $\pm$ 0.7 c	2.3 $\pm$ 0.1 c	83.4 $\pm$ 2.0 c
	Moringa	27 $\pm$ 1 a	57.0 $\pm$ 0.3 a	3.3 $\pm$ 0.1 a	124.6 $\pm$ 3.5 a
	Cypermethrin	15 $\pm$ 1 d	32.7 $\pm$ 0.3 d	1.9 $\pm$ 0.1 d	50.9 $\pm$ 1.3 d
	Neem	23 $\pm$ 1 b	49.7 $\pm$ 0.4 b	2.8 $\pm$ 0.1 b	106.6 $\pm$ 2.2 b
	LSD (0.05)	1	0.8	0.1	4.5
49	Control	30 $\pm$ 1 c	64.1 $\pm$ 0.9 c	3.9 $\pm$ 0.1 c	129.4 $\pm$ 4.6 c
	Moringa	37 $\pm$ 1 a	76.9 $\pm$ 1.8 a	4.6 $\pm$ 0.1 a	170.9 $\pm$ 11.0 a
	Cypermethrin	21 $\pm$ 1 d	48.2 $\pm$ 0.8 d	2.9 $\pm$ 0.1 d	75.9 $\pm$ 2.7 d
	Neem	33 $\pm$ 1 b	70.5 $\pm$ 1.2 b	4.2 $\pm$ 0.1 b	148.9 $\pm$ 5.0 b
	LSD (0.05)	2	2.3	0.2	12.4

Values with different letters within a column differ significantly (LSD, $p < 0.05$).

Shoot Dry Weight of *Amaranthus viridis*

Shoot dry weight (DW) of *Amaranthus viridis* L., differed significantly among treatments across all sampling stages (Table 5). At 21 DAS, Moringa extract produced the highest shoot DW (6.60 g), followed by Neem (6.07 g), while Cypermethrin yielded the lowest (3.00 g). This pattern persisted through 35 and 49 DAS, with Moringa and Neem consistently promoting greater biomass accumulation than the control and Cypermethrin treatments. The enhanced shoot DW under botanical pesticide treatments reflects improved nutrient uptake and physiological performance, whereas the reduced biomass under Cypermethrin likely indicates suppression of beneficial rhizosphere microorganisms and impaired nutrient assimilation.

Table 5. Shoot dry weight (DW, g) of *Amaranthus viridis* under different treatments

Treatment	21 DAS	35 DAS	49 DAS
Moringa	6.60 ± 0.10 a	12.98 ± 0.36 a	27.35 ± 0.86 a
Neem	6.07 ± 0.15 b	11.28 ± 0.35 a	28.26 ± 0.76 a
Control	4.17 ± 0.15 c	6.12 ± 0.26 b	18.25 ± 0.61 b
Cypermethrin	3.00 ± 0.10 d	4.62 ± 0.21 c	12.05 ± 0.67 c
LSD (0.05)	0.24	0.56	1.37

Values with different letters within a column differ significantly ($p < 0.05$)

DISCUSSION

Growth and biomass responses of *Amaranthus viridis* L., were clearly influenced by pesticide type. Plants treated with *Moringa oleifera* Lam., extract consistently produced taller shoots, more leaves, thicker stems, and higher shoot dry weight across all sampling stages. The higher shoot DW under moringa (27.35 g) and neem (25.18 g) compared with the control (18.25 g) and cypermethrin (12.05 g) confirms the superior growth-promoting capacity of organic formulations.

The stimulatory response under moringa aligns with previous findings that *M. oleifera* Lam., extracts are rich in micronutrients and natural phytohormones, particularly zeatin, gibberellins, and ascorbates, that stimulate chlorophyll synthesis, cell division, and enzymatic activity (Yuniati *et al.*, 2022; Sadak *et al.*, 2024). These bioactive constituents are known to accelerate metabolic efficiency and photosynthetic rate, leading to greater assimilate accumulation and partitioning towards vegetative tissues, thereby increasing biomass accumulation. Neem extract produced a similar, though slightly lower, effect, likely due to its secondary metabolites that exert mild nutritional and hormonal stimulation (Naz *et al.*, 2022; Sriraj *et al.*, 2022).

Conversely, cypermethrin-treated plants exhibited reduced biomass and vegetative vigour, consistent with studies linking pyrethroid exposure to oxidative stress, membrane damage, and impaired nutrient absorption (Güven *et al.*, 2018; Siddiqui, 2024; Yasir *et al.*, 2025). Such physiological stress likely suppresses chlorophyll formation and root metabolism, ultimately constraining shoot development.

The consistent superiority of plant treated with moringa and neem over cypermethrin indicates that botanical extracts function not only as pest control agents but also as biostimulants that enhance plant physiological performance. Their positive influence on vegetative growth without compromising soil or microbial health presents a clear advantage over synthetic pesticides, as similarly observed in other leafy vegetables (Tembo *et al.*, 2018; Ayilara *et al.*, 2023). Overall, these results indicate that moringa and neem extracts enhance physiological efficiency and promote more stable growth in *A. viridis*, whereas cypermethrin may induce subtle phytotoxic or metabolic stress even at standard rates. These findings provide a strong physiological basis for subsequent investigations linking vegetative responses to nutrient uptake and rhizosphere microbial interactions under organic versus synthetic inputs.

CONCLUSION

This preliminary evaluation demonstrates that botanical pesticide treatments, particularly *Moringa oleifera* Lam., and *Azadirachta indica* A. Juss. (neem) extracts, significantly enhanced the shoot dry weight and vegetative performance of *Amaranthus viridis* A. Juss. compared with the synthetic pesticide cypermethrin. The superior biomass observed under moringa and neem treatments likely results from the synergistic effects of plant-derived bioactive compounds and micronutrients that promote chlorophyll synthesis, nutrient assimilation, and overall metabolic efficiency (Mashamaite *et al.*, 2022; Patra *et al.*, 2025).

In contrast, the growth reduction under cypermethrin treatment suggests mild phytotoxicity or metabolic disruption, possibly arising from oxidative stress and interference with root enzymatic activity (Siddiqui, 2024). These contrasting outcomes emphasize the differing physiological effects of botanical and synthetic inputs, underscoring the agronomic and ecological relevance of natural formulations in sustaining plant vigour.

Overall, the findings position moringa and neem extracts as promising, environmentally compatible biostimulants capable of enhancing growth while reducing chemical dependence and offering safer pest management alternatives in leafy vegetable production (Yuniati *et al.*, 2022). This preliminary evidence establishes foundation ongoing research aimed at linking these observed growth responses with microbial population dynamics, nutrient uptake efficiency, and soil fertility changes. Such functional understanding will be critical for advancing sustainable and biologically based pest management systems in smallholder agriculture. However, further field validation is necessary before recommending widespread adoption. Implementing such approaches could potentially improve crop performance, safeguard beneficial soil microbes, and support long-term soil fertility, aligning with current goals for sustainable pest and nutrient management in smallholder vegetable production.

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IMPACT OF SHADE TREE DENSITY ON SOIL NUTRIENT DYNAMICS IN THE COCOA AGROFORESTRY SYSTEM

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ABSTRACT

Agroforestry is promoted to enhance the sustainability of cocoa cultivation, but the impact of shade tree density on soil chemical properties remains poorly quantified. This study evaluated the soil chemical properties under three land-use systems: a pure cocoa plantation (PCP), a sparse cocoa agroforestry system (SCAS), and a dense cocoa agroforestry system (DCAS). Soil samples were analysed for pH, organic matter (OM), major nutrients (N, P, K, Ca, Mg, Na), exchangeable aluminium (Al), and cation exchange capacity (CEC). Means were separated using Duncan's Multiple Range Test ($P < 0.05$). Results indicate that tree density significantly influences soil chemistry. The SCAS exhibited the most favourable soil conditions, with a significantly higher pH (6.81) and lower exchangeable Al (1.19 cmol(+)/kg) compared to the pure plantation (pH 6.13, Al 2.27 cmol(+)/kg) and the DCAS (pH 5.92, Al 0.83 cmol(+)/kg). The SCAS also had the highest levels of nitrogen (0.28%) and phosphorus (4.54 mg/kg). In contrast, the DCAS showed signs of nutrient competition and acidification, with significantly lower phosphorus and the lowest CEC (4.16 cmol(+)/kg). The pure plantation maintained higher levels of K and Ca, likely due to fertiliser inputs, but suffered from higher acidity and aluminium toxicity. The findings demonstrate that a sparse cocoa agroforestry system optimises the trade-offs between the benefits of shade trees and resource competition, leading to improved soil health and a reduced threat of aluminium toxicity. Therefore, to sustainably improve soil chemistry, cocoa agroforestry should use an optimal, not maximum, density of shade trees.

Keywords: Cocoa Agroforestry, Idanre Forest Reserve, Nigeria, Shade tree density, Soil chemical properties

INTRODUCTION

Cocoa (*Theobroma cacao* L.) remains a critically important cash crop for millions of tropical smallholder farmers. Originally cultivated under diverse shade canopies, cocoa cultivation has been intensified into monocultures that are frequently linked to soil degradation (Abdulai *et al.*, 2018). As an alternative, cocoa agroforestry systems (CAS) utilise integrated trees to establish a multi-stratum setting analogous to a natural forest. This structure has the potential to improve ecosystem services, notably the maintenance of soil fertility through processes like litterfall and nutrient cycling, as well as microclimate enhancement (Jacobi *et al.*, 2014).

Soil physicochemical properties are fundamental indicators of agroecosystem health. Management practices, root systems, and organic matter from litter determine how nutrients and organic carbon are distributed at different soil depths (Tittonell *et al.*, 2005). Additionally, emerging evidence suggests that land-use systems can significantly influence organic carbon dynamics even in subsoil layers. (Leifeld and Kögel-Knabner, 2005; Don *et al.*, 2011; Poeplau, 2011). Although the influence of land use on soil chemical properties has been widely investigated, little research has focused on how the density of shade trees in cocoa agroforestry systems (CAS) affects soil chemical properties. Given these knowledge gaps, this study aims to assess how the density of shade (non-cocoa) trees influences the chemical properties of different cocoa agroforestry systems.

MATERIALS AND METHODS

Study area

This study was conducted in the unrestricted zones of the Idanre Forest Reserve, situated in the Idanre Local Government Area of Ondo State, Nigeria. The reserve, which covers an area of 540.45 km², consists of lowland rainforest with elevations varying from 10 to 400 meters. The climate is characterised by a mean annual temperature of 25-26°C (with extremes of 19°C and 33°C) and an annual rainfall of 1200-1800 mm (Ikemeh, 2009). For the research, three sites with different land-use types were selected. These sites were classified based on the density of non-cocoa shade trees per plot: dense cocoa agroforestry (>15 trees), sparse cocoa agroforest (≤15 trees), and pure cocoa plantation (no other trees).

Soil sample collection

Systematic strip sampling was employed in laying out plots. Two transects were cut 100 m apart in each of the study sites, and three sampling plots of 25 m x 25 m in area were laid in alternate positions along each transect at 50 m intervals. Soil core samples were collected at 5 different points along the diagonal of each plot at three different depths of 0-15 cm, 15-30 cm and 30-45 cm using a 3cm diameter soil auger. Samples from each plot at each depth were bulked separately, and the composite soil samples were taken to the laboratory and analysed for the chemical properties.

Soil analysis

Standard procedures for soil chemical properties were followed during the course of the soil analysis. Soil pH was measured in a 1:2.5 soil-water suspension with a glass electrode pH meter (Bates, 1954). Available Phosphorus was extracted using a solution of 1N NH₄F and 0.5N HCl (Bray and Kurtz, 1945) and quantified spectrophotometrically at 660 nm. Calcium and Magnesium levels were determined by titration (Black, 1965), and total Nitrogen was assessed using the macro-Kjeldahl method (Black, 1965). Potassium and Sodium concentrations were measured in a 1N neutral ammonium acetate extract via flame photometry. Exchangeable acidity was also determined by titration (Mclean, 1965), the cation exchange capacity (CEC) was calculated by summation, and total organic matter was analysed by the wet oxidation technique (Walkley and Black, 1934).

Statistical analyses

An analysis of variance (ANOVA) was conducted using SPSS software to identify any statistically significant differences in the soil chemical properties. When significant differences were found, means were separated using Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

RESULTS AND DISCUSSION

Impact of the density of shade trees on the soil pH and Aluminium toxicity

The results of the analysis of variance show that there is a significant difference ($P < 0.05$) in the influence of shade tree density on soil pH and aluminium concentration (Table 1). It is noteworthy that there is a significant improvement in soil pH under the Sparse Cocoa Agroforestry system (SCAS) (6.81) compared to both the Pure Cocoa Plantation (PCP) (6.13) and the Dense Cocoa Agroforestry system (DCAS) (5.92). This higher pH in the SCAS is directly linked to a substantial reduction in exchangeable aluminium (Al) content (1.19), which is less than half that of the pure plantation (2.27). Aluminium toxicity is a major constraint in acidic tropical soils, as it can inhibit root growth and nutrient uptake (Kochian *et al.*, 2015). The reduction in Al saturation under SCAS suggests a natural liming effect, likely due to the decomposition of leaf litter from shade trees that is richer in base cations (Ca, Mg, K) compared to cocoa litter alone (Saj *et al.*, 2017). Conversely, the acidic pH and high Al level in the DCAS may indicate intense competition for base cations or the presence of acidifying tree species, a phenomenon noted by Isaac *et al.* (2005), who found that the net effect on soil pH depends on the specific functional traits of the associated trees.

Impact of the density of shade trees on Soil Macronutrient Dynamics

The results of the analysis of variance show that there is a significant difference ($P < 0.05$) in the influence of shade trees' density on Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and Sodium (Na), but no significant difference ($P < 0.05$) in the concentration of Magnesium (Mg). The data reveal a complex picture for the soil macronutrients, which will be discussed one at a time. As shown in the results of the mean separation with Duncan's Multiple Range Test (DMRT) in Table 1.

Nitrogen (N): The Sparse Cocoa Agroforestry system (SCAS) had the highest level of soil N (0.28), significantly greater than the Dense Cocoa Agroforestry system (DCAS) (0.17). This can be attributed to the inclusion of nitrogen-fixing trees commonly used in cocoa agroforestry, which directly add N to the system through biological fixation (Jagoret *et al.*, 2014). The lower N in the DCAS suggests that competition for nitrogen between cocoa and a dense overstory may outweigh the inputs from nitrogen fixers.

Phosphorus (P): Both the pure plantation (4.07) and SCAS (4.54) maintained significantly higher available Phosphorus (P) than the DCAS (2.80). P availability is sensitive to pH; the more favourable pH in the SAFS likely reduces P fixation by aluminium and iron oxides, making it more plant-available (Snoeck *et al.*, 2016).

The low P in the DCAS could result from both fixation at low pH and uptake by a greater biomass of tree roots. **Potassium (K), Calcium (Ca), Sodium (Na) and Magnesium (Mg):** The pure plantation showed the highest levels of K (0.13), Ca (0.70) and Na (0.22). This is likely as a result of mineral fertiliser application, which is common in intensive monocultures but less so in complex agroforests (Ofori-Frimpong *et al.*, 2010). The SCAS and DCAS had significantly lower Ca, and the SCAS had the lowest K, indicating that the trees are cycling these nutrients effectively, but the standing soil labile pool is lower without external inputs. The non-significant difference in Mg, despite large numerical differences, could call for further investigation.

Impact of the density of shade trees on Soil organic matter and cation exchange capacity

Soil organic matter (OM) is vital for fertility, but this study found that different densities of shade trees did not significantly change its levels ($P < 0.05$). However, the trees' density did significantly affect the soil's nutrient-holding capacity, as measured by Cation Exchange Capacity (CEC) ($P < 0.05$). As observed in the results shown in Table 1, while no significant difference ($P < 0.05$) in OM content was detected among the systems, the numerically highest value was observed in the SCAS (5.50%). This trend is reflected more dramatically in the Cation Exchange Capacity (CEC). The CEC of the SCAS (5.75 cmol(+)/kg) is intermediate but not significantly different ($P < 0.05$) from the pure plantation (10.53), while the DCAS has the lowest CEC (4.16). CEC is heavily influenced by both organic matter and clay content. The high CEC in the pure plantation could be attributed to a higher inherent clay content or different management history (e.g., fertiliser use). However, the very low CEC in the DCAS is a concern, as it indicates a reduced capacity of the soil to retain nutrient cations, making the system more susceptible to leaching. This aligns with research by Gama-Rodrigues *et al.* (2010), who reported that the benefits of agroforestry on CEC are not always immediate and can be offset by nutrient uptake and acidification from a dense tree canopy.

Table 1: Influence of the shade trees on the soil nutrient dynamics of different Cocoa Agroforestry Systems.

Land Use	pH	Al	N	P	K	Ca	Na	Mg	CEC	OM
PCP	6.13 ^b	2.27 ^a	0.19 ^{ab}	4.07 ^a	0.13 ^a	0.70 ^a	0.22 ^a	7.22 ^a	10.53 ^a	3.82 ^a
SCAS	6.81 ^a	1.19 ^b	0.28 ^a	4.54 ^a	0.09 ^b	.32 ^b	0.11 ^b	4.04 ^a	5.75 ^{ab}	5.50 ^a
DCAS	5.92 ^b	0.83 ^b	0.17 ^b	2.80 ^b	0.12 ^a	0.30 ^b	0.16 ^b	2.75 ^a	4.16 ^b	3.29 ^a

Means with the same letter along the column are not significantly different (Duncan's Multiple Range Test, $P < 0.05$).

CONCLUSION

This study compared three cocoa agroforestry systems and found that tree density has a significant impact on soil health. Contrary to the idea that more trees are always better, the data strongly support the concept of an optimal, rather than a maximal, tree density for soil fertility enhancement in cocoa systems. The Sparse Cocoa Agroforestry system emerged as the most balanced, demonstrating the key agroforestry benefits of reduced aluminium toxicity and a more neutral pH, likely without the high input costs of a pure plantation. The sparse system appears to, allow sufficient light penetration for litter decomposition and minimising negative competitive interactions, while still providing the ecological benefits of shade trees. Therefore, the design of cocoa agroforestry systems must carefully select tree species and manage their density to optimise the trade-offs between nutrient cycling and competition, with a focus on species that contribute to soil amelioration rather than acidification.

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EFFECT OF PLANTAIN PEEL SLURRY AND FERTILIZER ON THE GROWTH AND YIELD OF CUCUMBER (*Cucumis sativus* L.)

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ABSTRACT

The screen house experiment was conducted to evaluate the effects of plantain peels slurry and fertilizer on the growth and yield of cucumber. The experiment was conducted at the screen house in the Department of Agronomy, Faculty of Agriculture, Adekunle Ajasin University, Akungba - Akoko, Ondo State Nigeria, during the planting season. The study was laid out in a completely randomized design with four treatments and six replications of plantain peel slurry (control, 100 ml, 200 ml, 300 ml) and NPK fertilizer (control, 0.4 g, 0.6 g, 0.8 g.) Data were collected on the vine length, number of leaves, number of fruits per plant, leaf area, stem girth and total fruit yield. Polythene bags were filled with 8kg of top soil and wetted to field capacity, and left for about a week before sowing seed into it. Plantain peel slurry application significantly improved the number of fruits produced, while its effects on fruit length, weight, and diameter varied not statistically significant. NPK fertilizer had effects on cucumber yield components. The 0.6 g application emerged as the most effective dose, producing the greatest fruit length, weight, and diameter. However, application at 0.8 g appeared to suppress performance, particularly for the number of fruits and fruit size. Therefore, plantain peels slurry is recommended for cucumber production in the study area and other similar soil conditions.

Keywords: Plantain Peel Slurry, NPK Fertilizer, Cucumber Seed

INTRODUCTION

Cucumber (*Cucumis sativus* L.) is a popular vegetable crop grown for its edible fruits, which are consumed fresh or processed. It is rich in water, vitamins, and minerals, making it a valuable component of human nutrition. According to [Olaniyi *et al* 2009], Cucumber is a very good source of Vitamin A, C, K, B6, Potash and also provides dietary fiber and pantothenic acid, magnesium, phosphorus. Cucumber fruits can be used as low-income source of Vitamins and minerals that are lacking in most diets. It can be eaten in salads or sliced into stew as in the tropical regions. The ascorbic acid and caffeic acid contained in cucumber helps in reducing skin irritation (Okonmah, 2011).

In Nigeria, cucumber cultivation has expanded due to increasing urban demand and health awareness among consumers. However, productivity remains low, largely due to poor soil fertility and inadequate fertilizer application. (Olaniyi *et al*). Plantain peel slurry, derived from overripe or waste bananas blended with water, has been identified as a potential organic amendment. It is rich in potassium, calcium, and carbohydrates that enhance microbial activity and soil structure (Emaga *et al.*, 2011). Organic amendments such as banana slurry can complement inorganic fertilizers by improving nutrient use efficiency and soil health. Excessive use of chemical fertilizers without organic inputs has led to soil degradation, reduced soil organic matter, and environmental pollution (Velmurugan, 2011). Therefore, integrating organic and inorganic fertilizers may provide a balanced nutrient supply for optimal cucumber growth.

In spite of increasing relevance of cucumber in Nigeria, low yields are obtained in farmer's field because of declining soil fertility due to continuous cropping and disregard for soil amendments, which has led to several nutrients becoming deficient. Infertile soils result in bitter and misshapen fruits which are often rejected by consumer (Eifediyi and Remison, 2010).

MATERIALS AND METHODS

Experimental Site

The experiment was conducted at the screen house in the Department of Agronomy, Faculty of Agriculture, Adekunle Ajasin University, Akungba - Akoko, Ondo State Nigeria within a latitude of 7° 28'N and 7° 48'N and longitude 5° 45'E and 5° 38'E

Land Preparation

The soil was collected from AAUA teaching and research farm. The sample soil was collected at a depth of 0 -

10cm and was bagged into 48 polythene bags. The soil was sieve so as to separate the larger particles and other foreign bodies from the soil for accurate results. The soil was then watered for five days before sowing.

Treatments and Crop Establishment

The experiment was carried out in a completely randomized design (CRD) with four treatments and six replications for plantain slurry and for fertilizer getting a total of forty-eight experimental pots.

Preparation of Plantain Peels Slurry

The plantain peels were gotten from restaurants and roasted plantain sellers in Akungba Akoko, Ondo State. The plantain peels are separated from the pulp and washed thoroughly with clean water to remove any adhering dirt. The washed peels will then be chopped into small pieces and soaked in water at a ratio of 1:3 (peels: water) for a period of 5 days, allowing for fermentation. The resulting slurry will be filtered through a fine sieve to obtain a homogenous liquid.

Each experimental pot had 8kg of top soil with each treatment applied separately into the pot. 600ml of water was maintained for the potted soil throughout the period of the experiment. Plantain slurry: (control, 100ml, 200ml, 300ml) and fertilizer (control, 0.4g, 0.6g, 0.8g) were added 2 weeks after planting

Plant Materials, Planting and Crop Management

Amarisa Super F1 hybrid cucumber variety seed was used for the experiment, fresh plantain peels, water, closed container, sieve, knife, marker, tape rule, measuring scale and notebook. Two seeds were planted per pot. Support structures (trellises) will be provided for the climbing growth habit of the cucumber plants. Weeding was done manually by hand pulling as at when due.

Data Collection

Growth Parameters

Vine length: Vine length was determined using a meter rule. The tape was used to measure the vine length (cm) of the plant from the base of the stem to the tip of the youngest leaf at weekly intervals.

Number of leaves per plant: Number of leaves per plant was determined by counting the number of leaves per plant at weekly intervals.

Leaf area (cm) and stem girth (cm) were measured too.

Yield Parameters

Number of Fruits per Plant: Total number of fruits harvested from each plant were counted

Fruit Length (cm): Measured from the blossom end to the stem end of randomly selected mature fruits at each harvest. Fruit length was determined using a ruler. The ruler used to measure the fruits length of the plant from stalk end to the fruit apex.

Fruit Diameter (cm): Measured at the widest point of randomly selected mature fruits at each harvest.

Number of fruits/plant: Number of fruits/plant was determined by counting the number of fruits harvested from sample plants per plot.

Plant yield: Plant yield was determined by measuring the weight of cucumber fruits.

Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) at 5% level of probability. The treatment means were separated using least significant difference (LSD) at 0.05 probability level.

RESULTS

Effects of Plantain slurry on Growth of Cucumber

Table 1 show the effect of plantain slurry o growth of cucumber. Plant height showed a numerical increase with higher plantain slurry treatments, with the 300ml application recording the highest mean value (18.32 cm), followed by the 200ml (15.79 cm), and the control (13.60 cm). The lowest height was observed in the 100ml treatment (11.68 cm). Although these values suggest a trend towards enhanced growth at higher slurry volumes, the differences were not statistically significant, likely due to high variability among

replicates, as reflected in the large standard deviations.

In terms of leaf number, there was a consistent upward trend as slurry volume increased. The control group had the fewest leaves on average (8.89), whereas the 300ml treatment recorded the highest leaf count (10.89). This gradual increase suggests that plantain slurry may support vegetative expansion, yet the absence of significant differences limits definitive conclusions.

Leaf area measurements revealed that the 100ml plantain slurry treatment produced the largest leaf surfaces, with a mean value of 21.31 cm², exceeding all other treatments, including the control (15.42 cm²). Despite this apparent benefit at a moderate dosage, the variation within groups, particularly the high standard deviation (± 12.81), contributed to the lack of statistical significance. Stem girth values showed minimal differences across treatments, with slight increases in the slurry-treated groups compared to the control. The control measured an average girth of 1.14 cm, whereas the 100ml to 300ml treatments ranged narrowly from 1.18 to 1.19 cm. These changes were minor and not statistically significant.

Table 1: Effect of Plantain slurry on growth of cucumber

Parameters	Plant Height	Number of Leaves(cm)	Leaf Area (cm)	Stem Girth(cm)
Control	13.60 $\pm$ 7.23 ^a	8.89 $\pm$ 2.57 ^a	15.42 $\pm$ 6.01 ^a	1.14 $\pm$ 0.14 ^a
100ml	11.68 $\pm$ 5.68 ^a	9.78 $\pm$ 3.63 ^a	21.31 $\pm$ 12.81 ^a	1.19 $\pm$ 0.09 ^a
200ml	15.79 $\pm$ 11.36 ^a	10.61 $\pm$ 4.15 ^a	16.86 $\pm$ 5.24 ^a	1.18 $\pm$ 0.10 ^a
300ml	18.32 $\pm$ 11.22 ^a	10.89 $\pm$ 3.41 ^a	17.69 $\pm$ 6.07 ^a	1.18 $\pm$ 0.10 ^a

Values (Means $\pm$ SD) in the Table with the same column followed by the same superscript letter are not significantly different ($p > 0.05$) from each other.

Effects of NPK Fertilizer on Growth of cucumber.

Table 2, showed that the Plant height exhibited some fluctuation across treatments. The control group recorded a mean height of 13.71 cm, while the lowest height was observed in the 0.6g treatment (6.37 cm). Both the 0.4g (8.88 cm) and 0.8g (9.36 cm) treatments showed moderate heights. The statistical annotation reveals a distinction, where the 0.6g treatment is marked with a different superscript (b), suggesting it was significantly shorter than the control group (a), while the 0.4g and 0.8g treatments (ab) were not significantly different from either. This suggests that the mid-range fertilizer dosage may have temporarily suppressed stem elongation, while lower and higher doses did not have the same effect.

The number of leaves is not statistically significant across all treatments, with all values sharing the same superscript (a). The control group recorded a mean of 9.78 leaves, while the lowest was seen in the 0.6g treatment (6.89). Although the 0.4g and 0.8g treatments reported slightly lower and slightly higher values, respectively (8.67 and 9.44), the differences were not significant, implying that NPK application did not have a strong influence on leaf proliferation at the measured stage of growth.

In contrast, leaf area demonstrated a gradual numerical increase with fertilizer dosage. Starting from 15.77 cm² in the control group, the mean leaf area rose progressively to 15.22 cm² at 0.4g, 18.89 cm² at 0.6g, and peaked at 20.48 cm² in the 0.8g treatment. Despite these increases, all treatments were statistically similar (superscript a), indicating that while NPK may promote leaf expansion, the observed variability was too high to confirm significance. Stem girth followed a similar pattern. The control had a girth of 1.08 cm, which increased incrementally to 1.11 cm at 0.4g, 1.12 cm at 0.6g, and 1.20 cm at 0.8g. None of these changes were statistically significant, although the steady increase in values might suggest a mild structural response to NPK at higher concentrations.

Table 2: Effects of NPK on Growth of Cucumber

Parameters	Plant Height (cm)	Number of Leaves	Leaf Area(cm)	Stem Girth(cm)
Control	13.71 $\pm$ 8.06 ^a	9.78 $\pm$ 3.23 ^a	15.77 $\pm$ 4.31 ^a	1.08 $\pm$ 0.16 ^a
0.4g	8.88 $\pm$ 4.95 ^{ab}	8.67 $\pm$ 2.55 ^a	15.22 $\pm$ 5.45 ^a	1.11 $\pm$ 0.13 ^a
0.6g	6.37 $\pm$ 1.04 ^b	6.89 $\pm$ 2.03 ^a	18.89 $\pm$ 5.71 ^a	1.12 $\pm$ 0.10 ^a
0.8g	9.36 $\pm$ 4.04 ^{ab}	9.44 $\pm$ 4.22 ^a	20.48 $\pm$ 6.90 ^a	1.20 $\pm$ 0.12 ^a

Values (Means $\pm$ SD) in the Table with the same column followed by the same superscript letter are not significantly different ($p > 0.05$) from each other.

Effects of Plantain slurry on Cucumber Yields

Table 3: presents the effect of plantain slurry (PS) on cucumber yield parameters, including number of fruits (fruit length, fruit weight, and fruit diameter). The number of fruits increased significantly with plantain slurry application compared to the control. The control produced 11.33 fruits, while all slurry treatments yielded significantly higher numbers, ranging from 18.33 at 100ml to 22.00 at 200ml, before a slight reduction to 21.00 at 300ml. The superscripts indicate that the control was significantly lower, while all slurry treatments were statistically similar, demonstrating that plantain slurry substantially enhances fruit production regardless of volume applied.

For fruit length, values ranged from 15.73 cm in the control to a peak of 19.93 cm in the 200ml treatment. Although the slurry-treated groups showed numerically longer fruits, the shared superscript (a) indicates that these differences were not statistically significant, suggesting that slurry application does not significantly alter fruit elongation. A similar trend was observed in fruit weight, where the control produced the lowest mean value (0.11 kg) compared to higher values in the slurry treatments, ranging from 0.16 kg at 100ml to 0.25 kg at 200ml, with a slight decline to 0.21 kg at 300ml. Despite these increases, the shared superscript (a) shows no significant differences, likely due to high variability within the groups. For fruit diameter, all treatments were statistically similar, with values fluctuating around the control (14.70 cm). The 200ml treatment had the highest mean diameter (17.49 cm), while the 300ml treatment recorded a slight reduction (14.50 cm), though none of these differences were significant

Table 3: Effects of Plantain slurry on Yield of Cucumber

Parameters	Number of Fruits	Length of Fruit(cm)	Weight of Fruit(g)	Fruit Diameter(cm)
Control	11.33±4.73b	15.73±2.10a	0.11±0.01a	14.70±0.26a
100ml	18.33±2.08a	18.60±5.26a	0.16±0.07a	15.43±1.20a
200ml	22.00±2.00a	19.93±10.34a	0.25±0.22a	17.49±5.11a
300ml	21.00±2.65a	18.57±2.58a	0.21±0.16a	14.50±0.61a

Values (Means ± SD) in the Table with the same column followed by the same superscript letter are not significantly different ($p > 0.05$) from each other.

Effects of NPK Fertilizer on Yield of Cucumber.

Table 4, shows the influence of NPK fertilizer on cucumber yield parameters. For the number of fruits, the control treatment produced 16.33 fruits, which was similar to the 0.4g treatment (17.33) and the 0.6g treatment (15.67). However, the 0.8g treatment resulted in a decline to 13.67 fruits. These results suggest that moderate NPK application does not significantly change fruit number compared to the control, while higher application rates may reduce fruit production.

In terms of fruit length, the fertilizer treatments showed a more pronounced effect. While the control recorded an average length of 17.63 cm, the 0.6g treatment achieved the highest value at 21.30 cm, indicating that a moderate fertilizer dose may promote fruit elongation. The 0.4 g treatment (18.07 cm) was comparable to the control, while the 0.8g treatment (16.23 cm) produced the shortest fruits among all groups. For fruit weight, values increased with moderate fertilizer application. The control fruits weighed 0.14 kg on average, while the 0.4 g treatment showed a slight rise to 0.17 kg. The 0.6 g treatment produced the heaviest fruits at 0.24 kg, suggesting that this level of fertilizer was most effective in enhancing fruit biomass. At 0.8 g, the weight declined again to 0.15 kg, closer to the control. With respect to fruit diameter, the control group recorded 15.23 cm, while the 0.6 g treatment again stood out with the largest diameter at 16.45 cm. The 0.4 g and 0.8 g treatments yielded smaller diameters (13.13 cm and 14.02 cm, respectively), indicating inconsistency across different application level.

Table 4: Effect of NPK Fertilizer on Yield of Cucumber

Parameters	Number of Fruits	Length of Fruit(cm)	Weight of Fruit(g)	Fruit Diameter(cm)
Control	16.33±2.31a	17.63±4.62a	0.14±0.06a	15.23±1.40a
0.4g	17.33±6.43a	18.07±2.82a	0.17±0.10a	13.13±2.63a
0.6g	15.67±1.53a	21.30±4.66a	0.24±0.09a	16.45±3.22a
0.8g	13.67±6.66a	16.23±2.21a	0.15±0.06a	14.02±1.34a

Values (Means ± SD) in the Table with the same column followed by the same superscript letter are not significantly different ($p > 0.05$) from each other.

DISCUSSION

The observed improvement in cucumber growth and yield due to plantain peel slurry and fertilizer application may be attributed to the complementary effects of organic and inorganic nutrients. Plantain peel slurry provides potassium, calcium, and carbohydrates that enhance soil microbial activity and nutrient availability (Emaga *et al.*, 2011). The addition of NPK fertilizer supplied readily available nitrogen, phosphorus and potassium, promoting rapid vegetative growth. The results agree with the findings of Velmurugan (2011) and Nur (2010), who reported that combining organic and inorganic fertilizers improves nutrient uptake and crop yield. The enhanced fruit yield under the combined treatment also aligns with Oluremi *et al.* (2012), who observed increased fruit weight and quality in organically enriched cucumber plots. These findings demonstrate that plantain peel slurry can reduce dependence on synthetic fertilizers while maintaining high productivity.

CONCLUSION

This study concluded that plantain peel slurry has positive influence on the growth and yield of cucumber because it significantly improved the number of fruits produced while NPK fertilizer contributed to gradual and statistically significant improvements in all measured growth parameters of cucumber plants, with the most pronounced gains occurring in the third week, especially in plant height and leaf development. Therefore, the use of plantain peel slurry as organic fertilizer can save the cost of mineral fertilizer and minimize environmental pollution.

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DEVELOPMENT OF AN EMBEDDED SYSTEM FOR LIQUID FERTILIZER APPLICATION MACHINE

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ABSTRACT

Production agriculture has witnessed significant advances in ubiquitous sensing, artificial intelligence, smart actuators, and scalable cyberinfrastructure. This research focused on developing an embedded system for a liquid fertilizer application machine, comprising an instrumentation and control unit alongside an Android-based data logger. The instrumentation and control unit consists of an Arduino Nano board, Liquid Crystal Display (LCD), relay, transistors, resistors, diodes, control buttons, pull-up switch, opto controller, Bluetooth module, and an 18Ah 12V battery. It was designed for flexibility, allowing input parameters such as plant spacing, tractor wheel diameter, radius, time, and operation mode. The unit controls the pump, ensuring precise fertilizer delivery at each plant stand through the discharge nozzle. The Android data logger, functioning as an Internet of Things (IoT) device, stores operational data and location details while controlling fertilizer release. It connects to the control unit via Bluetooth. System evaluation revealed pump discharge accuracy, error, percentage error, and precision values of 0.010, 0.0052, 0.75%, and 0.47, respectively. Linearity tests showed fertilizer outputs of 30, 60, 90, 119, and 148 ml for set times of 5, 10, 15, 20, and 25 seconds, with corresponding discharge rates of 6, 6, 5.8, 5.95, and 5.9 ml/s. Calibration of a constant 20 ml nozzle yielded drop times of 1.98, 3.94, 5.94, 8.01, and 10.01 seconds for volumes of 20, 40, 60, 80, and 100 ml, achieving discharge rates around 10 ml/s. The system's efficiency depends on stable battery voltage. Overall, the developed machine enhances precision in liquid fertilizer application with minimal human involvement.

Keywords: Embedded-system, automated, IoT, Microcontroller, liquid-fertilize-machine.

INTRODUCTION

Food security is an increasing global concern, driving the need for sustainable agricultural practices that maximize crop productivity while preserving soil health. Fertilizer application plays a critical role in modern farming by supplying essential nutrients for plant growth. However, conventional methods like manual broadcasting and spraying often cause inefficiencies, including nutrient runoff, over-application, and soil degradation (FAO, 2016). Excessive fertilizer use disrupts soil microbial activity, weakens root structures, and reduces water absorption, leading to reduced yields and financial losses (Pavel *et al.*, 2022). Additionally, improper fertilizer management contributes to groundwater contamination and eutrophication, underscoring the importance of adopting more precise and sustainable approaches (Zhou *et al.*, 2021).

Advancements in precision agriculture now enable farmers to optimize inputs such as fertilizers, seeds, and herbicides on a site-specific basis. This technology reduces waste, boosts profitability, and maintains environmental quality. As Schumann (2010) noted, precision agriculture allows more efficient fertilization, ensuring nutrients remain within the root zone. One innovative solution is the integration of embedded systems into liquid fertilizer application machines, offering data-driven automation to overcome traditional limitations (Sharma *et al.*, 2020). Embedded systems, incorporating microcontrollers, sensors, actuators, and real-time monitoring, ensure precise application based on crop and soil needs (Patel and Singh, 2019).

Furthermore, embedding Internet of Things (IoT) technologies enhances functionality by enabling remote monitoring, data logging, and intelligent decision-making. IoT platforms help farmers analyze soil nutrients, track fertilizer use, and optimize applications using cloud-based analytics (Kumar *et al.*, 2022). GPS integration supports variable-rate application, allowing site-specific fertilizer distribution aligned with soil fertility and crop growth patterns (Behice *et al.*, 2022).

Despite benefits, challenges such as high initial costs, technical expertise requirements, and maintenance hinder widespread adoption (Zhou *et al.*, 2021). However, ongoing innovations in artificial intelligence (AI) and machine learning (ML) promise cost-effective, predictive solutions that improve efficiency. This research develops an embedded system for liquid fertilizer application, aiming to enhance precision, minimize

environmental impact, and optimize resource use. By leveraging IoT and sensor-driven automation, the study demonstrates the potential of embedded technologies in promoting sustainable and high-efficiency farming.

MATERIALS AND METHODS

The embedded system for the liquid fertilizer application machine comprises several integrated components, including sensors, a control panel, microcontroller, battery, wires, Arduino Nano, Liquid Crystal Display (LCD), relay, transistor, resistor, pull-up switch, diode, buttons, opto coupler, Bluetooth module, and a data logger. These components were combined into a comprehensive instrumentation device and Android-based data logger to enable precision control and monitoring.

System Control and Instrumentation Device

The system is designed for flexibility, allowing users to input parameters such as plant spacing, operation time, and tractor wheel diameter. The main control elements include the Arduino Nano, LCD, relay, transistor, resistors, pull-up switch, diodes, buttons, opto coupler, and Bluetooth module.

Arduino Nano: Serves as the core microcontroller, managing input pins, displaying processed data on the LCD, and triggering the relay to control the pump. It also stores operational parameters such as wheel radius, tractor speed, and plant spacing.

Liquid Crystal Display (LCD): An output device that displays project information, speed, and system parameters during setup and operation.

Relay: Functions as an electromagnetic switch to drive two pumps operating at 24 volts, while isolating the 5-volt microcontroller from pump voltage. The Arduino signals a BS547 transistor, which amplifies the voltage to close the relay circuit and power the pumps directly from the battery. A 28 mm × 39 mm relay was used.

Transistor: Amplifies voltage entering the relay coil and supports smooth pump activation. The BS547 silicon transistor with a 14 nm gate length was applied.

Resistors: 10k linear resistors and potentiometers (0603 package) regulate current flow, divide voltages, bias transistors, and prevent microcontroller damage.

Pull-up Switch: Ensures voltage division to protect the microcontroller from excessive voltage when using control buttons.

Diode: Prevents reverse current flow, safeguarding the microcontroller. The diode used measures 4.09 mm in length and 2.21 mm in diameter.

Control Buttons: Four buttons manage system parameters programming input, increasing and decreasing values, and starting or stopping the device.

Bulk Converter: Steps down the 12V battery power supply to 5V required by the microcontroller.

Opto Coupler: Isolates the microcontroller from voltage surges or back EMF effects within the relay circuit.

Bluetooth Module: Establishes wireless communication between the microcontroller and an Android device, enabling access to stored data.

LED Indicator: Glows when powered, showing the device's operational status.

Circuit Board and Software Integration

The circuit board interconnects all components using conductive pathways. System programming was done using C and C++ with Arduino Integrated Development Environment (IDE). Proteus 8.15 software was used for simulation and Printed Circuit Board (PCB) design, ensuring smooth integration and efficient operation.

Sensors and Data Logger

Sensors were strategically placed on the tractor's rear wheel to measure revolutions based on plant spacing. These sensors transmit signals to the microcontroller, which triggers the pump to release liquid fertilizer precisely at each plant stand. The data logger, developed using Java and MIT App Inventor within Android Studio IDE, records system performance, operational data, and real-time monitoring via IoT integration. Through Bluetooth connectivity, the Android-based logger allows users to review stored data, enhancing precision and decision-making in fertilizer application. This embedded system efficiently automates liquid fertilizer delivery, ensuring accurate application, protecting components from voltage fluctuations, and providing real-time operational insights. Its integration of hardware, sensors, and IoT-based logging contributes significantly to precision agriculture.

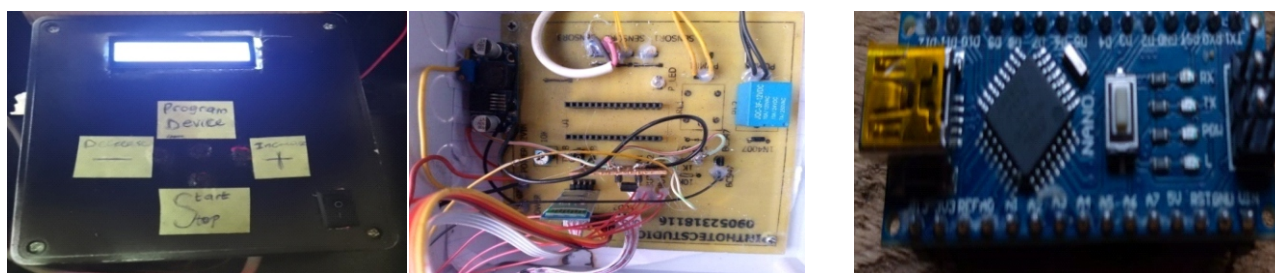


Plate 1: (a) Control box with LCD and Buttons, (b) Circuit board (c) Arduino Nano Micro controller

System Control and Instrumentation Circuits

The control and instrumentation circuits of the automated farmstead liquid fertilizer application machine comprise several interconnected subsystems, including the relay module, input buttons, LCD, power circuits, sensors, and Bluetooth module, all managed by the Arduino Nano microcontroller.

System Control Circuit

The Arduino Nano (Fig. 1) serves as the core microcontroller, managing and processing the entire system's activities. The Liquid Crystal Display (LCD) acts as an output device, showing information such as input speed, project name, and stored or edited parameters during operation. The LCD circuit contains 12 pins (P12), divided into two groups, LCD1 and LCD2, with six pins each: LCD1 pins are P1 (Ground connection) P2 (VCC (5V) for LCD power supply), P3 (Adjusts LCD contrast and brightness), P4 (Register Select (RS) for controlling the shift register), P5 (Read/Write (RW), grounded for screen writing) and P6 (Enable pin for displaying data from the microcontroller). LCD2 pins are P1–P4 (Connected to data pins D4–D7 of the microcontroller for interpreting input codes), P5 and P6 (Anode and ground for additional LCD power) and P13 (LCD power indicator).

Bluetooth Module Circuit

The HC05 Bluetooth module establishes wireless communication between the microcontroller and the Android data logger. It operates with a 3.3V logic level for Rx and Tx pins and functions within a 100m range. It uses AT commands for settings adjustments and has four pins: P1 and P2 (Power supply (anode and ground), P3: Connected to Rx_B, linked to the microcontroller's DoRx for receiving data, P4: Transmission pin (Tx_B), connected to D1/Tx for sending data wirelessly.

Power Circuit

A 12V battery powers the system, but the microcontroller requires only 5V. A bulk converter steps down the voltage from 12V to 5V by controlling the conduction state of its internal switch, ensuring stable power for all instrumentation components as in Figure 2.

Pump Circuit

Two 12V pumps (Fig. 3) are connected in parallel and triggered by the microcontroller via a relay module since its 5V output is insufficient to drive the pumps directly. The relay circuit integrates a 10k linear resistor, 10k potentiometer, transistor, diode, and opto coupler. The transistor amplifies current, while the opto coupler isolates the microcontroller from voltage surges and back EMF, protecting the system.

Sensor Circuit

Three analog sensors are connected to the microcontroller's A0, A3, and A5 pins. These sensors detect the number of wheel revolutions and send analog signals to the microcontroller, which processes and converts them into readable data displayed on the LCD.

Input Button Circuit

Four control buttons manage system functions. Programming Mode Button (Initializes input parameter settings), Increment Button (Increases input parameters as per programmed intervals), Decrement Button (Decreases input parameters), Start/Stop Button (Engages or disengages the machine). The buttons send signals to the microcontroller, which processes the commands and executes the corresponding actions. This

integrated system ensures accurate control, efficient power management, real-time monitoring, and seamless communication between components for precise liquid fertilizer application.

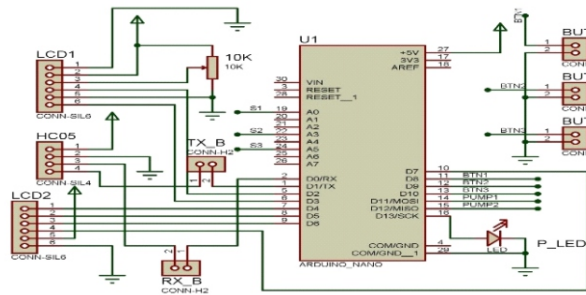


Figure 1: System control circuit

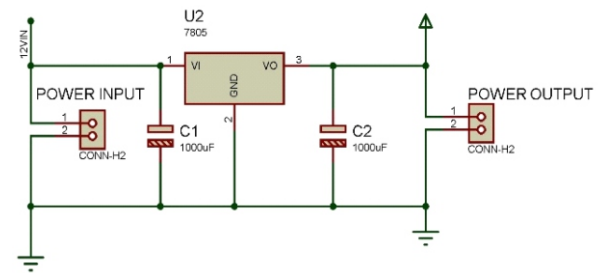


Figure 2: Power Circuit of the system

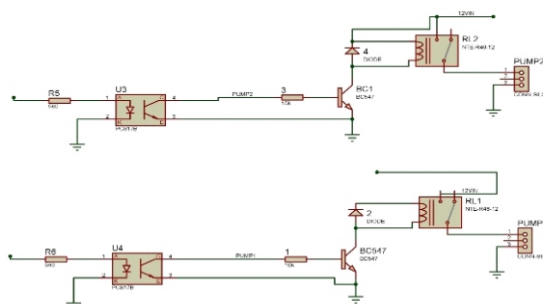


Figure 3: Pump Circuit

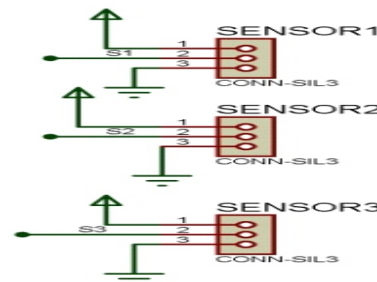


Figure 4: Sensor circuit

Data Logger

An android data logger application was design for the system to monitor the system performance, start and stop the pump instrumentation operation, record the parameters and take data of operation. It is connected to the system through Bluetooth device module and it can only allow a connection at a time. It automatically records and takes the address, longitude and latitude of where the machine is been used, date of operation, plant spacing, speed of operation, wheel radius, speed distance time (sec), mode of operation (speed or Time) number of drops of liquid fertilizer. The system application was prepare using java programming language and android studio ID.

DEVELOPMENT OF AUTOMATED FARMSTEAD LIQUID FERTILIZER APPLICATION MACHINE

Project by:
Engr. Kayode S.E

Disconnect

Disconnected

DATAS

AUTOMATED FARMSTEAD LIQUID FERTILIZER APPLICATION MACHINE

05/06/2024 05:51:21 PM

No address available

Lat. 7.29592 Lon. 5.15377

SPACING (cm)	0
SPEED (Km/h)	0
RADIUS (cm)	0
Speed Dis.TIME (sec)	0
Radius ROTATION	0
MODE	SPEED

Start

Stop

Plate 3: Android data logger home page interface

Evaluation of Instrumentation and Automation Device

The evaluation of the instrumentation and automation device was carried out in both the laboratory and workshop by assessing key instrumentation parameters such as error, accuracy, precision, connectivity, percentage error, range, stability, and linearity.

Accuracy and Percentage Error

Accuracy and percentage error were determined using Equation (1):

$$\text{Accuracy (ACC)} = \frac{\text{Measured value} - \text{True value}}{\text{True value}} \times 100$$

(1)

Instrumentation Error

Instrumentation error, specifically for pump power, was calculated using Equation (2):

$$E = (Acc)^{-2} \quad (2)$$

Precision

Precision was evaluated using the coefficient of variation (Cv). A lower Cv indicates higher precision, while a higher Cv implies lower measurement accuracy.

Range of Discharged Quantity

This represents the minimum and maximum quantity of liquid fertilizer the pump can discharge per second.

Linearity and Stability

Linearity was determined using regression analysis to evaluate how closely the instrument's response follows a straight line across its range. Stability was assessed by monitoring output variations over time.

During laboratory experiments, a stopwatch and measuring cylinder were used to measure fertilizer drops at 5, 10, 15, 20, and 25 seconds, repeated 10 times each. Average discharge rates were recorded, and the nozzle was calibrated to a constant 20 ml. Varying input times helped determine linearity, discharge rate, and the efficiency of the device.

RESULTS AND DISCUSSION

The results obtained from the automation device (Table 1) showed a coefficient of variation (CV) of 0.47, indicating a high level of operational precision. This value is considerably lower than the 1.54 reported by Abd El-Mageed (2015), demonstrating that the present device performs with greater consistency. Since a lower CV signifies higher precision, the outcome confirms the stability of the system during repeated measurements.

The accuracy of the instrument was determined to be ± 0.04 , meaning that measurements obtained from the automation device may deviate from the true value by up to 0.04 units. Although this level of accuracy may not be suitable for applications requiring extremely fine precision, it is appropriate for operations where minor deviations are acceptable. The accuracy range suggests that the device can still provide quick, reliable, and reasonably precise measurements while minimizing human error, enhancing data-driven decisions, and promoting consistency in field applications. Similar moderate-accuracy ranges have been reported in low-cost agricultural automation systems by Singh *et al.*, 2018; Adekunle and Oladimeji, 2020, supporting the effectiveness of such devices in precision-but-not-ultra-sensitive tasks.

Furthermore, the embedded system produced an error margin of ± 0.0052 , indicating extremely close alignment with the true value. This very low error level reflects a high degree of accuracy and reliability, making the system suitable for repeated measurements where stability and minimal variability are required. Comparable embedded systems with error ranges below 0.01 have been documented in similar low-flow dispensing systems (Zhang and Li, 2017), lending further support to the robustness of the present design.

Table 1: Result of Automation Matrix

SN	Evaluation Matrix	Value
1	Accuracy	0.04
2	Error	0.0052
3	Coefficient of Variation	0.47
4.	Range of discharge /secs	0.100 to 0.133L/s
5.	Linearity (correlation coefficient)	0.99

To further evaluate the system, the device was tested at 5-second intervals to determine both the discharged quantity and the time taken to deliver a calibrated 30 ml volume. As shown in Table 2, the system dispensed 30 ml, 60 ml, 90 ml, 120 ml, and 147 ml at intervals of 5, 10, 15, 20, and 25 seconds respectively. Figure 5 confirms a steady increase in discharged quantity with time, consistent with a linear flow pattern. The only noticeable deviation was at 25 seconds, which is attributed to reduced battery voltage affecting pump performance. This observation aligns with Abd El-Mageed (2015), who also reported voltage-related variability in automated dispensing systems.

Table 2: Result of average quantity of dropped liquid fertilizer at constant interval of 5 seconds using the designed Embedded system

Sn	Time (s)	Quantity (ml)	Discharge Rate (ml/s)	Standard Error (ml/s)
1	5	30	6.00	0.024
2	10	60	6.00	0.024
3	15	90	6.00	0.024
4	20	120	6.00	0.024
5	25	147	5.88	0.024

Table 3: The result of average quantity of liquid fertilizer dropped when the metering device was calibrated to the quantity of 20ml using the designed Embedded system

Sn	Quantity	Time	Discharge Rate	Standard Error (ml/s)
1	20	1.98	10.10	0.0315
2	40	3.94	10.15	0.0315
3	60	5.94	10.10	0.0315
4	80	8.01	9.98	0.0315
5	100	9.99	10.01	0.0315

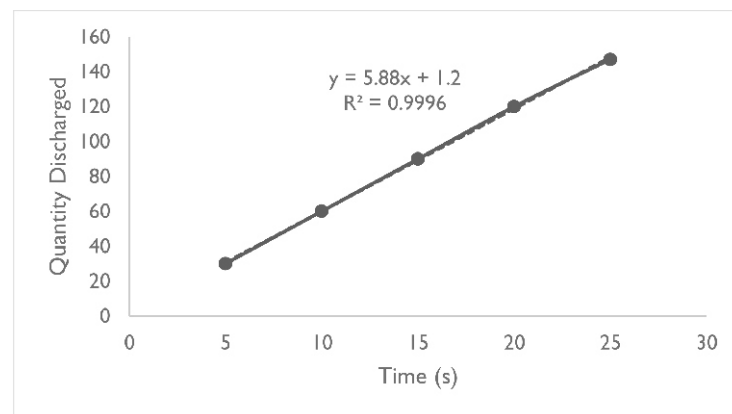
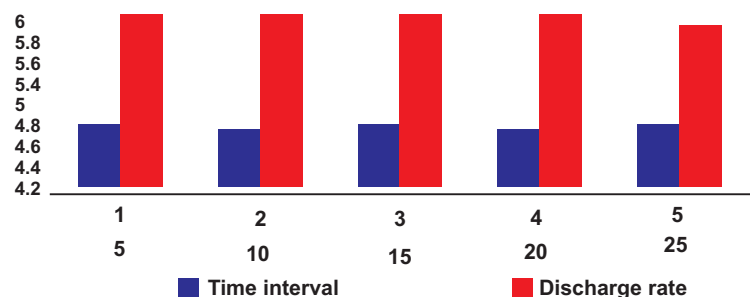
**Figure 5: Relationship between Time and Quantity Discharged**

Figure 6 further illustrates the discharge rate. The rate remained stable at approximately 6 ml/s across all intervals except at 25 seconds, where it slightly decreased to 5.88 ml/s. This minor fluctuation is likely caused by inadequate voltage delivery from the battery, which may have limited the pump's ability to lift the liquid fertilizer efficiently. Such voltage-related inconsistencies are common in portable embedded agricultural systems and have also been reported in earlier studies (Abd El-Mageed, 2015; Olawale *et al.*, 2019).

The linearity test of the embedded system produced a correlation coefficient (R) of 0.99, indicating a very strong and predictable relationship between input and output. This high degree of linearity implies minimal external interference, excellent system response, and high measurement efficiency. Comparable linearity values ($R \geq 0.98$) have been documented in other precision dispensing devices as in Adeoye *et al.*, 2021, which further validates the reliability of the developed system.

**Figure 6: Variation in the Discharge Rate at Each Time Interval**

CONCLUSION

The developed embedded system successfully automated liquid fertilizer application with high accuracy, minimal error, and reliable linearity. Integration of Arduino Nano, sensors, and IoT- based data logging ensured precise control and monitoring. The system demonstrated potential to enhance fertilizer use efficiency and reduce human intervention in precision agriculture. Future work should focus on field-scale testing, power optimization, and wireless data integration via cloud platforms.

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EFFECTS OF PLANTAIN PEEL SOLUTION ON MINERAL AND PROXIMATE COMPOSITION OF CUCUMBER (*Cucumis sativus* L.)

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ABSTRACT

Environmental concerns and the rising cost of chemical fertilizers have led to increased interest in organic waste as alternative nutrient sources. One such material is plantain peel solution, a nutrient rich by-product of plantain waste, valued for its high potassium, phosphorus, and carbohydrate content. This study investigates the effects of plantain peel solution on the mineral and proximate composition of cucumber (*Cucumis sativus* L.). The main objective is to assess and compare the impact of different concentrations of plantain peel solution and NPK (15:15:15) fertilizer to evaluate the potential of the organic solution as a substitute for synthetic fertilizers. A field experiment was conducted using a randomized complete block design (RCBD) with three replications. Treatments included plantain peel solution at 100 ml, 200 ml, and 300 ml per plant; NPK at 0.4 g, 0.6 g, and 0.8 g per plant; and a control (0 ml/0 g). Applications were made two weeks after planting. Proximate parameters analyzed include antioxidants, moisture, ash, crude protein, crude fiber, and carbohydrates. Mineral content assessed includes calcium, magnesium, potassium, phosphorus, and iron. The 200 ml plantain peel solution significantly enhanced both the mineral and proximate contents of the crop, with effects comparable to those observed in the 0.6 g NPK treatment. The 300 ml plantain peel solution performed less effectively, likely due to nutrient excess or microbial imbalance, while the 0.8 g NPK treatment caused mild phytotoxic effects. The control treatment recorded the lowest performance. Overall, this research supported sustainable agriculture through the reuse of organic waste, improvement of soil health, and protection of the environment.

Keywords: Plantain peel solution; cucumber; proximate composition; mineral content.

INTRODUCTION

Cucumber (*Cucumis sativus*) is widely cultivated in tropical and subtropical regions because of its nutritional and economic value. It is a major source of vitamins, minerals, and antioxidants (Ojeniyi *et al.*, 2012). Continuous use of inorganic fertilizers such as NPK has led to soil degradation and environmental pollution (Adeleye *et al.*, 2017). To mitigate this, researchers have turned to organic wastes as alternative soil amendments.

Plantain peels are rich in potassium, calcium, and magnesium as well as phenolic compounds that can improve plant growth and fruit quality (Ojo *et al.*, 2014). Converting agro-wastes like plantain peels into bio-extracts provides an eco-friendly solution to soil fertility problems. Studies have shown that aqueous extracts of plant materials can influence crop growth, nutrient content, and yield (Adewole *et al.*, 2016). Cucumber cultivation has expanded due to increasing urban demand and growing health awareness among consumers (FAO, 2017; Eifediyi & Remison, 2010). However, productivity remains low, largely due to poor soil fertility and inadequate fertilizer application, particularly in tropical and sub-Saharan African soils (Adekiya *et al.*, 2019; Okonmah, 2011). Plantain peel slurry, derived from overripe or waste bananas blended with water, has been identified as a potential organic amendment. It is rich in potassium, calcium, and carbohydrates that enhance microbial activity and soil structure (Emaga *et al.*, 2011). Organic amendments such as banana slurry can complement inorganic fertilizers by improving nutrient use efficiency and soil health. Excessive use of chemical fertilizers without organic inputs has led to soil degradation, reduced soil organic matter, and environmental pollution (Velmurugan, 2011). Therefore, integrating organic and inorganic fertilizers may provide a balanced nutrient supply for optimal cucumber growth.

In spite of increasing relevance of cucumber in Nigeria, low yields are obtained in farmer's field because of declining soil fertility due to continuous cropping and disregard for soil amendments, which has led to several nutrients becoming deficient. Infertile soils result in bitter and misshapen fruits which are often rejected by consumer (Eifediyi and Remison, 2010). Therefore, this study assessed the effects of aqueous plantain peel solution on the growth, proximate, and mineral composition of cucumber fruits compared with NPK fertilizer and untreated control.

MATERIALS AND METHODS

The experiment was conducted in the greenhouse of the Department of Agronomy, Faculty of Agriculture, Adekunle Ajasin University, Akungba-Akoko, Ondo state Nigeria. Mature plantain peels were collected, washed, air-dried, and soaked in distilled water for 72 hours to obtain the extract. The filtrate was diluted to prepare 100 ml, 200 ml, and 300 ml concentrations. NPK fertilizer was applied at 0.4 g, 0.6 g, and 0.8 g levels. A control received no amendment. Cucumber seeds were planted in perforated pots containing 5 kg of loamy soil, arranged in a randomized complete block design with three replicates. Standard agronomic practices were maintained.

At harvest, fruits were analyzed for proximate and mineral composition using AOAC (2010) methods. Data were subjected to ANOVA, and means separated with Duncan's Multiple Range Test at 5 % significance.

RESULTS

The results indicated significant differences ($P < 0.05$) among treatments in both mineral and proximate contents. Application of plantain peel solution increased mineral elements in cucumber fruits. Proximate analysis also showed improvements in crude protein and ash content, while moisture content slightly decreased with higher treatment concentration.

Antioxidant properties were also affected by both inputs. NPK fertilizer significantly enhanced, ABTS (2,2'-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) activity, phenolic content, flavonoids, and Vitamin C at moderate to high doses, reflecting improved secondary metabolite biosynthesis under nutrient-rich conditions. However, 2,2-Diphenyl-1-picrylhydrazyl (DPPH) activity was highest at 0.4 g and declined with increasing NPK, indicating that excessive fertilizer may reduce certain antioxidant functions despite overall increases in bioactive compounds. Plantain peel slurry showed the opposite trend: low to moderate doses (100–200 ml) improved DPPH and ABTS activity, but higher amounts reduced antioxidant performance. Phenolic content was highest in the control, suggesting that organic slurry did not promote phenolic synthesis. Flavonoid and Vitamin C contents remained largely unaffected by slurry application, which is consistent with that organic amendments which do not always enhance antioxidant compounds due to their slow release.

Effect of Plantain Peel Solution and NPK On Mineral Composition of Cucumber

As shown in Table 1 and 2, the mineral composition of cucumber fruits increased with higher concentrations of plantain peel solution and NPK fertilizer. Potassium, calcium, and magnesium values were highest at 300 ml Plantain Peel solution and 0.8 g NPK, showing improved nutrient uptake. Plantain peel performed almost as well as NPK, indicating it can serve as an organic alternative for mineral enrichment.

Table 1: Effects of Plantain Peel Solution on Mineral composition of Cucumber Pl

Parameters	Potassium	Calcium	Magnesium	Phosphorus	Iron
100ml	0.86±0.13b	1.27±0.10b	0.67±0.10a	29.52±10.59c	0.41±0.02a
200ml	1.21±0.13ab	1.36±0.10ab	0.72±0.06a	47.18±10.59bc	0.33±0.02b
300ml	1.20±0.13ab	1.21±0.10c	0.65±0.06a	69.26±10.59ab	0.35±0.02ab
Control	1.52±0.13a	1.40±0.10a	0.73±0.06a	83.23±10.59a	0.35±0.02ab

Values (Means ± SD) in the Table with the same row followed by the same super letter are not significantly different ($p > 0.05$) from each other.

Table 2: Effects of NPK on Mineral composition of Cucumber Plant

Parameters	Potassium	Calcium	Magnesium	Phosphorus	Iron
0.4g	1.14±0.13b	1.41±0.10a	0.74±0.06a	61.78±10.59a	0.36±0.02a
0.6g	1.04±0.13c	1.26±0.10b	0.66±0.06a	66.09±10.59a	0.37±0.02a
0.8g	1.26±0.13a	1.20±0.10c	0.65±0.06a	54.32±10.59b	0.35±0.02a
Control	1.35±0.13a	1.36±0.10b	0.72±0.06a	46.99±10.59c	0.35±0.02a

Values (Means ± SD) in the Table with the same row followed by the same super letter are not significantly different ($p > 0.05$) from each other.

Effect of Plantain Peel Solution and NPK On Proximate composition of cucumber

Table 3 and 4, shows that, Moisture, ash, and protein contents increased with higher treatments, while carbohydrate decreased slightly. Both plantain peel solution and NPK fertilizer enhanced nutritional quality, but the plantain peel gave better protein and fiber values, showing its effectiveness as an organic fertilizer source.

Table 3: Effects of Plantain Peel Solution on Proximate Composition of Cucumbers

PS	Moisture	Ash	Fibre	Fat	Protein	Carbohydrate
100ml	82.80a	0.51b	3.37c	1.09ab	2.51ab	9.72b
200ml	82.80a	0.80ab	3.63ab	0.53c	2.44b	9.77ab
300ml	82.60a	0.55b	3.77a	1.51a	2.28c	9.30c
Control	81.80a	0.85a	3.53b	0.99b	2.67a	10.16a

Values (Means $\pm$ SD) in the Table with the same row followed by the same superscript letter are not significantly different ($p > 0.05$) from each other.

Table 4: Effects of NPK on Proximate Composition of Plant Cucumbers

NPK	Moisture	Ash	Fibre	Fat	Protein	Carbohydrate
0.4g	80.38c	0.66ab	3.98a	0.81c	2.89a	11.29a
0.6g	84.74a	0.48b	3.57ab	1.1ab	2.35b	7.76c
0.8g	81.87b	1.08a	2.82b	0.90b	2.48ab	10.86ab
Control	83.05ab	0.49b	3.94a	1.31a	2.18c	9.04b

Values (Means $\pm$ SD) in the Table with the same row followed by the same superscript letter are not significantly different ($p > 0.05$) from each other.

Effect of Plantain Peel Solution and NPK On Antioxidant composition of cucumber

According to Table 5 and 6, antioxidant properties such as vitamin C, phenol, and flavonoid contents increased with higher treatment levels. The 300 ml plantain peel solution recorded the highest antioxidant values, indicating that the extract improved fruit quality more effectively than NPK fertilizer.

Table 5: Effects of Plantain Peel Solution on Antioxidant Composition of Cucumbers

PS	ABTS	DPPH	Phenol	Flavonoid	Vit.C
100ml	19.37b	29.63c	19.55a	1.19ab	0.22a
200ml	21.14ab	36.06b	7.85c	0.41b	0.23a
300ml	17.27c	31.53b	10.57b	0.41b	0.27a
Control	31.35a	38.17a	13.81b	1.59a	0.23a

Values (Means $\pm$ SD) in the Table with the same row followed by the same superscript letter are not significantly different ($p > 0.05$) from each other.

Table 6: Effects of NPK on Antioxidant Composition of Cucumbers

NPK	ABTS	DPPH	Phenol	Flavonoid	Vit.C
0.4g	16.22c	31.42ab	17.21a	0.61c	0.09c
0.6	19.00b	29.98b	10.79c	1.05a	0.28ab
0.8g	32.86a	45.82a	12.76ab	1.02a	0.32a
Control	21.05ab	28.17c	11.02b	0.92b	0.26b

Values (Means $\pm$ SD) in the Table with the same row followed by the same superscript letter are not significantly different ($p > 0.05$) from each other.

DISCUSSION

This study investigated the effect of plantain peel solution (organic amendment) and NPK fertilizer (inorganic input) on the proximate, mineral, and antioxidant composition of cucumber (*Cucumis sativus*). The findings revealed that both treatments influenced cucumber quality differently, with distinct strengths and weaknesses. Overall, the results demonstrate that the choice and level of fertilizer application play a critical role in determining not only the yield but also the nutritional quality of cucumber fruits.

In terms of proximate composition, NPK fertilizer improved protein and carbohydrate contents at low levels (0.4 g), reflecting enhanced nitrogen assimilation and carbohydrate accumulation. This agrees with Adekiya *et al.* (2019), who reported that moderate levels of mineral fertilizers stimulate protein and carbohydrate synthesis in vegetables. However, higher NPK doses reduced these nutrients, suggesting nutrient imbalance and over-stimulation of vegetative growth. Ash content, which represents the mineral fraction, was highest at 0.8 g NPK, indicating that inorganic fertilizer improved mineral accumulation, consistent with Ayeni *et al.* (2012). Fibre and fat contents, on the other hand, declined under high NPK application, showing that excessive fertilization may suppress structural carbohydrate and lipid biosynthesis. This trade-off highlights the importance of careful dosage when applying inorganic fertilizers.

Overall, plantain peel solution effectively improved mineral, proximate, and antioxidant properties of cucumber fruits, performing comparably or superior to NPK fertilizer, confirming its value as an organic alternative.

CONCLUSION

Aqueous plantain peel solution significantly enhanced mineral, proximate, and antioxidant composition of cucumber fruits. The extract provided essential nutrients, stimulated nutrient uptake, and improved fruit quality.

The use of plantain peel extract is environmentally friendly, cost-effective, and sustainable; farmers should adopt it for cucumber and similar crops.

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ASSESSING THE EFFICACY OF ORALLY ADMINISTERED *WHITFIELDIA LATERITIA* LEAF DECOCTION AS AN ALTERNATIVE TO IRON DEXTRAN INJECTION IN PIG PRODUCTION

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ABSTRACT

In an attempt to assess the efficacy of orally administered *Whitfieldia lateritia* leaf decoction (WLD) as an alternative to iron dextran injection in pig production, a study was designed to compare the body weight gain, hematological and serum profile of twenty-five (25) piglets. 5 piglets (with one animal per replicate) were allotted in a Completely Randomized Design (CRD) to five treatments: T₁ = Iron dextran injection (+ve control); T₂ = no iron dextran (-ve control), T₃ = 4 ml WLD/kg body weight; T₄ = 6 ml WLD/kg body weight and T₅ = 8ml WLD/kg body weight. Results obtained on body weight gain revealed similarity in T₁ (3.67±0.30kg) and T₃ (3.67±0.43kg) but significantly (P<0.05) higher than T₂, T₄ and T₅ with 2.97±0.80 kg, 2.41±0.40kg, and 2.41±0.65 kg respectively. All the haematological parameters were significantly (P>0.05) influenced with comparable higher values in T₁, T₃ and T₄ while comparable least values were obtained in animals in T₂ and T₅. The results on serum chemistry showed a similar trend as indicated in the hematological profile. Total cholesterol was significantly (P<0.05) reduced as dosage of the leaf decoction increased. The present results suggests that oral administration of *Whitfieldia lateritia* as an alternative to iron dextran injection improved the growth performance, hematological and serum biochemical indices at average dosage of 4ml/kg-6ml/kg body weight.

Keywords: *Whitfieldia lateritia*, oral administration, dextran injection, efficacy, dosage.

INTRODUCTION

Iron deficiency anemia (IDA) is the most common health disorder in suckling piglets (Prunier *et al.*, 2014). Katharina *et al.* (2019) reported the inborn iron reserves of only 35–50 mg in neonatal piglets. However, these reserves depleted quickly due to daily physiological demands for 7–16 mg iron (NRC, 2012). Iron is one of the micronutrients that is vital in neonatal stage of pig production for various physiological functions. Such functions may not be limited to electron transfer, gene regulation, oxygen movement and storage, energy metabolism, and redox reactions (Sheftel *et al.*, 2012).

The most commonly used method for preventing iron deficiency anemia in piglets is parenteral iron injection. Iron is given mostly by intramuscular (i.m.) administration of iron dextran (200 mg Fe) at days 2–3 of life. Nadia *et al.* (2021) noted the negative consequences of iron dextran injection to include pain at the injection site, risk of infections, overdosing, causes stress to the animals and is time consuming. In addition, poor iron injection techniques may cause considerable trauma to the muscles, staining of hams or create abscesses and lead to downgrading of the carcasses. The major effect of neonatal anemia in pigs are retarded growth and increased susceptibility to infectious diseases. Several studies (Rincker, *et al.*, 2005; Wei, *et al.*, 2005) observed failure in an attempt to improve or increase the maternal placental movement of iron to the fetus or giving high level of iron concentration feed to the sows, which subsequently increase same in milk or parenteral administration of high iron doses during pregnancy and lactation. The efficacy of oral iron application is hampered by the very low expression of duodenal iron transporters in pigs (Zhao, *et al.*, 2015). Moreover, oral iron therapy may also be limited by gastrointestinal side effects and such may include; nausea, vomiting, abdominal pain and diarrhoea. (Stokar-Regenscheit, *et al.*, 2017; Lipinski, *et al.*, 2010).

The efficacy of *Whitfieldia lateritia* had been acknowledged in phenylhy-drazine (PHZ) induced anemic cockerels (Okorie *et al.*, 2021) and treatment of anemia in rural communities of South-Eastern Nigeria (Aja *et al.*, 2016 and Njoku *et al.*, 2015). There is a dearth of information in available literature concerning oral administration of *Whitfieldia lateritia* leaf decoction as an alternative to iron dextran injection in pig production. In the present study therefore, we investigated the efficacy of different dosage of orally administered *Whitfieldia lateritia* leaf decoction as an alternative to iron dextran injection in pig production using weight gain, hematological and serum indices.

MATERIALS AND METHODS

Location

This research was carried out at Piggery Research and Teaching Farm of Alex Ekwueme Federal University Ndufu-Alike (AE-FUNAI), Ikwo Local Government Area of Ebonyi State. The State lies in the humid tropical agro-ecological zone of Nigeria within Latitudes 50° 40' N and 60° 45' N and Longitudes 70° 30' E and 80° 30' E (Okereke, 2012). In the year 2023, the study area was characterized by an annual rainfall of about 2710 mm. Mean daily temperature within the experimental period was 27.5°C. Mean monthly relative humidity at the study area, 12.00 GMT ranged from 75% to 90% in the rainy season and 62% to 67% in the dry season with a mean annual value of 81.75%. The meteorological data were collected from the Meteorological Station of AE-FUNAI, Ebonyi State.

Collection and preparation of *Whitfieldia lateritia* decoction (WLD)

Fresh leaves of *Whitfieldia lateritia* plant was collected from a backyard garden at Ndufu Echara Ikwo. The fresh leaves were destalked, weighed (digital kitchen scale) and then washed under a running tap water. 200g of the leaves were boiled with 5000 ml of distilled water at a temperature of 70°C for 45 minutes in order to extract the active ingredients of the plant in the form of *Whitfieldia lateritia* leaf decoction (WLD). Thereafter, the decoction extract was decanted into a sterilized air-tighten, well-labeled container (based on dosage) and stored in a refrigerator at 4°C temperature for later used.



Whitfieldia lateritia Plants



Whitfieldia lateritia Leaf Decoction (WLD)

Experimental Period, Design and Management

Unsexed twenty-five (25), 3-day old piglets from 2 mixed genotype sows (Land race × Large white) were used for this experiment. 5 piglets (one animal per replicate) from a particular sow were allotted in a Completely Randomized Design (CRD) to five treatments *vis-a-vis* T₁ = iron dextran (200 mg Fe) injection (positive control); T₂ = no iron dextran (negative control), T₃ = 4 ml WLD/kg body weight; T₄ = 6 ml WLD/kg body weight and T₅ = 8 ml WLD/kg body weight. Water was made available to the piglets and sows *ad libitum* through automated taps and creep feeding facilities were provided for piglets in addition to suckling of milk from the sow. The experiment lasted for 28 days with oral administering of the decoction at 3, 7, 14 and 28 days (weaning) which was carried out twice daily (morning and evening).

Blood samples collection and preparation

At the termination of the experiment (28 days) and based on medical examination guideline, piglets were starved for about 12 hours prior to blood collection. 10 ml of blood samples was drawn from 5 piglets per treatment through the jugular vein using a hypodermic needle and a syringe. The 10 ml from each animal or replicate was divided into two (5 ml each) and were dispensed respectively inside a well labelled anticoagulant sample bottle containing *ethylenediaminetetracetic acid* (EDTA) for hematological analysis and non-EDTA or plane bottles for serum biochemical. Blood samples in the EDTA bottles were shaken gently to prevent coagulation while those in the non-EDTA bottles were later spun in a centrifuge at 5000 revolutions for 10-minutes (Aja *et al.*, 2016), Serum was separated from the clot with Pasteur's pipette into another clean non-EDTA bottles. Both samples were stored at -20°C refrigerator for the analysis at appropriate time.

Data Collection and Statistical Analysis

Initial and final body weight for the individual piglets were measured using digital industrial hook hanging weighing scale (300kg capacity). Hematological parameters analysis was carried out at certified standard laboratory using Mindray hematology analyzer BS 480 (Toa Medical Electronics Co., Ltd., Kobe, Japan). The serum protein profile was

assessed on an automated multiparametric agarose gel electrophoresis system (Hydrasys, Sebia Italia). The results of the parameters obtained were subjected to one-way analysis of variance (ANOVA) using STATA version 17 software programme. Means $\pm$ SD found to be different significantly among treatment means ($p < 0.05$) were separated using the Duncan's Multiple Range Test (DMRT) of the same statistical package.

RESULTS AND DISCUSSION

Results obtained on body weight gain (Table 1) revealed similarity in +ve control (3.67 ± 0.30 kg) and those administered 4 ml/kg body weight (3.67 ± 0.43 kg) but significantly ($P < 0.05$) higher than T_2 , T_4 and T_5 with 2.97 ± 0.80 kg, 2.41 ± 0.40 kg, and 2.41 ± 0.65 kg respectively. The significant variations in total weight gain within the period of the experiment was in agreement with the findings of Oleforuh-Okoleh *et al.* (2015) who orally administered bitter leaf aqueous extract on broiler chickens.

Table 1: Variations in weight gain (Kg) of piglets orally administered WLD as an alternative to iron dextran injection

Treatment	Weight gain at Weaning (Kg)
T_1 (+ve control)	3.67 ± 0.30^a
T_2 (-ve control)	2.97 ± 0.80^b
T_3 (administered 4 ml WLD/kg body weight)	3.67 ± 0.43^a
T_4 (administered 6 ml WLD/kg body weight)	2.41 ± 0.40^b
T_5 (administered 8 ml WLD/kg body weight)	2.41 ± 0.65^b

^{a,b} Mean $\pm$ SD, values with the different superscript are significantly different at ($p < 0.05$); $n = 5$ T_1 = iron dextran (200 mg Fe) injection (positive control); T_2 = no iron dextran (negative control), T_3 = 4 ml WLD/kg body weight; T_4 = 6 ml WLD/kg body weight and T_5 = 8 ml WLD/kg body weight. WLD = *Whitfieldia lateritia* leaf decoction

Table 2 presents the mean value for hematological parameters across the treatments. PVC, HBC, RBC and WBC showed similar ($P > 0.05$) trend in T_1 , T_3 and T_4 and these were significantly higher ($P < 0.05$) than T_2 and T_5 . This suggests administration dosage of WLD for normal health status of the animal at 4 ml/kg and 6 ml/kg body weight. Dosages below or above the range (4 ml/kg-6 ml/kg) may be detrimental and affect production performance of the piglets.

Table 2: The mean hematological values for piglets orally administered WLD as an alternative to iron dextran injection.

Hematological Parameters	T_1	T_2	T_3	T_4	T_5
PVC (%)	37.46 ± 1.26^a	30.56 ± 1.94^b	35.42 ± 2.36^a	37.18 ± 1.98^a	29.30 ± 1.56^b
HBC (g/dl)	11.56 ± 0.42^a	10.06 ± 2.60^b	11.38 ± 0.62^a	11.86 ± 0.46^a	8.8 ± 2.22^c
RBC ($10^{12}/l$)	3.30 ± 0.14^a	2.68 ± 0.68^b	3.30 ± 0.14^a	3.07 ± 0.22^a	2.46 ± 0.62^b
WBC ($10^3/\mu l$)	251.40 ± 13.39^a	191.40 ± 52.28^b	236.60 ± 13.88^a	248.40 ± 20.24^a	198.20 ± 52.43^b
MCV (f/l)	114.24 ± 5.39^a	90.84 ± 23.15^b	107.12 ± 5.05^c	117.74 ± 11.60^a	95.62 ± 25.22^b
MCH (pg)	35.14 ± 0.96^a	29.92 ± 7.56^b	34.44 ± 1.23^a	37.56 ± 2.79^a	28.64 ± 7.30^b
MCHC (g/dl)	30.96 ± 1.26^a	26.44 ± 6.63^b	32.28 ± 0.54^a	32.22 ± 1.20^a	24.24 ± 6.14^b
Platelets ($10^9/l$)	1150.60 ± 32.73^a	916.60 ± 23.48^b	1031.20 ± 57.94^a	1014.20 ± 55.96^a	786.40 ± 206.57^c
Heterophilic (%)	47.45 ± 1.50^a	37.53 ± 9.40^b	49.22 ± 1.7^a	47.33 ± 1.67^a	31.39 ± 8.20^c
Eosinophil (%)	1.72 ± 0.66^a	0.66 ± 0.31^b	1.38 ± 0.38^c	1.67 ± 0.30^a	0.14 ± 0.40^b
Basophil (%)	0.00	0.00	0.00	0.12 ± 0.12^a	0.18 ± 0.18^a
Lymphocyte (%)	47.20 ± 1.94^a	39.06 ± 9.78^c	45.78 ± 2.06^b	47.28 ± 1.68^a	45.40 ± 11.68^b
Monocyte ($10^3/\mu l$)	3.62 ± 0.91^a	2.73 ± 0.75^b	3.61 ± 0.58^a	3.53 ± 0.30^a	1.92 ± 0.67^c

^{a,b,c} Mean $\pm$ SD in the same row with different superscripts are significantly different at ($p < 0.05$) PVC = Packed Cell Volume, HBC = Hemoglobin Concentration, RBC = Red Blood Cell, WBC = White Blood Cell, MCV = Mean Cell Volume, MCH = Mean Corpuscular Hemoglobin, MCHC = Mean Corpuscular Hemoglobin Concentration. WLD = *Whitfieldia lateritia* leaf decoction

Serum biochemical results of the present study follow the same trend as obtained in hematological values. All parameters evaluated for T_1 , T_3 and T_4 were higher and significantly different from T_2 and T_5 . The present results also

affirmed our assertion that lower or over dosage of WLD administration may possibly affects or detrimental to the performance of piglets at their early stage of life.

Table 3: The mean serum biochemical values for piglets orally administered WLD as an alternative to iron dextran injection .

Serum Biochemical Parameters	T ₁	T ₂	T ₃	T ₄	T ₅
Total protein (g/dl)	37.46±1.25 ^a	30.56±7.94 ^b	35.42±2.36 ^c	37.18±1.96 ^a	29.30±7.58 ^b
Albumin (g/dl)	3.64±0.19 ^a	2.87±0.72 ^b	3.55±0.19 ^a	3.60±0.12 ^a	2.85±0.73 ^b
Globulin (g/dl)	2.02±0.09 ^a	1.38±0.35 ^b	2.07±0.04 ^a	1.98±0.10 ^a	1.60±0.42 ^b
Urea (mg/dl)	42.54±2.34 ^a	34.12±8.64 ^b	39.92±3.13 ^c	43.46±2.16 ^a	32.98±8.87 ^b
Creatinine (mg/dl)	1.88±0.29 ^a	1.47±0.41 ^b	1.65±0.22 ^b	1.84±0.17 ^a	1.34±0.36 ^b
Glu (RBS) (mg/dl)	100.40±5.08 ^a	79.20±19.97 ^b	140.0±29.98 ^c	99.20±3.90 ^a	75.00±19.48 ^b
TC (mg/dl)	56.80±2.33 ^a	47.20±11.90 ^b	55.80±2.30 ^a	58.80±1.93 ^a	46.80±12.01 ^b
LDL (mg/dl)	11.68±0.24 ^a	10.29±2.84 ^b	12.61±1.09 ^a	13.76±1.25 ^a	10.86±3.07 ^b
HDL (mg/dl)	16.15±0.60 ^a	13.40±3.44 ^b	16.75±0.93 ^a	16.70±0.82 ^a	14.06±3.67 ^b
TG (mg/dl)	25.29±1.20 ^a	20.75±5.22 ^c	23.84±0.97 ^b	25.28±0.93 ^a	20.20±5.22 ^c

^{a,b,c} Mean ±SD in the same row with different superscripts are significantly different at ($p < 0.05$); TC= Total cholesterol, LDL= Low density lipoprotein, HDL= High density lipoprotein, TG= Triglycerides WLD= *Whitfieldia lateritia* leaf decoction.

The present results suggests that oral administration of *Whitfieldia lateritia* as an alternative to iron dextran injection improved the growth performance, hematological and serum biochemical indices at an average dosage of 4ml/kg to 6ml/kg body weight. Therefore, future research required the adequate and exact dosage that will balance the effect of the decoction on total serum cholesterol reduction and improving the productivity and health status of the piglets.

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IMPACT OF DIETARY CRUDE PROTEIN REDUCTION WITH ACIDIFIER SUPPLEMENTATION ON CARCASS TRAITS, PRIME-CUT PARTS, AND NITROGEN ECONOMY OF BROILER CHICKENS

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ABSTRACT

This experiment was conducted to evaluate the effects of acidifier supplementation to a low crude protein diet of broiler finisher chicken from 28 to 56 days of age on carcass attributes, prime-cut parts, and nitrogen economy. A total of 240 Arbor acre broiler chicks were randomly distributed into five dietary treatments of four replicates with 12 birds each in a completely randomized design. Five isocaloric diets were formulated to comprise T₁ as a positive control diet (20% CP), T₂ as a reduced protein diet (RPD, 17% CP), while T₃, T₄, and T₅ contained RPD with graded levels of acidifier at 100, 200, and 300 mg/kg, respectively. Results showed that all carcass and prime-cut parts indices of the birds were significantly ($p < 0.05$) affected by acidifier supplementation of RPD. Birds fed control and acidifier-supplemented RPD recorded higher ($p < 0.05$) mean values of live weight, carcass yield, and dressing % than those fed RPD. The relative weights of breast, thigh, drumstick, wing, and back of the birds were significantly ($p < 0.05$) influenced by acidifier supplementation to RPD. The nitrogen intake and nitrogen excretion were significantly ($p < 0.05$) lower in birds fed RPD with acidifier supplementation compared to the control diet group. Therefore, it was concluded that supplementation of acidifier resulted to improved carcass and prime-cut attributes with lower abdominal fat, and lower nitrogen excretion in broiler finisher chickens fed RPD.

Keywords: Acidifier, low-protein, carcass quality, nitrogen excretion, broilers.

INTRODUCTION

The biggest challenge in poultry farming is providing nutrition that fully meets the performance potential and physiological requirements of each category of poultry while ensuring financial profitability (Usturoi *et al.*, 2024). Feed costs, which account for approximately 65–75% of broiler production costs, are continuously increasing, and among these, crude protein (CP) accounts for approximately 15% of the total feed cost (Badawi *et al.*, 2019). Besides, intensive production of poultry meat with the use of expensive protein raw materials, such as soybean meal to meet the CP requirement of birds is also responsible for the emission of ammonia which can lead to water pollution (eutrophication) and soil acidification (Webb *et al.*, 2005). Undigested proteins and uric acid from excessive consumption of CP break down into ammonia and nitrous oxide, which are considered environmental pollutants (Brandejs *et al.*, 2022). Therefore, one possible solutions to address this environmental pollution as well as reducing feed cost emanating from the use of expensive protein raw materials, such as soybean meal is by lowering dietary CP (Badawi *et al.*, 2019; Chrystal *et al.*, 2020; Hur *et al.*, 2024; Son *et al.*, 2024). Also, decreasing dietary CP increases N utilization and reduces N excretion, which improves litter quality in poultry houses and prevents the development of footpad dermatitis (Belloir *et al.*, 2017; Chrystal *et al.*, 2020; Brink *et al.*, 2022). In most cases, decreased protein level is often accompanied by adverse effects, including the impairment of broiler growth rate, feed efficiency, and carcass quality (Usturoi *et al.*, 2023). However, In this case, decreasing dietary protein content should be followed by the improvement of the digestibility and absorption of protein in order to fulfil the protein needs of broiler for growth. Several studies demonstrated that the improvement of protein digestibility and absorption can be obtained by dietary supplementation of acidifier when the low crude protein diet was provided (Sharifuzzaman *et al.*, 2020).

According to earlier studies, it was proven that supplementing acidifiers in low-nutrient diets may compensate for the performance losses of broilers (Das *et al.*, 2012; Sharifuzzaman *et al.*, 2020; Islam *et al.*, 2021). The physiological mechanism of acidifiers demonstrating positive influence in poultry production is in connection with its effect to decrease the counts of pathogenic intestinal bacteria, reduce the pH of the

gastrointestinal tract content, improve the morphometry of the small intestine, and enhance the feed nutrients digestibility (Elnaggar and Abo El Maaty, 2017; Fikry *et al.*, 2021). Previous studies have demonstrated that the dietary addition of acidifier was considered to be potentially in broiler performance improvement via the increase in nutrients digestibility, resulting to enhanced protein deposition (Hernández *et al.*, 2012; Mahfudz *et al.*, 2020). In addition, providing a reduced level of CP required in diet of broilers with acidifier supplementation is expected to increase N availability in their bodies, reduce N excretion and ultimately, create a pleasant environment (litter and air quality) and rearing conditions suitable for animal welfare. Based on these hypotheses, this present study aimed to address these knowledge gaps by evaluating the effects of supplementing acidifier to reduce CP level in the diet of finisher broiler chickens on carcass attributes and nitrogen utilization.

MATERIALS AND METHODS

The current study was conducted at the Poultry Unit of the Teaching and Research Farm of the Department of Animal Production Technology, Federal College of Wildlife Management, New Bussa, Niger state. A total of 250 day-old Arbor Acres broiler chicks were obtained from a reputable hatchery in Ibadan, Oyo state and were brooded for the first 28 days on a commercial starter diet (23% CP and 3000 kcal ME/kg). Thereafter, 240 birds were randomly distributed into five dietary treatments with four replications of 12 broilers each in a completely randomized design. The birds were raised in an open-sided poultry pen under a deep litter management system. Feed and water were made available *ad libitum* for a period of 28 days of the experimental period. The dietary treatments were formulated to be isocaloric according to NRC (1994) recommendation to comprise the following T1: Positive Control (20% CP) diet, T2: Negative Control (reduced protein diet (RPD), 16% CP), while T3, T4 and T5 contained RPD with 100, 200 and 300 g/kg acidifier supplementation, respectively (Table 1). The acidifier used in this present study is a commercial product sourced from CIFEK INTERNATIONAL, Lagos, Nigeria and the ingredient composition of acidifier feed additive was citric acid, lactic acid, calcium formiate, calcium propionate, and caprylic acid. On day 56, two birds weighing closest to the pen mean were fasted overnight and euthanized by cervical dislocation for carcass measurements. The euthanized chickens were scalded at 60°C for 30 seconds, plucked manually, and eviscerated. The weights of the eviscerated carcass and economic prime-cut parts (breast, drumstick, and thigh) and abdominal fat were expressed as percentages of the live weight. Nitrogen economy parameters were estimated according to the methods of Belloir *et al.* (2017). All data were analyzed by an analysis of variance according to a completely randomized design using the PROC MIXED procedures of SAS 9.4 (SAS Institute, Cary, NC, USA). Means were separated using the Duncan post-hoc test and $p < 0.05$ was the criterion for significance.

Table 1 Gross composition of experimental diet

Ingredients	T ₁	T ₂	T ₃	T ₄	T ₅
Maize	59.70	66.60	66.50	66.40	66.30
Soybean	29.00	21.00	21.00	21.00	21.00
Fishmeal	2.00	2.50	2.50	2.50	2.50
Groundnut oil	3.00	3.00	3.00	3.00	3.00
Acidifier	0.00	0.00	0.10	0.20	0.30
DCP	2.50	2.50	2.50	2.50	2.50
Limestone	1.50	1.50	1.50	1.50	1.50
Inert filler	1.00	1.00	1.00	1.00	1.00
Salt	0.30	0.30	0.30	0.30	0.30
Methionine	0.30	0.60	0.60	0.60	0.60
Lysine	0.20	0.50	0.50	0.50	0.50
Vit/Min Premix	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00
Crude Protein, %	19.45	16.92	16.91	16.90	16.89
Energy, Kcal ME/kg	3052.67	3057.51	3054.29	3051.07	3047.86

RESULTS AND DISCUSSION

The result of carcass indices of the experimental birds fed RPD with graded levels of acidifier supplementation is displayed in Table 2. Birds fed a control diet and acidifier supplemented RPD recorded

higher ($p < 0.05$) mean values of live weight, carcass weight and dressed weight than those fed RPD. Carcass yield of the birds was significantly ($p < 0.05$) higher in the group fed 1% acidifier-supplemented RPD and similar to the groups fed 2% and 3% acidifier-supplemented RPD, followed by the control diet group than in the groups fed RPD. Dressing percentage of the birds followed the same trend observed in the live weights where higher ($p < 0.05$) mean values were recorded in the groups fed control diet and acidifier-supplemented RPDs than the group fed RPD. The breast weight of the birds was significantly ($p < 0.05$) higher in the group fed 1% acidifier RPD, followed by those fed the control diet than the group fed RPD. Thigh weight and drumstick of the experimental birds were significantly ($p < 0.05$) higher in the groups fed control diet and 1% acidifier RPD, followed by those fed 2% and 3% acidifier RPD than the group fed RPD. The weight of the chicken wings increased significantly ($p < 0.05$) in the groups fed control and 1% acidifier RPD followed by the 2% acidifier RPD group than those on the RPD and 3% acidifier RPD groups. Birds fed control diets and various levels of acidifier RPDs showed an increase ($p < 0.05$) in back weights than those fed RPD.

The abdominal fat weight increased significantly ($p < 0.05$) in the group fed LCPD compared to the groups fed acidifier-supplemented RPDs, which showed lower ($p < 0.05$) mean values followed by those on the positive control diet group. According to Malematja *et al.* (2023), carcass assessment is the most crucial aspect of broiler production because it reflects the amount of meat produced. The amount and quality of feed protein are important factors affecting the efficiency of protein utilization for production or growth (Ghazalah *et al.*, 2011). The condition in the present study was consistent to previous finding (Suthama, 2006) that the availability of protein had an important role in the process of accelerating the rate of protein synthesis supporting growth of birds. The significant variations observed due to acidifier supplementation to RPD of broiler finisher chickens in the present study for carcass indices agree with those obtained by Dehghani-Tafti and Jahanian (2016) who found that carcass yield was increased as the result of dietary inclusion of both citric and butyric acids while reducing dietary CP level decreased carcass yield. Manvatkar *et al.* (2022) reported that eviscerated yield, carcass yield, drumstick, breast meat, and relative organ weights were improved in broiler chickens fed with blend-coated organic acids. Providing dietary acidifier was reported to increase the surface area of the intestinal villi facilitating the more nutrients that can be absorbed (Elnaggar and El-kelawy, 2024), and this process resulted in higher live weight, carcass yield and dressing percentage. This result is in close agreement with findings of Sharifuzzaman *et al.* (2020), who reported that dressing percentage increased with the increased level of acidifier in diet of broilers.

The inclusion of acidifier in the feed helps maintain the optimal pH in the stomach and ensures proper protein digestion in the intestine by increasing the activity of proteolytic enzymes, which enhance protein accretion for carcass growth (Lückst"adt and Mellor, 2011; Elnaggar and El-kelawy, 2024). The significant increase in abdominal fat with reduced CP content obtained in the current study is in agreement with previous reports, which attributed the increase in abdominal fat due to the increase of dietary ME:CP ratio when reducing CP in the diets of broiler (Bellloir *et al.*, 2017). In addition, it has been shown that diets with a low protein content reduce the surface area of villus epithelial cells in the small intestine of broilers and promote abdominal fat accumulation (Buwjoom *et al.*, 2010; Son *et al.*, 2024). On the other hand, our result showed there is a decreasing trend of abdominal fat when the CP level was reduced with acidifier supplementation and this result is similar to the study of Zeng *et al.* (2015). Contrary to the present study, some studies showed that the organic acid supplementation in diet had no significant effects on carcass trait and abdominal fat (Elnaggar and Abo El Maaty, 2017; Fikry *et al.*, 2021).

The result of the response of experimental birds fed RPDs with acidifier-supplementation on nitrogen economy indices are presented in Table 3. The statistical analysis showed that only the mean values of nitrogen intake and nitrogen excretion were significantly ($p < 0.05$) different among the dietary treatments. Birds fed control diets recorded an increase ($p < 0.05$) in nitrogen intake than those fed RPD and acidifier-supplemented RPDs. Nitrogen excretion of the birds was significantly ($p < 0.05$) higher in the group fed a control diet but lower ($p < 0.05$) in the group that consumed 2% acidifier RPDs, which was similar to those fed other acidifier RPDs. Nitrogen excretion shows the amount of nitrogen that is unutilized by the birds and a decrease in nitrogen excretion indicates nitrogen utilized by the body of animals. Dietary CP levels significantly influence N utilization efficiency in broilers and lowering dietary CP levels decreased N excretion by approximately 10%, and increased N efficiency (Ullrich *et al.*, 2018; Alfonso-Avila *et al.*, 2022).

The results of this study suggest that the RPD with increasing levels of acidifier supplementation decreased N intake and excretion but did not negatively impact overall carcass growth, likely due to improved nutrient utilization efficiency (Waghmare *et al.*, 2025). The N excretion values obtained in our experiment are in line with the previously published results, which show that the N excretion of broiler chickens can be reduced using RPD diets with reduced CP levels (Striffler *et al.*, 2023). According to Belloir *et al.* (2017), the main impact of dietary CP reduction on the decrease in nitrogen excretion is seen as an improvement of the efficiency of nitrogen utilization. As a consequence, the simultaneous decrease of nitrogen intake and excretion leads to a strong and synergistic decrease of nitrogen amounts lost through volatilization, and thus an indication of reduced transformation of excreted nitrogen into ammonia (Méda *et al.*, 2011). Similarly, Such *et al.* (2021) observed in their study with broiler chickens that, besides the total N, the proportion of the urinary N excretion can also be reduced if RPD are fed.

Table 2: Effects of acidifier supplementation of reduced protein diet on carcass and parts indices of broiler chickens from 28 to 56 d of age

Treatment	T1	T2	T3	T4	T5	SEM	P-values
Live wt, g	2300.00 ^a	1850.00 ^b	2450.00 ^a	2250.00 ^a	2200.00 ^a	59.60	0.002
Carcass wt, g	2150.00 ^a	1675.00 ^b	2350.00 ^a	2150.00 ^a	2100.00 ^a	66.09	0.001
Dress wt, g	2075.00 ^a	1550.00 ^b	2250.00 ^a	2100.00 ^a	2000.00 ^a	70.30	0.001
Eviscerated wt, g	2000	1950	2025	2025	1900	36.04	0.824
Carcass yield, %	93.37 ^a	90.57 ^b	95.90 ^a	95.55 ^{ab}	95.42 ^{ab}	0.60	0.002
Dressing %	90.06 ^a	83.77 ^b	91.81 ^a	93.33 ^a	90.83 ^a	0.95	0.001
Breast, g	211.50 ^{ab}	139.96 ^b	237.60 ^a	204.00 ^b	162.92 ^{bc}	11.12	0.009
Thigh, g	166.21 ^a	114.00 ^b	164.05 ^a	130.93 ^b	122.63 ^{bc}	5.94	0.001
Drumstick, g	144.25 ^a	117.14 ^b	141.90 ^a	124.13 ^b	124.16 ^b	3.48	0.014
Abdominal fat, g	4.89 ^b	6.68 ^a	2.11 ^d	2.93 ^{cd}	3.70 ^c	0.46	0.001

^{a,b,c} means without a common superscripted letter within a line are significantly different ($p < 0.05$).

T1: Positive Control (20% CP) diet; T2: Negative Control (reduced protein diet (RPD, 16% CP); T3, T4 and T5 contained RPD with 100, 200 and 300 g/kg acidifier supplementation, respectively.

Table 3: Effects of acidifier supplementation of reduced protein diet on nitrogen economy of broiler chickens from 28 to 56 d of age

Treatment	T ₁	T ₂	T ₃	T ₄	T ₅	SEM	P-values
Nitrogen intake, g	58.21 ^a	52.09 ^b	50.74 ^b	51.09 ^b	52.55 ^b	0.81	0.001
Nitrogen retention, g	20.90	16.8	20.54	22.72	20.9	0.85	0.280
Nitrogen efficiency, %	35.97	32.44	40.49	44.70	39.82	1.86	0.303
Nitrogen excretion, g	37.30 ^a	35.30 ^{ab}	30.19 ^{ab}	28.38 ^b	31.65 ^{ab}	1.30	0.153

^{a,b} means without a common superscripted letter within a line are significantly different ($p < 0.05$).

T1: Positive Control (20% CP) diet; T2: Negative Control (reduced protein diet (RPD, 16% CP); T3, T4 and T5 contained RPD with 100, 200 and 300 g/kg acidifier supplementation, respectively.

CONCLUSION

Reducing dietary CP content from 20 to 17% significantly decreases the carcass performance and prime-cut parts of finisher broilers with increased abdominal fat deposition. Thus, a minimum of 100 mg/kg of acidifier supplementation is necessary to support carcass traits and is beneficial for reducing nitrogen excretion in broiler chickens fed diets with lower CP concentration.

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ALCHORNEA CORDIFOLIA LEAF EXTRACT AMELIORATIVE EFFECT ON AFLATOXIN B₁-INDUCED BLOOD ALTERATIONS IN BROILER CHICKEN

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ABSTRACT

Aflatoxin B₁ (AFB₁), a key *Aspergillus* mycotoxin in tropical poultry, induces systemic toxicity detectable via haematological profiling. This study evaluated the potential of *Alchornea cordifolia* leaf extract (AE) to ameliorate AFB₁-induced haematological alterations in broilers. Two hundred and forty day-old Cobbs broilers were allocated to four groups: control (CONT), AFB₁-only (AFB₀), AFB₁ + AE at 1g/L (ABAE1), and AFB₁ + AE at 2g/L (ABAE2). After 42 days, AFB₀ broilers showed significant reductions in packed cell volume (PCV; 27.33% vs. 38.00% in CONT), haemoglobin concentration (9.08 vs. 12.62 g/dl), red blood cell count (2.60 vs. $3.50 \times 10^{12}/L$), and white blood cell count (7.86 vs. $10.86 \times 10^9/L$), with marked leukocyte suppression ($P < 0.05$). ABAE1 partially restored erythrocytic and leukocytic values, while ABAE2 supplementation achieved PCV, haemoglobin, RBC, WBC, and leukocyte differentials statistically comparable to control. Mean cell haemoglobin concentration and mean cell volume were unaffected, but mean cell haemoglobin was significantly elevated in AFB₀ and ABAE1 ($P < 0.001$). The results indicate that AE, especially at 2g/L via drinking water, can effectively counteract AFB₁-induced haematological impairments in broilers.

Keywords: Haematological profiling, aflatoxin B₁, *Alchornea cordifolia*, Blood alterations, Ameliorative

INTRODUCTION

Aflatoxins, secondary metabolites produced predominantly by *Aspergillus flavus* and *A. parasiticus*, remain a major constraint to poultry production, particularly in tropical and subtropical regions where climatic conditions favour fungal proliferation. Among the different forms, aflatoxin B₁ is the most potent, exerting hepatotoxic, immunosuppressive, and growth-depressing effects in poultry. Chronic dietary exposure from the first day of life until market age can lead to significant physiological alterations, reduced production efficiency, and compromised meat safety (Naseem *et al.*, 2018).

Haematological profiling of broiler chickens under dietary-induced aflatoxicosis from day-old to 42 days is a critical investigative tool for elucidating the systemic impact of toxin exposure. This evaluation enables comprehensive health assessment, as aflatoxicosis-induced oxidative stress and hepatic damage often manifest as anaemia and other haematological abnormalities. (Barger, 2003). Tracking blood parameters over time helps show how dietary Aflatoxin B₁ exposure affects the blood. This reveals both short-term and long-term impacts on the blood-forming system. Changes like reduced red blood cell measures can hurt the bird's metabolism. In turn, this may slow growth and reduce feed efficiency (Abosede *et al.*, 2018). From a diagnostic standpoint, deviations from normal haematological ranges may serve as early warning signals of morbidity, enabling timely intervention to reduce production losses. Importantly, the evaluation of haematological parameters under aflatoxin challenge has direct implications for regulatory compliance and food safety. By linking poultry health status with potential public health risks, these findings can guide industry practices that align with international safety standards and consumer protection goals (Rathod *et al.*, 2017).

Alchornea cordifolia, widely used in tropical Africa for its medicinal properties which include antioxidant, anti-inflammatory, and anti-anaemic effects owing to its composition of phenolics, flavonoids, saponins, tannins, and alkaloids (Yilmaz *et al.*, 2018). Although, evidence exists for its protective effects against AFB₁-induced alterations in rats, its efficacy in poultry is yet to be scientifically validated. This study, therefore, investigates whether AE administration via drinking water offered daily can mitigate haematological impairments in AFB₁-challenged broilers.

MATERIALS AND METHODS

Fresh leaves of *Alchornea cordifolia* were harvested from their mother plant from undeveloped plot around the Teaching and Research Farms, Adekunle Ajasin University, Akungba-Akoko (AAUA), washed and air-dried under shade. Afterward the leaf samples were pulverized into *Alchornea cordifolia* leaf powder (ALP) and safed in an airtight container till use.

Aflatoxin B1 cultured maize meal was produced following the procedure described by Rahdi *et al.*, (2021) while quantification, concentration of *Aspergillus*-cultured meal and contamination of the experimental diet was done as outlined by Oloruntola *et al.* (2024) to obtain AFB0 concentration of 0.5 mgAFB1 per kilogramme basal feed.

Starters (22% CP; 3018 Kcal/kg ME) and finisher (20% CP; 3108 Kcal/kg ME) broiler chicken diets as experimental basal feed were compounded based on AOAC (2010) recommendation and shared into four equal parts and coded thus:

CONT: Control; no AFB1 contamination and extract supplements

AFB0: 0.3 mg AFB1-cultured meal per kg basal feed

ABAE1: AFB0 + 1000 mg *A. cordifolia* leaf powder in 1000ml daily drinking water

ABAE2: AFB0 + 2000 mg *A. cordifolia* leaf powder in 1000ml daily drinking water

Two hundred and forty day old cobb500 broiler chickens were randomly allocated to four treatment groups in five replicates of five broilers per replicate. Feed and water were supplied *ad libitum* throughout the six weeks experimental period.

On day 42, two broilers per replicate were sampled, weighed and blood samples taken beneath the wing into an ethylenediaminetetraacetic acid (EDTA) for haematological analysis including haemoglobin concentration, packed cell volume, red blood cell count, white blood cell count and their differentials. All data received were subjected to One-way ANOVA with Duncan's multiple range post hoc test ($P < 0.05$) using SPSS version 20.

RESULTS

Broiler chickens in the AFB0 show significantly depressed expression of haematological indices compared to the control (CONT). Packed cell volume (PCV) declined from 38.00% in CONT to 27.33% in AFB0 ($P = 0.01$), while haemoglobin concentration dropped from 12.62 g/dl to 9.08 g/dl ($P = 0.01$). Red blood cell counts showed a similar reduction ($3.50 \times 10^{12}/L$ in CONT vs. $2.60 \times 10^{12}/L$ in AFB0; $P = 0.02$). Supplementation with *A. cordifolia* extract improved these parameters, the broilers in the ABAE1 group (1 g/L) showed partial improvement in PCV (30.33%) and RBC counts ($3.00 \times 10^{12}/L$) while the broilers in the ABAE2 group (2 g/L) achieved PCV (37.00%), haemoglobin (12.29 g/dl), and RBC count ($3.40 \times 10^{12}/L$)

Table 1. Haematological parameters of Aflatoxin B1 -exposed broilers with and without *Alchornea cordifolia* leaf extract drinking water.

Parameters	CONT	AFB0	ABAE1	ABAE2	SEM	P value
Packed cell volume (%)	38.00 ^a	27.33 ^b	30.33 ^{ab}	37.00 ^a	1.44	0.01
Haemoglobin conc. (g/dl)	12.62 ^a	9.08 ^b	10.07 ^b	12.29 ^a	0.48	0.01
Red blood cells ($\times 10^{12}/L$)	3.50 ^a	2.60 ^b	3.00 ^{ab}	3.40 ^a	0.13	0.02
Mean cell haemoglobin conc. (g/dl)	33.26	33.25	33.20	33.26	0.02	0.78
Mean cell volume (fl)	108.43	120.91	119.67	111.28	4.83	0.80
Mean cell haemoglobin (pg)	36.02 ^b	40.17 ^a	39.75 ^a	36.97 ^b	1.60	0.01
White blood cells ($\times 10^9/L$)	10.86 ^a	7.86 ^b	9.58 ^{ab}	10.67 ^a	0.45	0.04
Granulocytes ($\times 10^9/L$)	3.69 ^a	2.67 ^b	3.25 ^{ab}	3.62 ^a	0.15	0.04
Lymphocytes ($\times 10^9/L$)	5.62 ^a	4.07 ^b	4.96 ^{ab}	5.52 ^a	0.23	0.04
Monocytes ($\times 10^9/L$)	1.52 ^a	1.10 ^b	1.34 ^{ab}	1.50 ^a	0.06	0.04

^{a,b}Row means with varying letters show significant different ($P < 0.05$); SEM Standard error of the mean; CONT:

No aflatoxin B1 contamination; no supplementation; AFB0: 0.3 mg/kg aflatoxin B1; ABAE1: 0.3 mg/kg aflatoxin

B₁ + 1000 mg/L *Alchornea cordifolia* leaf extract; ABAE2: 0.3mg/kg aflatoxin B₁ + 2000 mg/L *Alchornea cordifolia* leaf extract.

values which is statistically comparable to those expressed by the broilers in the CONT. Mean cell haemoglobin concentration (MCHC) and mean cell volume (MCV) were unaffected across the treatments ($P = 0.78$ and $P = 0.80$, respectively). However, mean cell haemoglobin (MCH) was significantly elevated in AFB₀ (40.17pg) and ABAE1 (39.75pg) compared to CONT (36.02pg) and ABAE2 (36.97pg) ($P < 0.001$). White blood cell (WBC) counts and leukocyte differentials followed a similar trend to erythrocyte indices. Total WBC counts declined sharply in AFB₀ broilers ($7.86 \times 10^9/L$) compared to those of CONT ($10.86 \times 10^9/L$; $P = 0.04$), alongside reductions in granulocytes, lymphocytes, and monocytes. ABAE2 supplementation group experienced restoration values statistically similar to those of CONT, while ABAE1 produced intermediate improvements that did not fully match CONT values.

DISCUSSION

The declines in PCV, Hb, RBC, WBC, and leukocyte counts observed in AFB₁-treated broilers in this study are consistent with earlier findings that aflatoxicosis disrupts haematopoiesis and compromises immune competence in broiler chickens. (Rathod *et al.*, 2017; Oloruntola *et al.*, 2025). The results of this study indicate that AFB₁ exposure induced anaemia, in agreement with the report of Moregaonkar (2007) and Oloruntola (2024), who noted that AFB₁ primarily inhibits protein synthesis, and very low levels can significantly reduce haemoglobin concentration in broilers over prolonged exposure (>40 days). The decline in haemoglobin during aflatoxicosis may be attributed to impaired iron absorption coupled with suppression of haematopoiesis (Rathod *et al.*, 2017). These impairments likely stem from hepatic damage, oxidative stress, and direct inhibition of haematopoietic organs. The liver, being the primary site of AFB₁ metabolism, converts it into AFB₁-8,9-exo,epoxide, a highly reactive metabolite that causes hepatic injury, thereby impairing protein synthesis and reducing secretion of erythropoietin, the hormone responsible for stimulating red bone marrow to produce RBCs (Ekpo *et al.*, 2024). Moreover, AFB₁ promotes excessive generation of reactive oxygen species (ROS), which exert oxidative stress on developing red blood cells, damaging their membranes and compromising their haemoglobin content and nutrient transport capacity, ultimately impairing oxygen affinity (Rathod *et al.*, 2017).

The reduced total leukocyte count observed in aflatoxicosis aligns with the findings of Oloruntola *et al.*, (2025) who reported leukocytopenia in broilers toxin exposure. The reduction in WBC values at higher AFB₁ concentrations in this study may indicate emerging immune suppression, a pattern also observed by, Rathod *et al.*, (2017), Mgbeahuruike *et al.* (2018) and Oloruntola *et al.*, (2025). These authors indicated that Aflatoxin B₁ cause significant changes in WBC counts, and its exposure can progressively weaken immune function thereby making the birds susceptible to disease infection.

The reversal of these effects by AE indicates a protective role, likely attributable to its hydroxyl-rich compounds, such as flavonoids and phenols, which possess potent antioxidant and free radical scavenging properties (Ogwuegbu and Mthiyane, 2024). These bioactive components may have counteracted AFB₁-induced oxidative damage while promoting erythropoiesis and leukopoiesis. The absence of significant changes in MCHC, MCV, and MCH suggests that aflatoxicosis induced a normocytic, normochromic anaemia, in agreement with earlier reports of Oloruntola *et al.* (2025), who demonstrated a similar ameliorative effect using bitter leaf.

CONCLUSION

This present study demonstrated that dietary exposure to aflatoxin B₁ at 0.3 mg AFB₁ per kilogramme basal feed significantly impaired haematological parameters in broiler chickens by inducing anaemia, leukocytopenia, and immune suppression, primarily through hepatic damage, oxidative stress, and disruption of haematopoiesis. The administration of *Alchornea cordifolia* leaf meal (AE) at 1000 mg/L or 2000 mg/L daily drinking water ameliorated these adverse effects, likely due to its antioxidant bioactive compounds such as flavonoids and phenols, which promoted erythropoiesis and leukopoiesis while scavenging free radicals. The results therefore highlight the potential of AE as a natural dietary strategy to mitigate aflatoxicosis in poultry.

Based on the findings of this study, it is recommended that *Alchornea cordifolia* leaf meal be included in

broiler diets at 1 g/kg and 2 g/kg feed via daily drinking water, with 2 g/kg proving most effective, as a practical and safe for mitigating the haematotoxic and immunosuppressive effects of aflatoxin B₁.

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A REVIEW OF ETHNOVETERINARY MEDICINE AND ITS ROLES IN LIVESTOCK PRODUCTION

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ABSTRACT

Ethnoveterinary medicine deals with people's knowledge, skills, methods, practices and beliefs about the care of their animals which is entrenched in culture and conviction, and it is multidimensional in nature. It covers the facts people have on diseases and their control. It is a practice developed since the time of taming of animals. But the advent of modern medicine posed serious threat on its existence which regarded it as superstition and almost put it to extinction. The shortcomings associated with modern medicine such as inadequate veterinarians, high cost of drugs, development of resistance by the pathogens to the active ingredients in drugs and many others, resuscitate the utilization of this practice in livestock production. Both the prophylactic and therapeutic roles of ethnoveterinary medicine in management of animal health cannot be over-emphasized. Herbal roles in various classes of animals, different plants and plant's parts used in combating the pathogens, and specific bioactive compounds in the plants that perform various functions are elucidated in this study. Therefore, it could be concluded that ethnoveterinary medicine serves as perfect alternatives to conventional anthelmintic, antibacterial and anti-parasitic drugs, and could be used as growth promoter and curative agent of different ailments in livestock. Its use should be encouraged with better sensitization and further researches should be intensified on the doses, frequency of administration, antioxidant effects on animals, mechanisms of action, possible interactions with other chemicals of herbal alternatives and above all on consumer's preferences and prospects.

Keywords: Animal health, Ethnoveterinary medicine, Herbal, Diseases, Traditional medicine

INTRODUCTION

Livestock is vital for many financial prudence in developing countries. As much as livestock sub-sector contributes much to the national economies of sub-Saharan African countries, its enlargement is hindered by diverse limitations (Khan *et al.*, 2019). These include rampant occurrence of animal disease, which results in loss of livestock and farm productivity, reduction in market opportunity, and impairment of human welfare. This obliged development of different methods of combatting diseases. Although, since the time of domestication of livestock, herders and smallholders throughout the world have developed their own ways of treating their animals and safeguard them from the effects of disease and weather (Willis, 2017). However, with the rise of modern medicine during the last two centuries, traditional animal health care has increasingly been superseded by modern veterinary medicine. Colonization and subsequent enlargement promoted spread of convention drugs into distant rural parts in developing nations. This made local practices to be tagged as fallacy and bewitchment (Khattak *et al.*, 2015).

This opinion started to change in light of evolving hitches and shortcomings of modern medicine and the failure or lack of consistency of schemes, like failed vaccinations and peculiarities of modern medicine to the cold regions in disparity to its efficiency in the hot areas of the world. This brought an end to the era in which ethnoveterinary medicine and any other ethnoknowledge system considered with suspicion and labeling it as myth, superstition and witchcraft. Ethnoveterinary medicine deals with people's acquaintance, abilities, procedures, practices and philosophies about the care of their animals (Rahman *et al.*, 2023). Ethnoveterinary knowledge is acquired through practical experience and has traditionally been passed down verbally from generation to generation (Gobana *et al.*, 2019). Prevalent attention in authenticating and legalizing ethnoveterinary practices arose in the early 1980s. Since then, quite a lot of studies had been carried out, many reports written and numerous conferences and workshops held (Khattak *et al.*, 2015). These actions have protected ethnoveterinary awareness from extinction, this is because most knowledge resided with elderly community members and wiped out as they died. The overview of modern practices also made it difficult for the younger generations to appreciate and use the beliefs and practices of their forefathers in mitigating occurrence of diseases (Gobana *et al.*, 2019).

Regardless of current efforts to encourage the use of ethnoveterinary knowledge worldwide, considerable information is only documented in field reports and scientific publications with little implementation in

practice (Gobana *et al.*, 2019). Ethnoveterinary medicine (EVM) is very vibrant and multifunctional, and it is an antidote to variety of livestock illnesses as well as being widely available in remote areas and less expensive than synthetic medicines (Bartha *et al.*, 2015). Very little attention has been given to documentation of plants used as EVM, and this cultural reservoir is disappearing day by day in some parts of the developed world. However, in remote and underdeveloped areas of the world, the EVM is silently playing a vital role in sustainable livestock production (Gobana *et al.*, 2019). It must be acknowledged that before the advent of chemosynthetic drugs, various plants have been used in the treatment of ailments in both human medicine and animal veterinary with great testimony of recovery (Singh *et al.*, 2012). Up till today, herbs remain one of the most significant sources of medicines and most of the modern drugs used in present age are obtained from plant products (Singh *et al.*, 2012, Ayankoso, 2025). Patil and Deshmukh (2015) indicated that many livestock owners in rural areas are faced with relatively few veterinarians and shortages of other facilities, and traditional medicinal plants are the only choice to treat many ailments. Shrivastava *et al.* (2017) also reported that in many developing countries, the supply of modern veterinary drugs is constrained by scarcity, uncertain supply, and costs.

Extracts of cumin seeds have been reported to cause damage to bacteria cell membranes and loosen of the intracellular organelles in livestock. Garlic extract has been reported to have a prophylactic effect against hepatic coccidiosis in rabbits (Gobana *et al.*, 2019), the *in vitro* and *in vivo* study on the use of garlic extract in control of *Haemonchus contortus* proved effective and worked favourably in comparison with conventional albendazole with better improvement on the performance of West African Dwarf goats (Ayankoso *et al.*, 2025a; 2025b). Therefore, the aim of this study is to provide a robust review on ethnoveterinary medicine and its role in livestock production.

HISTORICAL BACKGROUND OF VETERINARY DRUG

From Materia Medica to Veterinary Pharmacology and Therapeutics, the origins of veterinary pharmacology and therapeutics are the same as those of the equivalent human disciplines (Santos *et al.*, 2019). The history of Materia Medica, and the emergence of pharmacology and therapeutics in humans have been extensively described (Maramulla *et al.*, 2019). Lopes *et al.* (2020) has provided a recent summary of both the human and parallel veterinary developments. He wrote that the early records contained:

- i. In Egyptian papyri (1800–1200 BC), the contents of which became known only from 1822 when the Rosetta stone was translated and
- ii. In writings of the Greeks (notably Hippocrates, 430 BC) and later Galen (94 AD).

Hippocrates' and Galen's recommendations is prevalent in European medicine for many periods, through the medieval ages, until it was outdated in the “Age of Enlightenment”. We can certainly conclude that the same “drugs” were used in animals and man up to and beyond the Age of Enlightenment. There was, however, at this time an expression of concern relating to the use of drugs therapeutically in animals on the basis of human experience.

ETHNO-VETERINARY HEALTH MANAGEMENT PRACTICES IN RUMINANT ANIMALS

In the rural areas where modern medicine is inaccessible to farmers, EVM is often used to expel retained placenta in livestock. According to a study carried out by Moreki *et al.* (2012), the most common traditional remedies used for retained placenta in cattle are salty water (19.05%), soap detergent solution (19.05%), *Terminalia serecea* roots (14.29%), *Spirostachys africanum* bark (9.52%) and *Burkea africanum* bark (9.52%). Some other herbal plants include *Ziziphus mucronata*, *Peltophorum africanum*, *Elephantorrhiza elephantina*, *Pouzolzia mixta*, *Dicerocaryum eriocarpum*, *Asparagaus spp.*, *Hermania guerkeana*, *Ozoro apaniculosa*, *Scadoxus spp.* and *Boscia albitrunca*. Kubkomawa *et al.* (2020) reported that medicinal herbs are potential sources of therapeutics aids which played a significant role in health system all over the world for both humans and animals not only in the diseased condition but also as potential material for maintaining proper health. Moreki *et al.* (2012) stated that the predominant tree species appeared to be *T. serecea*, *S. africanum*, *P. africanum* and *Z. mucronata* and that *S. africanum* was facing extinction, indicating that conservation may be inevitable. The remedies were given either solely or as mixtures and administered either as a decoction or infusion.

Moreki *et al.* (2012) reported that the common plant parts used for treatment of retained placenta were barks

(57.14%), roots (40.48%) and bulbs (11.90%). Kubkomawa *et al.* (2020) reported that the parts of plants used for medicinal purposes by livestock producers were roots (59%), leaves (26%) and whole plant (13%). Furthermore, the authors also stated that parts and products of animals such as skins and hides, bones, milk, butter and even urine and dung are ingredients of EVM. Salty water, as reported by Koloka and Moreki (2011), in Kenya apart from being used as a tanning agent, is also used for medicinal purposes in both livestock and humans. *E. elephantine* is also used for medicinal purposes in both livestock and humans whereas the roots are used for high blood pressure (Kubkomawa *et al.*, 2020). Similarly, *E. elephantine* is a traditional remedy for a wide range of ailments both in humans and livestock. In goats, it is used by farmers in the Eastern Cape Province (South Africa) to control helminthes (Okoli *et al.*, 2010). Kubkomawa *et al.* (2020) reported that a decoction of *T. serecea* roots is administered orally to a cow suffering from a retained placenta and or internal parasites. Moreki *et al.* (2012) mentioned that a hot infusion of the roots' outer layers is used to make a fermentation for treating pneumonia, while a decoction of the roots is used to cure diarrhoea and relief colic. The roots of *P. mixta* are used for retained placenta (Okoli *et al.*, 2010) while Maphosa *et al.* (2010) reported that the leaves of *P. mixta* are used instead. These authors noted that *P. mixta* leaves are crushed to produce a slippery paste that is inserted in to the animal's vagina in order to stimulate the expulsion of the retained placenta. They also stated that *P. africanum* is widely used medically as the bark and roots contain tannins. In addition, powdered debarked roots are used as local application for wounds, diarrhea and dysentery.

The root of *P. africanum* is used to promote the fertility of cattle (Okoli *et al.*, 2010). It is suggested that the plants with multipurpose uses may contain more than one type of physiologically active ingredients (Chah *et al.*, 2009). According to Moreki *et al.* (2012), *B. albitrunca* was identified as one of the plants used for the treatment of retained placenta in cattle. *B. albitrunca* leaves are used in folk medicine for the treatment of inflamed and infected umbilical cords in Nigeria (Moreki *et al.*, 2012). Additionally, cold infusion of *B. albitrunca* leaves is applied as a lotion to the inflamed eyes of cattle while a decoction of the roots provides a treatment for haemorrhoids (Moreki *et al.*, 2012).

ETHNO-VETERINARY HEALTH MANAGEMENT PRACTICES IN MONOGASTRIC ANIMALS

Rural poultry farmers are aware of the need to keep birds in good health and when they are sick to seek for prescription and procure medicine for treating rural poultry diseases and parasites. A study by Mapiye and Sibanda (2005) has shown that large number of farmers gives traditional medicine to chickens indicating that traditional medicines in some instances have potential to improve the health status of rural household flocks. The major plant used by the rural chicken farmers for the treatment of rural chickens against Newcastle Disease (ND) are mahogany (*Khaya senegalensis*) bark/roots (25.1%), wild garden egg (*Solanum nodiflorum*) (20.3%), bitter leaf (*Vernonia amygdalina*) (7.8%) and pepper (*Capsicum frutescens*), as the main sources of remedies (Musa *et al.*, 2008) while ash is applied to domestic birds infested with mites and lice (Moreki *et al.*, 2012).

It was also observed that 2% of the farmers employed the use of white maggi (*Monosodium glutamate*), which they usually soak in water and administer to chickens orally for the treatment of ND (Moreki *et al.*, 2012). Their findings also revealed that about 50.16% of the farmers obtained prescription and medicine for the treatment of ND in chicken from ethno-veterinary sources, 29.40% from modern veterinary services, 9.74% from pharmaceutical shops and 10.71% from open shops/markets. In Nigeria, studies have shown that ND is endemic in both rural and commercial poultry with epidemic outbreaks being recorded in highly susceptible flocks (Okoli *et al.*, 2010). Traditional remedies are reported to be much more easily and readily obtained and affordable (Maphosa *et al.*, 2010). Some plants influence the immune system and/or are effective against internal and external parasites (Maphosa *et al.*, 2010). Anthelmintic and anti-protozoan properties of *Khaya senegalensis*, *Vernonia amygdalina* and *Solanum nodiflorum* have been reported by Moreki *et al.* (2012).

The practice of sourcing for medicine through the traditional method is mostly and popularly adopted by rural farmers for treatment of birds. It may not be perfect enough to ensure good health due to poor knowledge and understanding of the etiology and pathology of poultry disease by the farmers. Hence, they may succeed in treating the observable symptoms of the disease without dealing with the actual cause (Kubkomawa *et al.*,

2020). Dosages are imprecise as most of the remedies are soaked in water without regard to quantity of the remedy or volume of water used. This may expose the birds to dangers of over or under dosing and may lead to kidney or liver damage. These remedies used by rural farmers in the study may or may not have direct effect on ND virus, but could affect protozoan and helminth parasites of rural poultry by reducing the parasites burden, and boosting the immunity of the birds against infection (Kubkomawa *et al.*, 2020). As a result, extension services are required in educating rural farmers in matters relating to the use of appropriate medicaments and adopting new technologies for improving rural household chicken production and disease control. Moreki *et al.* (2012) have recommended extension services and community participation for the successful adoption of the oral feed vaccine for the control of Newcastle Disease (ND) in rural areas.

PLANT PHYTOCHEMICALS AND THEIR ROLES IN ANIMAL PRODUCTION

Medicinal plants contain secondary metabolites which possess various biological properties. The phytochemicals function in various ways, they hinder the functional processes in microbes like bacteria and worms, and also provide clinical means of treating infections (Oliveira *et al.*, 2019). The phytochemical efficacy of plants on *Haemonchus contortus* have been the current study embarked upon by researchers. The phytochemical screening of divers' plants revealed several components like phenol, alkaloids and tannins with anthelmintic property which demonstrated a complete destruction of L3 larva stage when present in higher concentration (Davuluri *et al.*, 2020). Plant secondary metabolites possess anthelmintic potentials which is influenced by their structure, quantity of intake and abundance in the digestive tracts of animals especially ruminants but when consumed in higher proportion it can have adverse effect in well-being and survivability of herbivores because of the antinutritional compounds present (Athanasiadou and Kyriazakis, 2004). Numerous phytochemicals found in forages with their bioactive properties have vital roles to perform in wellness of animals, most essentially small ruminants (Kearney *et al.*, 2016). Tannins reduces available protein in the feed, deactivate gastrointestinal microbes as well as cause irritation of intestinal tract (Kearney *et al.*, 2016). Anthocyanins performs medicinal purpose because of their adaptable free radical potentials (Khalid *et al.*, 2019) while flavonoid and carotenoid display antioxidant value (Graf *et al.*, 2005).

They are responsible for medicinal activities, in case of tannins when extracted from plants, it has displayed anti-parasitism and antibacterial properties (Kumar *et al.*, 2010) while Saponins have anthelmintic, antidiarrhoeal and anticancer properties. Glycosides and Steroids obtained from plant extracts have proved to be antidiarrhoea in their activities (Tiwari *et al.*, 2011). Flavonoid obtained from herbs demonstrated antidiarrhoea and anti-bacterial actions (Vidyadhar *et al.*, 2010). *In vitro* studies of extracts containing high level of polyphenol contents showed high efficacy of the extract against *Haemonchus contortus* (Castaneda-Ramirez *et al.*, 2017). The assessment of bioactive compounds in extracts had shown the presence of alkaloids, tannins, amino acids, and had been suggested to have been accountable for the anthelmintic effects noticed in a trial conducted by Davuluri *et al.* (2020). Many sulphur-rich compounds found in biochemical screening of *Allium sativum* could be associated to best significant reduction of *H. contortus*. This phenol, in conjunction with other bioactive compounds present such as 2,5-Furandicarboxaldehyde, 2,5-Furandione, 3-methyl-, 1H-Imidazole, 2(5H)-Furanone and (E)- 2,5-Furandione, 3-methyl-, and 1-(3,3-dimethyloxiranyl) Homopiperazine might be responsible for the restriction in growth and survival of the eggs due to their antioxidant, anthelmintic and antimicrobial properties by the principle of dehydration (Ayankoso *et al.*, 2025a)

CONCLUSION AND RECOMMENDATION

Conclusion

It could be concluded that the ethnoveterinary medicine plays vital roles as herbal natural feed additives as well as alternatives to conventional anthelmintic, antibacterial and antiparasitic drugs. Moreso, it could be used as growth promoter and curative agent of different ailments in all classes of livestock.

Recommendation

It could be recommended that ethnoveterinary medicine in livestock should be encouraged, and better sensitization should be given to its use. Moreso, further researches should be intensified on the recommended therapeutic doses, frequency of administration, and antioxidant effects on animals.

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PHYTOGENIC ADDITIVES *IN* BROILER NUTRITION: THE ROLE OF AVOCADO SEED MEAL

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ABSTRACT

Poultry production plays a pivotal role in global food security, contributing nearly 40% of total meat output and serving as an affordable protein source. However, rising feed costs, driven by competition for ingredients and climate-related shortages, present significant challenges to sustainable broiler production. Feed restriction and phytogetic feed additives have emerged as innovative strategies to enhance feed efficiency, reduce costs, and improve broiler health and performance. Controlled feeding methods, including quantitative restriction, skip-a-day feeding, and low-energy diets, have been shown to decrease fat deposition, improve feed conversion ratio, and reduce incidences of metabolic disorders without compromising final body weight. Concurrently, phytogetic additives derived from herbs, spices, and seeds have demonstrated growth-promoting, antioxidant, and antimicrobial properties, positioning them as viable alternatives to synthetic growth promoters. Seed meals, particularly avocado seed meal (ASM), represent an underutilised resource with significant nutritional potential. Rich in protein, fibre, bioactive compounds, and essential fatty acids, ASM has been shown to enhance growth performance, immune function, gut health, and meat quality in broilers, while also reducing production costs. However, anti-nutritional factors such as tannins, phytates, and enzyme inhibitors necessitate appropriate processing methods to optimise its benefits. Current literature highlights the promise of integrating feed restriction with avocado seed meal supplementation as a cost-effective and sustainable feeding strategy, though research on their synergistic effects remains limited. Further studies are required to elucidate optimal inclusion levels, processing methods, and long-term impacts on broiler health, productivity, and economic efficiency.

Keywords: Poultry production, feed restriction, Phytogetic additives, Avocado seed meal, Broiler performance

INTRODUCTION

Poultry production has become one of the fastest-growing livestock sectors worldwide, providing a reliable and affordable source of animal protein to meet the dietary needs of an expanding global population. Poultry meat alone contributes nearly 40% of total meat output globally, with annual production increasing from 9 million tonnes in 1961 to 363 million tonnes by 2024 (Nkukwana, 2018). In developing nations such as Nigeria, poultry is particularly important due to its relatively short production cycle, affordability, and adaptability to small- and large-scale systems (Nkukwana, 2018). Beyond meeting nutritional needs, the poultry industry contributes significantly to rural livelihoods, employment, and national economies (Alabi et al 2020).

Despite these advantages, the sector faces persistent challenges, the most critical being high feed costs, which account for approximately 70% of production expenses (Alhotan, 2021). Reliance on conventional feedstuffs such as maize and soybean meal intensifies competition between humans and livestock for resources, raising concerns about sustainability (Abro *et al.*, 2020). Climate variability further exacerbates feed shortages, while disease outbreaks, high chick mortality, and limited access to credit hinder the resilience of the poultry sector in Nigeria and across sub-Saharan Africa (Mappigau and Amar, 2020). These issues underscore the need for innovative and cost-effective feeding strategies that maintain productivity while ensuring profitability.

Among the strategies gaining prominence are feed restriction programmes and the use of phytogetic feed additives. Feed restriction, through quantitative or qualitative methods, regulates feed intake to enhance feed conversion efficiency, minimise metabolic disorders, and improve carcass quality (Amicarelli *et al.*, 2021). Phytogetics, derived from herbs, spices, and seeds, are increasingly recognised for their antimicrobial, antioxidant, and immunomodulatory properties, offering residue-free alternatives to synthetic growth promoters (Ganai *et al.*, 2022). Within this category, seed meals represent underutilised but nutrient-rich feed resources that align with sustainability goals.

Avocado seed meal (ASM), a by-product of avocado (*Persea americana*) processing, has attracted interest as a potential feed ingredient in broiler diets. Rich in proteins, fibre, unsaturated fatty acids, vitamins, minerals, and bioactive compounds, ASM has demonstrated benefits for growth performance, gut health, and meat quality in poultry (George *et al.*, 2020; Adelowo *et al.*, 2024). Importantly, its use contributes to waste reduction and circular economy principles by valorising a major fruit-processing by-product. However, the presence of anti-nutritional factors such as tannins and phytates necessitates proper processing to optimise its nutritional value (Runyogote *et al.*, 2021).

This review synthesises current knowledge on poultry production challenges, feed restriction methods, and the use of phytogenic feed additives, with a specific focus on avocado seed meal. It highlights the nutritional potential, functional properties, and limitations of ASM, while identifying research gaps on its integration with feed restriction strategies for sustainable broiler production.

REVIEW

Poultry production and feed challenges

The success of commercial poultry production depends heavily on efficient nutrient supply. Broiler chickens, bred for rapid growth, require carefully balanced diets rich in energy, protein, amino acids, vitamins, and minerals (Bailey, 2020). Essential amino acids such as methionine and lysine are critical for protein synthesis and feather growth, and deficiencies can lead to poor weight gain and feed efficiency (Chen *et al.*, 2020). Energy requirements are also high, as broilers convert dietary energy into rapid muscle accretion. Any imbalance in nutrient supply can therefore negatively affect growth performance, feed conversion ratio (FCR), immune competence, and overall profitability.

Feed costs, driven primarily by competition for maize and soybean meal, remain the greatest constraint to profitability, accounting for up to 70% of total production expenses (Alhotan, 2021). Global volatility in crop markets, coupled with climate variability, has further increased the unpredictability of feed ingredient availability and price. In Nigeria, these challenges are compounded by poor extension services, high disease prevalence, lack of access to affordable veterinary inputs, and infrastructural deficits that increase the cost of transporting feed ingredients (Mappigau and Amar, 2020). In some cases, feed adulteration and inadequate quality control in the feed industry exacerbate production inefficiencies, as farmers unknowingly supply nutritionally imbalanced rations to their flocks.

Beyond economic constraints, modern poultry producers also face increasing consumer demand for meat and eggs that are organic, residue-free, and produced with minimal environmental impact. This has pressured the industry to reduce reliance on synthetic growth promoters, antibiotics, and genetically modified feed ingredients (Nkukwana, 2018). At the same time, the need to improve feed efficiency and reduce the environmental footprint of poultry farming particularly nitrogen and phosphorus excretion has become an important sustainability goal (Alagawany *et al.*, 2021).

Feed restriction in broiler production

Feed restriction refers to limiting feed intake either quantitatively (reducing feed allowance) or qualitatively (reducing nutrient density). The practice has been widely explored as a strategy to lower feed costs, reduce mortality, and improve feed efficiency (Ebeid *et al.*, 2022). Quantitative and qualitative feed restriction are methods used to control the feeding parameters of poultry to reduce growth and metabolic rate to some degree, so reducing the occurrence of certain metabolic diseases and enhancing feed conversion in broiler chickens. The strategies encompass physical feed restriction, control of feed intake by skip-a-day feeding or reducing feeding illumination time, meal dilution, chemical feed restriction methods, and use of low protein or low energy diets (Karaarslan *et al.*, 2024). Each method has unique impacts on bird physiology and performance (Ebeid *et al.*, 2022). For instance, early feed restriction often leads to compensatory growth, where birds restricted in the starter phase achieve comparable final body weights to unrestricted counterparts (Gobane *et al.*, 2021). Moreover, feed restriction reduces abdominal fat deposition, improves feed conversion ratio (FCR), and lowers the incidence of metabolic disorders such as ascites (Bilal *et al.*, 2021).

However, results vary depending on the degree and timing of restriction. According to Gobane *et al.* (2021)

excessively severe restriction can delay market readiness and reduce carcass yield. Careful management is therefore essential to balance economic benefits with animal welfare.

Phytogenic feed additives in poultry nutrition

Phytogenics, derived from herbs, spices, and seeds, have received considerable attention as natural growth promoters. Their bioactive compounds including phenolics, alkaloids, terpenoids, and flavonoids are associated with antioxidant, antimicrobial, and immunomodulatory activities (Ganai *et al.*, 2022).

In broilers, phytogenic additives have been reported to improve gut health by modulating microbiota composition, enhancing nutrient absorption, and reducing pathogenic load (Upadhaya and Kim, 2017). For example, oregano and garlic extracts have demonstrated antibacterial properties that enhance growth performance and meat quality (Akande *et al.*, 2022). Furthermore, phytogenics improve oxidative stability, thereby extending shelf life of poultry meat (Orlowski *et al.*, 2018).

Despite their potential, the efficacy of phytogenics is influenced by plant type, dosage, and method of processing. Standardisation of phytogenic products and understanding their interactions with diet remain important research areas (Oloruntola *et al.*, 2020).

Seed meals as alternative feed resources

Seed meals, often by-products of oil extraction, are being explored as alternative protein sources for poultry. Soybean meal remains the most widely used, but rising costs and availability issues have stimulated interest in underutilised seeds such as papaya, cottonseed, and moringa seed meals (Kumar *et al.*, 2024).

These by-products offer essential nutrients including proteins, amino acids, fatty acids, vitamins, and minerals, while also contributing to sustainable waste utilisation (Bhat, 2021). Studies show that properly processed seed meals enhance growth performance, nutrient digestibility, and carcass yield in broilers (Onyimonyi and Okeke, 2022). However, their widespread adoption requires addressing anti-nutritional factors such as tannins and phytates through processing technologies.

Avocado seed meal in broiler nutrition

Avocado (*Persea americana*) processing generates large quantities of seeds, which account for nearly 13–18% of the fruit's weight and are often discarded as waste (Araújo *et al.*, 2018). These seeds contain proteins (8–15%), dietary fibre (10–70%), unsaturated fatty acids, and bioactive compounds such as flavonoids, phenolics, and saponins (Oboh *et al.*, 2019).

Research on avocado seed meal (ASM) inclusion in poultry diets has shown promising results. Broilers fed diets supplemented with ASM displayed improved weight gain, enhanced immune response, reduced oxidative stress, and improved gut morphology (George *et al.*, 2020; Adelowo *et al.*, 2024). Furthermore, ASM reduced production costs by partially replacing conventional protein sources (Alabi *et al.*, 2020).

However, ASM contains anti-nutritional factors including tannins, oxalates, and phytates, which can impair nutrient absorption (Bahru *et al.*, 2019). Processing methods such as drying, fermentation, and enzymatic treatment reduce these compounds and improve nutrient availability (Runyogote *et al.*, 2021; Bayomy *et al.*, 2023). The extent to which ASM can be safely included in broiler diets remains a subject of ongoing research, with studies suggesting inclusion levels of up to 8% are beneficial without adverse effects.

Integrating Feed Restriction and Avocado Seed Meal

Both feed restriction and ASM supplementation independently offer benefits for poultry production. Feed restriction reduces feed costs and improves efficiency, while ASM enhances growth performance, immune function, and meat quality (Salim *et al.*, 2018). According to Falowo *et al.* (2025) integrating these strategies could create a cost-effective and sustainable feeding approach that addresses multiple production challenges simultaneously.

However, studies on their combined use remain scarce. Critical gaps include determining optimal inclusion

levels of ASM under restricted feeding regimes, assessing long-term health impacts, and evaluating economic feasibility in large-scale production. Future research should also examine the effects of processing methods on ASM efficacy in restricted feeding systems.

CONCLUSION

The review underscores the importance of feed management strategies and alternative feed resources in sustainable poultry production. Feed restriction improves feed efficiency and reduces metabolic disorders, while phytogenic additives, particularly avocado seed meal, offer nutritional and functional benefits that support bird health and performance. The integration of these approaches holds promise for reducing production costs and enhancing sustainability. However, more empirical studies are required to establish optimal practices and clarify synergistic effects. Addressing these gaps could strengthen the resilience of the poultry industry, particularly in regions facing persistent feed challenges.

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DOMESTICATION OF *PTERNISTIS* AND *FRANCOLINUS* SPECIES AS POTENTIAL POULTRY SPECIES: A REVIEW

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ABSTRACT

Domestication of game birds offers novel solutions to food security, conservation of genetic resources, and improvement on poultry production. African bush fowl, which includes several species commonly known as francolins (*Francolinus*) or spurfowls (*Pternistis*), are known for their ecological adaptability and high nutritional potentials. However, contentious taxonomy and limited genetic data have historically obscured their potential in poultry production. This review evaluated current taxonomic discoveries, genetic diversity, nutritional and production attributes and domestication prospects of the species. Findings revealed prospects and challenges of integrating these game birds into structured poultry breeding programmes. Therefore, recommendations to advocate for sustainable production based on proper taxonomy, broader genetic and ecological studies, awareness, and pilot domestication trials are encouraged.

Keywords: African bush fowl, Domestication, Food security, *Francolinus*, *Pternistis*,

INTRODUCTION

The global rise in demand for animal protein has stimulated interest in the exploration of underutilized wild avian species with domestication potential (Boland *et al.*, 2013). In sub-Saharan Africa, where persistent food insecurity and protein malnutrition remain critical concerns, the search for alternative poultry species has intensified (FAO, 2019). Traditional poultry systems dominated by chickens and turkeys face increasing challenges such as disease outbreaks, climatic stress, and limited adaptability to diverse agro-ecological conditions (FAO, 2019). This has necessitated a paradigm shift toward locally adapted, genetically diverse, and ecologically resilient species.

Among the promising candidates are the spurfowls (*Pternistis*) and francolins (*Francolinus*) which are endemic galliforms with wide distribution across African landscapes. These birds have long been hunted and consumed in rural communities, valued for their flavourful meat and adaptability to natural environments (Oluwayelu *et al.*, 2014). Their reproductive traits, such as early sexual maturity, high hatchability, and tolerance to low-input management systems, make them particularly suitable species for integration into smallholder-based poultry production (Aro and Akinmoladun, 2015).

However, despite their agronomic and nutritional promise, these species remain underutilized in formal breeding programs. A major barrier to their domestication is the unresolved taxonomic status within the group (Hunter *et al.*, 2021). Historically classified under both *Francolinus* and *Pternistis*, recent taxonomic revisions have proposed collapsing all African spurfowls into the genus *Pternistis*, reducing recognized subspecies from 59 to 16 (Mandiwana-Neudani *et al.*, 2019a). While these changes aimed to clarify relationships, they have attracted criticism for methodological weaknesses, such as inadequate molecular sampling and arbitrary morphological scoring (Hunter *et al.*, 2021; Hustler, 2024). These taxonomic inconsistencies complicate conservation, ecological monitoring, and domestication strategies.

This review, therefore, synthesized the current understanding of the evolutionary history, genetic structure, nutritional and production values and ecological suitability of *Pternistis* and *Francolinus* species. Drawing

on recent global data, and outlined case for their domestication and recommendations to guide future research and policy interventions.

TAXONOMIC CHALLENGES AND IMPLICATIONS FOR DOMESTICATION

Taxonomy forms the foundation of species conservation and breeding strategies (Mandiwana-Neudani *et al.*, 2019b). The taxonomic classification of African bush fowls has long been fraught with confusion, largely due to overlapping morphological features and underrepresentation in molecular datasets (Hunter *et al.*, 2021). Historically, these birds were classified under *Francolinus*, but newer revisions advocate their inclusion in a broader *Pternistis* genus, as indicated in the work of Mandiwana-Neudani *et al.* (2019a), who consolidated spurfowls into a single genus and reduced recognized subspecies from 59 to 16.

This reclassification was primarily based on mitochondrial DNA and morphological observations (Hustler 2024). However, researchers such as Hunter *et al.* (2021) and Hustler (2024) criticized these revisions for lacking comprehensive continental sampling and for applying inconsistent character weighting, arguing that such restructuring could obscure true biodiversity and misinform conservation and domestication programs.

In practical terms, these taxonomic uncertainties pose significant challenges for domestication (Hunter *et al.*, 2021). For instance, farmers and researchers may misidentify species, leading to unintentional hybridization, genetic incompatibility, or misaligned breeding goals. Thus, a clear and universally accepted taxonomy based on integrative approaches combining morphology, mitochondrial and nuclear DNA is crucial for the successful domestication of these species.

GENETIC DIVERSITY AND DOMESTICATION POTENTIAL

Understanding genetic diversity is vital for selecting and breeding suitable domestication candidates (Mohapatra *et al.*, 2019). In avian species, high genetic diversity ensures adaptability, resilience to disease, and productive traits (McLaughlin *et al.*, 2020). Genetic studies using mitochondrial DNA, particularly cytochrome b (CYTB), provide insights into evolutionary relationships and potential domestication lineages (Feng *et al.*, 2020; Muhammad, 2025).

Muhammad (2025) study on African bush fowls in Southwestern Nigeria using CYTB sequences for phylogenetic analysis revealed diverse lineages within the sampled population. *Francolinus francolinus* was the most represented species, alongside *F. gularis* and *Pternistis bicalcaratus*. Notably, *P. bicalcaratus* exhibited the highest sequence similarity, marking it as genetically distinct and well-adapted—an ideal candidate for domestication. Other samples revealed moderate-to-high divergence, suggesting a pool of genetic variation valuable for breeding resilience and productivity.

COMPARATIVE DOMESTICATION WITH OTHER GALLIFORMS

Domestication of avian species within the order Galliformes has historically followed pathways where species exhibited traits such as high fecundity, adaptability to captivity, and nutritional value. The domestication of the red junglefowl (*Gallus gallus*), for example, gave rise to the domestic chicken, the most widespread poultry species globally (Romanov and Weigend, 2001). Similarly, the Japanese quail (*Coturnix japonica*) was domesticated from its wild counterpart in East Asia and is now widely used both for meat and egg production due to its small body size, rapid growth, and high egg yield (Feng *et al.*, 2020). In Africa, the helmeted guinea fowl (*Numida meleagris*) represents another successful domestication, integrated into traditional and commercial poultry systems because of its resilience to harsh environments and its cultural significance (FAO, 2019).

When compared with these established Galliforms, African spurfowls and francolins (*Pternistis* and *Francolinus spp.*) exhibit parallel traits, including early sexual maturity, high hatchability, and adaptability to semi-wild rearing systems (Aro and Akinmoladun, 2015). Moreover, their superior meat and egg quality (Onyenekwe, 1988; Cagr *et al.*, 2014) mirrors the consumer appeal that enabled quail and guinea fowl to penetrate both local and international markets. The main difference lies in their limited research exposure and unresolved taxonomy, which have prevented them from being systematically integrated into domestication programs (Hunter *et al.*, 2021). Thus, lessons learned from the domestication of chickens, quails, and guinea

fowls can guide pilot domestication of bush fowls by emphasizing selective breeding, controlled captive adaptation, and farmer engagement.

Behavioural Ecology and Domestication Barriers

The behaviour of wild species represents a critical determinant of their suitability for domestication. Bush fowls, like many galliforms, exhibit territoriality, strong flight response, and seasonal breeding cycles that complicate adaptation to captivity (Mandiwana-Neudani *et al.*, 2019a). For example, *Pternistis bicalcaratus* forms monogamous breeding pairs and is highly territorial, unlike the polygamous breeding behavior of chickens which has facilitated intensive production systems (Hustler, 2024). Additionally, wild francolins exhibit clutch sizes of 6–10 eggs, which is lower than the prolific laying capacity of domestic chickens and quails (Forcina *et al.*, 2012).

Another major barrier is aggression under confinement. Field observations indicated that male francolins and spurfowls engage in combative displays that can cause injury or mortality in captivity (Hunter *et al.*, 2021). Similarly, fear responses—such as frantic flight in enclosed spaces—may result in stress-induced weight loss or egg suppression. Overcoming these behavioral limitations requires strategies such as progressive semi-domestication, where wild birds are first raised in large enclosures mimicking natural habitats before gradual introduction into controlled farm environments (Dave *et al.*, 2021). Selective breeding over successive generations may also reduce aggression and increase docility, as demonstrated in the domestication of guinea fowl and Japanese quail (Romanov and Weigend, 2001).

Nutritional and Production Attributes

The African bush fowls, particularly *P. bicalcaratus*, exhibit several agronomically desirable traits that recommend them for domestication (Aro and Akinmoladun, 2015). Studies show that this species demonstrates early sexual maturity between 10 and 18 weeks, high hatchability rates (up to 100%), and a relatively low feed intake (1.25 kg per bird) for a cumulative weight gain of over 305 g, translating to a feed conversion ratio (FCR) of 4.10 (Aro and Akinmoladun, 2015).

In terms of nutritional profile, both the meat and eggs of bush fowls are superior to those of domestic chickens. The eggs have higher protein content and micronutrient density (Cagr *et al.*, 2014), while the meat is reported to be richer in protein, more flavorful, and more palatable (Onyenekwe, 1988). These attributes not only enhance consumer acceptance but also position the birds as premium products in niche and gourmet markets.

Furthermore, bush fowls are noted for their remarkable resilience to environmental stress and common poultry diseases such as Newcastle Disease and Infectious Bursal Disease Virus—offering a significant advantage over exotic breeds like chickens and turkeys, particularly in tropical regions where veterinary infrastructure is limited (Oluwayelu *et al.*, 2014). Thus, they align with low-input, organic, or semi-intensive poultry systems favored in rural and peri-urban Nigeria.

Health, Immunogenetics, and Disease Resistance

One of the most promising attributes of African bush fowls is their natural resilience to poultry diseases, which represents a significant advantage in tropical farming systems. Oluwayelu *et al.* (2014) reported the presence of antibodies against Newcastle Disease Virus (NDV) and Infectious Bursal Disease Virus (IBDV) in double-spurred francolins (*F. bicalcaratus*) in Nigeria, suggesting prior exposure and survival, unlike commercial poultry breeds that often require strict vaccination regimes. This resilience is consistent with the ecological adaptability of bush fowls in diverse African landscapes.

From a genetic standpoint, the Major Histocompatibility Complex (MHC) is central to disease resistance in poultry. Studies in chickens have shown that MHC polymorphisms are directly linked to resistance against Marek's disease, NDV, and avian influenza (Feng *et al.*, 2020). While MHC diversity has not yet been characterized in *Pternistis* and *Francolinus*, their demonstrated survival under endemic disease pressures strongly suggests unique immunogenetic adaptations. Investigating these genetic mechanisms could provide novel alleles for breeding disease-tolerant poultry populations.

Furthermore, integrating African bush fowls into poultry systems may reduce the dependence on intensive veterinary inputs, particularly in low-input, smallholder farming contexts common in sub-Saharan Africa (FAO, 2019). Their resistance also offers potential benefits for organic farming systems, where synthetic veterinary drugs are restricted. However, without structured domestication programs, these genetic resources risk being lost due to habitat degradation and overhunting (Salami and Akinyele, 2018).

Ecological Suitability and Conservation Considerations

Southwestern Nigeria, with its tropical rainforest biome, represents a biodiversity hotspot and a natural repository for wild avian species, including the African bush fowls. This region is identified as one of the most complex and genetically rich ecosystems in West Africa with diverse flora and relatively intact ecosystems offer ideal habitats for these ground-dwelling birds (Salami and Akinyele, 2018).

However, this ecological wealth is under constant threat from habitat degradation, deforestation, and urban encroachment (Salami and Akinyele, 2018). Without proper conservation strategies, wild populations of *Pternistis* and *Francolinus* may dwindle, thereby losing valuable genetic material needed for breeding and adaptation.

Domestication, when implemented responsibly, can serve a dual role as both a food security strategy and a conservation tool (Dave *et al.*, 2021). By ex-situ conserving genetically unique lineages under managed breeding programs, populations can be safeguarded from extinction, as demonstrated in similar efforts with species like the Japanese quail (*Coturnix japonica*) and red junglefowl (*Gallus gallus*) (Romanov and Weigend, 2001).

Moreover, ecological studies and DNA-based species identification can help revise current distribution maps and account for changes arising from climate shifts, human intervention, or species range expansion (Forcina *et al.*, 2012; Mandiwana-Neudani *et al.*, 2019b). These efforts are essential for understanding species ecology, informing breeding protocols, and aligning domestication with sustainable use goals.

Challenges to Domestication

Despite their potential, domestication of bush fowls faces practical and scientific barriers, some of which are: taxonomic ambiguity, lack of genomic resources, behavioural limitations, and limited research funding. Addressing these challenges requires interdisciplinary collaboration among geneticists, bioinformatics, ecologists, and poultry scientists, alongside government and institutional support.

Conclusion

The domestication of *Pternistis* and *Francolinus* species holds immense potential for enhancing food security, biodiversity conservation, and rural livelihoods in Africa. Despite lingering taxonomic and genetic uncertainties, evidence from Southwestern Nigeria indicates that these species—especially *P. bicalcaratus* are viable candidates for sustainable poultry development. With targeted research, genetic validation, and institutional backing, African bush fowls can transition from wild fowl to future poultry staples.

Recommendations and Future Directions

Sequel to the importance of African bush fowl species, and essentially for successful domestication, the following recommendations should be considered:

Proper taxonomy: The varying species should be properly identified combining molecular, morphological, and ecological data;

- (i) **Genetic and bioinformatic studies:** There should be more advanced genetic studies on African bush fowl species on their identification of their adaptive traits and employing high-throughput sequencing to generate their complete genomes;
- (ii) **Pilot domestication trials:** Breeding colonies in controlled environments could be established for more study the species behavior, nutrition, and adaptability;
- (iii) **Integration into national livestock plans:** African bush fowls should be integrate into poultry diversification and food security strategies for sustainability;
- (iv) **Creation of farmer awareness:** Awareness should be promoted whereby farmers will be educated of the species identification, husbandry, and value chain.

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COMPARATIVE LINEAR BODY MEASUREMENTS AND GROWTH PERFORMANCE OF COBB AND ARBOR ACRE BROILER CHICKENS AT THE STARTER PHASE

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ABSTRACT

This study investigated the comparative growth performance and linear body measurements between Cobb 500 and Arbor Acre broiler chickens during 28-day starter phase. A total of twenty-five day-old chicks of each breed were randomly distributed into 3 replicates (8,8,9) each; comprising 25 Cobb and 25 Arbor Acre. Both breeds were fed *ad-libitum*, vaccinated, and other brooding measures were adhered to at the same environment. Data on feed intake and body weight gained were taken, to analyse the growth parameters, feed conversion ratio (FCR), and feed efficiency (FE). Furthermore, data on body measurements were taken and analyzed through the use of Descriptive analysis and Multivariate procedure (MANOVA) using Statistical Package for the Social Sciences (SPSS) viz; Beak length (BL), Body length (BH), Breast length (BRL), Breast width (BRW), Right wing length (RWL), Shank length (SL), Shank circumference (SC), and Back length (BL). The study revealed that the RWL was significantly different between Arbor Acres and Cobb at Starter Phase. Both breeds had non-significant ($P > 0.05$) advantage in FCR, FE and Weight gained. The findings suggested that farmers can reliably select either breed for consistent production results, though Arbor Acre may offer a insignificant advantage over cobb 500 in FCR.

Keywords: Broiler, FCR, Body measurements and Feed Efficiency

INTRODUCTION

Poultry production is one of the most popular sectors of animal production where people of different tribes and culture get themselves involved with the sole aim of reducing or eliminating protein deficiencies at the global level (Adene and Oguntade 2006). Poultry breeders have documented several attempts at genetic improvement, with differing degrees of success, some of which have led to breeding and genetics approach that produces new breed of chickens (Olayinka *et al.*, 2025). To meet the global increasing demand for poultry products, new strains of broiler are developed for faster growth rate and carcass quality (Olawumi *et al.*, 2012). Broiler production is the largest agricultural revenue generator and has grown due to consumer's demand for affordable poultry meat source, therefore commercial broiler chicken is bred to be fast-growing in order to gain more weight. Broiler; a white meat chicken is documented to be superior to red meat because of its comparatively low-fat content and low cholesterol level (Sam *et al.*, 2010).

Cobb 500 and Arbor Acre, are known for their quick growth and high meat yield (Sam and Okon, 2022). Lee and Summer (2001) reported that Cobb chicks are known for having strong legs to support their weight and for producing plenty of breast meat, which is valuable in markets. They tend to eat more feed than some other breeds, which can help them grow, provided, a good quality feed. They can handle different environments, from small farms to big commercial operations. Farmers prefer raising broiler because they stay healthy even in tough conditions, like hot weather or crowded pens (Adene and Oguntade, 2006). Arbor Acre does well in different climates, including hot areas like Africa or Asia. Farmers in these places often choose them because they keep growing even when it is warm (Adebambo *et al.*, 2010; Olawumi and Fagbuaro, 2011). Arbor Acre chicks develop strong bodies with big breast muscles, making them a good choice for markets that want high-quality meat. They are also calm, which makes them easier to manage in large groups.

The growth and carcass yield of broiler chicken is of primary concern to the producers and consumers. Growth performance (body weight, weight gain, and feed intake and feed conversion ratio etc) and linear conformant depend on strain, nutrition, age, sex and management of the birds (Samacula *et al.*, 2011). Therefore, the objective of the research was to compare differences in the growth rate and linear body measurements between Arbor Acre and Cobb 500 strain of broiler chickens at starter phase.

MATERIALS AND METHODS

The research was carried out at the poultry unit, Teaching and Research Farm, Adekunle Ajasin University, Akungba-Akoko, Ondo State. A total of 50 day-old chicks (25 Cobb, 25 Arbor Acre) was obtained from reputable hatchery. The chicks were randomly distributed in triplicate of (8,8,9). The birds were fed *ad-libitum*, with commercial feed containing (22% protein, 3,000 kcal/kg, energy), while vaccination and other brooding measures were adhered to. Daily feed intake and weight gain were recorded and calculated to obtain the feed conversion ratio and feed efficiency. On the 28th day, linear body measurement parameters taken were; Beak length (BL), Body length (BH), Breast length (BRL), Breast width (BRW), Right wing length (RWL), Shank length (SL), Shank circumference (SC), and Back length (BL). Data collected were analyzed using statistical software of Statistical Package for the Social Sciences (SPSS), with data checked for normality and variances.

RESULTS AND DISCUSSION

Table 1 showed the comparison of body measurements between Arbor Acre and Cobb broilers at day 28. The results indicated that most traits did not differ significantly ($p > 0.05$). Beak length, height, breast length, breast width, shank length, shank circumference, back length, and live weight all showed no statistical difference between the two breeds, even though Cobb consistently had slightly higher mean values in several traits. The right wing length was significantly different ($p < 0.05$), with Cobb broilers exhibiting longer wings than Arbor Acre. This suggested that while overall body metrics and weight were similar between the strains at the starter phase, Cobb had a distinct morphological advantage in wing development. Further confirmed that, the body measurements of the two breeds differed significantly, although this difference may be primarily driven by the variation in wing length.

It has been noted that determining body weight from body measurements, is a useful and simple method, particularly for resource-constrained chicken producers (Semacula *et al.*, 2011). According to Egena *et al.*, (2014), body circumference was a measure of breast development, whereas morphometric characteristics including shank length and diameter were markers of leg development. Okpeku *et al.*, (2004) corroborated our findings, emphasizing that there was no significant difference in the height, shank length and breast length.

Adamu *et al.*, (2021) documented that shank circumference differ between different strain of poultry bird contrary to our obtained result. The significant differences obtained between the two strain of broiler can be linked to variance in the heritability due to inbreeding. There is a relationship between the wing length and body weight. Therefore, increase in the wing length and height, will cause a progressive increment in the body weight gained.

Table 1. Comparison of body measurements between Arbor Acre and Cobb broilers at day 28

Trait	Arbor Mean $\pm$ SD	Cobb Mean $\pm$ SD	F-value	p-value	Significance
Beak Length (cm)	1.34 $\pm$ 0.05	1.38 $\pm$ 0.06	3.48	0.075	NS
Height (cm)	22.92 $\pm$ 1.55	23.54 $\pm$ 1.21	1.21	0.283	NS
Breast Length (cm)	11.98 $\pm$ 1.70	12.93 $\pm$ 0.88	2.96	0.099	NS
Breast Width (cm)	14.80 $\pm$ 1.93	15.73 $\pm$ 0.86	2.33	0.141	NS
Right Wing Length (cm)	13.11 $\pm$ 1.68	15.71 $\pm$ 1.21	18.91	0.001	Significant
Shank Length (cm)	5.64 $\pm$ 0.66	5.44 $\pm$ 0.63	0.58	0.455	NS
Shank Circumference (cm)	4.13 $\pm$ 0.23	4.08 $\pm$ 0.35	0.17	0.683	NS
Back Length (cm)	16.07 $\pm$ 1.66	16.27 $\pm$ 1.30	0.11	0.746	NS
Weight (g)	838.7 $\pm$ 189.3	893.2 $\pm$ 123.8	0.70	0.413	NS

NS = Not Significant ($p > 0.05$)

Table 2 revealed the comparison between the growth performance of two commercial broiler strains, Cobb 500 and Arbor Acre, at day 28 days, using four performance traits: feed intake, body weight, feed conversion ratio (FCR), and feed efficiency (FE). Statistical analysis indicated that none of the parameters differed significantly ($p > 0.05$) between the two strains.

Cobb 500 and Arbor Acre exhibited identical growth rate, with mean body weights of Arbor Acre and Cobb

500 (457.91 ± 330.74 and 457.91 ± 330.74), simultaneously. This confirmed no difference in growth rate. This indicated that genetic differences between the strains did not influence early growth rate under the study conditions. Previous reports also suggest that modern broiler strains are genetically selected to achieve rapid growth rates within the first 4 weeks, hence strain differences are often negligible at this stage (Havenstein *et al.*, 2003). This lack of significant difference suggests that strain choice may not be critical during the early growth phase, provided both are reared under identical nutritional and management conditions. Similar findings were reported by Adedeji *et al.*, (2020), who observed that broiler strains often show no significant differences in performance traits during the starter phase. Moreover, Faruque *et al.*, (2010) emphasized that differences in performance traits among strains are more pronounced at later growth stages (finisher phase), where genetic potential for weight gain and carcass yield becomes clearer

Feed intake was similar (Cobb: 354.41 ± 214.75 g, Arbor Acre: 337.17 ± 219.31 g), with Arbor Acre consuming lesser feed. This suggests both strains have similar appetites and feed utilization capacity under the same management conditions. Previous studies corroborate this finding, showing that strain differences in feed intake are often minimal when birds are raised under identical dietary and environmental conditions (Olawumi and Fagbuaro, 2011).

Table 2. Comparative Growth Performance between Cobb 500 and Arbor Acre at day 28

Trait	Arbor (Mean $\pm$ SD)	Cobb (Mean $\pm$ SD)	Mean Diff.	p-value	Significance
Feed Intake (g)	337.17 ± 219.31	354.41 ± 214.75	-17.24	0.914	NS
Weight (g)	457.91 ± 330.74	457.91 ± 330.74	0.00	1.000	NS
Feed Conversion Ratio	0.765 ± 0.063	0.819 ± 0.120	-0.053	0.462	NS
Feed Efficiency	1.313 ± 0.109	1.241 ± 0.181	+0.072	0.520	NS

NS = Not Significant ($p > 0.05$)

There was equally non-significant difference ($P < 0.05$) in the FCR of Arbor Acre and Cobb 500 (0.765 ± 0.063) (0.819 ± 0.120) respectively. Arbor Acre showed a numerically better FCR compared to Cobb 500, meaning it required less feed to produce a unit of weight gain. However, the difference was not statistically significant. FCR is a key economic trait, as lower values indicate better efficiency of converting feed into body mass. Studies have shown that variations in FCR across strains are influenced by diet, environment, and management rather than genetic strain alone (Faruq *et al.*, 2010). Genetic composition of strains is a chief factor that can contribute to the feed intake level. However, despite consuming more feed, Cobb 500 recorded the least efficient feed conversion ratio (FCR = 0.819), while Arbor Acre had the best FCR values of 0.765. These result was in contrast with findings from Adedokun *et al.* (2022), who highlighted Cobb 500's superior feed efficiency.

FE was also similar (Arbor Acre: 1.313 ± 0.109 , Cobb: 1.241 ± 0.181) Cobb 500 appeared slightly more feed-efficient numerically, meanwhile, the difference was not significant. Feed efficiency is inversely related to FCR; thus, while Arbor Acre had a marginally better FCR, Cobb 500 showed a slightly better efficiency score. These small differences reflect natural biological variation and are not strong enough to suggest a genetic advantage of one strain over the other. These similarities in traits among strains suggest a shared genetic selection history for growth-related attributes (Obike *et al.*, 2020).

CONCLUSION

The non-significant differences may also reflect the impact of management and environmental factors, which can mask genetic differences between the breeds. No significant differences suggested that either breed can be used interchangeably during the starter phase, with final production outcomes depending on nutrition as well as other forms of management. In practice, both Cobb 500 and Arbor Acre are widely used in commercial poultry systems due to their fast growth, high carcass yield, and feed efficiency. Further studies should assess finisher phase performance for more information.

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EFFECT OF WONDERFUL KOLA (*BUCCHOLZIA CORICEA*) SEED MEAL SUPPLEMENTATION ON GROWTH HORMONE AND HEALTH STATUS OF WEST AFRICAN DWARF GOATS

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ABSTRACT

Wonderful kola (*Bucchozia coricea*) has been identified for its medicinal properties, capable of improving animal health and performance. Hence, *B. coricea* seed meal was supplemented in goats' diet at 0 (control), 0.2, 0.4, 0.6, and 0.8 g/kg feed. Twenty-five West African Dwarf (WAD) goats were used for this study, which lasted 56 days. Nutritional compositions of the test diets were determined, and blood samples were collected for health status assessment, while tissue samples (spleen, liver, rump, and heart) were collected to assess the expression of insulin-like growth factor (IGF-1) gene in the goats. From the results, *B. coricea* significantly ($P < 0.05$) influenced nutrient composition, nutrient intake (705.11g/day), and apparent nutrient digestibility coefficient values, though average daily weight gain (ADWG) and feed conversion ratio (FCR) were not significantly ($P > 0.05$) influenced. The values of haematological and serum biochemical indices were within the normal range for healthy goats. However, expression of the insulin-like growth factor (IGF-1) gene in assessed organs was up-regulated/ better expressed in goats fed diet B (0.20 g/kg *B. coricea*). Hence, it could be concluded that incorporation of wonderful kola (*Bucchozia coricea*) seed meal in goats' diet would not pose detrimental effects on the animal, but rather improve their health status and stabilize performance, particularly up to 0.40 g/kg.

Keywords: *Bucchozia coricea* seed, Insulin-like growth factor, organs, small ruminants, weight gain.

INTRODUCTION

The growing use of molecular research in ruminant studies, particularly in nutrition and physiology, has yielded a wealth of information on the cellular regulation mechanisms of important biological processes connected to growth, meat quality, marbling, and milk synthesis (Asmelash, 2018). Gene expression analysis studies are conducted in response to feed regimens. Nutrient-gene interactions (nutrigenomics) in ruminants could lead to livestock improvement and resilience in a changing climate, because they will aid in the development of genotype-matched animal feed by selecting nutrients that are tailored to a specific animal and genes, considerably enhancing health and productivity (Benitez *et al.* 2017). Growth hormone serves as a key regulator of postnatal growth and metabolism in mammals, influencing growth rate, body composition, health, milk production, and modulating aging (Yakar, 2002). Growth hormone stimulates the production of Insulin-like growth factor 1 (IGF-1) in the liver as an endocrine hormone and in target tissues as a paracrine/autocrine hormone. Insulin-like growth factor-1 (IGF-1) regulates the effects of growth hormone (GH) in the body and influences growth performance (Suliman, 2014, Asmelash, 2018).

IGF-1 serves as a crucial growth factor, stimulating the growth of all cell types, including cancer cells, and inducing significant metabolic effects (Aguirre *et al.*, 2016). A notable metabolic effect of IGF-1 is its ability to signal to cells the presence of adequate nutrients for cell hypertrophy and division, thereby inhibiting cell apoptosis and enhancing cell protein production (Aguirre *et al.*, 2016, Callaway *et al.*, 2022). Conversely, IGF-1 is believed to possess some anti-aging and enhancing properties, including the maintenance and augmentation of muscle and bone mass (Callaway *et al.*, 2022). Few plants and plant products are medicinal to support tissue development (growth) and used to improve animal' health. Among such plant is Wonderful kola (*Bucchozia coriacea*). *B. coricea* seed has been reported to contain; 13.28% CP, 1.70% EE, 3.50% CF, 4.53% Ash (Amaechi, 2012). It has antioxidant properties that helps fight oxidative stress. It can act as an anti-inflammatory, helping to alleviate conditions related to inflammation (Ezike *et al.*, 2015). It aids in digestion. The bioactive components (2-methyl-pyrrolidine-2-carboxylic acid) help to regulate the body's homeostasis, function as a blood cleanser, strengthen hair and the nervous system, prevent premature aging, prevent and treat infertility, cure typhoid, and treat fever (Erhirhie *et al.*, 2015). Moreover, blood examination offers a valuable opportunity to clinically evaluate feed quality, disease prognosis, therapeutic monitoring, and assess feed stress. Hence, the study investigated the effects of *Bucchozia coricea* seed meal on growth hormone (insulin-like growth factor-1) expression as it influences growth performance and health status of West African Dwarf goats.

MATERIALS AND METHODS

The study was carried out at the Small Ruminant Unit of the Teaching and Research Farm, Department of Animal Production and Health (APH), Federal University of Technology, Akure, Nigeria. Wonderful kola seeds (Plate 1a) were sourced, washed, sliced, dried in an oven at 40 °C for 72 hours, milled into powder form (Plate 1b) using grinding machine (blender), kept until use.



Plate 1a: Wonderful kola seed



Plate 1b: Wonderful kola seed meal

Twenty-five (25) West African Dwarf (WAD) goats weighing from 9.15-16.35 kg of age 6 - 12 months were used for the experiment, selected from the flock available at the farm. The animals were housed in individual pens. The goats were prophylactically treated against endo- and ecto-parasites and vaccinated against *Peste-Petit de Ruminante* (PPR/kata). An adjustment period of 7 days was observed before data collection. They were randomly allocated to five (5) treatments of five (5) replicates each. The goats were fed based on their body weight throughout the feeding trial. Water was given *ad libitum* along with the feed after washing the drinkers. A basal diet was formulated using feed ingredients at fixed quantities (Table 1) and divided into five equal portions, while *B. coriacea* seed meal was thoroughly mixed with each portion at 0 (control diet), 0.2, 0.4, 0.6, and 0.8 g kg⁻¹. The diets were designated as A (Control), B, C, D, and E, respectively.

Table 1: Gross composition of experimental diet

Ingredients	Quantity (kg)
Cassava peel meal	50.00
Wheat offal	26.00
Palm kernel cake	20.00
Premix	1.00
Urea	1.00
Bone meal	1.00
Salt	1.00
Total	100.00

Feed intake were calculated by deducting the weight leftover of diets from quantity served, while the weekly weight change were monitored using spring balance. The goats were moved to the metabolism cages in the last week of the study (7 days) for faeces and urine sample collection. Sub-samples of faeces samples (10%) were oven-dried at a temperature of 65 °C for three days, for dry matter determination. Two drops of 10% H₂SO₄ solution were added to the urine sample to prevent the escape of nitrogen. Prior to termination of the trial, which lasted 56 days, blood samples (5ml) were collected via the jugular vein puncture from each goat into bottles that contained anti-coagulant ethylene diamine-tetra-acetate (EDTA) bottles for haematological studies and into plain bottles to harvest serum to assay serum biochemical components. The data generated were statistically analyzed using one-way analysis of variance (ANOVA) using SPSS (2011) and differences between treatment means were separated by Duncan multiple range test of the same package and significance level was set at 95% confidence interval.

RESULTS AND DISCUSSION

Table 2 revealed that the nutritional composition of wonderful kola seed-supplemented diets fed to WAD goats were adequate to support the growth and development of growing goats. In this study, it was observed that wonderful kola seed meal had crude protein content of 15.56 g/kg, which was higher than value (13.28 g/kg) reported by Ijarotimi *et al.* (2015) when the authors determined the nutritional quality of raw, blanched and fermented wonderful kola (*B. coriacea*) seed meal. However, this variation might be due to growth

stages, growth conditions, processing and processing methods, and differences in nutritional ingredients used in diet formulation. The high dry matter indicates potential for storage over a long period of time without spoilage. The dietary crude protein contents were sufficient to support the production of enzymes necessary for the effective digestion, effective utilization of nutrients, and improve tissues, muscles, due to the production of amino acids necessary for synthesis in the organs and the overall health of the animals. The dietary crude fibre (26.13 – 28.70 g/kg) was adequate to encourage rumination by the animals to improve gut health. In addition, observed fibre fractions were adequate and would be beneficial for animal rumen health, increasing better feed efficiency and utilization.

Table 2: Nutrient composition (g/kg) of diets containing wonderful kola seed meal (WKSM)

Parameters	A (0.00)	B (0.20)	C (0.40)	D (0.60)	E (0.80)	SEM	P value
Dry matter	88.03	87.58	89.46	89.18	88.58	0.19	0.07
Crude fibre	25.80 ^c	26.13 ^b	27.82 ^{ab}	28.70 ^a	28.68 ^a	0.35	0.00
Crude protein	15.21	15.37	15.44	15.61	15.87	0.16	0.93
Ash	9.94 ^c	9.94 ^c	10.07 ^c	10.72 ^b	11.28 ^a	0.24	0.00
Ether extract	10.65 ^c	11.61 ^b	12.63 ^a	12.68 ^a	12.71 ^a	0.22	0.00
NDF	58.01 ^c	58.02 ^b	58.48 ^b	60.03 ^a	60.16 ^a	1.75	0.00
ADF	40.01 ^b	41.61 ^{ab}	42.01 ^a	42.31 ^a	42.74 ^a	1.11	0.00
ADL	10.82 ^c	13.64 ^d	15.25 ^c	15.53 ^b	15.88 ^a	0.50	0.00

^{abcd} means within the same row with different superscripts are significantly ($P < 0.05$) different. A = 0.00 g/kg WKSM, B = 0.20 g/kg WKSM, C = 0.40 g/kg WKSM, D = 0.60 g/kg WKSM, E = 0.80 g/kg WKSM. NDF=neutral detergent fiber, ADF= acid detergent fiber, ADL=acid detergent lignin. *Analyzed nutrient composition (g/kg) of WKSM is 97.31DM, 15.56CP, 3.80CF, 0.97Ash, 1.89EE.

Dry matter intake is an important factor in ruminant feed utilization and an important factor in voluntary intake, digestibility, energy utilization and performance in small ruminants (Devant *et al.*, 2000). The dry matter intake ranged from 660.71 to 705.11 g/day (Table 3). However, it is noteworthy that dietary protein quality and DM positively influence voluntary intake by ruminants.

Table 3: Nutrient intake (g/day) of diets containing Wonderful Kola Seed Meal (WKSM)

Parameters	A (0.00)	B (0.20)	C (0.40)	D (0.60)	E (0.80)	SEM	P value
Dry matter	660.71 ^c	660.19 ^c	705.11 ^a	685.82 ^b	680.11 ^b	4.49	0.00
Crude fibre	196.13 ^c	210.36 ^b	222.02 ^a	218.86 ^a	203.34 ^{bc}	2.72	0.00
Crude protein	136.64	138.88	145.30	144.53	141.96	1.46	0.29
Ash	75.83 ^c	76.94 ^c	86.76 ^a	80.45 ^b	76.12 ^c	2.16	0.00
Ether extract	79.93 ^c	87.80 ^d	89.94 ^a	88.42 ^b	86.34 ^c	2.02	0.00
NDF	336.26 ^c	378.50 ^d	473.52 ^a	457.83 ^b	405.92 ^c	13.53	0.00
ADF	247.83 ^c	249.68 ^c	315.33 ^a	315.26 ^a	302.47 ^b	8.26	0.00
ADL	85.53 ^c	103.13 ^d	125.18 ^a	118.08 ^b	116.57 ^c	4.03	0.00

^{abcd} means within the same row with different superscripts are significantly ($P < 0.05$) different. A = 0.00 g/kg WKSM, B = 0.20 g/kg WKSM, C = 0.40 g/kg WKSM, D = 0.60 g/kg WKSM, E = 0.80 g/kg WKSM. NDF=neutral detergent fiber, ADF= acid detergent fiber, ADL=acid detergent lignin.

Digestibility helps to identify the best source of nutrients for the animal's diet. All the diets were well digested and utilized, as apparent nutrient digestibility coefficient values were above 50% (Table 4). Values obtained are evidence of the diets' support for healthy digestive function, satisfy their amino acid needs, support better muscle growth, prevent digestive disorders, and improve general health and nutrient utilization. However, it is worth noting that goats fed diet C (0.40 g/kg WKSM) had the best feed/gain ratio (8.75) and the highest apparent nutrient digestibility coefficient values, highlighting its superior performance in promoting weight gain. This increased protein use could be attributed to a possible improvement in nitrogen availability in the rumen, which facilitates microbial growth and protein synthesis. Evaluation of growth performance is of economic importance to farmers, especially when goats are raised for meat production. Weight gain in ruminants is dependent on dry matter intake, protein intake, and the digestibility of the nutrients. The highest weight gain was obtained in goats fed diet C (Table 4) could be attributed to the afore-mentioned factors.

Table 4: Nutrient digestibility and weight gain of goats fed diets containing wonderful kola seed meal

Parameters	A (0.00)	B (0.20)	C (0.40)	D (0.60)	E (0.80)	SEM	P value
Digestibility (%)							
Dry matter	78.00 ^c	79.33 ^b	85.00 ^a	78.00 ^c	77.00 ^d	0.77	0.00
Crude fibre	82.62 ^d	87.17 ^b	88.06 ^a	85.29 ^c	84.71 ^c	0.52	0.00
Crude protein	88.33 ^a	85.28 ^b	88.73 ^a	82.36 ^c	80.69 ^c	0.87	0.00
Fat	94.80 ^b	93.54 ^c	96.67 ^a	95.75 ^{ab}	94.99 ^b	0.31	0.00
NDF	76.82 ^d	77.94 ^c	83.01 ^a	79.61 ^b	78.40 ^c	0.58	0.00
ADF	83.32 ^b	80.13 ^c	85.92 ^a	76.15 ^d	76.08 ^d	1.05	0.00
ADL	68.27 ^d	74.68 ^b	87.46 ^a	55.75 ^e	71.44 ^c	2.74	0.00
Growth Performance							
Initial Weight (kg)	13.73	13.77	12.50	12.77	11.88	0.71	0.93
Final Weight (kg)	17.96	17.41	16.82	16.94	15.37	0.79	0.91
Weight Gain (kg)	4.23	3.65	4.32	4.18	3.49	0.15	0.28
ADWG (g/day)	75.48	66.12	77.20	74.58	66.26	2.66	0.28
FCR	9.28	10.35	8.75	9.18	11.28	0.39	0.28

^{abcd} means within the same row with different superscripts are significantly ($P < 0.05$) different. A = 0.00 g/kg WKSM, B = 0.20 g/kg WKSM, C = 0.40 g/kg WKSM, D = 0.60 g/kg WKSM, E = 0.80 g/kg WKSM. NDF=neutral detergent fiber, ADF= acid detergent fiber, ADL=acid detergent lignin. ADWG – Average daily weight gain, FCR– Feed conversion ratio.

Haematological parameters are crucial markers in diagnosing and determining the actual physiological status of animals under any kind of physiological state (Ahmed and Egwu, 2020). Dietary treatment affected hematological parameters (Table 5). However, the obtained values were within the limits of healthy goats. The packed cell volume (PCV) was used as a toxicity index in feed samples, and a decrease in PCV concentration indicates the presence of toxic substances (Anyia *et al.*, 2018). The PCV values obtained in this study indicate the presence of good/quality dietary protein. The hemoglobin concentration values obtained in this study were within the range of hemoglobin values recommended for healthy goats (7-15 g/dl), indicating that goats had sufficient blood pigment to properly transport oxygen to their healthy lives. White blood cells (WBC) and their derivatives fight foreign bodies/infections by protecting the body through a process called phagocytosis. The level of lymphocytes observed in the goats in the study showed that the experimental goats were well protected against infections. The values of neutrophils, basophils, and monocytes observed in this study were within the range of values recommended for healthy goats, an indication that the dietary treatment did not cause an allergic reaction. Serum total protein observed is a reflection of sufficient dietary crude protein, translating into blood bloodstream when nutrients are absorbed. All the serum biomarkers assayed in this study favour goats fed diet C (0.40 g/kg WKSM). The globulin concentration observed in this study indicates that wonderful kola seed meal has the potential to improve immunity in goats due to its therapeutic potential of the seed (Ijarotimi *et al.*, 2015). Cellular protein synthesis was improved. AST and ALT are enzymes that are present in large amounts in the liver and is often used to detect liver damage (Pratt, 2010). However, the values observed in this study were within the normal range for ruminants by Ileyemi (2017). All the goats were in good health condition throughout the feeding trial

Table 5: Haemato-biochemical indices of goats fed diets containing Wonderful Kola Seed Meal

Parameters	A (0.00)	B (0.20)	C (0.40)	D (0.60)	E (0.80)	SEM	P value
Haematological indices							
PCV (%)	33.33 ^b	34.33 ^b	33.33 ^a	39.33 ^{ab}	36.33 ^b	2.35	0.04
WBC (x10 ³ µl)	5.87 ^b	8.93 ^{ab}	10.73 ^a	9.77 ^{ab}	8.83 ^{ab}	3.48	0.01
RBC (x10 ⁶ µl)	8.80 ^b	3.63 ^b	4.50 ^a	4.10 ^{ab}	3.77 ^b	0.24	0.04
Hemoglobin (g/dl)	12.53 ^b	11.43 ^b	14.53 ^a	13.57 ^{ab}	11.93 ^b	0.67	0.04
Lymphocytes (%)	37.33 ^{ab}	31.67 ^{bc}	28.00 ^c	43.33 ^a	28.33 ^c	3.22	0.01
Neutrophils (%)	58.33 ^b	64.67 ^{ab}	70.33 ^a	56.33 ^b	28.33 ^b	2.74	0.01
Monocytes (%)	4.33 ^a	1.33 ^b	1.00 ^b	1.33 ^b	0.33 ^b	0.37	0.00
Eosinophils (%)	0.00	1.33	0.00	0.00	0.00	0.02	0.13
Serum biochemical indices							
Total Protein (g/dl)	51.07 ^b	53.33 ^b	54.37 ^b	56.57 ^{ab}	62.93 ^a	2.49	0.01
Albumin (g/dl)	8.33 ^b	14.33 ^{ab}	18.33 ^a	20.33 ^a	20.00 ^a	1.15	0.99
Globulin (g/dl)	33.23 ^b	31.03 ^{bc}	38.93 ^a	29.33 ^c	28.40 ^c	0.54	0.00
AST	12.33 ^d	28.40 ^c	29.33 ^c	31.03 ^{bc}	38.93 ^a	2.98	0.72
PO3	8.33 ^b	14.33 ^{ab}	18.33 ^a	20.33 ^a	20.00 ^a	2.43	0.00
ALT	16.67 ^{bc}	22.67 ^a	18.67 ^{ab}	17.67 ^{bc}	12.67 ^c	2.08	0.02
Total Bilirubin (g/dl)	10.33	9.67	19.33	12.00	11.33	0.93	0.30

^{abcd} means within the same row with different superscripts are significantly ($P < 0.05$) different. A=0.00 g/kg WKSM, B=0.20 g/kg WKSM, C=0.40 g/kg WKSM, D=0.60 g/kg WKSM, E=0.80 g/kg WKSM. AST – Aspartate aminotransferase, PO3 – Alkaline phosphatase, ALT – Alanine transferase.

Figures 1-4 shows the expression of insulin-like growth hormone (IGF-1) genes in WAD goats fed wonderful kola supplemented diets. IGF-1 is mainly expressed in the liver. In this study, the expression of IGF-1 in the liver was down-regulated because its production is triggered mostly by consumption of animal protein (Yakar, 2002, Berton *et al.*, 2018). However, the expression level could be influenced age of the animals used. In the spleen, rump, heart and liver, IGF-1 were relatively expressed or up-regulated in all the goats fed diets supplemented with WKSM, particularly in diets B and C, confirming that the animals had sufficient growth hormones to support good performance in its tissues. Dietary protein intake serves as the primary determinant of IGF-1 level (Suliman, 2014) and higher proportions of daily calorie intake from protein, especially animal protein, correlate with elevated IGF-1 levels (Aguirre *et al.*, 2016).

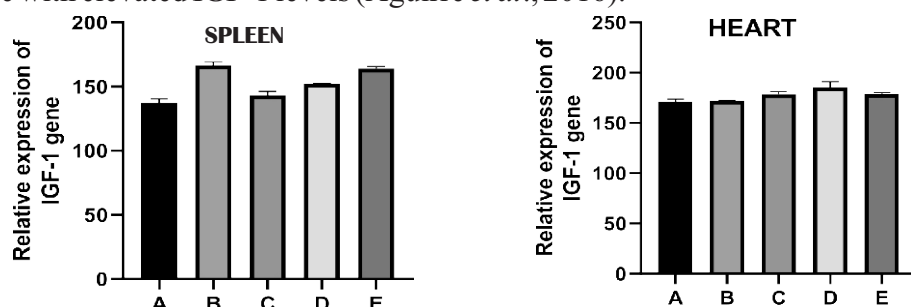


Figure 12: The Insulinlike Growth Factor (IGF) growth hormone expressed in spleen and heart of the WAD goats fed B. coriic supplemented diets A = 0.00 g/kg WKSM, B=0.20 g/kg WKSM, C=0.40 g/kg WKSM, D=0.60 g/kg WKSM, E= 0.80 g/kg WKSM.

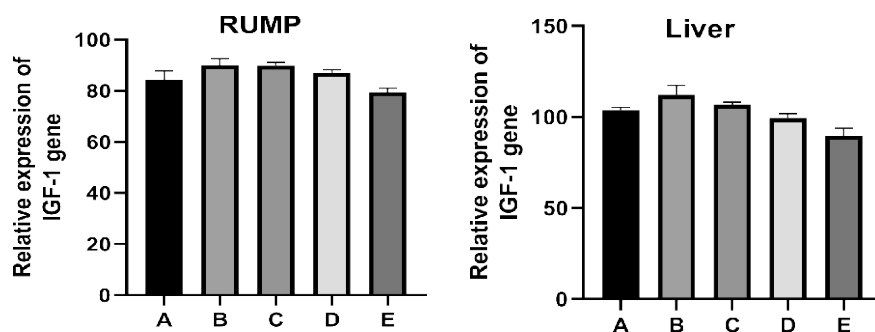


Figure3-4: The Insulinlike Growth Factor (IGF) growth hormone expressed in ~~liver~~ and rump of the WAD goats fed *B. coricea* supplemented diets A = 0.00 g/kg WKSM, B=0.20g/kg WKSM, C=0.40g/kg WKSM, D=0.60g/kg WKSM, E= 0.80g/kg WKSM.

CONCLUSION

Based on the foregoing, wonderful kola (*Buchholzia coricea*) seed meal in WAD goats' diet influenced growth hormone expression, weight gain, and health status of the animals. Supplementation of wonderful kola (*Buccholzia coricea*) seed meal in goat's diets at 0.4 g/kg had higher nutrient content, nutrient digestibility, without any detrimental health implications on the animals, and it is thus recommended to ruminant farmers for improved and sustained ruminant production.

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SUPPLEMENTATION OF SODIUM BICARBONATE IN GOATS' DIET: INFLUENCE ON RUMEN FERMENTATION AND MICROBIAL CHARACTERISTICS

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ABSTRACT

This study evaluated the effect of graded levels of dietary sodium bicarbonate supplementation on nutrient composition, intake, digestibility, rumen fermentation, and microbial characteristics of West African Dwarf (WAD) goats. Five dietary treatments were formulated: a basal diet supplemented with 0 kg (control – T1), 0.5 kg (T2), 1.0 kg (T3), 1.5 kg (T4), and 2.0 kg (T5) sodium bicarbonate per 100 kg. The feed samples were taken for nutrient analysis and the resultant diets were fed to 15 WAD goats for 56 days to assess the nutrient intake and digestibility. A metabolism trial was conducted where the rumen liquor of the goats was collected and taken to the laboratory to determine the rumen fermentation characteristics, total microbial count and identification of microbial isolates. Results revealed that dry matter intake remained consistent across all treatments, increase with increasing sodium bicarbonate inclusion, crude protein (CP) increased significantly with higher sodium bicarbonate inclusion, while crude fibre (CF) and nitrogen-free extract (NFE) decreased in higher inclusion diets. Rumen fermentation parameters were influenced, with goats fed T5 showing significantly higher concentrations across all parameters compared to T1. Rumen pH also increased (5.87 in T1 to 6.77 in T5), alongside increase in ammonia nitrogen values (0.29% in T1 and 0.40% in T5), reflecting improved buffering capacity and fermentation efficiency. Total microbial counts indicated that sodium bicarbonate significantly increased total bacterial, coliform, and fungal populations, while protozoa count remained unaffected, microbial isolates identified. Overall, sodium bicarbonate supplementation improved dietary CP and fibre fractions, enhanced fibre digestibility, stabilized rumen pH, and promoted favorable microbial balance, thereby supporting better nutrient utilization and rumen health in WAD goats.

Keywords: sodium bicarbonate, goats, rumen fermentation, microbial characteristics, basal diet.

INTRODUCTION

Ruminant production remains a significant sector contributing greatly to the animal protein sources in the diets of humans. However, the productivity of West African Dwarf (WAD) goats, which are a vital source of meat and milk for smallholder farmers in West Africa, is constrained by limited quality and quantity of feed (Ofori and Hagan, 2021), particularly during the dry season when pasture supply is scanty, resulting in poor nutrition and reduced optimal performance (Omotoso *et al.*, 2023).

The complex factor that affects livestock production is nutrition, as feed resources are limited in quantity and quality (Omotoso *et al.*, 2018). The increasing global demand for animal protein has intensified the need to improve ruminant productivity through efficient feeding strategies and enhanced rumen function. In small ruminants such as goats, which play a vital socio-economic role in many developing countries, optimizing rumen fermentation is critical to achieving better feed utilization and production performance. Rumen fermentation is a complex process driven by microbial populations, which convert fibrous plant materials into volatile fatty acids (VFAs), microbial protein, and gaseous products essential for the host animal's energy and nutritional needs (Mao *et al.*, 2015).

However, imbalances in rumen fermentation, particularly the excessive production of lactic acid, can lead to subacute or acute ruminal acidosis, a metabolic disorder that adversely affects microbial ecology, fibre digestion, and animal health (Plaizier *et al.*, 2012). To mitigate this, dietary buffers such as sodium bicarbonate (NaHCO_3) have been widely studied for their ability to stabilize ruminal pH, promote microbial activity, and improve fermentation efficiency (Ebrahimi *et al.*, 2021). Sodium bicarbonate acts as a neutralizing agent by buffering the excess acidity produced during carbohydrate fermentation, thereby creating a favourable environment for fibrolytic bacteria and protozoa (Li *et al.*, 2019).

MATERIALS AND METHODS

Experimental Site

The experiment was undertaken at the Small Ruminant Unit Section of the Teaching and Research Farm,

Federal University of Technology, Akure, Ondo State, Nigeria. The University sits at approximately latitude 7°18'13" N and longitude 5°08'20" E. The city of Akure receives around 1,805.9 mm of rainfall annually. Other sources cite a range of 1,250–1,500 mm in the region. The average annual temperature in Akure is approximately 27.3 °C ($\pm$ 5.6 °C). Other data show typical daily temperature ranges of 21 °C to 29 °C throughout the year. In the wet season, daytime highs reach around 38 °C and night time lows about 27 °C; in the dry season, temperatures range from approximately 23 °C to 39 °C. Moist, tropical conditions prevail with a mean annual relative humidity of around 75 % ($\pm$ 3%) (Adejoba *et al*, 2014).

Sourcing and Processing of feed ingredients

The cassava peels were collected at cassava processing industry at Igbatoro road, Akure, Ondo-State. The peel was sun dried until crispy is attained to enhance the milling and shelf-life of the concentrate to be formulated. Other feed ingredients such as wheat-offal, palm kernel cake (PKC), salt, premix, di-calcium phosphate (DCP) and urea were bought from Farm Support and some other reputable feed mills in Akure, Ondo State.

Experimental diets and design

The goats were allotted five treatments in a completely randomized design (CRD) experiment with three goats as replicate per treatment. The diets were compounded to have sodium bicarbonate at different inclusion levels of; Treatment 1 (0 %), T2 (0.5 %), T3 (1.0 %), T4 (1.5 %) and T5 (2.0 %). The quantity of other feed ingredients in the diets i.e., cassava peel, wheat-offal, palm kernel cake (PKC), salt, Di-calcium phosphate (DCP), urea and premix were kept constant. The diets were designated as T1 (control), T2, T3, T4 and T5.

Collection of rumen liquor samples and analysis

Rumen fluid samples were taken from each goat's rumen using stomach tubes and placed in sterile sample vials. A pH meter was used to rapidly detect the rumen's pH. The liquid and solid fractions were separated without using any wash, the rumen fluid was strained through four layers of sterile cheesecloth. After then, the liquid fraction was split into two parts. The initial portion of the strained rumen fluids was acidified with 0.2 mol/L HCL solution and retained in labeled sample vials stored at -20°C until needed for the measurement of volatile fatty acids and rumen ammonia nitrogen. The second portion of the rumen fluid was preserved in a 10% formalin solution and immediately placed in ice before being held at - 20°C pending additional microbial population analysis. Rumen ammonia nitrogen (NH₃-N) concentration was determined by the method described by Lanyasunya *et al*. (2008). Total volatile fatty acids distillate concentration was determined by titration of sample with 0.1N NaOH solution expressed as volatile fatty acid content. Microbial population in the rumen fluids was by total direct count of bacteria, protozoan and fungal zoospores as described by Dehority (2003).

Microbial isolate and count

Microbial isolates from goat rumen liquor were identified by culturing them on appropriate growth media, while microbial counts were determined using serial dilution and plate counting techniques, with results typically expressed as colony-forming units per milliliter (CFU/mL). The rumen houses a diverse community of anaerobic bacteria, fungi, and protozoa, whose specific populations are influenced by diet and age, leading to significant variations in microbial numbers and types. Common bacterial genera found in the rumen include *Bacillus*, *Streptococcus*, *Escherichia coli*, and *Prevotella*, while fungal presence is also common.

Table 1: Gross composition of experimental diet (%)

INGREDIENTS	TREATMENT
Cassava Peel	49.70
Wheat Offal	34.00
PKC	13.00
Premix	0.60
Di-calcium phosphate	1.00
Salt	0.70
Urea	1.00
Total	100.00

RESULTS

Rumen fermentation characteristics in West African Dwarf goats fed diets containing graded levels of sodium bicarbonate

The rumen characteristic production rate by WAD goats fed diets contained graded levels of sodium bicarbonate is presented in table 1. All parameters evaluated were significantly ($P < 0.05$) different. Goats fed diet T1 had the least acetic acid (9.21 mmole/100ml), total volatile acid (130.63 mmole/100ml), and lactic acid (11.31 mmole/100ml) while the highest value were observed in goats fed diet T5, acetic acid (14.41 mmole/100ml), total volatile acid (206.75 mmole/100ml), and lactic acid (18.09 mmole/100ml). The highest propionic acid (13.83 mmole/100ml), butyric acid (13.39 mmole/100ml) and valeric acid (13.44 mmole/100ml) content were observed in goats fed diet T5 while the least values in goats fed diet T1, propionic acid (8.76 mmole/100ml), butyric acid (8.36 mmole/100ml), and valeric acid (8.30 mmole/100ml). The pH content of the rumen was observed to significantly increase as the levels of sodium bicarbonate increased in the diet, the pH ranged from 5.87 to 6.77. The ammonia nitrogen ranged from 0.29 to 0.40 having the highest value in goats fed diet T5 and the least value in goats fed diet T1.

Table 2: Rumen fermentation characteristics in West African Dwarf goats fed diets containing graded levels of sodium bicarbonate

PARAMETERS	T1	T2	T3	T4	T5	SEM	P-value
Acetic Acid (mmole/100ml)	9.21 ^c	9.42 ^c	11.89 ^b	14.05 ^a	14.41 ^a	0.64	0.00
Butyric Acid (mmole/100ml)	8.36 ^c	8.44 ^c	10.92 ^b	13.28 ^a	13.39 ^a	0.62	0.00
Propionic Acid (mmole/100ml)	8.76 ^c	8.82 ^c	11.40 ^b	13.63 ^a	13.83 ^a	0.63	0.00
Valeric Acid (mmole/100ml)	8.30 ^c	8.34 ^c	10.69 ^b	13.30 ^a	13.44 ^a	0.64	0.00
Lactic Acid (mmole/100ml)	11.31 ^c	12.04 ^c	14.70 ^b	18.07 ^a	18.09 ^a	0.82	0.00
Total Volatile Acid (mmole/100ml)	130.63 ^c	133.77 ^c	167.69 ^b	204.29 ^a	206.75 ^a	9.30	0.00
pH	5.87 ^c	6.27 ^b	6.30 ^{abc}	6.37 ^{ab}	6.77 ^a	0.09	0.02
NH ₃ -N (%)	0.29 ^d	0.32 ^{cd}	0.35 ^{bc}	0.38 ^{ab}	0.40 ^a	0.01	0.00

abcde: Mean with different superscript along the same row are significantly ($P < 0.05$) different. SEM = Standard Error of Mean. T1 = Basal diet (control), T2 = Basal diet + 0.5kg of Sodium bicarbonate (NaHCO₃)/100kg feed, T3 = Basal diet + 1kg of Sodium bicarbonate (NaHCO₃)/100kg feed, T4 = Basal diet + 1.5kg of Sodium bicarbonate (NaHCO₃)/100kg feed, T5 = Basal diet + 2kg of Sodium bicarbonate (NaHCO₃)/100kg feed.

Total microbial count in the rumen of West African Dwarf goats fed experimental diets containing graded levels of sodium bicarbonate

Microbial count in the rumen of WAD goats fed diets contained graded levels of sodium carbonate is presented in figure 1. It was observed that total bacterial count, total coliform count and total fungi count were significantly influenced by the varying levels of sodium bicarbonate while the total protozoa count was not significantly influenced.

The total bacteria count was least in the goats fed diet T1 (4.58×10^6 cfu/ml) while goats fed diet T5 had the highest value (6.29×10^6 cfu/ml). Total coliform count in goats fed diet T5 obtained the highest value (2.60×10^2 cfu/ml), the goats fed diet T1 had the least value (1.53×10^2 cfu/ml). The highest total fungi count (2.3×10^3 cfu/ml) was observed in the rumen liquor of goats fed diet T5 while the least value 1.63×10^3 cfu/ml was obtained in goats fed diet T1. The protozoa count is in the range of (2.00×10^{-3} cfu/ml to 3.3×10^{-3} cfu/ml) in the goats fed diet T1 while goats fed T5 has the highest value.

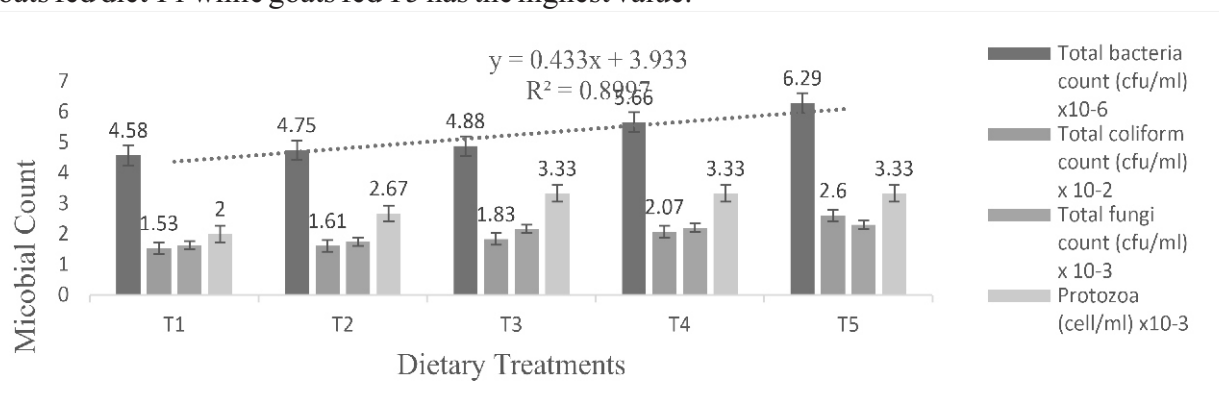


Figure 1 Total microbial count in the rumen of WAD goats fed diets containing graded levels of sodium bicarbonate

DISCUSSION

Rumen Fermentation Characteristics in West African Dwarf Goats Fed Diets Containing Graded Levels of Sodium Bicarbonate

The rumen fermentation profile of West African Dwarf (WAD) goats fed diets containing graded levels of sodium bicarbonate. All the parameters measured were significantly influenced by dietary treatments. Goats fed the control diet (T1) recorded the least concentrations of acetic acid, total volatile fatty acids, and lactic acid, while the highest values were observed in goats fed diet T5. Similarly, the concentrations of propionic acid, butyric acid, and valeric acid were significantly elevated as sodium bicarbonate inclusion increased.

The pH of rumen liquor showed significant improvement with increasing levels of sodium bicarbonate, this suggests that sodium bicarbonate inclusion enhanced rumen buffering capacity, preventing excessive acidification and creating a more stable environment for microbial activity (Giger-Reverdin *et al.*, 2014; Zhu *et al.*, 2019). Ammonia nitrogen ($\text{NH}_3\text{-N}$) concentration ranged upward, reflecting enhanced protein degradation and nitrogen availability for microbial protein synthesis as sodium bicarbonate levels increased (Khampa and Wanapat, 2021).

Overall, the results indicate that sodium bicarbonate supplementation positively influenced rumen fermentation by increasing total volatile fatty acid production, stabilizing rumen pH, and improving nitrogen availability. These findings are in agreement with earlier reports that sodium bicarbonate improves fibre digestion and enhances microbial efficiency by moderating rumen acidity (Li *et al.*, 2020). Thus, incorporating sodium bicarbonate into goat diets can serve as a practical strategy to optimize rumen fermentation dynamics and nutrient utilization in small ruminants.

Total Microbial Count in the Rumen of West African Dwarf Goats Fed Experimental Diets Containing Graded Levels of Sodium Bicarbonate

The effect of graded levels of sodium bicarbonate on the microbial population in the rumen of West African Dwarf (WAD) goats. Results showed that total bacterial count (TBC), total coliform count (TCC), and total fungi count (TFC) were significantly influenced by dietary sodium bicarbonate inclusion, whereas protozoa count was not significantly affected.

Goats fed the control diet (T1) had the lowest bacterial population, while goats on diet T5 recorded the highest. A similar trend was observed in coliform count, with T1 goats recording the least value and T5 goats the highest. Fungal count also increased significantly with sodium bicarbonate supplementation. However, protozoa population showed no significant variation across treatments.

The increase in bacterial, coliform, and fungal populations with sodium bicarbonate supplementation suggests that improved rumen buffering (as observed in fermentation characteristics) provided a more favourable environment for microbial proliferation (Plaizier *et al.*, 2018; Khampa and Wanapat, 2021). Enhanced bacterial growth, in particular, is critical for fibre degradation and nutrient release, while elevated coliform and fungal counts may reflect the improved breakdown of structural carbohydrates (Ogunade *et al.*, 2019). The absence of significant variation in protozoa counts aligns with previous findings that rumen protozoa are less sensitive to dietary buffers compared to bacteria and fungi (Dai *et al.*, 2020).

This study indicates that sodium bicarbonate supplementation enhanced the growth of beneficial microbial groups without altering protozoal stability. This microbial balance is vital for efficient rumen fermentation and nutrient utilization in small ruminants, further supporting the role of sodium bicarbonate as an effective dietary buffer.

CONCLUSION

It is demonstrated that supplementing West African Dwarf (WAD) goat diets with sodium bicarbonate had a clear influence on nutrient composition, rumen fermentation, and microbial characteristics. Collectively, these findings show that sodium bicarbonate inclusion not only enhanced dietary quality but also improved physiological stability and microbial balance in WAD goats.

Recommendations

It could be recommended that sodium bicarbonate be included up to 2 kg in goat diets, this practice will reduce problems like rumen acidosis and support better digestion.

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HAEMATOLOGICAL INDICES AND MINERAL STATUS OF WEST AFRICAN DWARF GOATS FED SUPPLEMENTARY LEVELS OF TURMERIC POWDER DIETS

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ABSTRACT

56-day research was conducted to evaluate the potentials of Turmeric (*Curcuma longa*) in goat nutrition while measuring parameters like nutrients intake, blood profile and performance of West African Dwarf (WAD) does fed graded levels of Turmeric in a complete concentrate diet. Four diets were formulated; a concentrate diet supplemented with 0g (control-diet A), 5g (diet B), 10g (diet C), 15g (diet D) of turmeric per 100kg. The experimental diets were fed to 12 WAD does between age 2 to 2½ years with an average weight of 11.66 ± 0.23 , divided into three goats per treatment in a complete randomized design experiment. Parameters assessed include chemical composition (proximate and fibre fractions) of the experimental diets, raw turmeric powder and guinea grass (*Panicum maximum*), haematological and serum biochemical profile. Results revealed that dry matter intake remained consistent across all treatments, increase with increasing turmeric inclusion, crude protein (CP) increased significantly with higher turmeric inclusion, while crude fibre (CF) and nitrogen-free extract (NFE) decreased in higher inclusion diets. The result from this experiment revealed that there was significant difference among haematology (Red Blood Cell ranges from 13.57 to $13.74 \times 10^6/\mu\text{l}$, White Blood Cell ranges from 10.94 to $12.17 \times 10^3/\mu\text{l}$) and serum (Protein ranges from 60.77 to 66.01g/dl , albumin ranges from 30.46 to 334.03g/dl) parameters observed although they were all within the normal range for healthy goat. Raw Turmeric powder could be an effective feed ingredient in improving blood characteristics of goat and reducing the build-up of cholesterol in the system of animals

Keywords. Haematology, Serum, Turmeric, Mineral, Metabolizable energy

INTRODUCTION

Livestock provides about one-third of global protein intake, and demand continues to rise due to population growth, increasing incomes, and changing dietary preferences (FAO, 2009). Ruminant animals have been a promising channel through which animal protein can be obtained with the least cost of production due to their ability to feed on numerous industrial waste and agricultural by-products or waste (Odeyinka and Ajayi, 2004). They play a significant role in ensuring food security and supplying animal protein to a population of over 211 million people. However, poor nutrition has been a major setback in ruminant animal production in recent days due to climate change which directly and or indirectly influence the nutrients composition of forages available to these animals. Meanwhile, nutrition has been geared toward the utilization of phytogenic feed additives which include plants, herbs, spices, fruits, vegetables and nutritional immune-modulators (Dhama *et al.* 2015).

They are preferred because they are safe, cost-effective, locally available, and enhance animal health, meat quality, flavour, digestibility, and productivity with minimal side effects (Abou-Elkhair *et al.*, 2014). Turmeric bioactive curcuminoids possess antioxidant, anti-inflammatory, antimicrobial and immune-boosting properties (Ashraf *et al.*, 2020; Adebisi *et al.*, 2022), improving rumen fermentation, digestive enzyme activity, and nutrient digestibility as well as metabolic responses.

Studies show that turmeric supplementation improves immune performance, oxidative stress control, and metabolic efficiency in livestock (Nouzarian *et al.*, 2011). In goats, turmeric influences erythropoiesis, white blood cell profiles, and liver and kidney function markers, supporting its role as a natural health promoter. This study aims to evaluate the haematological indices and mineral status of WAD goats fed diets supplemented with different levels of turmeric powder

MATERIALS AND METHODS

Experimental site

The experiment was carried out at the small ruminant section of the Teaching and Research Farm of the

Federal University of Technology, Akure, Ondo State (Daniel, 2015). Laboratory analyses of the experimental diets was carried out at the Nutrition Laboratory while blood analysis was carried out at the Microbiology Laboratory of the institution.

Experimental diets

A concentrate diet was formulated to meet the nutrient requirement of the goats. However, Turmeric (*Curcuma longa*) was supplemented daily throughout the feeding trial at the rate of 5.00g/300.00g to make four experimental diets as follows: A Control diet (0g Turmeric), B (5.00g), C (10.00g), D (15.00g) (Table 1).

Table 1: Gross compositions (%) of basal experimental concentrate supplement

Ingredients	Inclusion (%)
Cassava Peel	52.5
Wheat Offal	17.0
Palm Kernel Cake	10
Brewer's Dried Grain	17.5
Bone Meal	1.0
Common Salt	1.0
Premix	1.0
Total (kg)	100
Calculated Analysis	
Crude Protein (%)	9.99
Crude Fibre (%)	13.51
Calcium (%)	0.41
Phosphorus (%)	0.24
Metabolizable Energy (Kcal/kg)	1660.00

Chemical analysis

Samples of feed offered: turmeric powder and grass were analysed for crude protein, ether extract, ash, mineral and fibre fractions were determined

Blood collection and analysis

Blood sample of 10 ml each was collected from each goat via the jugular vein puncture (Frandsen 1986) at the end of the study period. The blood samples were collected in Ethylene Diaminetera Acid (EDTA) bottles to prevent coagulation. Analysis of the blood samples was carried out immediately and analyzed for WBC count, RBC count, Haematology, Total protein, Serum globulin were determined following (Kohn and Allen, 1995).

Experimental design and statistical analysis

Twelve mature (12) WAD does of about 2 to 2½ years of age were assigned to four experimental diets with four (3) replicates per treatment in a completely randomized design (CRD) experiment. Data collected were subjected to the one-way analysis of variance (ANOVA) using the general linear model procedure of SAS (2008). Where significant differences were observed, Duncan's Multiple Range Test (DMRT) was used to separate the means.

RESULT AND DISCUSSION

Proximate composition of Guinea grass (*Panicum maximum*) and Raw Turmeric powder

The result of the chemical composition of guinea grass (*Panicum maximum*) and raw turmeric powder as observed in this study as shown in Table 2, revealed that dry matter portion of the guinea grass (*Panicum maximum*) was 27.24% which was in close range with the report of Aderinboye and Olanipekun, (2021) who obtained a value of 31.43%. The report of Adebayo *et al.* (2022) on crude protein was 8.02%, which was similar to the result obtained in this experiment having a value of 7.35%, however, the crude fibre and ash content from this experiment were 18.24% and 3.85 respectively which were lower than the report of Adebayo *et al.*, (2022).

The Dry matter of turmeric powder was 90.31%. The Crude protein of the raw turmeric powder used in this experiment was 10.24% similar in value to the observation of Rajan *et al.*, (2020) who stated that raw

Turmeric powder contains a Crude protein value of 6.30%. The Crude fibre portion was 8.04% which is lower than the report of Amosu *et al.*, (2020) who stated a value of 24.21%. The Metabolizable energy (Kcal/Kg) as from turmeric powder was 3359.82 (Kcal/Kg).

Table 2: Chemical composition of Grass (*Panicum maximum*), Concentrate and Turmeric powder

	GRASS	CONCENTRATE	TURMERIC
Dry matters (%)	94.65	85.39	90.31
Crude protein (%)	7.35	10.05	10.24
Crude fibre (%)	18.24	12.89	8.04
Ash (%)	3.85	3.85	3.62
Ether extract (%)	3.43	3.43	4.58
Nitrogen free extract (%)	61.78	69.78	73.52
Metabolizable energy (Kcal/Kg)	3126.8	2807.03	3359.82

Chemical composition of experimental diets fed wad does

As shown in Table 3, all the composition of the experimental diets showed significant ($p < 0.05$) difference. The significance of compounding concentrate diet was to help provide all necessary nutrient in right proportion in a single diet, which also helps to prevent selective consumption of feed ingredient by the goats. It will further enhance micro nutrient intake and ultimately seen to enhance performance of the goat by means of better feed intake and utilization as compared to feeding singly ingredients. The Dry matter in feed ingredient serves as the bulk portion of the diet that support rumination, help in maintaining rumen ecosystem and use as estimate for nutrient intakes. The Dry matter in the diets was sufficient to support the healthy status of the animals which could be attributed to the texture of Turmeric powder and other feed ingredient. The Crude protein (CP) obtained were (10.05 to 11.17%) which is adequate to support growth and muscle development in goat as supported by (Omotoso *et al.*, 2017).

Table 3: Chemical composition of experimental diets fed WAD does

	A	B	C	D	SEM	P-value
Dry matter concentrate	85.39 ^b	86.27 ^a	84.00 ^c	84.75 ^b	0.94	0.01
Crude Protein	10.05 ^c	11.01 ^b	11.06 ^b	11.17 ^a	0.48	0.00
Crude fibre	12.89 ^b	13.49 ^a	13.57 ^a	13.73 ^a	0.43	0.05
Ether Extract	3.43 ^b	3.75 ^b	3.95 ^b	4.25 ^a	0.33	0.00
Ash	3.85 ^a	4.41 ^b	4.60 ^b	4.89 ^a	0.41	0.00
Nitrogen Free Extract	69.78 ^a	67.34 ^b	66.81 ^b	65.95 ^c	1.51	0.00
Metabolizable Energy (Kcal/kg)	3126.87	3101.81	3201.05	3099.16	5.16	0.18
Acid detergent lignin	6.08 ^c	6.27 ^c	6.80 ^b	7.57 ^a	0.63	0.00
Acid detergent Fibre	34.37 ^d	36.45 ^c	39.27 ^b	43.07 ^a	3.49	0.00
Neutral detergent fibre	65.32 ^b	66.28 ^a	66.87 ^a	66.90 ^a	0.74	0.00
Hemicellulose	30.95 ^a	29.83 ^a	27.59 ^b	23.83 ^c	2.99	0.00
Cellulose	28.29 ^d	30.18 ^c	32.48 ^b	35.5 ^a	2.90	0.00

Means with different superscript (a,b,c,d) along the same row are significantly difference ($P < 0.05$)

Haematological parameters of wad does fed

The haematological parameter of the WAD does fed experimental diets as investigated in this research (Table 4) were not significantly ($P > 0.05$) different across treatment with the exception of White blood cell. The value of erythrocyte sedimentation rate (ESR) obtained in this study suggests that The Pack cell volume (PCV) result from the experiment showed that all the WAD does fed experimental diet were within the recommended value of 21-37%. The Red blood cells (RBC) values obtained in this study were within the range of $9.9\text{--}18.7 \times 10^6/\mu\text{l}$ as reported by Taiwo and Ogunsanmi (2003) hence the inclusion of Turmeric powder may not be significant ($P > 0.05$) in improving red blood cell production in goats.

The white blood cells values obtained were within the normal range for healthy goats to be $4\text{--}13 (\times 10^3/\mu\text{l})$, this range suggests that the animals did not experience any stress to have triggered the body's immune system to produce more white blood cells for defence. However, the significant ($P < 0.05$) increase in WBC of the experimental animals suggest that Turmeric powder can be used to boost WBC production to support the immune system during shortage. Haemoglobin results obtained are within the normal range of 7.00 – 15.00 (g/dl) as suggested for healthy goats by (Susan, 2015).

Table 4. Haematological parameters of WAD Does fed experimental diets

	A	B	C	D	SEM	P-value
ESR(mm/hr)	0.67	0.50	0.50	0.50	0.04	0.441
Packed Cell Volume (%)	29.33	31.000	32.00	32.67	0.58	0.194
Red Blood Cell ($\times 10^6/\mu\text{l}$)	13.57	13.28	13.96	13.74	0.27	0.842
White Blood Cell ($\times 10^3/\mu\text{l}$)	10.90 ^{ab}	10.11 ^b	10.54 ^{ab}	12.17 ^a	0.32	0.110
Haemoglobin (g/dl)	9.76	9.78	9.89	10.32	0.14	0.522
Lymphocyte (%)	58.00	58.33	58.00	61.33	1.05	0.681
Neutrophil (%)	29.33	29.67	37.00	36.67	1.75	0.228
Monocyte (%)	3.33	2.33	2.33	2.33	0.29	0.582
Eosinophil (%)	2.68	2.33	2.67	2.33	0.15	0.802
Basophil (%)	1.33	0.67	0.67	1.00	0.15	0.363
Mean Cell Haemoglobin	7.20	7.37	7.11	7.53	0.10	0.475
Mean Cell Volume (fl)	21.6028 ^b	23.36 ^a	22.97 ^a	23.79 ^a	0.30	0.019
MCHC (g/dl)	33.32 ^a	31.54 ^{ab}	30.95 ^b	31.61 ^{ab}	0.35	0.075

Means with different superscript (a,b,c,d) along the same row are significant ly difference (P<0.05)

ESR: Erythrocyte sedimentation rate, MCHC: Mean corpuscular haemoglobin concentration

Serum biochemical indices of wad does fed experimental diets

Blood biochemical indices directly express the status of metabolism, nutrition and health of animals. All parameters from the serum biochemical analysis indicated that there was significant deference (P<0.05) in all the parameters (Table 5).

In this study, the serum total protein of the does fed with different levels of turmeric powders was significantly (p<0.05) different. The total protein helps to mobilize and maintain the body immune status and haemodynamic balance. The Albumin values obtained were all within the normal range of 24–44 g/l in a healthy goat as reported by Tambuwal *et al.*, (2002) and Susan, (2015). There was significant increase of Globulin across treatments in this experiment. The serum enzymes values of ALT, AST and ALP obtained in this study fell within the normal ranges of .6-19 (U/L), 167-513 (U/L) and 93–387 (U/L) respectively

Table 5: Serum biochemical indices of WAD does fed experimental diets

	A	B	C	D	SEM	P-value
Protein(g/dl)	60.77 ^a	66.70 ^b	66.70 ^b	66.01 ^b	0.93	0.011
Albumin(g/dl)	30.46 ^b	33.46 ^a	33.26 ^a	34.03 ^a	0.07	0.003
Globulin(g/dl)	30.30 ^b	33.24 ^a	34.22 ^a	31.98 ^{ab}	0.55	0.029
ALT (U/L)	7.63 ^c	8.87 ^{bc}	12.03 ^a	11.30 ^{ab}	0.65	0.023
AST (U/L)	260.63 ^b	263.97 ^b	270.50 ^a	273.90 ^a	1.78	0.005
ALP(U/L)	167.86 ^c	171.52 ^b	173.83 ^{ab}	175.84 ^a	0.98	0.002
Glucose (mmol/L)	2.51 ^b	3.39 ^a	3.86 ^a	3.51 ^a	0.57	0.001
Cholesterol(mg/dl)	105.28 ^a	101.66 ^b	98.25 ^c	93.42 ^d	1.35	0.000

Means with different superscript (a,b,c,d) along the same row are significant ly difference (P<0.05)

ALT: Alanine aminotransferase, AST: Aspartate aminotransferase, ALP: Alanine aminotransferase

Parameters of wad does fed graded level of turmeric powder

Minerals play an important role in growth, health and reproduction functions of livestock (Gonul *et al.* 2009) and have been recognized as potent nutrients and deficiency can impair utilization of other nutrients (Szefer and Nriagu, 2007). Calcium level from the experimental animal was between 8.38 to 12.42 mg/dl. A range of 9.2 – 11.6mg/dl has been reported to be required for healthy performance in goat. The serum phosphorus values were within the recommended range.

Table 6: Electrolyte parameters (mg/dl) of WAD does fed graded level of Turmeric powder

	A	B	C	D	SEM	P-value
Calcium	8.38 ^b	8.29 ^b	9.65 ^b	12.42 ^a	0.54	0.001
Phosphorus	4.62	5.22	6.22	4.21	0.29	0.119
Magnesium	2.59 ^b	2.86 ^b	3.69 ^a	2.59 ^b	0.16	0.015
Potassium	3.55 ^c	4.52 ^b	5.56 ^a	6.03 ^a	0.30	0.000

Means with different superscript (a,b,c,d) along the same row are significant ly difference (P<0.05)

CONCLUSION

The study revealed that turmeric powder (*Curcuma longa*) supplementation is needed to facilitate healthy performance, and the control of haematological parameters due to its high amount of crude protein, minerals, and phytochemicals. Thus, it could be used as an alternate component to lower cholesterol build up, act as antitumor, antioxidant and facilitate better feed digestion and metabolism in WAD does. It could therefore be supplemented at 10g/300g concentrate in goats' diet without adverse effect on health status.

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COMPARATIVE PERFORMANCE OF RABBITS WITH DIFFERENT FUR COLOURS FED TRIDAX MEAL SUPPLEMENTED DIETS.

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ABSTRACT

Fur colour is a potential indicator of the overall health and growth of rabbits. This study investigated the influence of fur colour on the growth performance and feed conversion ratio (FCR) of rabbits fed diets supplemented with *Tridax procumbens* meal. Thirty-six rabbits consisting of white, black, grey and ash fur were allotted into four treatments and three replicates per treatment. The *Tridax procumbens* was treated to meal form and added into the basal diet at 0g (diet 1), 50g (diet 2), 100g (diet 3) and 150g (diet 4) per 1kg. The four experimental diets (Diet 1, Diet 2, Diet 3, and Diet 4) were administered to rabbits of different fur colours: White, Gray, Ash, and Black. The results showed significant variations in weight gain and FCR across fur colour groups and diets. White rabbits exhibited the highest weight gain on Diet 2 (70.50 ± 3.58 g), but the difference was not statistically significant ($P > 0.05$) across the diets. Gray rabbits showed the highest weight gain on Diet 2 (69.67 ± 3.84 g) and the lowest on Diet 1 (57.50 ± 5.24 g) ($P = 0.048$). Ash rabbits gained more weight on Diet 4 (65.82 ± 3.77 g), and the significant differences were observed among the diets ($P = 0.018$). Black rabbits had the highest weight gain on Diet 3 (73.33 ± 3.74 g), with significant differences noted between Diet 3 and other diets ($P = 0.011$). For FCR, White rabbits showed a significantly improved FCR on Diet 2 (0.14 ± 0.02) compared to other diets ($P = 0.017$). Gray rabbits had the lowest FCR on Diet 2 (0.13 ± 0.02), which was significantly better than the other diets ($P = 0.011$). Ash rabbits had the most efficient FCR on Diet 1 (0.16 ± 0.02), but significant differences were found between Diet 1 and Diet 4 ($P = 0.044$). Black rabbits showed no significant differences in FCR across the diets ($P = 0.102$). These findings indicate that fur colour may influence the growth and feed conversion efficiency in rabbits, with the degree of response varying by diet and fur colour. This suggests that phenotypic characteristics like fur colour could be important factors in improving the productivity of rabbits fed *Tridax procumbens*-based diets.

Keywords: *Oryctolagus cuniculus*, weight gain, growth, feed conversion, hair

INTRODUCTION

The reliance on rabbit production as a source of cheap animal protein in solving malnutrition cannot be overstated as available crop and animal protein sources are usually not sufficiently produced to meet the minimum daily protein needs of an average adult (Tembachako and Mrema, 2016). Meanwhile, the need to minimize the cost of production of meat has mandated the use of plant materials with medicinal properties as feed supplement capable of enhancing the performance of the animal (Odoemelam *et al.*, 2013). Plant materials like *Tridax procumbens* can be mixed with animal diets to improve the nutritive value, promote animal growth rate and enhance feed conversion efficiency (Odoemelam *et al.*, 2013).

The forage, *Tridax procumbens*, is the most relished herbage by rabbits (Obinne, 2005). Taiwo *et al.* (2004) observed higher weight gain in rabbits fed mixed regime of *T. procumbens* with concentrates than those on sole concentrate. It has been established that supplementation or inclusion of *Tridax procumbens* in rabbit diet aligns with the specific nutritional needs of rabbits and does not pose any health risks (Akinmoladun *et al.*, 2018). Ragab *et al.* (2021) established that the growth rate in rabbits is influenced by a combination of genetic, nutritional, and environmental factors. Fur colour in rabbits are both distinctive features shaped by genetic factors and selective breeding practices (Fontanesi, 2006).

Therefore, this experiment was conducted to investigate the effect of fur colour on growth rate and feed conversion ratio of rabbit fed *Tridax procumbens* as supplement.

MATERIALS AND METHODS

The study was carried out at the Rabbitry unit of the Teaching and Research Farms, Adekunle Ajasin University, Akungba Akoko (AAUA), Ondo State, Nigeria. The farm site is located on 7° 28' 0" North, 5° 44' 0" East (Google earth, 2024).

The whole plant of *Tridax procumbens* were harvested, air dried and grinded to powdery form. The basal diet was formulated using 18% crude protein and 3000 kcal metabolizable energy (Table 1). The grinded *Tridax procumbens* were only added to diet 2, 3 and 4 at the rate of 10g per 1kg of feed.

Table 1: Gross composition of experimental diets

Ingredients	Diet 1	Diet 2	Diet 3	Diet 4
Maize	25.00	25.00	25.00	25.00
Wheat offal	50.00	50.00	50.00	50.00
GNC	11.00	11.00	11.00	11.00
Fish meal	6.00	6.00	6.00	6.00
Salt	1.00	1.00	1.00	1.00
Bone meal	2.00	2.00	2.00	2.00
Oil	4.00	4.00	4.00	4.00
Premix	1.00	1.00	1.00	1.00
Total	100.00	100.00	100.00	100.00
TLM	0.00	5.00	10.00	15.00

A total of 36 weaner rabbit ranging between 5 to 7 weeks of age were randomly distributed into the four treatments of nine rabbits per treatment and replicated thrice with three rabbits per replicate. The rabbits were firstly grouped based on fur colour before being randomly allotted to treatments and replicates. Feed and water was given to the animal *ad libitum* and the experiment lasted for eight weeks.

Data collection and statistical analysis

The data obtained on weight gain and feed intake were used to calculate the feed conversion ratio and analysed through one-way analysis of variance of SPSS (2015) in a completely randomized design. The means between treatments were separated for significance using the Duncan multiple range test (DMRT) of the same package at probability level of 0.05.

RESULTS AND DISCUSSION

Effect of fur colour on weight gain of rabbit

The effect of fur colour on growth performance of rabbit as presented in Table 2 showed that the growth of brown and white rabbits did not differ significantly ($P>0.05$) with the addition of *Tridax procumbens* though white rabbit (70.50g) fed diet 2 had the highest numerical value. The results showed that gray rabbits (69.67g) had significantly ($P<0.05$) better growth on diet 2 while diet 2 produced the lowest weight gain. Diet 4 produced the highest significantly ($P<0.05$) different weight gain in ash fur rabbits while black fur rabbit had significantly ($P<0.05$) better weight feeding on diet 3. This could be due to the fact that the experiment was carried out during the wet season thus allowing black fur rabbits to use more of the feed for muscle deposition. Abe (2006) reported improved growth in rabbit when plant residues were added to their diet. Mazouzi-Hadid *et al.* (2014) on the contrary reported that there was neither effect of coat colour nor any interactions between coat colour, season and physiological status of does on the growth of rabbit.

Table 2. Mean effect of fur colour on weight gain of rabbit

Parameters (g)	Treatments				P-value
	Diet 1	Diet 2	Diet 3	Diet 4	
White	64.83 $\pm$ 5.02	70.50 $\pm$ 3.58	68.17 $\pm$ 1.17	67.67 $\pm$ 3.65	0.066
Gray	57.50 $\pm$ 5.24 ^b	69.67 $\pm$ 3.84 ^a	67.58 $\pm$ 3.37 ^a	65.17 $\pm$ 3.06 ^a	0.048
Ash	60.00 $\pm$ 4.78 ^b	62.33 $\pm$ 5.23 ^{ab}	64.33 $\pm$ 3.66 ^a	65.82 $\pm$ 3.77 ^a	0.018
Black	62.55 $\pm$ 3.33 ^c	64.71 $\pm$ 3.85 ^b	73.33 $\pm$ 3.74 ^a	67.17 $\pm$ 2.30 ^{ab}	0.011

^{a,b,c} = means on a row with the same superscripts letters are not significantly ($P>0.05$) different.

Effect of fur colour on feed conversion ratio

The feed conversion ratio (FCR) of rabbits was significantly influenced by the interaction between fur colour and dietary treatment (Table 3). Across the experimental diets, rabbits with lighter fur colours (White, Gray, and Ash) generally exhibited better feed conversion efficiency than Black rabbits, particularly when fed Diets 2 and 3. Diet 2 consistently produced the lowest FCR values across fur colours, with Gray (0.13) and Ash (0.12) rabbits showing the most efficient feed utilization, followed closely by White rabbits (0.14). This trend

suggests a superior utilization of nutrients in Diet 2 by rabbits with lighter fur pigmentation.

Comparatively, White rabbits recorded the highest FCR on Diet 1 (0.20), indicating poorer feed efficiency under this dietary regime, while Gray rabbits also showed a relatively high FCR on the same diet (0.18). In contrast, Ash rabbits maintained comparatively lower FCR values across diets, suggesting a more stable feed utilization pattern among the lighter-coloured rabbits. Black rabbits showed no significant variation in FCR across all diets ($P > 0.05$), with values ranging narrowly between 0.16 and 0.18, indicating a limited response to dietary variation relative to other fur colours.

Overall, the results demonstrate that fur colour influenced feed conversion efficiency, with lighter-coloured rabbits responding more favorably to dietary manipulation, particularly diets supplemented with *Tridax procumbens*. Similar trends have been reported by earlier studies indicating that phenotypic traits such as coat colour may be associated with metabolic efficiency and nutrient utilization in rabbits (Gatti et al., 2018; Feng et al., 2020). The observed variation across fur colours aligns with reports that genetic and phenotypic differences can affect growth efficiency and feed utilization in small livestock species (Harel et al., 2017; Sadeghi et al., 2021).

Table 3. Mean effect of fur colour on feed conversion ratio of rabbit

Parameters	Treatments				P-value
	Diet 1	Diet 2	Diet 3	Diet 4	
White	0.20 ^a	0.14 ^b	0.16 ^{ab}	0.17 ^{ab}	0.017
Gray	0.18 ^a	0.13 ^c	0.17 ^b	0.16 ^b	0.011
Ash	0.16 ^b	0.12 ^c	0.15 ^b	0.17 ^a	0.044
Black	0.16	0.17	0.17	0.18	0.102

^{a,b,c} = means on a row with the same superscripts letters are not significantly ($P > 0.05$) different.

CONCLUSION

The study affirms the suitability of *Tridax procumbens* as a supplement in rabbit feed because rabbits fed with diet containing *Tridax procumbens* had better performance than the control diet. Furthermore, the study confirms that interaction of *Tridax procumbens* and fur colour had the highest influence on the weight performance of rabbit at 15% addition.

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BIOMASS YIELD, CHEMICAL AND *IN VITRO* FERMENTATION CHARACTERISTICS OF HYDROPONICALLY GROWN FODDER AND THEIR PREFERENCE BY YANKASA RAM

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ABSTRACT

The limited availability of land for pasture production, scarcity of high-quality feed, and high cost of animal feed significantly contribute to the challenges of sustainable ruminant production in Nigeria. Whereas hydroponically grown fodders are highly palatable and digestible, they have the potential to address this issue. However, information on the use of hydroponic fodders is scanty. Therefore, this study evaluated the chemical characteristics, *in vitro* digestibility, and acceptability of selected hydroponically grown fodders by Yankasa rams. Millet, sorghum, wheat, and maize were selected to be grown hydroponically to form hydroponic millet fodder (HMF), hydroponic sorghum fodder (HSF), hydroponic wheat fodder (HWF), and hydroponic maize fodder (HMzF). On the 9th day, the fodders were harvested to determine the biomass yield (%). Samples were oven-dried and examined for their chemical composition and *in vitro* characteristics. Acceptability of the fodders by Yankasa rams was carried out using the coefficient of preference (CoP) procedure. The biomass yield of the hydroponic fodders ranged from 3.64 kg (HWF) to 4.56 kg (HMzF). The Crude protein ranged from 10.67% in HWF to 12.12% in HSF, showing that $p < 0.05$ among the fodders. HMF had the highest value of OMD (30.95%), ME (4.28 KJ/kg DM), and SCFA (0.19 mol), followed by HSF, while the lowest values were obtained from hydroponic wheat fodder. This study demonstrated that Maize fodder, having the highest CoP and excellent nutritional value, can be produced hydroponically and fed to Yankasa rams for optimum productivity and profitability.

Keywords: Biomass yield, Maize, Millet, Sorghum, Wheat, nutrient composition, *in vitro*

INTRODUCTION

In tropical regions like Nigeria, forage availability and quality are increasingly constrained by land scarcity, climate variability, and poor pasture management (Okoli *et al.*, 2024). Most natural forages are low in nutrients, particularly crude protein, calcium, and phosphorus, especially during the dry season (Akinmoladun *et al.*, 2023). Feed shortages and poor quality remain major limitations to livestock productivity (Ibeawuchi *et al.*, 2021), while rising land costs further hinder pasture cultivation (Fadare *et al.*, 2020). Small ruminants such as sheep and goats are vital to rural livelihoods but often depend on low-quality forages with anti-nutritional factors like tannins and lignin that reduce nutrient availability (Abubakar *et al.*, 2013; Akinmoladun *et al.*, 2023). To sustain productivity, year-round access to nutritious, safe, and affordable feed resources is essential (Gupta *et al.*, 2014). Hydroponic fodder production provides an alternative approach by growing cereal or legume seeds without soil and with minimal water, producing nutrient-rich green feed within 7–10 days (Al-Karaki and Al-Hashimi, 2022). This system enhances digestibility and performance due to the inclusion of shoots, roots, and grain remnants, and it is environmentally sustainable (Adejoro *et al.*, 2022; Okoli *et al.*, 2024). However, research on the yield and acceptability of hydroponically grown fodders for small ruminants in Nigeria remains limited. Therefore, this study evaluates the biomass yield and preference of hydroponically grown wheat, sorghum, and millet fodders by Yankasa rams under Nigerian conditions.

Materials and methods

The study was conducted at the Ruminant Unit, Teaching and Research Farm, University of Ibadan, Nigeria. Four cereals: millet, sorghum, wheat, and maize were grown hydroponically for nine days following standard protocols. Fresh biomass yield was recorded, and samples were analyzed for proximate and fibre composition (AOAC, 2005; Van Soest *et al.*, 1991). *In vitro* gas production was measured using Menke and Steingass (1988) procedure. Feed preference was assessed in five Yankasa rams using the cafeteria method to determine the coefficient of preference (CoP), where $\text{CoP} > 1$ indicates acceptance. Data were analyzed using ANOVA and means separated by Duncan's test (SAS, 1999).

Results and discussion

Biomass yield of the selected hydroponically grown fodders

Presented in Table 1 is the Biomass yield of the selected four hydroponic fodders in kg/kg of the seeds. The Biomass yield of the fodders ranged from 3.64 - 4.56 kg of the seeds spread. The fodder produced from maize had the highest Biomass yield, followed by that of millet, while wheat produced the lowest biomass.

Table 1: Biomass yield of the hydroponically grown fodders

Parameter	HMF	HSF	HWF	HMzF	SEM	P
Biomass Yield (kg)	4.26 ^a	4.14 ^a	3.64 ^b	4.56 ^a	0.18	0.0041
Dry Matter (%)	16.57 ^b	22.56 ^{ab}	19.38 ^b	24.44 ^a	0.87	0.0001

^{a,b} means within column with different superscript differ ($p < 0.05$). SEM= standard error of mean, p = probability, HMF= Hydroponic Millet Fodder, HSF = Hydroponic Sorghum Fodder, HWF= Hydroponic Wheat Fodder, HMzF= Hydroponic Maize Fodder.

Differences in biomass yield among hydroponically grown fodders may be due to variations in genetic makeup, nutrient use efficiency, and physiological adaptability under hydroponic conditions. Each crop species possesses unique traits that influence nutrient uptake, carbon partitioning, and photosynthetic capacity, all of which determine its ability to convert available nutrients into biomass (Guo *et al.*, 2024; Singh *et al.*, 2023). Root system characteristics such as root density, hair proliferation, and symbiosis with mycorrhizal fungi further enhance nutrient absorption and growth performance (Li *et al.*, 2024; Pérez-López *et al.*, 2021). Differences in nitrogen uptake and utilization efficiency (NUpE and NUtE) among species also explain the observed yield disparities, as hydroponic systems provide uniform nutrient availability, making intrinsic physiological efficiency the key yield determinant (Mishra *et al.*, 2022; Chen *et al.*, 2023).

In this study, hydroponic maize (HMzF and HMF) and sorghum fodders (HSF) produced slightly below 5 kg of fresh fodder per kg of seed, consistent with findings by Ramchandra *et al.* (2019). Yield variations likely reflect species-specific differences in seed nutrient reserves, metabolic rates, and adaptability to humid hydroponic conditions (Kumar *et al.*, 2022).

Chemical characteristics of the selected hydroponically grown fodders

The chemical characteristics of the hydroponic fodders are presented in Table 2. Dry matter content of all the fodders were relatively high, though hydroponic maize fodder had higher DM, and thus would not encourage mold growth, which facilitate spoilage, and hence predispose animals to metabolic/nutritional disorders. The crude protein contents of the fodders ranged from 10.67 - 12.12%CP. Hydroponic sorghum fodder had the highest CP, followed by hydroponic maize fodder (11.39%), while hydroponic wheat fodder had the lowest percentage of CP.

Table 2: Chemical composition of the selected hydroponically grown fodders

Parameters (%)	HMF	HSF	HWF	HMzF	SEM	P
DM	88.55 ^c	89.97 ^b	88.23 ^c	90.67 ^a	0.07	<.0001
CP	11.22 ^b	12.12 ^a	10.67 ^c	11.39 ^b	0.02	<.0001
ASH	9.89 ^a	8.67 ^b	6.52 ^a	8.83 ^b	0.06	<.0001
EE	2.67 ^b	3.02 ^a	2.40 ^c	2.33 ^c	0.01	0.0016
NDF	47.09 ^b	44.10 ^d	49.33 ^a	45.37 ^c	0.07	<.0001
ADF	34.07 ^c	32.33 ^d	35.93 ^a	34.73 ^b	0.02	<.0001
ADL	13.50 ^c	12.20 ^d	15.87 ^a	14.13 ^b	0.07	<.0001

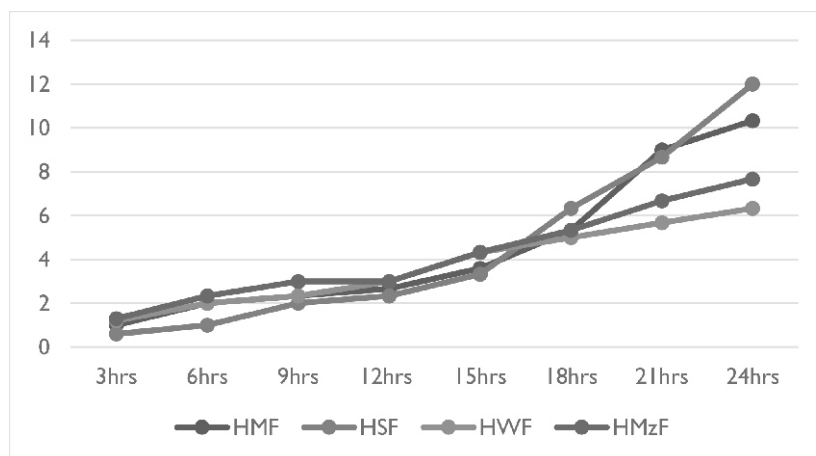
^{a,b,c,d} means within column with different superscript differ significantly ($p < 0.05$). SEM= standard error of mean, p = probability, CP =Crude Protein, EE= Ether Ext DM= Dry Mater, NDF= Neutral Detergent Fibre, ADF= Acid Detergent Fibre, ADL= Acid Detergent Lignin, HMF= Hydroponic Millet Fodder, HSF = Hydroponic Sorghum Fodder, HWF= Hydroponic Wheat Fodder, HMzF= Hydroponic Maize Fodder

Soaking and germination significantly enhance the crude protein (CP) content of hydroponic fodders due to protein mobilization, amino acid synthesis, and dry matter loss during sprouting, which concentrates nutrients (Kumar *et al.*, 2022; Adekeye, 2024). In this study, CP values exceeded the 8% threshold required for efficient rumen microbial synthesis (Satter and Slyter, 1974), indicating that these fodders can serve as valuable protein supplements during feed-scarce periods. Similar CP improvements have been reported in hydroponic maize and barley fodders, confirming the nutritional benefits of hydroponic systems in upgrading seed-based feeds (Muhammad *et al.*, 2025; Al-Shrouf, 2023). The proximate composition revealed moderate ash

(6.52–9.89%), ether extract (2.33–3.02%), and balanced fibre fractions, reflecting a favorable nutrient profile. Higher ash content compared with previous studies (Musa *et al.*, 2023) may result from direct mineral absorption under controlled hydroponic conditions (Ogunyemi *et al.*, 2024). Ether extract levels were consistent with typical hydroponic cereal values, supporting adequate lipid-based energy and vitamin absorption. Fibre components: NDF (44.10–49.33%), ADF (32.33–35.93%), and ADL (12.20–15.87%) indicated moderate structural carbohydrates suitable for rumen motility and digestibility (Zhao *et al.*, 2022).

In-vitro gas production of the selected hydroponically grown fodders

Figure 1 shows the *in vitro* gas production of the selected hydroponically grown fodders from 3rd to 24th hour incubation. At early incubation time (3-9hrs), the quantity of gas production was deferred and the fodders and the values ranged from 0.50-3.00 ml.



HMF= Hydroponic Millet Fodder, HSF = Hydroponic Sorghum Fodder,
 HWF= Hydroponic Wheat Fodder, HMzF= Hydroponic Maize Fodder

Figure 1: 3-hourly *in vitro* gas production of the selected hydroponically grown fodders at each Incubation time.

The progressive increase in gas production during mid-fermentation (12–24 h) reflects active microbial degradation of carbohydrates and efficient fermentation, with values ranging from 5.67 mL to 12.00 mL across the fodders. The gas output suggests fermentable substrate availability due to comparable growth stages (Kumar *et al.*, 2022). Moderate gas volumes indicate balanced proportions of soluble and structural carbohydrates, supporting steady microbial activity and stable rumen fermentation (Menke and Steingass, 1988; Getachew *et al.*, 2021).

In-vitro estimated parameters of the selected hydroponically grown fodders

Presented in Table 4 are the *in-vitro* gas production parameters consisting of the metabolizable energy ME (kJ/kg DM), organic matter digestibility OMD (%), and short-chain fatty acid SCFA (mol). AFRC (1993) explained metabolizable energy as the portion of the feed energy that can be utilized by the animal. The ME of the selected hydroponic fodders ranged from 3.71-4.28 KJ/kgDM, with millet fodder having the highest value.

Table 3: *In vitro* estimated parameters of the selected hydroponically grown fodders

Parameters	HMF	HSF	HWF	HMzF	SEM	P
ME (KJ/kgDM)	4.28	4.11	3.71	3.93	0.16	0.398
OMD (%)	31.00	28.60	25.20	27.90	0.27	0.117
SCFA (mol)	0.19	0.15	0.09	0.12	0.005	0.444

^{a,b,c,d} means within column with different superscript differ significantly ($p < 0.05$).

SEM = standard error of mean, p = probability, ME = Metabolizable Energy, OMD = Organic Matter Digestibility, SCFA = Short Chain Fatty Acid, HMF = Hydroponic Millet Fodder, HSF = Hydroponic Sorghum Fodder, HWF = Hydroponic Wheat Fodder, HMzF = Hydroponic Maize Fodder.

The metabolizable energy (ME), organic matter digestibility and short chain fatty acid values of all the hydroponically grown fodder were not significantly ($p > 0.05$) influenced, and thus any of the fodders has the potentials to be used as feedstuff, either as sole or supplement. The energy value is an indication of high

carbohydrate accumulation, and reduced lignification under controlled hydroponic conditions (Mokashi *et al.*, 2023; Turan *et al.*, 2024). Similar findings by Das *et al.* (2023) confirmed that hydroponic maize and sorghum fodders exhibit higher ME due to their elevated soluble carbohydrate fractions and lower structural fiber content. Organic matter digestibility (25.20–30.95%) was also favorable, suggesting efficient rumen degradability and nutrient utilization consistent with earlier studies (Ahmed *et al.*, 2023).

Short-chain fatty acid (SCFA) concentrations (0.09–0.19 mol) were uniform across fodders and higher than those reported for conventional Panicum maximum systems (Yildiz *et al.*, 2025), reflecting efficient microbial fermentation and balanced substrate utilization. These SCFAs, primarily acetate, propionate, and butyrate, are critical for ruminant energy metabolism and growth (Ajayi and Babayemi, 2023).

Acceptability of the selected hydroponically grown fodders by Yankasa rams

Table 4 shows the acceptability of the selected hydroponically grown fodders by Yankasa Rams. The rate at which the animals consumed the fodders was different, and the average intake values ranged from 0.73–1.50kg DM, with HMzF having the highest dry matter intake, followed by HSF and HMF, while HWF had the least mean intake.

The low intake of hydroponic wheat fodder (HWF) by Yankasa rams may be due to its lower organic acid content, which reduces palatability and flavor appeal (Dhia Al-Khayat, 2018; Patel *et al.*, 2024). Preference values (CoP) varied significantly, with hydroponic maize fodder (HMzF = 1.25) showing the highest acceptance, followed by sorghum (HSF = 1.08) and millet (HMF = 1.07), while HWF (0.61) was least preferred. These differences likely reflect variations in aroma, texture, and nutrient composition, particularly crude protein and moisture levels that enhance feed appeal and digestibility (Ahmed *et al.*, 2023; Turan *et al.*, 2024).

Table 4: Acceptability of the selected hydroponically grown fodders by Yankasa rams

Parameters	HMF	HSF	HWF	HMzF	SEM	P
Av. Intake (kg) DM	1.26 ^b	1.31 ^b	0.73 ^c	1.50 ^a	0.03	<.0001
CoP	1.07 ^b	1.08 ^b	0.61 ^c	1.25 ^a	0.01	<.0001
% Preference	27.00 ^{ab}	27.00 ^{ab}	15.00 ^b	31.00 ^a	0.05	0.01
Ranking	3 rd	2 nd	4 th	1 st		
Remark	A	A	NA	A		

^{a,b,c,d} means within rows with different superscript differ significantly ($p < 0.05$).

SEM= standard error of mean, CoP= Coefficient of Preference, A= Accepted, NA= Not Accepted, HMF= Hydroponic Millet Fodder, HSF= Hydroponic Sorghum Fodder, HWF= Hydroponic Wheat Fodder, HMzF= Hydroponic Maize Fodder

CONCLUSION

Hydroponic fodder production represents a viable precision agriculture technique for producing high-quality, sustainable livestock feed in land-limited environments. Hydroponic maize fodder, in particular, demonstrated superior biomass yield, nutrient composition, and acceptability by Yankasa rams. Its adoption could enhance feed security, animal productivity, and environmental sustainability.

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EFFECTS OF AQUEOUS *SENNA ALATA* LEAF EXTRACT ON THE HAEMATOLOGICAL AND SERUM BIOCHEMICAL INDICES OF BROILER CHICKENS

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ABSTRACT

This study evaluated the effects of aqueous *Senna alata* leaf extract (ASALE) on the haematological and serum biochemical indices of broiler chickens over a 42-day period. A total of 200 day-old chicks were randomly allocated to five treatment groups of 40 birds each, with four replicates of 10 birds per replicates, using a completely randomized design. All birds were fed the same basal diet, while the treatment groups received ASALE in their drinking water at inclusion levels of 0, 5, 10, 15, and 20 ml per litre of water. At the end of the trial, 5 ml of blood was collected from selected birds for laboratory analysis. Data obtained were subjected to one-way analysis of variance at 5% significance level. The results showed that ASALE had no significant ($P > 0.05$) effect on most haematological parameters, except white blood cell (WBC) count. WBC values differed significantly among treatments, with birds receiving 0, 10, 15, and 20 ml ASALE recording comparable values ($15.98, 15.42, 16.03, \text{ and } 16.43 \times 10^3/\mu\text{L}$, respectively), which were significantly higher ($P < 0.05$) than those of birds administered 5 ml ASALE ($13.28 \times 10^3/\mu\text{L}$). Serum biochemical indices were similarly unaffected by ASALE, except triglyceride levels, which varied significantly ($23.67\text{--}36.67 \text{ mg/dL}$), with the highest value observed in birds receiving 20 ml ASALE. It was therefore concluded that ASALE had no adverse effects on broiler chickens and can be safely administered in drinking water at levels of up to 20 ml per litre.

Keywords: Antibiotics, prophylactic, metaphylactic, synthetic antimicrobials, growth promoters

INTRODUCTION

Broiler chicken production is a vital component of the livestock subsector in many developing countries, including Nigeria, due to its short production cycle, high feed efficiency, and increasing demand for poultry meat (Oloso *et al.*, 2022). Poultry meat remains one of the most affordable sources of animal protein, thereby playing a crucial role in improving food security and reducing protein malnutrition (Akinola *et al.*, 2023). The rapid growth rate of broiler chickens also makes them well suited for intensive production systems. However, optimal productivity largely depends on effective nutrition, management practices, and disease control strategies (Akinola *et al.*, 2023). To mitigate disease challenges and enhance growth performance, the prophylactic and metaphylactic use of antibiotics has become common practice among broiler producers in Nigeria. While antibiotics may improve productivity, their indiscriminate and prolonged use has raised serious concerns, particularly the development of antimicrobial resistance and the presence of drug residues in poultry products. These issues pose significant risks to public health and have led to increased restrictions on the use of synthetic antimicrobials and growth promoters in animal production.

In response to these challenges, there is growing interest in the use of natural, plant-based alternatives as safe and sustainable substitutes for conventional antibiotics. *Senna alata*, commonly known as candle bush or ringworm plant and locally referred to as “asunwon oyinbo” in Yoruba, is a medicinal shrub belonging to the family Fabaceae. The plant is widely distributed across tropical and subtropical regions and has long been used in traditional medicine for the treatment of various ailments, including skin infections, gastrointestinal disorders, and parasitic infestations (Oladeji *et al.*, 2020). Phytochemical studies have shown that *Senna alata* leaves contain several bioactive compounds such as anthraquinones, flavonoids, tannins, alkaloids, and saponins (Oladeji *et al.*, 2020), which are known to exhibit antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory properties. These attributes suggest that the plant may positively influence physiological and metabolic processes when administered to animals.

Haematological and serum biochemical indices are reliable indicators of the health, nutritional status, and physiological condition of animals. Evaluating these parameters provides valuable insight into the safety and biological effects of dietary or medicinal interventions. Therefore, this study was designed to assess the effects of aqueous *Senna alata* leaf extract on the haematological and serum biochemical indices of broiler

chickens, with the aim of determining its potential as a safe natural supplement in poultry production.

MATERIALS AND METHODS

Study location: The experiment was conducted at the Teaching and Research Farm of the Federal College of Animal Health and Production Technology, Moor Plantation, Apata, Ibadan, Nigeria.

Preparation of the test ingredient: Fresh *Senna alata* leaves were collected, cleaned weighed and grinded. 100g of the ground leaves were soaked in 1 litre of distilled water for 24hrs before filtering using a muslin cloth.

Experimental Animals, management, and design: A total of 200 day old chicks were used for the study. The chicks were randomly distributed into five treatment groups of 40 birds each. Each treatment was replicated four times, with 10 birds per replicate, in a completely randomized design (CRD). All treatment groups were fed the same diet formulated to meet the nutrient requirements of broiler chickens, throughout the experiment. Feed and water were provided *ad libitum*, and the experimental pens were cleaned daily to ensure optimal biosecurity. **Aqueous *Senna alata* leaf extract (ASALE)** was administered to the broiler chickens via their drinking water at 0, 5, 10, 15 and 20mLs per litre of water to formulate five treatment groups

Data collection: At the end of the six-week experimental period, blood samples were collected from two randomly selected birds per replicate (eight birds per treatment) via the jugular vein using sterile syringes. The samples were divided into two portions: one was placed in EDTA-coated tubes for haematological analysis, while the other was transferred into plain tubes for serum biochemical evaluation.

RESULTS AND DISCUSSION

Presented in Table 1 is effect of aqueous *Senna alata* leaf extract on the haematological indices of broiler chickens. Aqueous *Senna alata* leaf extract (ASALE) had no significant ($P > 0.05$) influence on virtually all the haematological indices except the white blood cell (WBC). The WBC values of the experimental chickens differed significantly among treatments, with birds receiving 0, 10, 15, and 20 mL ASALE recording comparable values ($15.98, 15.42, 16.03$, and $16.43 \times 10^3/\mu\text{L}$, respectively), which were significantly higher ($P < 0.05$) than those of birds administered 5 mL ASALE ($13.28 \times 10^3/\mu\text{L}$). The higher WBC counts observed in broiler chickens administered ASALE may be attributed to a stimulation of the innate immune response by the bioactive constituents present in the extract. White blood cells are essential for disease prevention and immune defense; therefore, animals with low WBC levels are more susceptible to infections. Broilers receiving ASALE, with WBC values comparable to the control group, exhibited elevated WBC counts, suggesting an enhanced capacity for antibody production and increased resistance to diseases (Zekarias *et al.*, 2002).

Table 1: Effects of Aqueous *Senna alata* leaf extract on the Haematological indices of broiler Chickens

Parameters	T ₁ (0mL)	T ₂ (5mL)	T ₃ (10mL)	T ₄ (15mL)	T ₅ (20mL)	SEM	P value	N/R
PCV (%)	32.00	30.00	31.00	32.67	32.33	0.63	0.73	22-35
HB (g/dL)	10.23	9.67	10.10	10.63	10.63	0.22	0.68	7-13
RBCx10 ³ μL	3.07	3.00	2.99	3.18	3.18	0.06	0.79	2.5-3.5
WBCx10 ³ μL	15.98 ^a	13.28 ^b	15.42 ^a	16.03 ^a	16.43 ^a	0.37	0.02	12-30
PLTx10 ⁵ μL	13.43	12.90	12.37	12.87	13.27	0.28	0.84	1.5-3.2
Lymphocyte (%)	61.67	58.67	62.67	64.33	64.33	0.99	0.38	45-70
Heterophils (%)	30.67	33.00	29.67	28.00	28.67	1.09	0.69	3000-6000
Monocyte (%)	1.33	2.67	3.67	3.00	3.33	0.34	0.24	1-8
Eosinophils (%)	5.00	5.33	3.67	4.67	3.67	0.34	0.43	1.0-6.0
Basophils (%)	0.67	0.33	0.33	0.33	0.33	0.13	0.93	0.00-1.00

^{a,b}; Means with different superscripts along the same row are significantly different ($p < 0.05$) S.E.M – Standard error mean
N/R – Normal Range P.C.V- Packed Cell Volume, HB- Haemoglobin, RBC- Red Blood Cell, PLT – Platelet,

Table 2 presents the effect of aqueous *Senna alata* leaf extract (ASALE) on the serum biochemical indices of broiler chickens. The results showed that ASALE did not significantly ($P > 0.05$) affect most of the serum biochemical parameters evaluated in this study, indicating that the extract had no adverse effect on the metabolic health of the birds. However, a significant difference ($P < 0.05$) was observed in the triglyceride

values among the treatment groups. The triglyceride values obtained in this study decreased across the treatment groups as the ASALE administration increased. This reduction observed in birds on ASALE administration might be attributed to bioactive compounds such as saponins and phenolic substances, which are known to reduce lipid absorption in the intestine or regulate lipid metabolism in the liver (Ding *et al.*, 2023).

Table 2: Effect of Aqueous *Senna alata* leaf extract on the Serum Biochemical indices of broiler Chickens

Parameter	T ₁ (0mL)	T ₂ (5mL)	T ₃ (10mL)	T ₄ (15mL)	T ₅ (20mL)	SEM	P value	N/R
TP (g/L)	3.53	3.60	3.20	3.30	3.67	0.09	0.54	3.26-8.80
ALB (g/dL)	0.63	0.67	0.60	0.53	0.67	0.02	0.30	1.0-3.0
ALP (μ/L)	114.67	90.67	110.33	120.67	102.00	4.52	0.26	1.46-1.52
ALT (μ/L)	28.00	27.67	22.33	23.33	30.33	1.30	0.26	8.00-28.67
AST (μ/L)	186.33	184.00	179.00	181.67	184.33	1.27	0.46	8.00-33.00
CRT (mg/dL)	0.47	0.50	0.43	0.47	0.50	0.01	0.38	0.10-0.40
GLU (mg/dL)	177.33	177.33	172.67	174.00	178.33	1.26	0.62	180-250
CHOL (mg/dL)	202.00	195.00	190.00	192.67	203.67	2.19	0.20	129-297
TRIG (mg/dL)	36.67 ^a	33.67 ^{ab}	33.33 ^{ab}	25.67 ^{ab}	23.67 ^b	1.95	0.14	<150
HDL (mg/dL)	103.00	98.67	104.00	101.33	105.67	1.14	0.39	22-130
LDL (mg/dL)	90.60	89.70	80.93	86.20	91.33	1.86	0.41	24-43

^{ab}; Means with different superscripts along the same row are significantly different (p < 0.05) S.E.M – Standard error mean
N/R – Normal Range T.P- Total Protein, ALB- Albumin, GLB- Globulin, AST – Aspartate aminotransferase, ALT – Alanine aminotransferase, ALP – Alkaline Phosphate, CRT- Creatinine, TRIG- Triglyceride, GLU- Glucose, CHOL- Cholesterol
HDL- High Density Lipoprotein, LDL- Low-Density Lipoprotein

CONCLUSION

It can therefore be concluded that administering ASALE to broiler chickens at levels of up to 20 mL enhanced immune response and supported hepatic lipid regulation, as evidenced by increased WBC counts and reduced triglyceride levels.

Recommendation: Future research should focus on identifying the specific bioactive compounds responsible for the observed effects, as well as evaluating the long-term safety, cost-effectiveness, and practical implications of ASALE supplementation in poultry nutrition.

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APPLICATION OF MACHINE LEARNING MODELS FOR PREDICTION OF FEED INTAKE IN BROILER CHICKEN AT THE STARTER PHASE

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ABSTRACT

Feed cost constitutes approximately 65–75% of the total expenditure in broiler chicken production underscoring the importance of efficient feed management for improved profitability. This study employed two machine learning (ML) models, K-Nearest Neighbors (KNN) and M5 Prime (M5P), to predict daily feed intake in two major broiler strains, Cobb and Arbor Acres, during the starter phase (1–28 days). A total of 100 birds (50 per strain) were reared under controlled conditions. Data on daily feed intake were obtained. Results of progressive daily feed intake (1–28 days) ranged from 9.53 g to 89.75 g, and were analyzed using WEKA 3.8.6. The KNN algorithm achieved a flawless fit with a mean absolute error (MAE) of 0.00 g and an R^2 of 1.00 for both strains, which suggested potential overfitting. Conversely, the M5P model yielded more realistic and robust predictions, with a combined MAE of 4.64 g and a root mean squared error (RMSE) of 6.85 g, effectively capturing non-linear variations within the dataset. Prediction errors for M5P ranged between an underestimation of –11.74 g and an overestimation of +9.86 g. Strain-specific analysis showed Cobb broilers had higher early feed intake (10.03–51.21 g/day) during the first two weeks, while Arbor Acres reached similar final weights with lower consumption (9.53–50.17 g/day), indicating greater feed efficiency later in the starter phase. The study validated that ML models, particularly the M5P algorithm, offered a robust tool for optimizing feed planning, enhancing strain-specific feeding strategies, and improving the economic efficiency of broiler production.

Keywords: Broiler chicken; feed intake; machine learning; K-Nearest Neighbors; M5 Prime

INTRODUCTION

Poultry farming, specifically broiler production, is a rapidly expanding sector globally, with chicken meat being the world's most consumed animal protein. The economic viability of this industry is fundamentally linked to feed efficiency, as feed accounts for 65% to 75% of the total production cost. Accurate prediction of feed intake is paramount for effective feed management, cost control, and maximizing the feed conversion ratio (FCR), a critical economic indicator. Sub-optimal intake leads to diminished growth and increased costs. Feed intake is a complex trait influenced by genetics, nutrition, health, and environmental conditions. Commercial broiler strains, such as Cobb and Arbor Acres, exhibit notable differences in appetite, growth rate, and feed utilization efficiency. This strain-specific variability necessitates tailored feeding strategies. Modern broiler management is increasingly adopting Precision Livestock Farming (PLF), integrating data analytics and automation. Machine learning (ML), a core component of PLF, can analyze large-scale farm data (genetics, feed composition, environmental metrics) to predict performance traits like feed intake with higher accuracy than conventional methods. Current feeding models often rely on generalized standards, failing to account for critical variables like breed, leading to feed wastage and inconsistent performance. This study aimed to evaluate ML-based models (KNN and M5P) for predicting daily feed intake in Cobb and Arbor Acres broilers during the starter phase.

MATERIALS AND METHODS

Study Location and Experimental Design: The study was conducted at Teaching and Research Farm, Adekunle Ajasin University, Akungba-Akoko, Ondo State. A Completely Randomized Design (CRD) was employed, with the two strains, Cobb and Arbor Acres, serving as treatments. Each strain was subdivided into eight replicates.

Animals and Rearing Conditions: A total of 100 day-old broiler chicks (50 Cobb and 50 Arbor Acres) were utilized. Birds were managed in cages under standard feeding and husbandry practices. The starter phase lasted for 28 days. Temperature was controlled at $\pm 36^\circ\text{C}$ and monitored using a digital thermometer.

Data Collection and Pre-processing: Daily feed intake was recorded, and body weight was recorded weekly using a digital scale. The collected data were organized into a structured dataset, grouped by strain type, and prepared for machine learning analysis. Prior to model development, the dataset underwent pre-processing, including feature normalization or scaling to ensure equitable contribution during model learning. The data were partitioned into training and testing sets, and cross-validation was used during the training phase to robustly assess model performance and mitigate overfitting.

Software And Algorithms: All machine learning model development and analysis were executed using WEKA (Waikato Environment for Knowledge Analysis) software, version 3.8.6. The following regression algorithms were employed:

K-Nearest Neighbors (KNN): A non-parametric, instance-based learning algorithm that predicts the target value based on the average of its K-nearest neighbors.

M5 Prime (M5P) Algorithm: A model tree algorithm that combines decision tree learning with linear regression functions at the leaves, which is effective for handling continuous numerical data and identifying complex decision boundaries.

Model Development and Evaluation: Separate models were developed for the Cobb and Arbor Acres strains to predict weekly feed intake. Performance was assessed on the unseen test dataset using standard regression metrics: Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Coefficient of Determination (R^2).

RESULTS AND DISCUSSION

Exploitation of ML approaches paved sustainability in broiler chicken production (Milosevic, 2019). The evaluation of the KNN and M5P algorithms revealed distinct performance. For both Arbor Acres and Cobb strains, the KNN algorithm achieved a perfect prediction, with an MAE of 0.00 g and an R^2 of 1.00 (Tables 1 and 2). This zero-error performance suggests that the model overfit the training data, capturing noise or specific characteristics of the observed dataset rather than generalizing the underlying relationship, making it unreliable for predicting future, unseen data.

Table 1. Actual feed intake, predicted feed intake, and error values for Arbor Acre using KNN algorithm at starter phase

ACTUAL FEED INTAKE(g)	PREDICTED FEED INTAKE (g)	ERROR VALUES(g)
9.53	9.53	0
19.13	19.13	0
32.54	32.54	0
32.27	32.27	0
50.17	50.17	0
64.39	64.39	0
83.99	83.99	0
83.61	83.61	0

M5P Algorithm Performance:

The M5P model generated more realistic and robust results, better reflecting prediction uncertainty in biological data (Tables 2 and 4). The largest prediction error was an underestimation of -11.74 g for Cobb and an overestimation of +9.86 g for Arbor Acres. The overall performance metrics for M5P were an MAE of 4.64 g and an RMSE of 6.85 g. This performance confirms M5P's capacity to handle the inherent non-linearity and variability of feed intake data, making it a more reliable tool for practical application.

Table 2. Actual feed intake, predicted feed intake, and error values for Cobb using KNN algorithm at starter phase

ACTUAL (g)	PREDICTED (g)	ERROR (g)
10.03	10.03	0
19.4	19.4	0
29.28	29.28	0
38.09	38.09	0
51.21	51.21	0
72.45	72.45	0
89.75	89.75	0
83.25	83.25	0

Breed-Specific Feed Intake Patterns

Analysis of the data confirmed significant strain-specific differences. Cobb broilers exhibited a higher initial feed intake (10.03 g to 51.21 g/day) during the first two weeks, aligning with typical Cobb growth profiles. Arbor Acres showed a slightly lower initial intake (9.53 g/day) but demonstrated superior feed efficiency later in the starter phase, achieving comparable final weights with a lower overall predicted consumption. These strain-specific patterns underscore the importance of including breed as a core variable in predictive modeling to develop precise, breed-aligned feed management protocols.

Table 3. Actual feed intake, predicted feed intake, and error values for Arbor Acre using M5P algorithm at starter phase.

ACTUAL FEED INTAKE(g)	PREDICTED FEED INTAKE (g)	ERROR VALUES(g)
9.53	6.74	-2.79
19.13	19.61	0.478
32.54	29.26	-3.28
32.27	42.13	9.86
50.17	51.78	1.61
64.39	64.65	0.26
83.99	74.30	-9.69
83.61	87.17	3.56

CONCLUSION

The study concludes that while KNN showed a perfect fit suggestive of overfitting, the M5P model proved to be the more robust and reliable predictor (MAE = 4.64g, RMSE = 6.85g, effectively capturing the inherent non-linear variability in the data. Key strain differences were confirmed: Cobb broilers demonstrated higher early feed consumption, while Arbor Acres exhibited greater feed efficiency in the later starter phase. The results validated that ML models, particularly M5P, are valuable tools for data-driven decision-making to improve the precision of feed allocation and economic efficiency in commercial broiler production.

RECOMMENDATIONS

Future research should extend the study period to the full production cycle to assess lifetime feed efficiency and economic implications comprehensively. Also, advanced ML approaches, such as time series analysis or ensemble methods, should be investigated to further refine prediction accuracy, especially for capturing long-term growth trends. The integration of environmental and management factors (e.g., temperature, ventilation, and pen density) into the predictive model datasets is recommended to enhance field applicability and precision.

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COMPARATIVE PHYTOCHEMICAL PROFILE OF AQUEOUS AND METHANOLIC *Gmelina arborea* LEAF EXTRACTS

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ABSTRACT

This study evaluated the phytochemical profiles of aqueous and methanolic *Gmelina arborea* leaf extracts (AGALE and MGALE) and assessed their potential relevance to ruminant nutrition and production. Both extracts contained key bioactive compounds, including tannins, phenols, flavonoids, alkaloids, and saponins, as revealed by qualitative and quantitative analyses. However, notable differences were observed in their concentration levels: MGALE exhibited higher contents of phenols (110.0 ± 0.1 mg/100 mL), flavonoids (1378 ± 13.0 mg/100 mL), and alkaloids (425.0 ± 0.2 mg/100 mL), whereas AGALE showed greater levels of tannins (103.88 ± 0.12 mg/100 mL) and saponins (1010 ± 20 mg/100 mL). The study therefore concluded that both AGALE and MGALE possess promising applications in ruminant nutrition and health management, with the extraction solvent playing a critical role in determining the yield and effectiveness of the bioactive constituents.

Keywords: Secondary metabolites, bioactive, beechwood, ethno-medicine, qualitative and qualitative Analysis

INTRODUCTION

Plants remain a vital source of therapeutic agents and continue to serve as the foundation of traditional and modern medicine due to their affordability, accessibility, and minimal side effects. In many developing countries, increasing attention has been directed toward the documentation of traditional medicinal knowledge and the scientific evaluation of medicinal plants for the development of herbal remedies (Wight, 2018). Virtually all plants contain bioactive compounds with antimicrobial or pharmacological potential (Khan *et al.*, 2011). These compounds form an important basis for drug discovery and the development of new therapeutic agents for the management of various diseases (Adegbesan, 2019). Phytochemical constituents of plants are not only important for the identification of novel drug candidates but also serve as sources of economically valuable natural compounds for chemical synthesis and industrial applications. The diverse phytochemicals present in plants often exhibit complementary or synergistic effects that enhance their biological activity. Consequently, the scientific validation and standardization of herbal medicines have become essential areas of research, aimed at ensuring the safety, efficacy, and reproducibility of natural products (Nida and Rahimullah, 2022).

Plant-derived compounds have long been utilized in the treatment of a wide range of diseases, including infectious and metabolic disorders (Roy *et al.*, 2024). *Gmelina arborea* Roxb. (family Verbenaceae), commonly known as beechwood or white teak, is a fast-growing deciduous tree native to tropical and subtropical Asia. It has been widely introduced in West Africa, particularly in Nigeria and Côte d'Ivoire, where it is valued for both its medicinal and fodder potential (Tiwari *et al.*, 2008). Ethnobotanical reports indicate that *G. arborea* possesses multiple medicinal properties, including aphrodisiac, astringent, diuretic, analgesic, and tonic effects (Doughari *et al.*, 2007). The leaves have been traditionally used in the treatment of hypertension, malaria, and insect or scorpion stings, while the stem bark and fruits are applied in managing diarrhea, wounds, and fever (Moronkola *et al.*, 2001; Nayak *et al.*, 2011). Phytochemical studies show that *G. arborea* contains important secondary metabolites such as alkaloids, flavonoids, saponins, glycosides, tannins, phenolics, steroids, and triterpenoids. These compounds are linked to antimicrobial, antioxidant, and anti-inflammatory activities, supporting the plant's traditional use as a broad-spectrum therapeutic agent (N'gaman *et al.*, 2009; Nayak *et al.*, 2012). Its fruits and leaves also exhibit antibacterial effects, justifying their use in managing wounds, burns, sores, and other inflammatory conditions (Akyala *et al.*, 2013). They are natural bioactive compounds that influence plant colour, flavour, and aroma play key roles in promoting health and preventing disease (Sangeeta *et al.*, 2006). They are broadly classified into phenolic acids, flavonoids, stilbenes, and lignans, with flavonoids further divided into groups such as anthocyanins, flavones, flavanones, isoflavones, and flavonols (Arts and Hollman, 2005).

A comparative evaluation of *G. arborea*'s bioactive components utilizing various solvent extraction techniques is required due to the growing significance of its natural pharmacological potential. This study compared the phytochemical content of aqueous and methanolic leaf extracts in order to provide scientific proof for *Gmelina arborea*'s traditional therapeutic purposes as well as future uses in the formulation of natural products and medication development.

MATERIALS AND METHODS

Preparation of *Gmelina arborea* Leaf

A total of 50 kg of fresh *Gmelina arborea* leaves was collected from the Botanical Garden of the Federal College of Animal Health and Production Technology, Moor Plantation, Ibadan, Oyo State, Nigeria. Only healthy, disease-free leaves were selected. The leaves were thoroughly washed to remove dirt and debris, then air-dried under shade to prevent loss of phytochemicals from direct sunlight. The dried leaves were subsequently ground into a fine powder to increase surface area and improve extraction efficiency.

Extraction of Aqueous and Methanolic from *Gmelina arborea*

Aqueous extract was prepared by soaking a total of 30 kg of *Gmelina arborea* leaf meal in 45 L of distilled water for 24 hours. The mixture was first strained through a muslin cloth and then filtered using Whatman No. 1 filter paper. The filtrate was concentrated using a rotary evaporator equipped with a water bath, condenser, sender flask, receiver flask, pressure system, and control unit. The filtrate was placed in the sender flask, and the water bath temperature was maintained at 50 °C to prevent heat degradation. As the machine operated, vapor from the filtrate condensed and collected in the receiver flask. Once the extract thickened, it was transferred into Petri dishes. The semi-solid extract was then freeze-dried to obtain a crystalline aqueous *Gmelina arborea* leaf extract.

The methanolic extract was prepared by placing 20 kg of *Gmelina arborea* leaf meal in a glass container and adding 75 L of 70% methanol. The mixture was stirred at two-hour intervals and allowed to extract for 72 hours. The solvent mixture was then strained through a muslin cloth and further filtered using Whatman No. 1 filter paper. The remaining residue was re-extracted with an additional 75 L of 70% methanol using the same procedure. The combined filtrates were concentrated using a rotary evaporator (Heidolph Laborator 400 Efficient, Model 517-01002-002) set at 40 °C, after which the concentrate was dried in a vacuum oven at 40 °C and 700 mmHg to obtain the methanolic extract of *Gmelina arborea* leaves.

Qualitative and Quantitative Phytochemical Screening

Aqueous and Methanolic extract of *Gmelina arborea* leaf meal were subjected to preliminary screening of phytochemical constituents. The procedure were described by Idowu *et al.* (2024).

Determination of tannin Content: 0.1g of the sample was added 10mL of distilled water in a test tube and filtered. 0.1% FeCl₃ was added to the filtered samples and observed for brownish green or a blue black colouration which shows the presence of tannins. The tannins were determined by Folin - Ciocalteu method. The sample was prepared and about 0.1 mL was added to a volumetric flask (10 mL) containing 7.5 mL of distilled water and 0.5 mL of Folin-Ciocalteuphenol reagent, 1 mL of 35% Na₂CO₃ solution and dilute to 10 mL with distilled water. The mixture was shaken well and kept at room temperature for 30 min. A set of reference standard solutions of gallic acid were prepared in the same manner as described earlier. Absorbance for test and standard solutions were measured against the blank at 725 nm with an UV/Visible spectrophotometer. The tannin content was expressed in terms of mg of GAE /g of extract

Determination of saponins: 0.1g of the sample was added 10mL of distilled water and shaken vigorously to obtain a stable persistent froth. The frothing was then mixed with 3 drops of olive oil and observed for the formation of emulsion which indicates the presence of saponins. 2.0g of the sample was weighed into a 250mL conical flask. 100 mL of 20% C₂H₅OH was added. The mixture was then heated over a hot water bath for 4 hours with continuous stirring at about 55°C and filtered with a filter paper. The residue was re-extracted with another 200mL of 20% C₂H₅OH. The combined extract was then reduced to 40ml over a water bath at about 90°C. The concentrated extract was transferred into a 250mL separator funnel and 20mL of (CH₃CH₂)₂O was added to the extract and shaken vigorously. The aqueous layer was recovered while the (CH₃CH₂)₂O

layer discarded. This purification process was repeated. 60ml of n-butanol added and the combined n-butanol extract was washed twice with 10mL of 5% NaCl solution. The remaining solution was then heated on a water-bath in a pre-weighed 250mL beaker. After evaporation, the residue was dried in an oven to a constant weight. The % saponins was then calculated by difference.

Determination of flavonoids: A few drops of 1% NH_3 solution was added to the aqueous and methanolic extract of the sample in a test tube. A yellow coloration which disappears with the addition of concentrated sulphuric acid was observed if flavonoids compound are present. Total flavonoid content was measured by the aluminium chloride colorimetric assay. The reaction mixture consists of 1 mL of sample prepared and 4 mL of distilled water taken in a 10 mL volumetric flask. To the flask, 0.30 mL of 5 % sodium nitrite was treated and after 5 minutes, 0.3 mL of 10 % aluminium chloride was mixed. After 5 minutes, 2 mL of 1M Sodium hydroxide was treated and diluted to 10 mL with distilled water. A set of reference standard solutions of quercetin were prepared in the same manner as described earlier. The absorbance for test and standard solutions were determined against the reagent blank at 510 nm with an UV/Visible spectrophotometer. The total flavonoid content was expressed as mg of QE/g of extract.

Determination of alkaloids: 0.1 g of the sample was diluted to 10 mL with acid alcohol and filtered. To 5 mL of the filtrate was added 2 mL of dilute ammonia. 5mL of chloroform was added and shaken gently to extract the alkaloidal base. The chloroform layer was extracted with 10 mL of acetic acid. This was divided into two portions. Mayer's reagent was added to one portion and Dragendorff's reagent to the other. The formation of a cream (with Mayer's reagent) or reddish brown precipitate (with Dragendorff's reagent) was regarded as positive for the presence of alkaloids. 2g of the sample was placed in a 250mL beaker and 200mL of 10% acetic acid in ethanol was added. The mixture was covered and allowed to stand for 4 hours. It was then filtered and the filtrate concentrated on a water bath until it reached a quarter of its original volume. Concentrated NH_4OH was added until precipitation was complete. The mixture was allowed to settle and the precipitate collected on a weighed filter paper and washed with dilute NH_4OH . The precipitate alkaloid was dried and weighed.

Determination of total phenol content: 0.1g of the sample was dissolved in a test tube with ethanol, shook and filtered into another test tube and few drops of ferric chloride added and observed for a green or blue-black colouration which indicates the presence of phenol. Total phenolic compound contents were determined by the Folin-Ciocalteu method (Lee *et al.*, 2003). The sample was prepared and 0.5 mL of different dilutions were mixed with Folin Ciocalteu reagent (5 mL, 1:10 diluted with distilled water) for 5 min and aqueous Na_2CO_3 (4 mL, 1 M) were then added. The mixture was allowed to stand for 15 min and the phenols were determined by colorimetric method at 765 nm. The standard curve was prepared and solutions of Gallic acid in methanol: water (50:50, v/v). Total phenol values were expressed in terms of Gallic acid equivalent (mg/ g of dry mass), which is a common reference compound.

Data Analysis

Data collected in triplicate were pooled and expressed as mean $\pm$ standard deviation, then analyzed using SPSS (Statistical Package for Social Science) software version 2017. Student t-test was carried out to ascertain the level of significance at 0.05.

RESULTS

Table 1 shows the comparative quantitative phytochemical analysis of aqueous and methanolic *Gmelina arborea* leaf extract. It was observed that tannins, phenols, flavonoids, alkaloids, and saponins were present in *Gmelina arborea* leaf extract. The quantitative phytochemical screening of *Gmelina arborea* leaves revealed marked variations between methanolic and aqueous extracts. In the methanolic extract, flavonoids were found in the highest concentration (1378.0 ± 13.0 mg/100 mL), followed by saponins (640.0 ± 0.4 mg/100 mL), alkaloids (425.0 ± 0.2 mg/100 mL), phenols (110.0 ± 0.1 mg/100 mL), and tannins (96.0 ± 0.3 mg/100 mL). In contrast, the aqueous extract contained higher levels of saponins (1010.0 ± 20 mg/100 mL) and tannins (103.88 ± 0.12 mg/100 mL), but relatively lower flavonoids (117.01 ± 0.33 mg/100 mL) and phenols (76.25 ± 0.35 mg/100 mL). Alkaloid content in the aqueous extract was recorded at (330.0 ± 10 mg/100 mL).

Table 1: Comparative Quantitative phytochemical analysis of aqueous methanolic *Gmelina arborea* leaf extract

Parameters	AGALE Quantitative Extract	MGALE Quantitative Extract
Tanin (mg/100mL)	103.88±0.12 ^a	96.0 ± 0.3 ^b
Phenols (mg/100mL)	76.25±0.35 ^a	110.0 ± 0.1 ^b
Flavonoids (mg/100mL)	117.01±0.33 ^a	1378 ± 13.0 ^b
Alkaloids (mg/100mL)	330±10 ^a	425.0 ± 0.2 ^b
Saponin(mg/100mL)	1010±20 ^a	640.0 ± 0.4 ^b

^{a,b} means along the same row with different superscripts are significant difference
 AGALE: Aqueous *Gmelina arborea* Leaf extract Quantitative Extract, MGALE
 Methanolic *Gmelina arborea* Leaf extract

Table 2 shows the comparative qualitative phytochemical analysis of aqueous and methanolic *Gmelina arborea* leaf extract. The qualitative analysis confirmed the presence of all tested phytochemicals in both extracts, but at varying intensities. Methanol extract showed moderate presence (++) for tannins, phenols, flavonoids, alkaloids, and saponins, while aqueous extract showed weaker detection (+) for tannins, phenols, alkaloids, and saponins, but a moderate presence (++) for flavonoids.

Table 2: Comparative Qualitative phytochemical analysis of aqueous and methanolic *Gmelina arborea* leaf extract

Parameters	<i>Gmelina arborea</i> (aqueous) Qualitative Extract	<i>Gmelina arborea</i> (methanolic) Qualitative Extract
Tanin (mg/100mL)	+	++
Phenols (mg/100mL)	+	++
Flavonoids (mg/100mL)	++	++
Alkaloids (mg/100mL)	+	++
Saponin (mg/100mL)	+	++

Present +, Moderately present ++

DISCUSSION

The present study compared the phytochemical profiles of aqueous and methanolic extracts of *Gmelina arborea* leaves, and further evaluated the antioxidant activity of the aqueous and methanolic extract. The findings demonstrated that methanol was more efficient than water in extracting major secondary metabolites such as flavonoids, tannins, phenolics, and alkaloids. This was in line with the results reported by Edeoga *et al.* (2005), who highlighted higher yields of alkaloids and polyphenols with methanol compared to aqueous extraction. This result agrees with the observations of previous researchers (Olubodun and Osagie, (2016); Olubodun *et al.* (2021)) who reported the presence of some phytochemicals in different solvent extracts of the leaves, fruit or other plant parts of *A. boonei* and other plant species. The variations in the plant materials, the range of chemical components in the plant materials and their varying solubility characteristics in various solvents, the chemicals to be extracted, and/or extraction techniques could all contribute to the observed variations (Olubodun *et al.*, 2021). The study revealed that methanol is better for extraction of phytochemicals in *Gmelina arborea* leaf meal when compared with aqueous extraction.

CONCLUSION

It can therefore be concluded from the findings of this study that, the aqueous *Gmelina arborea* leaf extract contained generally lower levels of phytochemicals than the methanolic extract, except for tannins and saponins, which were comparatively higher. It was also discovered that, methanol proved to be a more effective solvent for extracting phytochemicals from *Gmelina arborea* leaf meal.

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BROILER GROWTH RESPONSE AND CARCASS CHARACTERISTICS UNDER PHYTASE-SUPPLEMENTED DIETS WITH DIVERSE ENERGY SOURCES

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ABSTRACT

This study evaluated the effects of different cereal-based diets, with or without phytase supplementation, on the growth performance and carcass characteristics of broiler chickens. Six experimental diets were formulated using maize (T1), wheat (T2), sorghum (T3), maize plus phytase (T4), wheat plus phytase (T5), and sorghum plus phytase (T6). Growth performance parameters measured included initial body weight (IBW), final body weight (FBW), average feed intake (AFI), average weight gain (AWG), and feed conversion ratio (FCR), while carcass characteristics assessed were live weight (LW), eviscerated weight (EVW), thigh weight (TW), drumstick weight (DSW), and breast weight (BW). Dietary treatments significantly influenced growth performance of broilers ($p < 0.05$). Birds fed sorghum-based diets (T3) recorded the highest final body weight (2106.10g) and average weight gain (1315.00g), while phytase supplementation notably improved feed efficiency, with the lowest FCR observed in broilers fed wheat having 2.93 (T2) and sorghum plus phytase with 3.10 (T6). Feed conversion ratio was generally improved in phytase-supplemented diets compared to their non-supplemented counterparts, indicating enhanced nutrient utilization. Carcass characteristics were also significantly affected by dietary treatments ($p < 0.05$). Broilers fed wheat plus phytase (T5) exhibited superior live weight (2128.00g), eviscerated weight (14897.7g), thigh weight (247.33g), and breast weight (499.33g) compared to other treatments. Diets without phytase supplementation generally produced lower carcass yield parameters, while phytase inclusion enhanced carcass development across cereal sources. The inclusion of phytase in cereal-based broiler diets improved growth performance, feed efficiency, and carcass yield, with wheat- and sorghum-based diets showing the most pronounced responses. These findings suggest that phytase supplementation is an effective nutritional strategy for optimizing broiler productivity when alternative cereal grains are used in place of maize.

Keyword: Maize, wheat, sorghum, eviscerate weight, energy

INTRODUCTION

Growth performance and carcass characteristics are key indicators of efficiency and profitability in broiler production. The rapid genetic improvement in broiler chickens over the past decades has increased their nutrient requirements, particularly for energy and phosphorus, which are essential for muscle development, skeletal formation, and metabolic functions (Leeson and Summers, 2005). Dietary energy is the most expensive component of poultry feed, accounting for over 60% of total feed cost (Adeyemi *et al.*, 2012). Therefore, identifying alternative energy sources that maintain performance without compromising carcass quality is of great practical importance in poultry nutrition.

Conventional energy sources such as maize are increasingly limited by competition between humans and livestock as well as by price fluctuations. This has led to interest in non-conventional feed ingredients such as cassava, sorghum, millet, and yam peel meal, which may serve as partial substitutes for maize (Olukosi *et al.*, 2008). However, these ingredients often contain anti-nutritional factors (ANFs) and phytate-bound phosphorus, which reduce nutrient availability and feed efficiency (Selle and Ravindran, 2007). Phytate chelates minerals and forms complexes with proteins and starch, thereby impairing digestion and nutrient absorption (Ravindran *et al.*, 2006).

To counter these limitations, the inclusion of exogenous enzymes such as phytase has become an important strategy in poultry diets. Phytase catalyzes the hydrolysis of phytate (myo-inositol hexakisphosphate), releasing phosphorus and other bound nutrients, which enhances their utilization and reduces environmental phosphorus excretion (Selle *et al.*, 2009). Numerous studies have reported that phytase supplementation improves growth performance, feed conversion ratio, and carcass yield in broilers fed diets with varying nutrient compositions (Onyango *et al.*, 2005; Olukosi and Adeola, 2008; Cowieson *et al.*, 2011). The effects of phytase, however, may vary depending on the energy source used in the diet. Energy sources differ in their chemical composition, fibre content, and nutrient binding capacity, which can influence enzyme efficiency

and nutrient digestibility (Selle and Ravindran, 2008). Hence, understanding the interaction between dietary energy source and phytase supplementation is essential for optimizing nutrient utilization, growth rate, and carcass quality in broiler chickens.

Therefore, this study was designed to evaluate the growth performance and carcass characteristics of broiler chickens fed different energy source diets supplemented with phytase. The findings will contribute to developing cost-effective feeding strategies that enhance productivity while minimizing nutrient waste and feed cost.

MATERIALS AND METHODS

Experimental Site

The experiment was carried out at the poultry training pen of Aquatech College of Agriculture and Technology Fodasis, Ibadan, Oyo State. The farm is located on latitude 7.34838° N and longitude: 3.86882° E (Google, 2025)

Experimental animal and management

A total of 72 broilers were used for the experiment. They were randomly allotted into 6 treatments (T1, T2, T3, T4, T5, and T6) and it was replicated 3 times (R1, R2, R3), with 4 birds in each replicate. Deep liter system was used for the experiment and it was partitioned into eighteen cells for the treatment and replicate. Chicken net and wood were used for the partitioning of the cells. Normal routine management of birds were observed throughout the experimental period which lasted for 6 weeks. The birds were allowed free access to water and feed.

Experimental Diets

Feed Preparation: The phytase was bought from an agro allied store in Ibadan while the different energy source was bought from a local market at Ibadan. The phytase was added to feed formulated with different energy source (maize, wheat, sorghum) at the same level.

Six diets were prepared for the experiment prepared for the experiment each with crude protein (18%).

The control diet (T1) = Maize without phytase.

T2 = Wheat without phytase,

T3 = Sorghum without Phytase,

T4 = Maize with phytase

T5 = Wheat with Phytase

T6 = Sorghum with phytase

The first three diets served as the control while the other three served as treatments.

Table 1. Composition of experimental diets

Ingredients	Treatments					
	T1	T2	T3	T4	T5	T6
Maize	55	0	0	55	0	0
Wheat	0	55	0	0	55	0
Sorghum	0	0	55	0	0	55
SBM	23	23	23	23	23	23
Soya oil	0.7	0.7	0.7	0.7	0.7	0.7
DCP	0.28	0.28	0.28	0.28	0.28	0.28
Fish meal (65)	2	2	2	2	2	2
Wheat bran	12	12	12	12	12	12
Rice bran	2	2	2	2	2	2
OKC	2	2	2	2	2	2
Premix	0.3	0.3	0.3	0.3	0.3	0.3
Methionine	0.15	0.15	0.15	0.15	0.15	0.15
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Limestone	2	2	2	2	2	2
Phytase	0	0	0	0.02	0.02	0.02
Total	100	100	100	100	100	100

Measurement of Growth Parameters

Feed Intake: The birds were fed *ad libitum*, data of the feed supplied and leftover feed was taken. The daily feed was calculated by subtracting the leftover feed supplied.

Feed Intake = Feed Supplied – Leftover Feed (Mwaleet *et al.*, 2008)

Weight Gain: The birds were weighed to determine the weight of the birds. The initial weight and the final weight of the birds were measured with use of a sensitive weighing scale. The weight was calculated by subtracting the initial weight from the final weight of the birds.

Weight gain (g) = Final Weight (g) – Initial Weight (g)

Feed Conversion Ratio (F.C.R): The feed conversion ratio was calculated by dividing the feed intake by the total weight gain.

Feed Conversion Ratio =
$$\frac{\text{Feed Intake (F.I)}}{\text{Total Weight Gain (TWG)}} \quad (\text{Mwaleet } et al. 2008)$$

Measurement of Carcass Characteristics

Dressed Weight: The birds were weighed after slaughtering, removal of feathering and evisceration.

Dressing Percentage: Dressing percentage is based on the relationship between dressed carcass weight and the live animal weight after things like the feather and internal organs have been removed.

Dressing Percentage =
$$\frac{\text{Carcass Weight}}{\text{Live Weight}} \times 100$$

Eviscerated weight: The weight after all the offals and visceral has been removed.

RESULT AND DISCUSSION

Effect of Different Energy Source based Diet Supplemented with and without Phytase on the growth Performance of Broilers

The growth performance of broiler chickens as influenced by the experimental diets is presented in Table 2. Initial body weight (IBW) did not differ markedly among treatments, indicating that birds were relatively uniform at the start of the experiment and that subsequent differences in performance were attributable to dietary effects rather than initial weight variation. In contrast, final body weight (FBW), average feed intake (AFI), average weight gain (AWG), and feed conversion ratio (FCR) were significantly affected by dietary treatments ($p < 0.05$).

Broilers fed the sorghum-based diet without phytase (T3) recorded the highest FBW (2106.10 g) and AWG (1315.00 g), which were significantly higher than values obtained with the maize-based diet (T1) and comparable or superior to other treatments. This suggests that sorghum can effectively support growth in broilers when properly formulated, corroborating earlier findings that sorghum is a viable alternative energy source to maize in poultry diets (Nyannor *et al.*, 2007; Selle *et al.*, 2010). However, the relatively higher FCR observed in T3 compared with phytase-supplemented diets indicates less efficient feed utilization, likely due to the presence of anti-nutritional factors such as phytate in sorghum (Ravindran *et al.*, 2013).

Phytase supplementation improved growth efficiency across cereal types. Birds fed wheat plus phytase (T5) and sorghum plus phytase (T6) exhibited improved feed conversion, with the lowest FCR recorded in T6 (2.93), followed closely by T2 (3.10) and T5. The improved FCR observed in phytase-supplemented diets is consistent with reports that phytase enhances phosphorus availability and overall nutrient digestibility, thereby improving growth performance and feed efficiency in broilers (Cowieson *et al.*, 2011; Adeola and Cowieson, 2014). Notably, birds on wheat plus phytase (T5) also recorded the highest AFI, suggesting enhanced palatability or improved nutrient utilization associated with enzyme supplementation.

Maize-based diets supplemented with phytase (T4) showed moderate improvements in FBW and AWG compared to the maize-only diet (T1), although FCR remained relatively high. This may indicate that while maize contains lower phytate levels than wheat and sorghum, the response to phytase supplementation is still beneficial but less pronounced (Selle and Ravindran, 2007). Overall, the results demonstrate that both the type of cereal grain and phytase supplementation significantly influence broiler growth performance.

The findings indicate that alternative cereals such as wheat and sorghum can effectively replace maize in

broiler diets, particularly when supplemented with phytase. Phytase inclusion consistently improved feed conversion efficiency and supported better growth performance, confirming previous reports on the efficacy of exogenous enzymes in enhancing nutrient utilization in poultry production systems (Bedford and Cowieson, 2012; Ravindran, 2013). On the contrary, Selle *et al.* (2010) reported that sorghum-based broiler diets do not respond robustly to exogenous enzymes, including phytase. Also Liu *et al.* (2014) reported that this is possibly because conventional exogenous enzymes do not address the anti-nutritive effect of one or more factors inherent in sorghum. However, the feed conversion ratio and weight gain (although not significantly different) was numerically higher in the birds fed sorghum based diet (with and without phytase) and this observation is in accordance with Liu *et al.* (2014) who reported that numerically, sorghum was fractionally better than maize, which was somewhat surprising and that in his research, sorghum-based diets supported the highest weight gain and the most efficient FCR. Liu *et al.* (2014) also reported that the sorghum used in his research had low protein content (82.4g/kg) and the correspondingly low kafirin proportion of protein may have contributed to the acceptable performance of birds offered sorghum based diets. And Selle *et al.* (2010) reported that sorghum has been associated with inconsistent or even sub-optimal broiler performance under Australian conditions, which may be attributable to the various anti-nutritive effects of kafirin, phytase and phenolic compounds. Meanwhile, Taylor *et al.* (1984) found that kafirin proportions of total sorghum protein increases with protein concentrations.

Table 2. Effect of Experimental diet on the growth of broilers

Parameters(g)	T1(M)	T2(W)	T3(S)	T4(MP)	T5(WP)	T6(SP)	MSE
IBW	787.42	831.58	791.33	786.33	766.17	773.75	75.07
FBW	1986.10 ^c	2042.80 ^b	2106.10 ^a	2031.20 ^{bc}	1997.70 ^c	2052.00 ^b	148.22
AFI	440.60 ^{ab}	4076.90 ^{ab}	4307.50 ^{ab}	4218.00 ^{ab}	4530.90 ^a	3731.60 ^b	353.01
AWG	1198.60 ^c	1211.20 ^b	1315.00 ^a	1244.80 ^b	1231.50 ^b	1278.30 ^{ab}	185.02
FCR	3.81 ^a	3.10 ^b	3.36 ^{ab}	3.56 ^{ab}	3.68 ^b	2.93 ^b	0.55

Means on the row with the same superscripts letter are significantly different ($p < 0.05$).

IBW = Initial Body Weight, FBW = Final Body Weight, AFI= Average Weight Gain, FCR = Feed Conversion Ratio. M = Maize, W= Wheat, S= Sorghum, MP = maize with phytase, WP = Wheat with phytase, WP = Wheat with phytase, SP = Sorghum and phytase.

Effect of diet containing Different energy source supplement with and without phytase on the Carcass Weight of Broiler Chicken.

The effects of experimental diets on carcass characteristics of broilers are summarized in Table 3. Dietary treatments significantly influenced several carcass parameters, including live weight (LW), eviscerated weight (EVW), thigh weight (TW), and breast weight (BW) ($p < 0.05$), while drumstick weight (DSW) showed no significant differences among treatments.

Broilers fed wheat plus phytase (WP, T5) exhibited the highest LW (2128.0 g) and EVW (1494.7 g), which were significantly higher than birds on maize (T1), wheat (T2), sorghum (T3), maize plus phytase (T4), and sorghum plus phytase (T6). Similarly, BW was highest in T5 (499.33 g), indicating that phytase supplementation improved carcass yield, particularly when combined with wheat. Thigh weight was also significantly higher in T5 (247.33 g) compared to other diets, while drumstick weight did not differ significantly across treatments.

The superior carcass characteristics observed in phytase-supplemented diets are consistent with earlier reports showing that exogenous phytase enhances nutrient availability, particularly phosphorus and amino acids, which are critical for muscle accretion and overall carcass development in broilers (Cowieson *et al.*, 2011; Adeola and Cowieson, 2014). Wheat-based diets supplemented with phytase appeared particularly effective, likely due to the higher phytate content of wheat relative to maize and sorghum, allowing greater improvement in nutrient utilization when phytase was added (Selle and Ravindran, 2007).

Broilers on maize-based diets (T1 and T4) and sorghum-based diets (T3 and T6) showed comparatively lower LW and EVW, suggesting that phytase supplementation had a more pronounced effect in wheat diets than in maize or sorghum diets. This supports previous findings that the response to phytase varies with the cereal type, with wheat and barley showing higher responses due to greater phytate content (Ravindran *et al.*, 2013; Selle *et al.*, 2010).

Phytase supplementation significantly improved carcass yield, particularly in wheat-based diets, enhancing LW, EVW, BW, and TW. These results underscore the importance of enzyme supplementation in maximizing carcass characteristics and overall production efficiency in broilers fed alternative cereals. Furthermore, Liu *et al.* (2014) reported that the addition of phytase to maize-based diets generated relatively pronounced growth performance responses and even more pronounced responses in nutrient utilization. However, it correlates with the report of Ravindra *et al.* (1999) where phytase supplementation increased average ileal digestibility coefficients of 14 amino acids in wheat by 9.04% (0.774 versus 0.844) and by 3.36% (0.774) versus 0.800) in maize. In contrast, Leske and Coon (1996) reported that phytase hydrolysis by 28.2% (0.590 versus 0.308) in maize but by only 16.1% (0.468 versus 0.307) in wheat in 22 day-old broilers chickens.

Table 3. Effect of experimental diet on the carcass characteristics of broilers

Parameters(g)	T1(M)	T2(W)	T3(S)	T4(MP)	T5(WP)	T6(SP)	MSE
LW	1927.3	1866.3	1876.3	1909.3	2128.0	1868.7	182.75
EVW	1315.3 ^b	1297.7 ^{bc}	1297.7 ^{bc}	1249.3 ^c	1494.7 ^a	1232.7 ^c	67.67
TW	237.00 ^a	204.00 ^b	209.67 ^b	208.00 ^b	247.33 ^a	205.67	32.25
DSW	221.00	190.00	192.33	181.33	203.67	187.67	23.74
BW	398.33 ^b	428.67 ^{ab}	403.33 ^b	397.00 ^b	499.33 ^a	394.67 ^b	63.18

Means on the row with the same superscripts letter are significantly different ($p < 0.05$).

LW = Live Weight, EVW= Eviscerated Weight, TW = Thigh Weight, DWS = Drum Stick Weight
BW = Breast Weight, M = maize, W = wheat, S = sorghum, MP = maize with phytase, WP = wheat with phytase, SP = sorghum and phytase

CONCLUSION

In conclusion, sorghum-based diet supplemented with phytase increased weight gain and feed conversion ratio. Meanwhile the inclusion of phytase to wheat-based diet produced the highest carcass weight of the birds. This result thereby confirms the hypothesis that phytase would improve these parameters irrespective of the type of grain on which the diets were based. It is therefore recommended that phytase should be added to broiler diet irrespective of the energy, though better when maize is not involved. Thus, the use of alternative cereals such as wheat and sorghum, when supplemented with phytase, can effectively replace maize in broiler diets, supporting enhanced growth performance and carcass yield. These findings highlight the importance of diet formulation and enzyme supplementation as strategies to improve poultry productivity and feed efficiency.

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EVALUATION OF THE CHEMICAL AND MINERAL COMPOSITION OF *GMELINA ARBOREA* LEAF MEAL

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ABSTRACT

Gmelina arborea leaf meal (GALM) was evaluated for its chemical and mineral composition. Fresh leaves were thoroughly washed to remove adhering dirt and debris, air-dried at room temperature for five days, milled into a fine powder, and sieved to obtain a uniform leaf meal. Sub-samples of the processed leaf meal were subjected to chemical and mineral analyses. The results showed that GALM contained $93.32 \pm 0.04\%$ dry matter, $18.45 \pm 0.01\%$ crude protein, $3.27 \pm 0.02\%$ ether extract, $10.06 \pm 0.07\%$ crude fibre, $5.34 \pm 0.04\%$ ash, and $54.20 \pm 0.01\%$ nitrogen-free extract. Fibre fractions recorded were $56.13 \pm 0.01\%$ neutral detergent fibre, $15.64 \pm 0.01\%$ acid detergent fibre, $4.95 \pm 0.02\%$ acid detergent lignin, $10.69 \pm 0.03\%$ cellulose, and $40.49 \pm 0.01\%$ hemicellulose. Mineral analysis revealed appreciable concentrations of calcium (1297.00 ± 0.04 mg/100 g), magnesium (521.25 ± 0.13 mg/100 g), potassium (233.59 ± 0.05 mg/100 g), sodium (271.80 ± 0.12 mg/100 g), phosphorus (331.89 ± 0.17 mg/100 g), and zinc (1.623 ± 0.01 mg/100 g). This can therefore be concluded that GALM possesses valuable nutritional qualities and can serve as a protein-rich supplement to enhance livestock productivity and performance.

Keywords: Bioactive compounds, *Gmelina arborea*, herbs, phytochemicals, browse plant, non-convectional

INTRODUCTION

Gmelina arborea leaves represent an important non-conventional feed resource that is available throughout the year. Notably, the leaves retain their green coloration for most of the dry season and have been successfully utilized in ruminant feeding with favorable outcomes (Lamidi *et al.*, 2009). Several studies have reported that *Gmelina arborea* leaves are rich in protein, with crude protein content ranging from 10.01% to 38.4% (Osakwe and Udeogu, 2007), making them a valuable nutritional resource. The year-round availability of *Gmelina arborea* leaves ensures a steady feed supply for livestock, particularly during periods of feed scarcity in the dry season (Amata, 2014). The tree is widely distributed across Nigeria, especially within the rainforest and derived savanna zones, and is among the unconventional feed resources commonly exploited in animal nutrition (Jiwuba *et al.*, 2016). The leaves are recognized as a useful nutrient source for both ruminant and non-ruminant animals. In addition to their nutritional value, various parts of the *Gmelina arborea* plant including the leaves, flowers, roots, and bark possess medicinal properties (Kumaresan *et al.*, 2014) and have been reported to function as natural growth promoters (Arumugam *et al.*, 2024). Previous research has also shown that *Gmelina arborea* leaves meal can serve as cost-effective protein supplements capable of improving voluntary feed intake, enhancing nutrient digestibility, and promoting better animal performance when included in low-quality diets (Kakengi *et al.*, 2001). Furthermore, the presence of bioactive compounds in the leaves may interact with dietary nutrients and fibre to confer protective health benefits against diseases (Sangeeta and Sujata, 2006). Based on these attributes, this study was designed to evaluate the chemical and mineral composition of *Gmelina arborea* leaf meal.

MATERIALS AND METHODS

Source and Processing of the test ingredient: Fresh, mature *Gmelina arborea* leaves were harvested from the Botanical Garden of the Federal College of Animal Health and Production Technology, Moor Plantation, Ibadan, Oyo State, Nigeria. The leaves were thoroughly rinsed with water to remove dirt and debris. The leaves were then air dried under room temperature for five days, ground into a fine powder, and sieved to achieve a smooth leaf meal.

Chemical Analysis: The proximate analysis of the *Gmelina arborea* leaf meal (GALM) were determined according to the procedures of (AOAC, 2001). The **dry matter** content was obtained by drying a known weight of the homogenized sample in an oven at **105°C** until a constant weight was achieved. For **ash**

determination, the sample was incinerated in a muffle furnace at 550°C to obtain the total ash content. The crude fat was extracted using petroleum ether in a Soxhlet apparatus, while the crude protein content was determined using the Kjeldahl method. The total carbohydrate content was estimated by difference that is, by subtracting the sum of ash, crude fibre, crude protein, and crude fat percentages from 100% of the dry weight sample. While the Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin (ADL) were determined by Van Soest *et al.* (1991)

Mineral Analysis: *Gmelina arborea* leaf meal (GALM) was digested using a nitric acid–perchloric acid mixture (HNO₃/HClO₄) in a 20:5 (v/v) ratio. The resulting digest was diluted to 100 mL in a standard volumetric flask using deionized water. The concentrations of calcium (Ca), sodium (Na), potassium (K), zinc (Zn), magnesium (Mg), and phosphorus (P) were determined according to Emmanuel *et al.* (2024) using an Atomic Absorption Spectrophotometer (Model 420, Gallenkamp & Co. Ltd.). Phosphorus was specifically estimated using the vanadomolybdate colorimetric method, and the developed colour was measured with a spectrophotometer at a wavelength of 420 nm.

Statistical Analysis: Data were analyzed using SPSS Version 20.0. Results were expressed as Mean $\pm$ SD of three replicates determinations.

RESULTS

Chemical and mineral Composition of *Gmelina arborea* leaf meal

Presented in Table 1 is the Chemical and Mineral composition of *Gmelina arborea* leave meal. The Dry matter, crude protein, Ether extract, Crude fibre, Ash and Nitrogen free extract, Neutral detergent fibre, Acid detergent fibre, Acid detergent lignin, Cellulose and Hemicellulose in leaves were $93.32 \pm 0.04\%$, $18.45 \pm 0.01\%$, $3.27 \pm 0.02\%$, $10.06 \pm 0.07\%$, $5.34 \pm 0.04\%$, $54.20 \pm 0.01\%$, $56.13 \pm 0.01\%$, $15.64 \pm 0.01\%$, $4.95 \pm 0.02\%$, $10.69 \pm 0.03\%$ and $40.49 \pm 0.01\%$, respectively. The results showed that the leaf meal contained appreciable levels of calcium (1297.00 ± 0.04 mg/100 g), magnesium (521.25 ± 0.13 mg/100 g), potassium (233.59 ± 0.05 mg/100 g), sodium (271.80 ± 0.12 mg/100 g), and phosphorus (331.89 ± 0.17 mg/100 g), as well as zinc (1.623 ± 0.01 mg/100 g).

Table 1: Chemical and Mineral Composition of *Gmelina arborea*

Parameters			
Chemicals Composition	%	Mineral Composition	mg/100g
Dry matter	93.32 ± 0.04	Calcium	1297.00 ± 0.04
Crude Protein	18.45 ± 0.01	Magnesium	521.25 ± 0.13
Ether extract	3.27 ± 0.02	Potassium	233.59 ± 0.05
Crude fibre	10.06 ± 0.07	Sodium	271.80 ± 0.12
Ash	5.34 ± 0.04	Phosphorus	331.89 ± 0.17
Nitrogen Free Extract	54.20 ± 0.01	Zinc	1.623 ± 0.01
Neutral Detergent Fibre	56.13 ± 0.01		
Acid Detergent Fibre	15.64 ± 0.01		
Acid Detergent Lignin	4.95 ± 0.02		
Cellulose	10.69 ± 0.03		
Hemicellulose	40.49 ± 0.01		

DISCUSSION

The proximate composition of *Gmelina arborea* leaf meal (GALM) obtained in this study comprising dry matter, crude protein, crude fibre, ether extract, ash, and nitrogen-free extract was generally consistent with the findings of Abdullahi *et al.* (2020). The dry matter content ($93.32 \pm 0.04\%$) closely aligns with the value reported by Omotoso *et al.* (2014), indicating good storage stability and suitability for feed formulation. The crude protein content of GALM ($18.45 \pm 0.01\%$) was slightly lower than the 21.6% reported by Adejumo and Oyelade (2017), but remained within the range reported for tropical forage and browse plants (10–37%) by Bamikole *et al.* (2003). Importantly, the protein level exceeded the minimum 8% required for effective rumen microbial activity (Van Soest, 1994) and the 11.0–13.05% range recommended for maintenance and moderate growth in goats (NRC, 2002). This highlights the potential of GALM as a valuable protein supplement capable of supporting growth, tissue repair, immune function, and overall animal productivity. The ether extract content ($3.27 \pm 0.02\%$) was comparable to values reported by Adejumo and Oyelade (2017)

and Ademola *et al.* (2018), indicating moderate lipid content that can contribute to dietary energy supply. The crude fibre level ($10.06 \pm 0.07\%$) suggests that GALM can support normal digestive function and gut health in ruminants, helping to prevent digestive disorders such as bloat and acidosis. The ash content ($5.34 \pm 0.04\%$) reflects the presence of essential minerals required for bone development, muscle contraction, reproduction, and metabolic activities. All mineral values recorded were within the recommended ranges for grazing livestock (NRC, 2002). Browse plants such as *Gmelina arborea* are known to be rich in minerals and vitamins (Asaolu *et al.*, 2011), suggesting that GALM can meaningfully contribute to meeting the mineral requirements of livestock.

CONCLUSION

It can therefore be concluded that GALM possesses adequate nutritional quality and mineral content, supporting its use as a supplementary feed resource for livestock production.

Recommendation: It can be recommended that *Gmelina arborea* leaf meal could be used as feed ingredient in livestock production being a good source of protein.

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PREDICTION OF GROWTH PERFORMANCE IN BROILER CHICKENS USING MACHINE LEARNING TECHNIQUES

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ABSTRACT

Machine Learning (ML) application has revolutionized various disciplines in which poultry production is not exempted. Prediction of growth performance in poultry production will definitely harness profitability in animal agriculture. In this study, ML approach was employed to predict the growth performance of arbor acre and cobb broiler chicken at starter phase. Fifty broiler chickens each of arbor acre and cobb breeds were raised at poultry unit, Teaching and Research Farm, Adekunle Ajasin University, Akungba-Akoko, Ondo State. Data on weekly basis were recorded for each breed till 4th week. K-Nearest Neighbors (KNN) and M5Prime (M5P) models of Weka software were trained with previous recorded data and tested using training and supply strategy. Results showed that both models predicted the growth performance in line with the trained data set. In the arbor acre breed, the KNN algorithm predicted weight gain(g) which perfectly matched the actual weight gain(g) values across all the data points, resulting in zero error. The M5P model exhibited deviations in the actual weight gain(g) values of 132.2, 247.6, 487.9, and 802.9, from the predicted weight gain(g) values of 79.79, 305.03, 530.27, and 755.51 respectively, with -52.41, 57.43, 42.37, and -47.39 as predicted weight gain(g) errors values. For the Cobb breed, KNN algorithm predicted weight gain (g) values of 134.5, 271.2, 541.82, and 884.14 which matched exactly the actual weight gain (g) values with zero error across all entries. The M5P model displayed deviations in the actual weight gain(g) values of 134.5, 271.2, 541.82, and 884.14, from the predicted weight gain(g) values of 79.94, 331.94, 583.89, and 835.85 respectively, leaving -54, 60.74, 42.07, and -48.29 as the predicted weight gain(g) errors values. The algorithm produced prediction errors ranging from -54 to 60.74, with both overpredictions and underpredictions observed. This variability indicates that while M5P is capable of approximating the overall trend in the data, it lacks the fine-grained accuracy of the IBK approach. In conclusion, though both models worked well, however, M5P showed better prediction approach. It is recommended that further research should employ advanced ML approaches, such as time series analysis or ensemble methods, should for prediction accuracy.

Keywords: Machine leaning; broiler chicken; growth performance; K-Nearest Neighbors (IBK), M5P,

INTRODUCTION

Poultry industry, particularly broiler production, plays a vital role in meeting the global demand for protein-rich food sources. Broilers are selectively bred for rapid growth, efficient feed conversion, and desirable meat qualities. However, variability in growth performance can arise from a multitude of factors, including genetics, nutrition, environmental conditions, and management practices (Smith *et al.*, 2021). As the industry continues to evolve, the integration of data analytics and machine learning (ML) techniques have become crucial for optimizing production efficiency and enhancing growth performance predictions (Alhörn and Johansson, 2014). ML is a subset of artificial intelligence (AI) that enables computer to learn from data and improve their performance on a task without being explicitly programmed (Kamilaris and Prenafeta-Boldu, 2020).

Predictive analytics has emerged as a powerful tool in various agricultural applications, including livestock management. The integration of data science and ML techniques allows researchers to analyze complex datasets and uncover hidden patterns that can inform decision-making processes (Hastie *et al.*, 2017). In the context of broiler production, predictive models can be used to forecast growth performance based on multiple variables, such as genetic background, dietary inputs, and environmental conditions. Several studies have employed ML algorithms to predict growth performance in livestock. For instance, regression models and decision trees have been utilized to evaluate the effects of different feeding strategies on growth rates (Almeida *et al.*, 2020). These models not only enhance the understanding of the factors affecting growth but also support the optimization of management practices to improve profitability.

Arbor Acre and Cobb broilers are globally recognized for their rapid growth rates, feed efficiency, and meat quality. Arbor Acre broilers are known for their robust structural traits and efficient feed conversion, making them ideal for large-scale production settings. In contrast, Cobb broilers emphasize uniformity, rapid growth, and high breast meat yield (Kogut *et al.*, 2020). ML techniques have emerged as a powerful tool for handling this complexity, providing opportunities to optimize growth performance in breeds such as Arbor Acre and Cobb broilers (Boulanger *et al.*, 2021)

Growth performance in broiler production is essential in determining profitability and taking decisions. It assists farmers on exact time to terminate production either at starter or finisher phase. The knowledge of predicting performance based on growth indices will definitely assist farmers to know breed of better performance and be abreast of financial implication of the production. ML has made this easier to predict the performance through its various algorithm models. Therefore, the objective of this study was to predict the growth performance in broiler chickens using ML approach.

MATERIALS AND METHODS

Experimental Site The research was carried out at the Poultry Unit of the Teaching and Research Farm, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria.

Experimental Design: This study employed a data-driven predictive modeling approach, using experimental data to build ML models for estimating the growth performance of Arbor acre and Cobb broiler chickens. Data on weekly growth performance on 48 Arbor acre and 48 Cobb broiler chickens were obtained over a period of 4 weeks. The dataset contains records on weekly body weight, and the type of breed (Arbor acre and Cobb), with the rearing temperature maintained at approximately 36°C. Each breed was further divided into eight replicates.

Data-Preprocessing: Before model development, the raw data was subjected to several pre-processing steps to enhance its quality and sustainability for ML. These steps include:

- (i) **Data transformation:** It converts raw data into a suitable format for ML. It includes normalization, standardization, encoding categorical variables, and transformations like log scaling to reduce skewness. These steps improve model accuracy and efficiency.
- (ii) **Data training:** Data training involves feeding the prepared dataset into the model so it can learn patterns and relationships. It includes features selection, feature engineering, and applying cross-validation to ensure reliable learning.
- (iii) **Data splitting:** Data splitting divides the dataset into training, validation and test sets. This prevents overfitting, helps fine-tune the model, and ensures unbiased evaluation on unseen data.

Software and Algorithms: The development and analysis of the ML model were carried out using WEKA (Waikato Environment for Knowledge Analysis) software, version 3.8.6. The following regression algorithms were employed: **K-Nearest Neighbors (KNN) and M5P Algorithm:**

Model Development and Evaluation: The selected algorithms, IBK and M5P, were implemented using the WEKA platform. Separate predictive models were constructed for each breed—Cobb and Arbor Acre—to forecast weekly weight gain. These models were trained using a designated training dataset and evaluated against a separate test dataset to ensure unbiased performance assessment.

Model accuracy and effectiveness were measured using standard regression evaluation metrics, which includes;

Root Mean Squared Error (RMSE): Indicates the average magnitude of prediction errors by calculating the square root of the average squared differences between predicted and actual values.

Mean Absolute Error (MAE): Represents the average of the absolute differences between predicted and actual values, offering a simple and intuitive measure of prediction accuracy.

Coefficient of Determination (R-squared, R^2): Reflects the proportion of variance in the target variable that can be explained by the model. An R^2 value closer to 1 signifies a stronger fit.

Additionally, the models were evaluated for their ability to detect the onset of the "marginal weight" plateau. This analysis involved predicting weekly weight gains to identify the point at which weight gain begins to level off effectively highlighting the threshold of diminishing returns based on model predictions.

RESULTS AND DISCUSSION

The following results showed the predictive performance of two ML algorithms IBKNN (instance-Based K-nearest neighbors) and M5P (A model tree algorithm) in estimating the weights of two broiler chickens, arbor acre and cobb. Table 1 showed the actual, predicted and error values of arbor acre using IBKNN algorithm. For arbor acre breed, the IBKNN algorithm achieved exceptional performance. The predicted values (g) (132.2, 247.6, 487.9, 802.9) perfectly matched the weight gain (g) values (132.2, 247.6, 487.9, 802.9) across all the data points, resulting in zero error.

Table 1. Actual, predicted, and error value of arbor acre using IBK algorithm

ACTUAL (g)	PREDICTED (g)	ERROR (g)
132.2	132.2	0
247.6	247.6	0
487.9	487.9	0
802.9	802.9	0

Table 2 revealed the actual, predicted and error values of arbor acre using M5P algorithm. This table presents the performance of the M5P algorithm on the same arbor acre dataset. The M5P model exhibited noticeable deviations from the actual values (g). The predicted values (g) OF 79.79, 305.03, 530.27, and 755.51) recorded predictions errors values (g) of 52.41, 57.43, 42.37, and -47.39 respectively. Table 3 indicated the actual, predicted and error value of cobb using IBK algorithm. The results for the Cobb breed followed a similar trend.

Table 2. Actual, predicted, and error value of arbor acre using M5P algorithm

ACTUAL (g)	PREDICTED (g)	ERROR (g)
132.2	79.79	-52.41
247.6	305.03	57.43
487.9	530.27	42.37
802.9	755.51	-47.39

At Table 3, the IBK algorithm once again demonstrated perfect prediction accuracy, with predicted values (g) of 134.5, 271.2, 541.82, and 884.14 exactly equaling the actual values (g) of 134.5, 271.2, 541.82, and 884.14 with zero error across all entries. This consistent performance across two different breeds highlights IBKNN's strong reliability and precision in this context.

Table 3. Actual, predicted, and error value of Cobb using IBK algorithm

ACTUAL (g)	PREDICTED (g)	ERROR (g)
134.5	134.5	0
271.2	271.2	0
541.82	541.82	0
884.14	884.14	0

Table 4 revealed the actual, predicted and error value of cobb using M5P algorithm. However, this table also presented the performance of the M5P algorithm on Cobb dataset. The M5P model displayed noticeable deviations from the actual values (g) (134.5, 271.2, 541.82, 884.14), the predicted values (g) (79.94, 331.94, 583.89, 835.85) and predictions errors values (g) (-54, 60.74, 42.07, -48.29). The algorithm produced prediction errors (g) ranging from -54 to 60.74, with both overpredictions and underpredictions observed. This variability indicated that while M5P is capable of approximating the overall trend in the data, and lacks the fine-grained accuracy of the IBK approach.

Table 4. Actual, predicted, and error value of Cobb using M5P algorithm

ACTUAL (g)	PREDICTION (g)	ERROR (g)
134.5	79.94	-54
271.2	331.94	60.74
541.82	583.89	42.07
884.14	835.85	-48.29

These findings are consistent with previous studies highlighting breed-specific differences in growth performance and feed utilization. Cobb broilers are typically characterized by rapid early growth however with higher early feed intake, while Arbor Acres tend to exhibit delayed but efficient growth, likely reflecting inherent metabolic and genetic differences (Xu et al., 2021; Akinyemi et al., 2025). The prediction of growth performance in broiler breeds using Weka software presents a promising avenue for enhancing productivity in the poultry industry. By leveraging ML techniques and addressing existing challenges, researchers and practitioners can develop more accurate predictive models that support informed decision-making in broiler management (Wang and Chen, 2022).

CONCLUSION

This study suggested that the IBK algorithm is significantly more accurate than M5P for both Arbor Acre and Cobb breed. Its consistent zero-error performance across all test instances makes it a highly reliable choice, especially for smaller and cleaner datasets where instance-based learning is feasible. The M5P demonstrated the ability to capture broader trends, its lower accuracy and higher variance in predictions indicate that it may be more appropriate for larger or more complex datasets where generalization is necessary. The findings confirmed that ML can significantly aid poultry farmers, breeders, and researchers in making informed decisions about feeding regimes, genetic selection, and production planning. This technology-driven approach not only enhances productivity but also supports cost-effective and sustainable poultry farming.

RECOMMENDATIONS

Based on the findings of this study, it is recommended that poultry farmers and industry stakeholders adopt ML-based predictive tools to support efficient management of broiler production. It is also recommended that further research should employ advanced ML approaches, such as time series analysis or ensemble methods, should for prediction accuracy.

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ASSESSMENT OF ACUTE TOXICITY EFFECT OF ETHANOLIC EXTRACT OF *HUNTERIA UMBELLATA* ON LIVER ENZYMES OF WISTAR RAT

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ABSTRACT

Oral acute toxicity studies of the Ethanol *Hunteria umbellata* seed extract (EHUSE) was carried out to evaluate its effect on the Liver enzymes of Wistar Rat. Forty (40) male Wistar rats with body weights of 120g-150g were randomly assigned into eight groups and kept under suitable environmental conditions. The control group was administered normal saline, while other treatment groups were given varying concentrations of the extract at 0, 50, 100, 200, 400, 1000, 3000, and 5000mg/kg. Data Collected was subjected to analysis of variance (ANOVA) at 5% level of probability using minitab analytical tools. Qualitative analysis of the extract revealed the presence of saponins, tannins, glycosides, flavonoids, terpenoids, steroids, phenol, quinone, and alkaloids. Saponins had the highest value compared to others. Results revealed that group administered 5000mg/kg EHUSE showed signs of weakness, redness of the eyes, and scattered fur, but there was no record of death. The results showed that AST and ALP levels were generally lower in the treatment groups compared to the control group, although the decreases were not always dose-dependent. It can be concluded that EHUSE exerted a beneficial effect on liver health, possibly by mitigating hepatic damage or promoting liver function.

Keywords. *Hunteria umbellata*, acute toxicity, qualitative, phytochemicals, ethnomedicine, extract

INTRODUCTION

Hunteria umbellata K. Schum (family Apocynaceae) is a shrub or small tree reaching a height of approximately 15–22 m and is widely distributed across West and Central Africa. It is commonly known as “Osu” in Edo, “Nkpokiri” in Igbo, and “Erin” in Yoruba-speaking regions of southern Nigeria. The plant is prevalent in sub-Saharan Africa and is highly valued for its medicinal importance, with extensive domestic and ethnomedicinal uses. Various parts of the plant, including the seeds, pulp, and bark, are traditionally prepared as infusions and have been reported to be effective in the management of fever, leprosy, sores, menstrual disorders, and infertility. Additionally, the seeds are locally used in the treatment of diabetes mellitus (Olumide *et al.*, 2021), while the unripe fruits are employed in malaria therapy (Onyegeme-Okerenta *et al.*, 2023). These reported therapeutic applications suggest that *H. umbellata* contains several bioactive compounds responsible for its biological and pharmacological activities. Despite its widespread use, there is limited information on its oral toxicity, and comprehensive safety data necessary for establishing safe dosage levels in humans are lacking. Therefore, the present study was designed to evaluate the safety of the ethanolic seed extract of *Hunteria umbellata* following a single oral administration.

Materials and Methods

Experimental site

This study was conducted at the Teaching and Research farm of the Federal College of Animal Health and Production Technology, Moor Plantation Apata, Ibadan.

Source and Processing of the test Ingredients

Fresh *Hunteria umbellata* was procured from Bode Market, Ibadan, washed with distilled water, air-dried, pulverized into fine powder, and weighed for extraction. The extraction was done using the method of maceration and the use of ethanol as solvent. Each group was administered varying concentrations of the ethanolic extract and closely monitored for 14 days.

Experimental Animals

Forty (40) male Wistar rats were used for the experiment. Before the arrival of the animals, all experimental cages were thoroughly cleaned and disinfected. The rats were fed the same diet across all treatment groups and were provided with fresh, clean drinking water *ad libitum*. The animals were randomly assigned to eight

treatment groups, with five rats per group, following a completely randomized design.

Data Collection

The rats were sacrificed on the 28th day through cervical dislocation, and blood samples were collected for biochemical analysis. Liver function test was carried out using specific enzyme kits.

Statistical Analysis

Data collected was subjected to analysis of variance (ANOVA) and means separated using Duncan multiple range test (DMRT) at 5% level of probability using Minitab analytical tools.

RESULTS AND DISCUSSION

Presented in Figure 1 is the quantitative analysis of ethanolic *Hunteria umbellata* seed extract revealed that saponins were the most abundant phytochemicals, with a yield of $3.15 \pm 0.001\%w/w$, followed by alkaloids ($1.65 \pm 0.004\%w/w$) and terpenoids ($1.50 \pm 0.001\%w/w$). Tannins, total phenols, and flavonoids were present in lower amounts, with yields of $0.96 \pm 0.002\%w/w$, $0.60 \pm 0.002\%w/w$, and $0.45 \pm 0.041\%w/w$. The high saponin content reported collaborates with what was reported by Rates 2021 and Burkill, 2020.

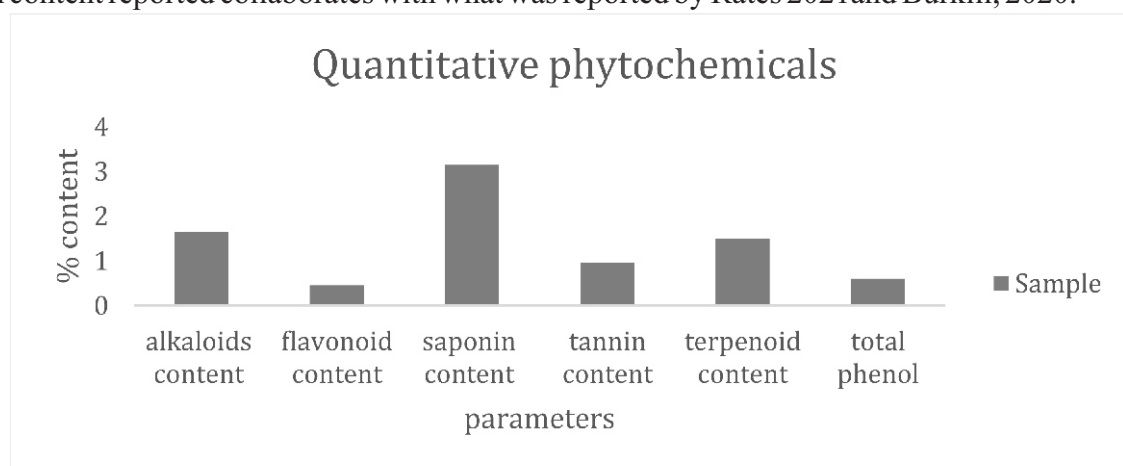


Figure 1: Quantitative Analysis of *Hunteria umbellata* Seed

Table 1 shows the presence of various phytochemicals in *Hunteria umbellata*, saponins, tannins, glycosides, terpenoids, steroids, phenols, quinones, and alkaloids, indicating that the plant may have diverse medicinal properties. These phytochemicals may contribute to the plant's potential antimicrobial, anti-inflammatory, antioxidant, and anticancer effects. The combination of these compounds may also enhance the plant's therapeutic efficacy

Table 1 Qualitative Analysis of *Hunteria umbellata* Seed

Parameters	Extract
Saponins	++ve
Tannins	+ve
Flavonoids	+ve
cardiac glycosides	+ve
Anthraquinones	+ve
Terpenoids	+ve
Steroids	+ve
Alkaloids	++ve
Phenol	+ve

+ve: present, ++ve: abundant

Indicated in Table 2 is the acute toxicity evaluation of ethanolic *Hunteria umbellata* seed extract indicated that the extract was well-tolerated across a wide range of doses (50–5000mg/kg bodyweight), with no mortality observed in any of the treated groups. At lower doses (50–1000mg/kg), rats showed no signs of toxicity, suggesting that these concentrations are physiologically safe and do not produce detectable stress or adverse

effects. Physical changes became noticeable only at higher doses. At 3000mg/kg, rats exhibited mild weakness, indicating the onset of dose-related physiological effects. At the highest dose of 5000mg/kg, more pronounced effects were observed, including weakness, difficulty in breathing, and redness of the eyes. These observations suggest that while the extract has a relatively wide safety margin, very high doses can induce transient physiological stress.

Table 2: Acute Toxicity Profile of Ethanolic *Hunteria umbellata* Seed Extract

Doses (mg/kg bw)	Mortality	Physical Observation
0	0/3	No sign of toxicity
100	0/3	No sign of toxicity
200	0/3	No sign of toxicity
500	0/3	No sign of toxicity
1000	0/3	No sign of toxicity
2000	0/3	No sign of toxicity
3000	0/3	Weakness
5000	0/3	Weakness, difficulty in breathing and redness of the eyes

Table 3 shows the effects of Ethanolic *Hunteria umbellata* seed extract on liver enzyme levels, specifically ALT, AST, and ALP. The administration of the extract resulted in significant decreases in liver enzyme levels, suggesting a potential hepatoprotective effect. The decrease in ALT levels was particularly notable, with a significant reduction observed at a dose of 50 mg/kg. This finding is consistent with previous studies reported by Adedapo *et al.* (2011) on the hepatoprotective effects of certain plant extracts. The reduction in ALT levels suggests that *Hunteria umbellata* extract may help protect the liver from damage, potentially by reducing oxidative stress or inflammation. The results also showed that AST and ALP levels were generally lower in the treatment groups compared to the control group, although the decreases were not always dose-dependent. These findings suggest that *Hunteria umbellata* extract may have a beneficial effect on liver health, potentially by reducing liver damage or promoting liver function.

Table 3: Effect of Ethanolic *Hunteria Umbellata* Seed Extract on Liver Enzymes of Wistar Rats

Treatment (mg/kg bw)	ALT	AST	ALP
C	22.0±1.91 ^a	22.7±2.74 ^a	74.7±8.70 ^a
50	9.0±1.41 ^c	14.0±1.41 ^b	45.5±0.71 ^b
100	9.0±2.83 ^c	14.0±2.83 ^b	48.5±3.54 ^b
200	8.0±1.41 ^c	11.5±0.71 ^b	49.0±1.41 ^b
400	10.5±0.71 ^b	14.0±1.41 ^b	52.5±6.36 ^b
1000	6.0±0.00 ^c	10.5±0.71 ^b	46.5±2.12 ^b
3000	9.0±1.41 ^b	14.0±0.00 ^b	54.0±1.41 ^b
5000	11.0±1.41 ^b	14.5±2.12 ^b	49.5±0.71 ^b

Means along the same column with different superscripts are significant (P < 0.05) different based on Turkey's test at P < 0.005 * = significant, ALT=Alanine Aminotransferase, AST=Aspartate Aminotransferase, ALP Alkaline Phosphatase

CONCLUSION

The study assessed the acute toxicity of ethanolic *Hunteria umbellata* seeds extract on Wistar rats. Phytochemical screening showed bioactive compounds with therapeutic potentials. No mortality or severe toxicity was observed, indicating that the extract is relatively safe at therapeutic levels. Hence the study provides valuable insights into the safety profile of *Hunteria umbellata* and suggests that it may be safe for use in traditional medicine. However, further studies are needed to confirm its efficacy and safety in humans.

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THE EFFECT OF DIETARY LEVELS OF METHIONINE ON GROWTH PERFORMANCE AND HAEMATOLOGICAL CHARACTERISTICS OF BROILER CHICKS

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ABSTRACT

This study evaluated the effect of graded dietary levels of methionine on growth performance and haematological indices of Arbor Acre broiler birds. Four experimental diets (T1–T4) containing varying methionine levels were fed to the birds, and growth performance parameters including initial weight, final weight, weight gain, daily weight gain, and feed intake were measured. Results showed that dietary methionine supplementation had no significant ($p>0.05$) effect on growth performance indices across treatments. Final body weight ranged from 1513.83 g to 1712.22 g, while daily weight gain varied between 39.75 g and 47.32 g, indicating comparable growth responses among treatments. However, methionine levels significantly influenced several haematological parameters. Packed cell volume, white blood cell count, neutrophils, lymphocytes, eosinophils, mean corpuscular volume, mean corpuscular haemoglobin, mean corpuscular haemoglobin concentration, and platelet counts differed significantly ($p<0.05$) among treatments. Birds fed diets T2 and T3 showed improved immune-related indices, particularly white blood cell differentials, suggesting enhanced immune response. Haemoglobin concentration and red blood cell counts were not significantly affected by dietary treatments. In conclusion, varying dietary methionine levels did not markedly influence growth performance of Arbor Acre broilers but significantly affected haematological and immune parameters. Adequate methionine supplementation may therefore play a vital role in maintaining physiological balance and immune competence in broiler production.

Keywords: Methionine, arbor acre, dietary, white blood cell, feed intake

INTRODUCTION

Methionine is an essential sulfur-containing amino acid that plays a pivotal role in the growth and metabolism of poultry. It is often regarded as the first limiting amino acid in typical corn–soybean meal diets for broiler chickens (Bunchasak, 2009; Kidd *et al.*, 2000). As a precursor of cysteine, taurine, carnitine, and glutathione, methionine is crucial for protein synthesis, antioxidant defense, and immune function (Brosnan and Brosnan, 2006). Adequate dietary methionine is therefore vital for optimal growth performance, feed efficiency, and overall health of broiler chicks.

The rate of muscle protein accretion in broilers depends on the balance and availability of essential amino acids. When methionine supply is suboptimal, protein synthesis is impaired, resulting in reduced growth rate, poor feed conversion, and lowered carcass yield (NRC, 1994; Zhai *et al.*, 2016). Conversely, excessive methionine supplementation can lead to metabolic stress and oxidative imbalance, thereby affecting physiological and haematological functions (Ghazalah *et al.*, 2011). Hence, achieving the optimal dietary level of methionine is essential for both performance and metabolic stability.

Beyond growth, methionine influences several haematological and biochemical parameters, which serve as indicators of the physiological and health status of birds. Adequate methionine enhances erythropoiesis and haemoglobin synthesis, while deficiency may cause anaemia, reduced red blood cell counts, and lowered immune competence (Swain and Johri, 2000; Esteve-Garcia and Mack, 2000). Moreover, methionine acts as a methyl group donor in methylation reactions and contributes to the synthesis of vital compounds such as S-adenosylmethionine (SAM), which supports immune response and antioxidant protection (Finkelstein, 2000). Recent advancements in poultry genetics have increased growth potential and feed efficiency, thereby elevating the requirement for sulfur amino acids like methionine (Zhang *et al.*, 2018). However, dietary recommendations vary depending on the strain, age, and environmental conditions of the birds. This variation underscores the need for further evaluation of dietary methionine levels on performance and physiological responses of modern broiler genotypes under tropical conditions.

Therefore, this study was designed to evaluate the effect of graded dietary levels of methionine on growth performance and haematological characteristics of broiler chicks. The findings will contribute to formulating

nutritionally balanced diets that enhance productivity, maintain physiological balance, and promote the welfare of broiler chickens.

MATERIALS AND METHODS

The experiment was carried out at coordinate of latitude 7.34838° N and longitude: 3.86882° E (Google, 2025)

The experiment was designed in a complete randomized structure with four treatments and three replicates per treatment, consisting of varying dietary level of methionine at 25%, 50%, 75% and 100%. Experimental diets were fed to the chicks with free access and likewise water. Light was provided for a minimum of 20 hours per day.

Table 1: Ingredient composition of the experimental diet (per kilogram)

Ingredient	T1 (100%)	T2 (75%)	T3 (50%)	T4 (25%)
Maize	60	60	60	60
S.B.M	23	23	23	23
Fish Meal	4	4	4	4
Wheat Offal	10	10	10	10
Oyster shell	2.5	2.5	2.5	2.5
Premix	0.20	0.20	0.20	0.20
Lysine	0.20	0.20	0.20	0.20
Methionine	0.20	0.15	0.10	0.05
Common salt	0.10	0.19	0.10	0.10

A total of 96-day old arbor acre birds used for this study were sourced from a commercial hatchery in Ibadan. The experiment lasted for 42 days.

The day-old chicks were weighed at the start of the experiment and then at the end of each week for six weeks. Body weight gain and feed intake were recorded weekly throughout the experimental period. Mortality was also recorded weekly throughout the experimental period.

Blood samples were collected through the vein of the bird into four different tubes for each treatment which was taken to the laboratory for further analysis.

Data collected were analyzed using Statistical package for Social Sciences (SPSS) version 22.0. the mean value per treatment group was calculated and analysis of variance (ANOVA) was used to test for differences in the means of the treatment groups. Multiple comparisons were done using Duncan Post Hoc analysis. Statistical significance was set at $p=0.05$

RESULTS AND DISCUSSION

Growth performance of Arbor Acre birds fed dietary levels of methionine

The results of the growth performance of Arbor Acre broiler birds fed graded dietary levels of methionine are presented in Table 2. Initial body weight did not differ significantly ($p>0.05$) among treatments, indicating that the birds were homogeneous at the start of the experiment. Similarly, final body weight, total weight gain, daily weight gain, total feed intake, and daily feed intake showed no significant differences ($p>0.05$) across all dietary treatments.

Although birds fed diet T4 recorded numerically higher final body weight, weight gain, and daily weight gain compared to other treatments, these improvements were not statistically significant ($p>0.05$). This suggests that the methionine levels used in the experimental diets were adequate to meet the birds' growth requirements, and additional methionine beyond this level did not confer a significant growth advantage. This finding aligns with previous reports that broilers respond to methionine supplementation only when the basal diet is deficient, while adequate diets show minimal performance differences (Kidd *et al.*, 2004; NRC, 1994). The similarity in feed intake across treatments further indicates that methionine inclusion did not adversely affect diet palatability or feed utilization, corroborating the findings of Ojano-Dirain and Waldroup (2002).

Table 2: Growth performance of arbor acre birds fed dietary levels of meth ionine

	Treatments				SEM	p-value
	T1	T2	T3	T4		
Initial weight	473.67 ^a	481.33 ^a	480.33 ^a	482.00 ^a	3.42	0.858
Final weight	1645.25 ^a	1517.83 ^a	1513.83 ^a	1712.22 ^a	54.48	0.550
Weight gain	1117.58 ^a	1036.50 ^a	1033.50 ^a	1230.22 ^a	54.20	0.530
Daily weight gain	45.00 ^a	40.87 ^a	39.75 ^a	47.32 ^a	2.00	0.565
Total feed intake	10821.67 ^a	11249.00 ^a	10776.09 ^a	11268.67 ^a	353.17	0.953
Daily feed intake	2.75 ^a	2.79 ^a	3.23 ^a	2.52 ^a	0.14	0.259

Mean with same superscript letter are not significantly different ($p > 0.05$)

Haematological indices of Arbor Acre birds fed dietary levels of methionine

The haematological parameters of the birds are shown in Table 3. Packed cell volume (PCV) differed significantly ($p < 0.05$) among treatments, with birds on T2 recording the highest PCV values. PCV is an important indicator of oxygen-carrying capacity and general physiological status, and the observed values across treatments fall within the normal range reported for healthy broiler chickens (Mitraka and Rawnsley, 1977).

The white blood cell counts and differential leukocyte counts (neutrophils, lymphocytes, and eosinophils) were significantly influenced ($p < 0.05$) by dietary methionine levels. Birds on T2 showed higher white blood cell and neutrophil counts, while lymphocyte values were highest in T3. These variations suggest that methionine supplementation may influence immune function, as white blood cells and their differentials are key indicators of immune responsiveness. Methionine has been reported to play a role in immune modulation through its involvement in protein synthesis and antioxidant defense mechanisms (Swain and Johri, 2000; Wu, 2009).

Erythrocyte indices such as mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) also differed significantly ($p < 0.05$) among treatments, indicating that methionine levels influenced red blood cell morphology and haemoglobin synthesis. Platelet counts were significantly higher in methionine-supplemented diets, suggesting improved blood clotting potential and physiological stability.

Overall, the results indicate that while dietary methionine levels did not significantly affect growth performance, they had marked effects on haematological and immune-related parameters, highlighting the importance of methionine in maintaining physiological and immunological health in broiler chickens.

Table 3: Haematological indices of arbor acre birds fed dietary levels of meth ionine

	Treatments				SEM	p-value
	T1	T2	T3	T4		
Packed cell volume	32.00 ^b	33.00 ^a	30.00 ^a	30.00 ^a	0.46	0.014
HB	10.08 ^a	10.06 ^a	9.45 ^a	9.50 ^a	0.26	0.787
Reb blood cell	3.05 ^a	3.18 ^a	2.77 ^a	2.80 ^a	0.25	0.947
White blood cell	2.10 ^a	3.50 ^a	0.80 ^b	1.20 ^b	0.36	0.007
Neutrophils	49.00 ^b	70.00 ^a	38.00 ^c	42.00 ^b	3.73	0.000
Lymphocytes	50.00 ^b	28.00 ^c	62.00 ^a	56.00 ^b	3.88	0.000
Eosino phils	1.00 ^b	2.00 ^a	0.03 ^c	2.00 ^a	0.25	0.000
Mean Corpuscular Volume	105.00 ^b	104.00 ^b	108.00 ^a	107.00 ^a	0.54	0.004
Mean Corpuscular Hemoglobin	33.40 ^c	31.60 ^c	34.10 ^a	33.90 ^b	0.30	0.000
Mean Corpuscular Hemoglobin Concentration	31.3 ^b	30.30 ^c	31.50 ^b	33.90 ^a	0.40	0.000
Platelets	3.30 ^c	5.00 ^a	4.30 ^b	4.00 ^b	0.19	0.000

Mean with same alphabets are not significantly different $p > 0.05$

CONCLUSION

The study demonstrated that varying dietary levels of methionine had no significant effect on the growth performance of Arbor Acre broiler birds, indicating that the diets adequately met the birds' growth requirements. However, methionine supplementation significantly influenced haematological and immune-related parameters, suggesting its important role in maintaining physiological balance and immune

competence. Therefore, while additional methionine may not enhance growth performance under adequate dietary conditions, appropriate inclusion levels are essential for optimal health and immune status of broiler chickens.

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EFFECT OF SUPPLEMENTAL ASCORBIC ACID (VITAMIN C) ON THE GROWTH PERFORMANCE AND BLOOD PROFILE OF *CLARIAS GARIEPINUS* FED PLANT PROTEIN-BASED DIET

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ABSTRACT

This study aimed to assess the effects of supplemental Ascorbic acid (Vitamin C) on the growth performance and blood profile of *Clarias gariepinus* fed plant protein-based diet. Two hundred and twenty-five juveniles of *C. gariepinus*, aged eight weeks and weighing 106 ± 2.00 grams, were randomly assigned to five different diets with varying inclusion levels of Vitamin C (g/100g). The dietary treatments are as follows; control $V_0 = 0$ g/100g vitamin C $V_1 = 0.075$ g/100g vitamin C, $V_2 = 0.15$ g/100g vitamin C, $V_3 = 0.225$ g/100g vitamin C, $V_4 = 0.3$ g/100g vitamin C. For 56 days, the fish were fed to satiation. Each treatment was in triplicate. The control diet (V_0), with no vitamin C supplementation, yielded the highest final mean weight gain (17.39 ± 1.46) and total feed consumption (38.97 ± 1.44). However, diets with vitamin C supplementation generally showed improved specific growth rate, protein intake and survival rates. Supplementation of Vitamin C in plant protein-based diet for *C. gariepinus* had no significant influence on the final weight and feed conversion ratio (FCR). Packed cell volume (PCV) was significantly higher at V_0 inclusion ($27.00 \pm 4.24\%$), and lower at V_2 ($16.00 \pm 1.41\%$). Highest haemoglobin value was observed in V_0 (9.00 ± 1.41 g/dL) and least values at V_2 (5.34 ± 0.47 g/dL). Highest Aspartate aminotransferase was observed at V_1 (177.95 ± 8.13 IU/L) and least values at V_3 (83.00 ± 38.61 IU/L). Diet V_3 showed the highest survival rate, signifying a trade-off between growth optimization and survival. The significant variations in haematological and serum biochemical parameters across treatments highlight the intricate physiological responses of *C. gariepinus* to different levels of dietary Vitamin C.

Keywords: Haemato-biochemistry, Packed Cell Volume, Fish Feed, Aquaculture, Juvenile Fish.

INTRODUCTION

Aquaculture is a rapidly expanding sector globally, providing most immediate solution to declining capture fisheries (Ogunji and Wuertz, 2023) and meeting the increasing demand for protein, provision of employment, fish food security, nutritional diet and a trade commodity for export (Finegold, 2009; Ojelade *et al.*, 2022). The aquaculture industry has been the fastest-growing global agro-industrial sector in the last four decades (Adewunmi and Olaleye, 2010) and among the fast-growing species is African Catfish (*Clarias gariepinus*). *Clarias gariepinus*, is a highly valued aquaculture species due to its fast growth rate, hardiness, and adaptability to various culture systems. However, optimizing its nutritional requirements, particularly for essential micronutrients like Vitamins, is critical for sustainable production and fish health (Ojelade *et al.*, 2022).

Vitamin C (ascorbic acid) is an essential water-soluble antioxidant and co-factor required for normal physiological and metabolic processes in fish, including collagen biosynthesis, wound healing, stress resistance, antioxidant defense, dietary iron absorption and immune modulation (Yu *et al.*, 2020). Unlike mammals, most teleost fishes lack the enzyme *L-gulonolactone oxidase* and thus cannot synthesize Vitamin C endogenously, making dietary supplementation indispensable (Drouin *et al.*, 2011). Deficiency in Vitamin C can lead to various pathological conditions such as reduced growth, skeletal deformities, impaired immune function, and increased susceptibility to diseases (Abdelwahab, 2020). In aquaculture nutrition, especially when plant proteins replace fishmeal, adequate Vitamin C is vital to counter oxidative stress and maintain tissue integrity (Yu *et al.*, 2020).

Plant protein-based diets are increasingly being used in aquaculture to reduce reliance on expensive and unsustainable fishmeal (Oyedokun *et al.*, 2024). While these diets offer economic and environmental benefits, they can sometimes be deficient in certain essential nutrients or contain anti-nutritional factors that may affect nutrient utilization and fish health (Ogunji *et al.*, 2021; Oyedokun *et al.*, 2024). Supplementation with essential Vitamins like Vitamin C can mitigate these challenges and enhance the overall performance of

fish fed such diets. However, several research documents have reported supplementation of Vitamin C in the diet of *Clarias gariepinus* and has shown that it improves growth, haematological balance, promotes strong antioxidant properties that protect against oxidative stress and improve iron absorption (Adewolu and Aro, 2009; Okhionkpmwonyi, and Edema, 2017; Adeyemi-Doro and Iyiola, 2017; Samuel and Kolo, 2022; Xu *et al.*, 2022). Despite these findings, there remains limited information on optimal Vitamin C inclusion in plant protein-based diets for African catfish under tropical conditions. This study therefore investigated the influence of graded levels of supplemental Vitamin C on the growth, haematological, and serum biochemical parameters of *C. gariepinus* fed a plant protein-based diet.

MATERIALS AND METHODS

Study Area

The experiment was carried out at Fisheries and Aquaculture research laboratory, located at the central laboratory of Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria

Experimental Procedure

Three hundred and Fifty pieces (350) eight *C. gariepinus* juveniles weighing 6.82 ± 0.24 g were brought from Federal University of Technology Teaching and Research Farm, Akure Ondo State. The fish were acclimatized under laboratory condition for three weeks at the Fisheries and Aquaculture Research Laboratory. During acclimatization period, the fish were fed with commercial feed to satiation. Of the 350 *C. gariepinus* procured, 250 were randomly distributed into fifteen (15) transparent plastic tanks with 60 cm $\times$ 45 cm $\times$ 30 cm dimension of 30litres capacity each at a stocking density of fifteen (15) fish per tank. The fish were left for a day unfed before the experimental feeding commenced. The fish were fed to satiation twice daily (08:00 and 17:00 hours) for 56 days. The set up was covered with transparent net to avoid fish from jumping out. Water replacement was done every three (3) days, eliminated faecal matter and unutilized feed by the fish. The weight of the fish was monitored every two weeks.

Formulation and Preparation of Experimental Diets

Five isonitrogenous chemical composition tested diets were formulated with varying levels of Vitamin C as shown in Table 1. The diet was fixed at 40% crude protein level for the optimum growth of the experimental fish (Faturoti *et al.*, 1986). The ingredients were procured from a reputable feed meal in Ikare - Akoko, Ondo State. The feedstuffs were finely grounded using hammer mill were thoroughly mixed together. Each diet mixture was pelleted at 60°C, using 4mm pellet die to form noodle-like strands, which were manually crumbled into a suitable size for the *C. gariepinus* juveniles. The varying inclusion levels of Vitamin C used to formulate five (5) dietary treatments as follows; $V_0 = 0$ g/100g inclusion of Vitamin C, $V_1 = 0.075$ g/100g inclusion of Vitamin C, $V_2 = 0.15$ g/100g inclusion of Vitamin C, $V_3 = 0.225$ g/100g inclusion of Vitamin C, $V_4 = 0.3$ g/100g inclusion of Vitamin C

Table 1: Composition of Experimental Diets used for Feeding

INGREDIENT	V_0	V_1	V_2	V_3	V_4
Soyabean meal	36.14	36.14	36.14	36.14	36.14
Groundnut cake	34.01	34.01	34.01	34.01	34.01
Maize	24.84	24.84	24.84	24.84	24.84
Lysine	0.4	0.4	0.4	0.4	0.4
Methionine	0.6	0.6	0.6	0.6	0.6
Salt	0.2	0.2	0.2	0.2	0.2
D.C.P.	0.5	0.5	0.5	0.5	0.5
Vitamin premix	0.5	0.5	0.5	0.5	0.5
Vitamin C	0	0.075	0.15	0.225	0.3
Starch	2.61	2.535	2.46	2.385	2.31
Soya Oil	0.2	0.2	0.2	0.2	0.2
Total	100	100	100	100	100
Analysed crud protein	39.12	40.26	40.85	41.27	39.81

$V_0 = 0$ g/100g Vitamin C inclusion; $V_1 = 0.075$ g/100g Vitamin C inclusion; $V_2 = 0.15$ g/100g Vitamin C inclusion; $V_3 = 0.225$ g/100g Vitamin C inclusion; $V_4 = 0.3$ g/100g Vitamin C inclusion. DCP = Dicar phosphate

Chemical composition

Crude protein of the formulated diets was analysed chemically (AOAC, 2005).

Growth studies

The following growth and nutrient utilization parameter were calculated as described by Falayi (2009). Initial weight, Final Weight, Feed Conversion Ratio (FCR), Gross efficiency Feed Conversion (GEFC), Protein Intake (PI), Specific Growth Rate (SGR) Protein Efficiency Ratio (PER), Protein Intake (PI) and survival rate were calculated using recommended procedures.

Haematological analysis.

Blood (1-3 mL of fish) was collected from the fish on the last day of the feeding trial. Collection of blood was done through the vertebral caudal vessel with the help of disposable hypothermic syringe and needle. Blood was emptied into 10ml sample bottle treated with anti-coagulant, Ethylene Diamine Tetracetic Acid (EDTA). Haematological analysis of fish followed the method described by Svobodoval *et al.* (1991). Blood cell counts (erythrocytes and leucocytes) was carried out in an improved Neubauerhaemocytometer using a modified Yokoyama diluting fluid. The erythrocyte indices, mean cell haemoglobin concentration (MCHC) was computed from haemoglobin values and erythrocyte counts.

Serum Biological Analysis

Blood samples for biochemical analysis were centrifuged for 5 minutes at 3000 rpm with Hawsley Minor Bench Centrifuge (P spectra, Centromix no 231254 CD7000549, Spain). The blood was stored at -20°C and analysis was conducted at DavBuk Medical Laboratory and Diagnostic Centre, km5, Cultural centre avenue, Akure, Ondo State for total protein, aspartate amino transaminase, alkaline phosphatase, alanine amino transaminase, (Henry, 1974).

Statistical Analysis

The results were subjected to a one-way ANOVA and data were analyzed using statistical package for social sciences, version 20 (SPSS Inc., Chicago, il, USA). Differences between mean were compared using Duncan's new multiple test range of differences ($P > 0.05$) among dietary treatments.

RESULTS

Table 2 presents the growth performance indices of *Clarias gariepinus* fed experimental diets containing varying levels of Vitamin C. The initial body weights of fish were statistically similar across all treatments, ranging from 102.67 ± 0.58 g to 105.33 ± 3.06 g, indicating uniformity at the start of the experiment. Dietary Vitamin C supplementation in the plant protein-based diets did not exert any significant effect ($P > 0.05$) on final body weight, feed conversion ratio (FCR), or gross efficiency of feed conversion (GEFC). However, the final mean weight gain (FMWG) differed significantly ($P < 0.05$) among treatments. Fish in the control group (V_0) exhibited the highest FMWG (17.39 ± 1.46 g), which was significantly higher than those in V_2 (14.74 ± 1.30 g) and V_3 (14.68 ± 0.15 g). Similarly, total feed consumption (TFC) followed the same trend, with the highest value recorded in V_0 (38.97 ± 1.44 g), which was significantly different from other dietary groups. The specific growth rate (SGR) was greatest in fish fed the control diet (0.70 ± 0.09 % day⁻¹) and lowest in those fed diet V_3 (0.58 ± 0.03 % day⁻¹). Protein efficiency ratio (PER) and protein intake (PI) were also significantly ($P < 0.05$) higher in the control group, with values of 0.43 ± 0.04 and 11.59 ± 0.58 g respectively. Notably, fish fed diet V3 exhibited the highest survival rate (97.78 ± 3.85 %).

The haematological parameters of *Clarias gariepinus* fed diets supplemented with varying inclusion levels of Vitamin C are presented in Table 3. Packed cell volume (PCV) ranged from 16.00 ± 1.41 % in fish fed diet V_2 to 27.00 ± 4.24 % in the control group (V_0). Fish in the control group had a significantly ($P < 0.05$) higher PCV values compared to those fed diet V_2 , while other treatments (V_1 , V_3 , and V_4) showed intermediate values. Red blood cell (RBC) count followed a similar pattern, with the highest value ($2.15 \pm 0.07 \times 10^6$ mm⁻³) observed in V_0 and V_2 , which were significantly different ($P < 0.05$) from diets V_3 ($1.90 \pm 0.00 \times 10^6$ mm⁻³) and V_4 ($1.75 \pm 0.07 \times 10^6$ mm⁻³). Haemoglobin concentration (Hb) ranged from 5.34 ± 0.47 g/dL (V_2) to 9.00 ± 1.41 g/dL. Mean corpuscular volume (MCV) and mean corpuscular haemoglobin (MCH) showed similar trends, with higher values in control diet (125.33 ± 15.61 fL and 41.78 ± 5.20 pg, respectively), while diet V_2

Table 2: Growth Performance parameters of *Clarias gariepinus* Fed Experimental Diets with varied inclusion of Vitamin C

Parameters	V ₀	V ₁	V ₂	V ₃	V ₄
Initial weight	105.33±3.06	104.67±3.21	102.67±0.58	105.00±3.61	103.00±2.00
Final Weight	248.43±17.53	219.37±30.51	210.90±11.36	215.37±10.15	225.97±30.9
IMWG	7.02 ± 0.20	6.97 ± 0.21	6.84 ± 0.34	7.00 ± 0.24	6.86 ± 0.14
FMWG	17.39 ± 1.46 ^a	16.41 ± 0.99 ^{ab}	14.74 ± 1.30 ^b	14.68 ± 0.15 ^b	15.72 ± 1.49 ^{ab}
TFC	38.97 ± 1.44 ^a	27.12 ± 0.67 ^b	26.88 ± 0.38 ^b	24.69 ± 1.10 ^c	25.49 ± 0.34 ^{bc}
SGR	0.70 ± 0.09 ^b	0.66 ± 0.03 ^{ab}	0.59 ± 0.07 ^{ab}	0.58 ± 0.03 ^b	0.64 ± 0.06 ^{ab}
FCR	2.83 ± 0.37	2.89 ± 0.28	3.46 ± 0.55	3.22 ± 0.27	2.92 ± 0.39
PER	0.43 ± 0.04 ^b	0.41 ± 0.02 ^{ab}	0.37 ± 0.03 ^b	0.37 ± 0.00 ^b	0.39 ± 0.04 ^{ab}
Protein Intake	11.59 ± 0.58 ^a	10.85 ± 0.27 ^b	10.75 ± 0.15 ^b	9.87 ± 0.44 ^c	10.19 ± 0.14 ^{bc}
GEFC	35.69 ± 4.36	34.81 ± 3.30	29.38 ± 4.53	31.19 ± 2.53	34.72 ± 4.95
Survival Rate%	95.56 ± 7.70	88.89 ± 7.70	95.55 ± 3.85	97.78 ± 3.85	95.55 ± 3.85

The values with different superscripts (a, b, c) within the same rows were significantly different ($P < 0.05$). V₀=0g/100g Vitamin C inclusion; V₁= 0.075g/100g Vitamin C inclusion; V₂= 0.15g/100g Vitamin C inclusion; V₃= 0.225g/100g Vitamin C inclusion; V₄= 0.3g/100g Vitamin C inclusion. FMWG= final mean weight gain, SGR=specific growth rate, FCR= feed conversion ratio, PER=Protein efficiency ratio, IMWG, GEFC, TFC

exhibited the least MCV (74.59 ± 9.03 fL) and MCH (24.86 ± 3.01 pg). Mean corpuscular haemoglobin concentration (MCHC) values were relatively stable (33.33–33.43 g/dL) across all treatments, showing no significant variation ($P > 0.05$). White blood cell (WBC) counts and differential leucocyte percentages also varied among treatments. WBC counts ranged from $4.60 \pm 0.57 \times 10^3 \text{ mm}^{-3}$ (V₁) to $6.50 \pm 0.42 \times 10^3 \text{ mm}^{-3}$ in the control group, with no significant difference noted. Lymphocyte counts (LYM) were higher in V₀ ($5.45 \pm 0.07 \times 10^3 \text{ mm}^{-3}$) and least in V₁ ($2.65 \pm 0.78 \times 10^3 \text{ mm}^{-3}$), corresponding with lymphocyte percentages (LYMPER) that ranged from $57.00 \pm 9.90\%$ (V₁) to $85.00 \pm 7.07\%$ (V₃). Granulocyte percentages (GRAPER) varied significantly ($P < 0.05$), with the higher value in V₁ ($40.00 \pm 11.31\%$) and the least in V₃ ($15.00 \pm 7.07\%$). Monocytes were absent in most treatments except V₁ and V₂, where low but significant counts ($0.15 \pm 0.07 \times 10^3 \text{ mm}^{-3}$) were recorded.

Table 3: Haematological parameters of *Clarias gariepinus* fed with Vitamin C diet.

Parameters	V ₀	V ₁	V ₂	V ₃	V ₄
PCV	27.00 ± 4.24^a	19.00 ± 1.41^{ab}	16.00 ± 1.41^b	21.00 ± 4.24^{ab}	19.00 ± 2.83^{ab}
RBC	2.15 ± 0.07^a	1.95 ± 0.07^b	2.15 ± 0.07^a	1.90 ± 0.00^{bc}	1.75 ± 0.07^c
MCHC	33.33 ± 0.00	33.34 ± 0.1	33.43 ± 1.14^{ab}	33.33 ± 0.00^{ab}	33.43 ± 0.13
MCV	125.33 ± 15.61^a	97.37 ± 3.72^{ab}	74.59 ± 9.03^b	110.53 ± 22.33^{ab}	108.34 ± 11.79^{ab}
MCH	41.78 ± 5.20^a	32.45 ± 1.24^{ab}	24.86 ± 3.01^b	36.85 ± 7.45^{ab}	36.11 ± 3.93^{ab}
HAEMO	9.00 ± 1.41^a	6.34 ± 0.47^{ab}	5.34 ± 0.47^b	7.00 ± 1.41^{ab}	$6.34 \pm .94^{ab}$
WBC	6.50 ± 0.42	4.60 ± 0.57	4.70 ± 0.14	5.30 ± 0.14	5.70 ± 1.56
GRA	1.05 ± 0.49	1.80 ± 0.28	0.75 ± 0.21	0.75 ± 0.35	1.40 ± 1.13
GRAPER	16.00 ± 5.66^b	40.00 ± 11.31^a	16.50 ± 4.95^{ab}	15.00 ± 7.07^b	23.00 ± 12.73^{ab}
LYM	5.45 ± 0.07^a	2.65 ± 0.78^c	3.80 ± 0.42^{bc}	4.55 ± 0.49^{ab}	4.3 ± 0.42^{ab}
LYMPER	84.00 ± 5.66^a	57.00 ± 9.90^b	80.50 ± 6.36^a	85.00 ± 7.07^a	77.00 ± 12.73^{ab}
MONO	0.00 ± 0.00^b	0.15 ± 0.07^a	0.15 ± 0.07^a	0.00 ± 0.00^b	0.00 ± 0.00^b
MONPER	0.00 ± 0.00^b	3.00 ± 1.41^a	3.00 ± 1.41^a	0.00 ± 0.00^b	0.00 ± 0.00^b

Means in the same column having similar superscript are not significantly different ($p > 0.05$). RBC: Red Blood Cell count; WBC: White Blood Cell count; HAEMO: Haemoglobin concentration; PCV: Packed Cell Volume. V₀: 0g/100g composition of Vitamin C, V₁: 0.075g/100g composition of Vitamin C, V₂: 0.15g/100g composition of Vitamin C, V₃: 0.225g/100g composition of Vitamin C, V₄: 0.3g/100g composition of Vitamin C.

The serum biochemical indices of *Clarias gariepinus* fed Vitamin C supplemented diets are presented in Table 4. Serum creatinine values ranged from $15.95 \pm 17.61 \mu\text{mol/L}$ in V₁ to $67.40 \pm 50.20 \mu\text{mol/L}$ in V₂, showing no consistent pattern of variation across treatments. Urea levels also remained relatively stable ($7.75\text{--}9.70 \mu\text{mol/L}$) among the dietary groups with no significant differences observed. Enzyme activities, however, showed significant variation ($P < 0.05$) with Vitamin C inclusion. Aspartate aminotransferase (AST) was higher in fish fed V₁ ($177.95 \pm 8.13 \text{ U/L}$) and least in V₃ ($83.00 \pm 38.61 \text{ U/L}$). Similarly, alanine

aminotransferase (ALT) activity peaked at 301.70 ± 0.00 U/L in V_3 and was least (108.85 ± 53.25 U/L) in V_4 . Total serum protein ranged from 27.85 ± 16.05 g/dL in V_3 to 110.00 ± 53.88 g/dL in the control group, with the highest values recorded in unsupplemented fish.

Table 4: serum analysis of *Clarias gariepinus* fed with varied inclusion of vitamin c.

	V_0	V_1	V_2	V_3	V_4
CREATININE	62.10 ± 37.62	15.95 ± 17.61	67.40 ± 50.20	58.55 ± 7.57	44.35 ± 32.60
UREA	9.05 ± 0.50	9.00 ± 0.85	9.70 ± 4.00	7.75 ± 5.73	8.45 ± 4.03
AST	143.70 ± 22.06^{ab}	177.95 ± 8.13^a	125.10 ± 12.16^{ab}	83.00 ± 38.61^b	119.90 ± 20.08^{ab}
ALT	199.80 ± 59.40^{ab}	250.95 ± 24.40^a	136.75 ± 17.32^b	301.70 ± 0.00^c	108.85 ± 53.25^{bc}
TOTAL PROTEIN	110.00 ± 53.88^a	102.00 ± 23.62^{ab}	56.45 ± 10.39^{ab}	27.85 ± 16.05^b	67.80 ± 0.00^{ab}

AST= Aspartate aminotransferase, ALT= Alanine transaminase,

The values with different superscripts (^{a, b, c}) within the same rows were significantly different ($P < 0.05$).

V_0 =0g/100g Vitamin C inclusion; V_1 = 0.075g/100g Vitamin C inclusion; V_2 = 0.15g/100g Vitamin C inclusion; V_3 = 0.225g/100g Vitamin C inclusion; V_4 = 0.3g/100g Vitamin C inclusion.

DISCUSSION

Vitamin C (ascorbic acid) is essential for fish, which generally cannot synthesize it due to lack of gulonolactone oxidase (Adewolu and Aro, 2009). It acts as a potent antioxidant and cofactor in collagen synthesis, supporting growth, feed efficiency, stress resilience and immune defense (Adewolu and Aro, 2009). Most studies report improved growth with VC in fish diets. For example, Chen *et al.* (2025) found that juvenile largemouth bass fed a low-fishmeal diet with moderate VC (0.66–0.81 g/kg) had significantly higher final weight and weight gain (FBW, WGR, SGR) than the unsupplemented control Zhao *et al.* 2025. Nazir *et al.* (2024) likewise showed dose-dependent growth boosts in snakehead (*Channa marulius*) with the fish fed higher VC up to ~276 mg/kg had much larger weight gain and better FCR. In African catfish, Okhionkpmwonyi & Edema (2017) reported that *Clarias* juveniles fed 46–92 mg/kg VC grew significantly better than those on diets with 0–23 mg/kg and the low-VC groups showed deficiency signs (skin lesions, spinal problems) whereas 46–92 mg/kg fish remained healthy. By contrast, Lee *et al.* (2024; 2025) found that walleye pollock only gained more weight up to an optimal VC level ~156 mg/kg) while above that, growth plateaued and hematology remained unaffected.

On the contrary, *Clarias gariepinus* fed diet without Vitamin C had a better Final Mean weight Gain, Total Feed Conversion and Specific Growth Rate while Vitamin C supplementation had no significant influence on weight gain and Feed Conversion Ratio. The result observed could be attributed to sole plant protein in the experimental diet and the antinutritional factors present could interfere with ascorbate utilization and metabolism. This implies that when nutrients are limiting through antinutritional factor, Vitamin C supplementation alone might stimulate growth. (Langi *et al.*, 2024). Furthermore, Vitamin C could have been degraded during feed preparation and fish may not have absorbed enough active ascorbate to show measurable difference. Xu *et al.* (2022) and Guo *et al.* (2024) emphasized that Vitamin C is thermolabile and easily oxidized, and that coated or stabilized forms (e.g., ascorbyl-2-polyphosphate) are better retained and more effective.

The haematological indices of *C. gariepinus* fed plant protein-based diet supplemented with Vitamin C revealed significant variations in several blood parameters as shown in Table 3. The control group (V_0) displayed significantly higher Packed Cell Volume (PCV) ($27.00 \pm 4.24\%$) and Red Blood Cell (RBC) counts ($2.15 \pm 0.07 \times 10^6 \text{ mm}^{-3}$) compared to some supplemented groups (e.g., V_2 for PCV, V_3 and V_4 for RBC). Similarly, Mean Corpuscular Volume (MCV) and Mean Corpuscular Haemoglobin (MCH) were highest in the control diet, while Haemoglobin (Hb) concentration was also highest in V_0 (9.00 ± 1.41 g/dL). These findings suggest that the unsupplemented diet maintained better oxygen-carrying capacity and overall red blood cell health. In contrast, Mean Corpuscular Haemoglobin Concentration (MCHC) remained stable across all treatments, indicating consistent haemoglobin saturation within red blood cells. White Blood Cell (WBC) counts did not show significant differences, although the control group had the highest count. Lymphocyte counts (LYM) and percentages (LYMPER) were higher in V_0 , while granulocyte percentages (GRAPER) were significantly higher in V_1 ($40.00 \pm 11.31\%$). Monocytes were observed only in V_1 and V_2 . These haematological responses are crucial indicators of fish health and immune status. Few research

findings demonstrated that Vitamin C can positively influence haematological parameters and immune responses in fish, particularly under stress conditions (Ibrahim *et al* 2010; Shahkar *et al.*, 2015; Samuel and Kolo, 2022). The observed higher values in the control group for several parameters might imply that the basal diet provided sufficient nutrients for optimal haematopoiesis, or that higher levels of Vitamin C in supplemented diets might have induced some physiological adjustments affecting these parameters (Joseph *et al.*, 2025).

Furthermore, serum biochemical indices showed that creatinine and urea levels remained relatively stable and without significant differences across treatments, meaning that kidney function was not markedly affected by Vitamin C supplementation within the tested range. However, enzyme activities, specifically Aspartate Aminotransferase (AST) and Alanine Aminotransferase (ALT), exhibited significant variations. AST was highest in V₁ (177.95 ± 8.13 U/L) and lowest in V₃ (83.00 ± 38.61 U/L), while ALT peaked in V₃ (301.70 ± 0.00 U/L) and was lowest in V₄ (108.85 ± 53.25 U/L). These enzymes are often indicators of liver health and metabolic stress. Fluctuations in their levels can connote a cellular damage or altered metabolic pathways. Total serum protein was highest in the control group (110.00 ± 53.88 g/dL) and lowest in V₃ (27.85 ± 16.05 g/dL). Total serum protein is a general indicator of nutritional status and immune function (Guo *et al.*, 2024). The higher values in the control group align with its superior growth performance, suggesting better protein synthesis and overall physiological well-being. Rahimnejad *et al.* (2021) explored the effects of Vitamin C and E supplementation on blood biochemistry, among other parameters, in fish, highlighting the complex interplay of these nutrients. The varied responses of AST, ALT, and total serum protein across different Vitamin C levels underscore the need for precise dietary formulations to avoid potential metabolic imbalances.

CONCLUSION

In conclusion, while Vitamin C supplementation in plant protein-based diets for *C. gariepinus* did not entirely enhance growth parameters, the control diet (V₀) consistently demonstrated better growth performance, protein utilization, and several haematological indicators. Conversely, diet V₃ showed the highest survival rate, signifying a trade-off between growth optimization and survival. The significant variations in haematological and serum biochemical parameters across treatments highlight the intricate physiological responses of *C. gariepinus* to different levels of dietary Vitamin C.

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DIETARY VITAMIN C REQUIREMENT IN PLANT PROTEIN- BASED DIETS: ASSESSING THE EFFECTS ON GROWTH PERFORMANCE, NUTRIENT RETENTION, AND OXIDATIVE STRESS IN AFRICAN CATFISH (*C. GARIEPINUS*)

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ABSTRACT

This study investigated the role of varying dietary vitamin C inclusion in plant protein-based diets on the growth performance, nutrient retention, and oxidative stress of African Catfish (*C. gariepinus*). Two hundred and Twenty-five (n=225) juveniles of *C. gariepinus*, aged eight weeks and weighing 104±2.00grams, were randomly assigned to five different diets with varying inclusion of Vitamin C (g/100g). The dietary treatments are as follows; control V₀= 0g/100g vitamin C, V₁=0.075g/100g vitamin C, V₃= 0.15g/100g vitamin C, V₃= 0.225g/100g vitamin C, V₄= 0.3g/100g vitamin C. For 56 days, the fish were fed ad- libitum. Each treatment was in triplicate. The control diet (V₀), with no vitamin C supplementation, yielded the highest final mean weight gain (17.39 ± 1.46g) and total feed consumption (38.97 ± 1.44g). However, diets with vitamin C supplementation generally showed improved specific growth rate and protein intake and survival rates. Supplementation of Vitamin C in plant protein-based diet for *C. gariepinus* had no significant influence on the final weight, feed conversion ratio (FCR). Nitrogen retention efficiency was higher in V₀ (20.31 ± 1.93%), whereas phosphorus retention efficiency varied, with V₀ and V₃ Jointly having the highest value. Significantly higher (P>0.05) value (1.51±0.01 µmol/L) for MDA was observed in Fish fed diet V₄. These findings suggested that while high levels of vitamin C supplementation may not always enhance growth performance and nutrient retention in *C. gariepinus* fed plant-based diets, it can positively reduce oxidative stress in the experimental fish.

Keywords: Vitamin C, Nutrient Retention, Plant protein, African Catfish, Oxidative Stress

INTRODUCTION

Aquaculture plays a pivotal role in global food security, with African Catfish (*C. gariepinus*) being a significant species due to its rapid growth, resilience, and adaptability to various culture systems (Lisachov *et al.*, 2023; Okon *et al.*, 2025). As the aquaculture industry expands, there is an increasing demand for sustainable and cost-effective feed ingredients (Alawode and Ajagbe, 2020). This has led to a growing interest in replacing conventional fishmeal with plant-based protein sources such as soybean meal, groundnut cake, and maize (Oyedokun *et al.*, 2022; Hussain *et al.* 2024). While plant-based diets offer economic and environmental benefits (Evrendilek, 2024), they often present challenges in meeting the complete nutritional requirements of fish, necessitating careful formulation and supplementation with additives such as vitamins, growth enhancers etc.

Among the essential micronutrients, vitamin C (ascorbic acid) is crucial for fish health and growth. Fish, including *C. gariepinus*, are unable to synthesize vitamin C endogenously due to the absence of L-gulonolactone oxidase, the enzyme required for its biosynthesis (Adeyemi-Doro and Iyiola, 2017; Oyedokun *et al.*, 2024). Consequently, dietary supplementations of vitamin C are indispensable for normal physiological functions, including collagen synthesis, immune response, stress resistance, and antioxidant defense (Carr and Maggini, 2017). Deficiencies in vitamin C can lead to various pathological conditions, such as reduced growth, skeletal deformities, impaired wound healings, and increased susceptibility to diseases (Adeyemi-Doro and Iyiola, 2017).

Previous research has explored the effects of vitamin C supplementations in various fish species, including *C. gariepinus*, demonstrating its positive impact on growth performance and overall health (Ibrahim *et al.*, 2020; Xu *et al.*, 2022). Studies have indicated that optimal levels of ascorbic acid are required for rapid growth and health in African Catfish, with some suggesting ranges between 31–42 mg/kg of diet (Okhionkpmwonyi, and Edema, 2017). However, the specific requirements can vary depending on the diet compositions,

particularly when plant protein sources are extensively utilized, as these may influence nutrient bioavailability and metabolic demands (Opazo-Navarrete *et al.*, 2025). The interactions between plant-based ingredients and vitamin C metabolism in *C. gariepinus* remains an area requiring further investigation. Therefore, this study aims to evaluate the effects of different dietary vitamin C inclusion in plant protein-based diets on the growth performance, nutrient retention, and oxidative stress of African Catfish (*C. gariepinus*).

MATERIALS AND METHODS

Study Area

The experiment was carried out at Fisheries and Aquaculture research laboratory, located at the central laboratory of Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria

Experimental Procedure

Three hundred and Fifty pieces (350) of *C. gariepinus* juveniles weighing 6.82 ± 0.24 g were brought from Federal University of Technology Teaching and Research Farm, Akure Ondo State. The fish were acclimatized under laboratory condition for three weeks at the Fisheries and Aquaculture Research Laboratory. During acclimatization period, the fish were fed with commercial feed to satiation. Fish were randomly distributed into fifteen (15) transparent plastic tanks with 60 cm $\times$ 45 cm $\times$ 30 cm dimension of 30litres capacity each at a stocking density of fifteen (15) fish per tank. Total of two hundred and twenty-five (n=225)-*C. gariepinus* juveniles' fish were distributed into treatments. The fish were left for a day unfed before the commencement of the feeding trials. The fish were fed to satiation twice daily (08:00 and 5:00 hours) for a period of 56 days. The set up was covered with transparent net to avoid fish from jumping out. Water replacement was done every three (3) days, this eliminated faecal matter and unutilized feed by the fish. The weight of the fish was monitored every two weeks as reported by Oyedokun *et al.* (2022).

Formulation and Preparation of Experimental Diets

Five isonitrogenous chemical composition tested diets were formulated with varying levels of vitamin C Table 1. The diet was fixed at 40% crude protein level for the optimum growth of the experimental fish (Faturoti *et al.*, 1986). The ingredients were procured from a reputable feedmill in Ikare - Akoko, Ondo State. The feed ingredient was finely grounded using hammer mill. The ingredients were thoroughly mixed together and each diet mixture was pelleted at 60°C, using 4mm pellet dies to form noodle-like strands, which were manually crumbled into a suitable size for the *C. gariepinus* juveniles. Plant protein diets supplemented with varying inclusion of vitamin C were used to formulate five (5) dietary treatments as follows; V 0 = 0g/100g inclusion of vitamin C, V 1 = 0.075g/100g inclusion of vitamin C, V 2 = 0.15g/100g inclusion of vitamin C, V 3 = 0.225g/100g inclusion of vitamin C, V 4 = 0.3g/100g inclusion of vitamin C

Table 1: Composition of Experimental Diets used for Feeding Trial

INGREDIENTS (%)	V ₀	V ₁	V ₂	V ₃	V ₄
Soyabean meal	36.14	36.14	36.14	36.14	36.14
Groundnut cake	34.01	34.01	34.01	34.01	34.01
Maize	24.84	24.84	24.84	24.84	24.84
Lysine	0.4	0.4	0.4	0.4	0.4
Methionine	0.6	0.6	0.6	0.6	0.6
Salt	0.2	0.2	0.2	0.2	0.2
D.C.P.	0.5	0.5	0.5	0.5	0.5
*Vitamin premix	0.5	0.5	0.5	0.5	0.5
Vitamin C	0	0.075	0.15	0.225	0.3
Starch	2.61	2.535	2.46	2.385	2.31
Soya Oil	0.2	0.2	0.2	0.2	0.2
Total	100	100	100	100	100
Analysed crude protein	39.12	40.26	40.85	41.27	39.81

V₀=0g/100g Vitamin C inclusion; V₁= 0.075g/100g Vitamin C inclusion; V₂= 0.15g/100g Vitamin C inclusion; V₃= 0.225g/100g Vitamin C inclusion; V₄= 0.3g/100g Vitamin C inclusion. DCP = Dicarboxylate phosphate. *1 kg of premix contains Vitamin A: 22,000I.U, Vitamin D3: 5,000I.U, Vitamin E: 300 mg, Vitamin K3: 10 mg, Vitamin B1: 20 mg, Vitamin B2: 25 mg, Vitamin C: 300 mg, Niacin: 120 mg, Calcium pantothenate: 60 J mg, Vitamin B6: 10 mg, Vitamin B12: 0.05 mg, Folic acid: 5 mg, Biotin: 1 mg, Choline chloride: 500 mg, Inositol: 50 mg, Manganese: 30 mg, Iron: 35 mg, Zinc: 45 mg, Copper: 3 mg, Iodine: 5 mg, Cobalt: 2 mg, Lysine: 85 mg, Selenium: 0.15 mg, Anti-oxidant: 80 mg and Methionine: 100 mg

Chemical composition

Crude protein and mineral content of the formulated diets was analysed chemically (AOAC, 2005).

Growth studies

The following growth and nutrient utilization parameter were calculated as described by Falayi (2009). Initial weight, Final Weight, Feed Conversion Ratio (FCR), Gross efficiency Feed Conversion (GEFC), Protein Intake (PI), Specific Growth Rate (SGR) Protein Efficiency Ratio (PER), Protein Intake (PI) and survival rate were calculated using recommended procedures.

Nutrient Retention

The following nutrient retention parameters was calculated as described by Preetha *et al* (2012). Nitrogen Retention, Gross Nitrogen Retention, Nitrogen Retention Efficiency, Phosphorus Retention Efficiency and Phosphorus Retention were calculated using recommended procedures.

Oxidative Stress Analysis

Blood samples for antioxidant defense enzyme analyses were ice cold prior to analyses after which they were centrifuged for 5 minutes at 3000 rpm with Hawsley Minor Bench Centrifuge (P spectra, Centromix no 231254 CD7000549, Spain). The resulting supernatant were used for further biochemical analyses (Magwere *et al.*, 1997). Superoxide Dismutase (SOD) activity evaluated using procedures from Magwere *et al.*, (1997). Catalase (CAT) activity followed procedures from Sinha (1972). Malondialdehyde (MDA) constitutes part of the final output of lipid peroxidation. MDA levels were analysed according to Buege and Aust (1978) methods.

Statistical Analysis

The results were subjected to a one-way ANOVA and data were analyzed using statistical package for social sciences, version 20 (SPSS Inc., Chicago, il, USA). Differences between mean were compared using Duncan's new multiple test range of differences ($P > 0.05$) among dietary treatments.

RESULTS

Initial weights were comparable across all groups, ranged from 102.67 ± 0.58 g to 105.33 ± 3.06 g (Table 2). Supplementation of Vitamin C in plant protein-based diets for *C. gariepinus* had no significant ($P > 0.05$) influence on the final weight, feed conversion ratio (FCR), and Gross Efficiency Feed Conversion (GEFC). The final mean weight gain (FMWG) showed significant differences ($P < 0.05$) among the treatment groups. The control group (V_0) exhibited the highest FMWG (17.39 ± 1.46 g), which was significantly different from V_2 (14.74 ± 1.30 g) and V_3 (14.68 ± 0.15 g). Total feed consumption (TFC) was also highest in V_0 (38.97 ± 1.44 g), significantly differing from other treatments. The specific growth rate (SGR) was highest in V_0 (0.70 ± 0.09 g) and lowest in V_3 (0.58 ± 0.03 g). Protein efficiency ratio and protein intake had a significantly ($P > 0.05$) better value of $0.43 \pm 0.04\%$ and $11.59 \pm 0.58\%$ recorded in the fish fed the control diet, respectively. *C. gariepinus* fed diet V_3 had the higher survival rate value of 97.78 ± 3.85 .

Table 2: Growth Performance of *C. gariepinus* Fed Experimental Diets with varied inclusion of Vitamin C
Performance of *C. gariepinus* fed plant protein- based diets supplemented with vitamin C. *C. gariepinus* in plastic tanks

Parameters	V_0	V_1	V_2	V_3	V_4
Initial weight (g)	105.33 ± 3.06	104.67 ± 3.21	102.67 ± 0.58	105.00 ± 3.61	103.00 ± 2.00
Final Weight (g)	248.43 ± 17.53	219.37 ± 30.51	210.90 ± 11.36	215.37 ± 10.15	225.97 ± 30.9
FMWG (g)	17.39 ± 1.46^a	16.41 ± 0.99^{ab}	14.74 ± 1.30^b	14.68 ± 0.15^b	15.72 ± 1.49^{ab}
TFC	38.97 ± 1.44^a	27.12 ± 0.67^b	26.88 ± 0.38^b	24.69 ± 1.10^c	25.49 ± 0.34^{bc}
SGR	0.70 ± 0.09^a	0.66 ± 0.03^{ab}	0.59 ± 0.07^{ab}	0.58 ± 0.03^b	0.64 ± 0.06^{ab}
FCR	2.83 ± 0.37	2.89 ± 0.28	3.46 ± 0.55	3.22 ± 0.27	2.92 ± 0.39
PER	0.43 ± 0.04^a	0.41 ± 0.02^{ab}	0.37 ± 0.03^b	0.37 ± 0.00^b	0.39 ± 0.04^{ab}
Protein Intake (g)	11.59 ± 0.58^a	10.85 ± 0.27^b	10.75 ± 0.15^b	9.87 ± 0.44^c	10.19 ± 0.14^{bc}
GEFC	35.69 ± 4.36	34.81 ± 3.30	29.38 ± 4.53	31.19 ± 2.53	34.72 ± 4.95
Survival Rate%	95.56 ± 7.70	88.89 ± 7.70	95.55 ± 3.85	97.78 ± 3.85	95.55 ± 3.85

The values with different superscripts (a, b, c) within the same rows were significantly different ($P < 0.05$). $V_0 = 0$ g/100g Vitamin C inclusion; $V_1 = 0.075$ g/100g Vitamin C inclusion; $V_2 = 0.15$ g/100g Vitamin C inclusion; $V_3 = 0.225$ g/100g Vitamin C inclusion; $V_4 = 0.3$ g/100g Vitamin C inclusion. FMWG= Final Mean Weight Gain, SGR= Specific Growth Rate, FCR= Feed Conversion Ratio, PER=Protein Efficiency Ratio, GEFC = Gross Efficiency Feed Conversion, TFC = Total Feed Conversion

The nutrient retention parameters for *C. gariepinus* fed plant protein-based diets supplemented with varied levels of Vitamin C did not show significant differences across the groups for Nitrogen retention. However, Nitrogen Retention Efficiency was significantly higher ($P>0.05$) in fish fed diet V_0 (20.31 ± 1.93) and least in fish fed diet V_2 (15.20 ± 1.31). Phosphorus Retention Efficiency also showed significant variations, with the fish fed V_0 (23.59 ± 2.47^a) and V_3 (19.32 ± 1.60) diets exhibited higher values compared to the fish fed V_1 (15.57 ± 1.06) and V_2 (11.15 ± 2.26) diets. Gross Nitrogen Retention and Phosphorus Retention also displayed significant differences among the treatments.

Table 3 : Nutrient retention (nitrogen and phosphorus) of *C. gariepinus* fed plant protein - based diets supplemented with vitamin C in plastic tanks

Parameters %	V_0	V_1	V_2	V_3	V_4
Nitrogen Retention	102.24 ± 0.58	99.36 ± 2.43	92.14 ± 11.46	96.91 ± 1.44	100.48 ± 1.84
Gross Nitrogen Retention	639.00 ± 3.59	621.03 ± 15.17	578.87 ± 71.63	605.74 ± 8.99	627.99 ± 11.49
Nitrogen Retention Efficiency	20.31 ± 1.93^a	18.80 ± 1.15^{ab}	15.20 ± 1.31^c	16.18 ± 0.33^{bc}	18.02 ± 1.179^{ab}
Phosphorus Retention Efficiency	23.59 ± 2.47^a	15.57 ± 1.06^c	11.15 ± 2.26^d	19.32 ± 1.60^b	16.44 ± 1.93^{bc}
Phosphorus Retention	114.51 ± 21.91^a	79.63 ± 0.34^{bc}	63.73 ± 6.80^c	112.13 ± 10.07^a	88.06 ± 6.33^b

a,b,c,d= indicate that mean on the same row but with different superscript are statistically significant ($P<0.05$). $V_0=0\%$ Vitamin C inclusion; $V_1=0.075\text{g}/100\text{g}$ Vitamin C inclusion; $V_2=0.15\text{g}/100\text{g}$ Vitamin C inclusion; $V_3=0.225\text{g}/100\text{g}$ Vitamin C inclusion; $V_4=0.3\text{g}/100\text{g}$ Vitamin C inclusion level

The oxidative stress parameters of the experiental fish shows significant differences among the treatment as shown on table 4. Significantly higher ($P>0.05$) value for MDA was observed in Fish fed diet V_4 (1.51 ± 0.01) and the least value in control diet (0.38 ± 0.52). However, GSH, SOD, and CAT follows similar trend with the higher ($P>0.05$) values of 1.30 ± 0.07 , 8.71 ± 0.4 , 4.51 ± 0.55 in fish fed control diet, respectively compared to other diets.

Table 4: Oxidative stress of *C. gariepinus* fingerlings fed plant protein-based diets in plastic tanks

Parameters Nmolml ⁻¹	V_0	V_1	V_2	V_3	V_4
MDA	0.38 ± 0.52^c	0.72 ± 0.02^d	0.84 ± 0.05^c	1.36 ± 0.05^b	1.51 ± 0.01^a
GSH	1.30 ± 0.07^a	1.04 ± 0.04^b	0.95 ± 0.05^b	0.68 ± 0.05^c	0.58 ± 0.02^c
SOD	8.71 ± 0.40^a	4.48 ± 0.35^b	3.47 ± 0.34^c	1.47 ± 0.26^d	1.04 ± 0.08^d
CAT	4.51 ± 0.55^a	3.12 ± 0.16^b	2.96 ± 0.09^b	1.55 ± 0.17^c	1.08 ± 0.04^c

The values with different superscripts (a, b, c) within the same rows were significantly different ($P<0.05$). $V_0=0\text{g}/100\text{g}$ Vitamin C inclusion; $V_1=0.075\text{g}/100\text{g}$ Vitamin C inclusion; $V_2=0.15\text{g}/100\text{g}$ Vitamin C inclusion; $V_3=0.225\text{g}/100\text{g}$ Vitamin C inclusion; $V_4=0.3\text{g}/100\text{g}$ Vitamin C inclusion

DISCUSSION

Vitamin C is well known for its role in the optimization of growth, immune, and stress resistance in fish. Its often supplied in trace amounts through their diet (Zhou *et al.* 2012; Dawood and Koshio, 2018). Contrary to expectations that vitamin C supplementation would enhance growth performance, the results from this experiment revealed that the control diet, without added vitamin C, exhibited superior growth performances (FMWG, TFC, SGR, and protein intake) compared to most supplemented groups. This observation suggested that at the tested inclusion, particularly in diets V_2 and V_3 , vitamin C might not have conferred additional growth benefits, or perhaps even exerted a suppressive effect on feed intake and growth efficiency in *C. gariepinus* fed plant-based diets. Previous studies have indicated that optimal vitamin C levels are crucial for fish growth, with deficiencies leading to reduced growth (Dawood and Koshio, 2018; Xu *et al.*, 2022; Tanwi *et al.*, 2025). However, excessive levels can also be detrimental or simply not provide further benefits, as fish have specific requirements (Adeyemi-Doro and Iyiola, 2017). The plant-based nature of the diets, primarily composed of soybean meal, groundnut cake, and maize, might influence the bioavailability and metabolic demand for vitamin C. Plant-based proteins can sometimes contain anti-nutritional factors that affect nutrient absorption and utilization, potentially altering the fish's response to micronutrient supplementations (Oyedokun *et al.*, 2024; Serra *et al.*, 2024). It is possible that the basal vitamin C content in the plant ingredients, combined with the fish's metabolic capacity, was sufficient for the V_0 group, or that higher levels interfered with other metabolic pathways.

Furthermore, the reduced growth performance might also be attributed to the specific plant protein sources used, the overall diet formulations, or the levels of vitamin C supplementation. The current study used higher inclusion (up to $0.3\text{g}/100\text{g}$ or $3000\text{ mg}/\text{kg}$), which might exceeded optimal levels, potentially leading to no

additional benefits or even adverse effects on growth if the metabolic cost of processing excess vitamin C outweighs its benefits. It is also possible that the plant-based ingredients in the current study influenced nutrient bioavailability differently, as noted by Opazo-Navarrete *et al.* (2025), who highlighted challenges in meeting complete nutritional requirements with plant-based diets.

Nutrient retention efficiencies also presented interesting patterns as we have it in growth performances. Nitrogen Retention Efficiency was highest in the fish fed control diet (V0) and lowest in fish fed V2 diet, indicating that the absence of supplemental vitamin C or specific inclusion might optimize protein utilization. This aligned with the growth performance data where the fish fed V0 diet showed better protein retention. Phosphorus Retention Efficiency varied significantly, with fish fed V0 and V3 diets showing higher values. Vitamin C is known to enhance the absorption of certain minerals, including phosphorus (Morales *et al.*, 2013). The observed fluctuations suggested that the interaction between vitamin C levels and phosphorus retention is not linear and might be influenced by other dietary components or physiological demands. The use of plant-based diets, which can have varying phosphorus bioavailability, further complicated this interaction (Morales *et al.*, 2013).

The study found that vitamin C supplementations positively reduced oxidative stress in the experimental fish, with significantly higher MDA values observed in fish fed diet V4 (1.51 ± 0.01 $\mu\text{mol/L}$) and the least in the fish fed the control diet (0.38 ± 0.52). However, the results for GSH, SOD, and CAT followed a similar trend, with higher values in the fish fed the control diet. This particular finding for GSH, SOD, and CAT is counterintuitive, as vitamin C is known for its antioxidant properties, and higher levels of these enzymes are generally indicative of a robust antioxidant defense system. This warrants further investigation, as typically, vitamin C supplementation is expected to enhance antioxidant enzyme activity or reduce oxidative markers like MDA.

Previous research consistently supports the role of vitamin C as a crucial antioxidant in fish. For instance, Reda *et al.* (2021) found that while immunological responses and antioxidant status of *C. gariepinus* were not affected when fishmeal was replaced by up to 50% with plant protein (soybean and sunflower meal) supplemented with methionine and lysine, 100% fishmeal replacement impaired total globulin, nitric oxide (NO), and cumulative mortality. This suggests that the balance of nutrients, including essential amino acids, is critical when formulating plant-based diets to maintain immune function and antioxidant status. The current study's observation of reduced MDA with vitamin C supplementation aligns with the general understanding of vitamin C's role in mitigating oxidative stress (Adeyemi-Doro and Iyiola, 2017). The unexpected trend in GSH, SOD, and CAT levels in the current study could be due to complex interactions between the high levels of vitamin C, the specific plant protein sources, and other dietary components, or it could indicate a compensatory mechanism where the fish's endogenous antioxidant system is upregulated in the absence of external vitamin C to cope with potential stressors.

CONCLUSION

The research findings from this experiment indicates that the highest growth performance and nitrogen retention efficiency were observed in the absence of supplemental vitamin C, suggesting that the basal levels in the diet or other factors might be sufficient or that higher levels could be counterproductive under these specific dietary conditions. However, this study confirms vitamin C's role in reducing oxidative stress in *C. gariepinus* fed plant protein-based diet, but the observed trends in antioxidant enzyme activity warrant further detailed investigation into the biochemical pathways involved in plant protein-based diet.

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HISTOLOGICAL ALTERATIONS IN JUVENILE *CLARIAS GARIEPINUS* EXPOSED TO PRETILACHOR + PYRIBENZOXIM HERBICIDE

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ABSTRACT

Environmental contamination by agricultural chemicals, particularly herbicides, poses a significant threat to aquatic ecosystems and their inhabitants, including fish. This study aimed to evaluate the acute histological and behavioral alterations induced by exposure to a pretilachlor + pyribenzoxim herbicide mixture in *Clarias gariepinus* juveniles. Two hundred and fifty healthy *C. gariepinus* juveniles were acclimatized for two weeks. Batches of 10 fish per tank were randomly distributed into 18 experimental tanks. Following range-finding tests, a definitive acute toxicity test was conducted over 96 hours using various concentrations (0.40, 0.425, 0.45, 0.475, and 0.5 ml) of the herbicide. Throughout the experiment, water quality parameters, behavioral patterns, and mortality were meticulously monitored. Post-exposure, samples were collected for comprehensive histological analysis. Behavioral observations revealed significant stress indicators, including loss of reflex, air gulping, erratic swimming, barbell deformation, and motionless state. Histological examination of the gills showed infiltration of the mucous membrane of the secondary lamellae, which were also overlaid with detritus. In the kidneys, mild degeneration of the renal tubules accompanied by diffuse cellular infiltration was evident. Furthermore, the epidermis of the skin appeared detached from the underlying dermis. These pronounced histological and behavioral changes underscore the acute toxic effects of pretilachlor + pyribenzoxim on *C. gariepinus*. The study suggests that histological analysis is a highly useful method for assessing the acute impacts of herbicides on cultured fish. Consequently, the potential toxic effects of pretilachlor + pyribenzoxim must be carefully considered during its application near aquatic environments to mitigate ecological harm.

Keywords: *Clarias gariepinus*, Pretilachlor + pyribenzoxim herbicide, Histological alterations, Acute toxicity, Aquatic environment.

INTRODUCTION

The African catfish is a fresh water fish that is widely distributed in Africa. In addition to being significant in capture fisheries, it is a key specie in aquaculture. It is widely available and valued by farmers due to its quick development, large size tolerance to poor water quality parameters, omnivores feeding behavior, adaptability to crowding and high market value. It has also been successfully propagated artificially. Yet, its wellbeing and species' survival are in danger due to aquatic environments being polluted by toxicants (Agbebi and Owioye 2012).

Herbicides enter aquatic ecosystems primarily through runoff from precipitation, application near surface water resources, or direct disposal of empty containers. This contamination alters water quality and impacts associated aquatic flora and fauna (Aghoghovwia *et al.*, 2019). Fish are frequently employed as bioindicators to evaluate herbicide effects, which include disruptions to reproduction, food conversion efficiency, growth, and increased mortality rates (Aghoghovwia *et al.*, 2019).

Histopathological studies provide crucial data by detecting cellular and subcellular changes in organs much earlier than the manifestation of external symptoms. A key advantage of histopathological biomarkers in environmental toxicology is their ability to reveal toxicant-induced damage in target organs like gills, kidneys, and liver, where structural alterations are often more discernible than functional impairments (Fanta *et al.*, 2003). These structural changes serve as early indicators of organismal health compromise. Histopathology is a sensitive tool for establishing causal links between contaminant exposure and biological responses, effectively identifying direct chemical effects within target organs in laboratory settings (Boran *et al.*, 2012). Therefore, this study aims to investigate the histological alterations in *C. gariepinus* juveniles exposed to Pretillachlor + Pyribenzoxim herbicide.

MATERIALS AND METHODS

Fish collection and acclimatization

Two hundred and fifty (250) healthy and active *C. gariepinus* juveniles were collected from Research Farm of Federal University of Technology Akure, Ondo State, Nigeria; and transported in a plastic container filled with pond water to the Central Laboratory of Fisheries and Aquaculture Department, Faculty of Agriculture,

Adekunle Ajasin University Akungba-Akoko, Ondo State. Fish collected were acclimatized under laboratory conditions for two weeks (14 days) prior to the commencement of the experiment.

Range finding and definitive tests

A range-finding test experiment was carried out to determine the effective concentrations of pretilachlor + pyribenzoxim to be used. 96h definitive tests was carried out based on the results from the range finding test, following static bioassay procedures described by Parish (1985). Batches of 10 juvenile *C. gariepinus* were distributed into a set of 18 rectangular plastic tanks (75x45x45 cm) each filled with 30L of unchlorinated water. Six test solutions of pretilachlor + pyribenzoxim (0.00, 0.40, 0.425, 0.45, 0.475 and 0.5ml) determined from the range finding test was introduced in a single dose directly into the treatment tanks containing the fish in triplicate and covered with net and perforated lid. The test fish were not fed throughout the 96 hours test. The behavioral patterns and mortality of the test fish in each treatment tank was monitored and recorded every 15min for the first one hour, every hour for 4 hours, every 4 hours for 24hours and every 24hours for 96hours. Dead fish was removed immediately with scoop net to avoid contamination due to rotting.

Histopathological examination

Histopathological examinations were carried out to assess possible alterations in the skin, gills, and kidneys of test fish for each treatment. The organs and tissues were preserved in sampling bottles containing 10% formalin before examination. The organs and tissues were removed from the fish with the use of new and clean razor blade. The examinations were carried out at the Department of Veterinary Pathology Laboratory, Faculty of Veterinary Medicine, University of Ibadan, Nigeria, following Lynch's medical laboratory procedures.

The organs were dehydrated in periodic acid Schiff's reagent (PAS) following the method of Hughes and Perry (1976) in graded levels of 50%, 70%, 90% and 100% alcohol for 3 days, to allow paraffin wax to penetrate the tissue during embedding. The organs were cleaned and embedded in melted wax and carefully sliced into thin sections with a rotatory microtome (5µm thick). The cut sections were again cleaned by placing them in warm water (38 °C) from where they were transferred into clean slides and oven-dried at 58 °C for 30 minutes to melt the wax and stained with Harris' haematoxylin-eosin (H and E) stain (Bancroft and Cook 1994). The slides containing sectioned tissues were cleaned using xylene and graded levels of 50%, 70%, 90%, 95% and 100% alcohol for two minutes each. The sections were again stained in haematoxylin-eosin for ten minutes and mounted in diptex on glass slides. To obtain their photomicrography, the stained sections were examined and photographed at different magnifications (x40, x100 and x400) by means of a binocular light microscope (Olympus Japan 312545) fitted with a digital camera (Olympus CH XSZ-107BBN), a photographic attachment (Olympus C35 AD4) and an automatic light exposure unit (Olympus PM CS5P). The photomicrograph organs were read and recorded accordingly.

RESULTS AND DISCUSSION

The most sensitive indicators of potentially fatal pesticide/herbicide effects in fish are behavioral changes (Banaee *et al.*, 2011; Rauf and Arain, 2013). The behavioral responses observed during *C. gariepinus* exposure to pretilachlor + pyribenzoxim herbicide in this study is similar to what was observed by Alkahemal-Balawi *et al.*, 2011 on the responses of *Cyprinus carpio* exposed to different concentrations of fenthion. Fish in the experimental groups exhibited abnormal behavior such as loss of reflex, air gulping, erratic swimming, barbell deformation, and motionless state. This abnormal behavior was caused by the inhibition of acetyl cholinesterase activity, which led to the accumulation of acetylcholine in cholinergic synapses and caused hyper stimulation of the toxicants. As a result, swimming ability is one of the metrics thought to be a potential sensitive indication of toxicant exposure. According to reports of Alkahemal-Balawi *et al.*, 2011, when fish are under stress, they become hyperactive, possibly to escape the unpleasant environment, hence, they require more oxygen to meet their energy needs.

Histological alterations have been used as significant indicators in order to examine specific target organs during environmental monitoring. The histological results observed in the tissues of *C. gariepinus* in this study indicate that pretilachlor + pyribenzoxim herbicide caused moderate to severe alteration in the gill and kidney which are important organs performing vital functions such as osmoregulation, respiration and acid

Table 1: Behavioral response of *C. gariepinus* exposed to Pretilachlor + Pyribenzoxim herbicide

Behavior	24 hours of exposure				48 hours of exposure				72 hours of exposure				96 hours of exposure			
	0	0.40	0.425	0.45	0	0.40	0.425	0.45	0	0.40	0.425	0.45	0	0.40	0.425	0.45
Loss of reflex	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Air gulping	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Erratic swimming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barbell deform	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Motionless state	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Key: - represent absent, + represent present

base balance. The alterations observed in the gill of juvenile *C. gariepinus* in this research shows mucous membrane of the secondary lamellae appeared infiltrated and overlaid with detritus. The concentrations of pretilachlor + pyribenzoxim used as well as the different exposure periods showed different degrees of histological changes. Histological results indicated that gill was the primary target tissue affected by pretilachlor + pyribenzoxim. Since the gills are the main point of entry for pesticides, they are often regarded as an excellent indicator of water quality. Gills are essential for fish's respiratory, osmoregulation, and excretory processes (Adewumi *et al.*, 2018). The mucous membrane of the secondary lamellae overlaid with detritus can be attributed to increased capillary permeability (Olurin *et al.*, 2006). Damages observed in the gills indicated that acute toxicity of pretilachlor + pyribenzoxim caused impairment in gaseous exchange efficiency of the gills and this is similar to the findings reported by Boran *et al.*, 2012; Alarape *et al.*, 2015 and Patnaik *et al.*, 2011.

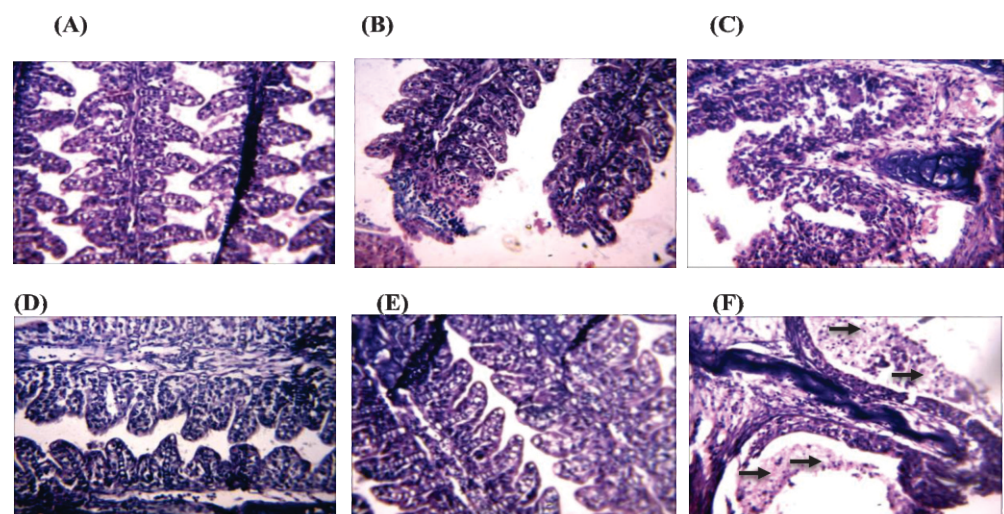


Fig 1: Gill of *C. gariepinus* juvenile exposed to different concentrations of pretilachlor + pyribenzoxim (HE x400) (A) Control fish showing normal gill. (B) Fish exposed to 0.40 ml showing no visible lesions. (C) Fish exposed to 0.425 ml showing no visible lesions (D) Fish exposed to 0.45 ml showing no visible lesion. (E) Fish exposed to 0.475 ml showing no visible lesion. (F) Fish exposed to 0.50 ml showing mucous membrane of the secondary lamellae infiltrated and overlaid with detritus.

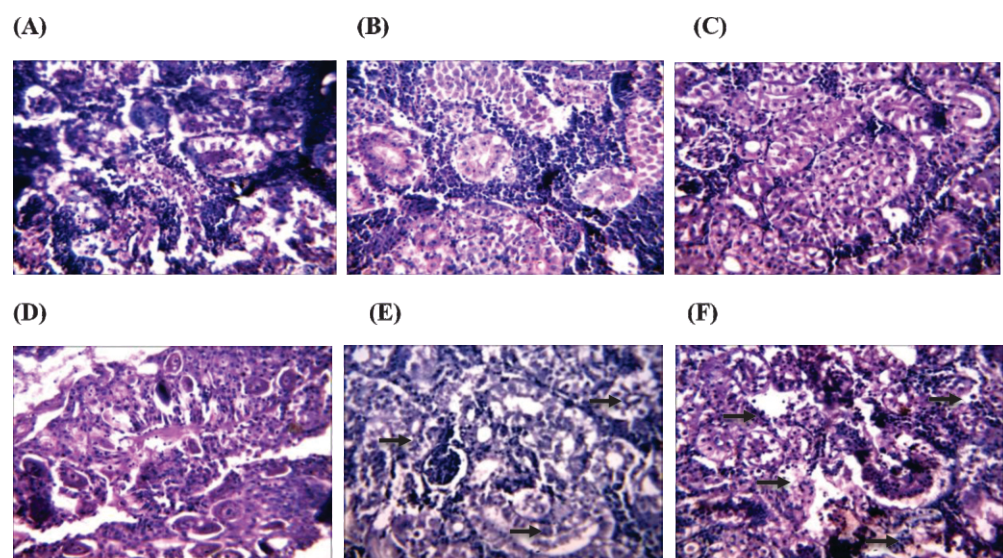


Fig.2: Kidney of *C. gariepinus* juvenile exposed to different concentrations of pretilachlor + pyribenzoxim (HE x400). (a) Control fish showing normal kidney with no lesion. (b) Fish exposed to 0.40 ml showing no observable lesion. (c) Fish exposed to 0.425 ml of showing no observable lesion (d) Fish exposed to 0.45 ml showing no observable lesion (e) Fish exposed to 0.475 ml showing no observable lesion. (f) Fish exposed to 0.50 ml showing mild degeneration of the renal tubules and diffused cellular infiltration

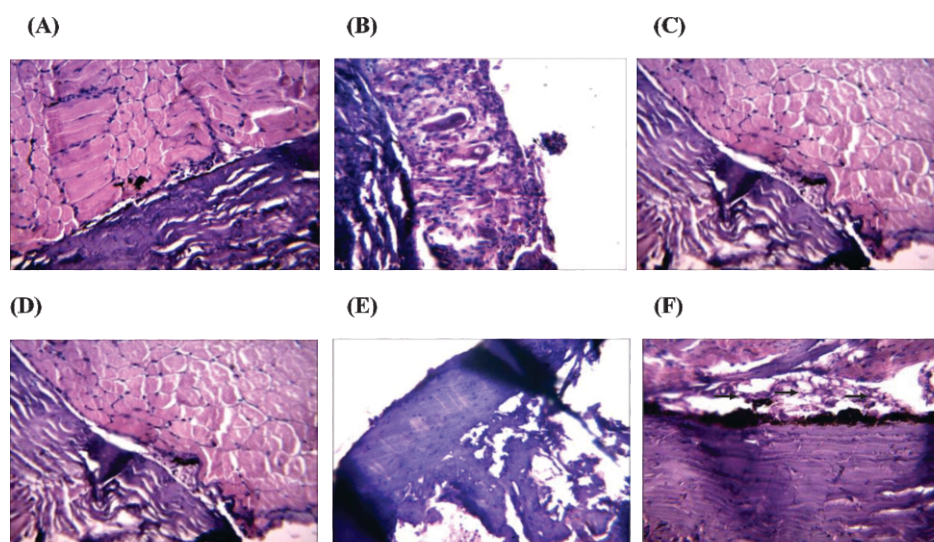


Fig. 3: Skin of *C. gariepinus* juvenile exposed to different concentrations of pretilachlor + pyribenzoxim (HE x400). (a) Control fish showing normal skin. (b) Skin exposed to 0.40 ml of showing no observable lesion. (c) Skin exposed to 0.425 ml of showing no observable lesion. (d) Skin exposed to 0.45 ml of showing no observable lesion. (e) Skin exposed to 0.475 ml of showing no observable lesion. (f) Fish exposed to 0.50 ml of showing epidermis detached from the underlying dermis.

An essential part of the kidney's job is to keep the body's homeostasis in check. In addition to removing waste from blood, it is also in charge of selective reabsorption, which aids in preserving the volume, pH, and erythropoiesis of blood and bodily fluids (Iqbal *et al.*, 2004). The alterations observed in the kidney of *C. gariepinus* exposed to acute concentrations of pretilachlor + pyribenzoxim in this study includes mild degeneration of the renal tubules and diffuse cellular infiltration which are in accordance with the findings of Oulmi *et al.*, 2005 and Ayoola 2008. The acquired data showed that changes in water quality were most detrimental to the kidney. This might be as a result of the fact that the kidney is one of the main detoxifying sites in fish bodies.

Skin and gills are highly sensitive to pollutants due to their direct contact to aquatic environment. It has also been highlighted that fish skin plays a crucial role in responding to chemical stressors and hormonal activity (Forgione *et al.*, 2023). Alteration was observed in the treatment exposed to highest concentration of pretilachlor + pyribenzoxim shows that the epidermis appeared detached from the underlying dermis. This can be pointed to a physiological response such as, detached pavement cells, vacuolation of the cytoplasm and severely deformed cell nuclei stated by Sayed *et al.*, 2012. Generally, the lesions detected in cells, tissues or organs represent an integration of cumulative effects of physiological and biochemical stressors and therefore, can be linked to the exposure and subsequent metabolism of chemical contaminants (Adeyemo, 2008).

CONCLUSION

The histological and behavioral changes that were observed in *C. gariepinus* juveniles exposed to acute concentrations of pretilachlor + pyribenzoxim herbicide caused moderate and severe damage to the organs. These adverse effects on the skin, gills and kidney were simultaneously correlated with sever biochemical, physiological changes. This suggest that histological analysis may be a useful method for observing the effects of herbicide on cultured fish. Therefore, the toxic effects of pretilachlor + pyribenzoxim should be taken into concern during its use near the aquatic environment.

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EFFECT OF AFRICAN OIL BEAN SEED (*Pentaclethra macrophylla*) ON THE BIOCHEMICAL PROFILE OF *OREOCHROMIS NILOTICUS* JUVENILES

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ABSTRACT

This study evaluated the sub-lethal toxicity of African oil bean (*Pentaclethra macrophylla*) seed powder on *Oreochromis niloticus* juveniles by analyzing biochemical stress biomarkers alongside behavioral alterations under controlled laboratory conditions. Fish were exposed to graded concentrations of the seed powder for 96 hours, and serum indices, such as alkaline phosphatase (ALP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), total protein, cholesterol, and creatinine, were analyzed using standard protocols. Behavioral changes-loss of reflex, air gulping, erratic swimming, hyperactive and motionless state were also observed and recorded. Results showed significant ($p < 0.05$) reductions in ALP and AST activities across treatments, indicating hepatic and metabolic disturbances, while ALT remained relatively stable. Decreases in total protein, cholesterol, and creatinine with increasing concentration suggested impaired protein synthesis, altered lipid metabolism, and renal stress. Behavioral anomalies such as air gulping, erratic swimming, and motionlessness intensified with higher exposure levels and longer durations. The 96-hour Lethal Concentration 50 value was estimated at approximately 0.96 mg/L, indicating high acute toxicity. The study concludes that *P. macrophylla* seed powder can induce biochemical and behavioral stress in *O. niloticus*, posing potential ecological risks if improperly discharged into aquatic environments. It is therefore recommended that effluents from oil bean processing be effectively managed to prevent contamination of aquaculture systems and natural water bodies.

Keywords: *Pentaclethra macrophylla*, *Oreochromis niloticus*, biochemical biomarkers, aquatic toxicology, behavioral stress, LC₅₀

INTRODUCTION

Oreochromis niloticus, commonly known as Nile tilapia, is a cichlid fish species indigenous to freshwater bodies across tropical Africa and the Middle East. The species has adapted to a variety of freshwater habitats, ranging from large lakes to slow-moving rivers, and exhibits considerable ecological plasticity allowing it to thrive in diverse environments (Froese and Pauly, 2024). The evolutionary origins of *O. niloticus* traces back to the East African Rift Valley lakes, where evolution events within the *Oreochromis* genus have been linked to geographic isolation and environmental heterogeneity (Kramer *et al.*, 2007).

Various plant species have been employed indiscriminately in both stagnant and flowing water bodies to capture fish. Toxic components such as roots, barks, leaves, fruits, and seeds are commonly used as fish poisons. *Pentaclethra macrophylla*, commonly known as African oil bean, contains bioactive compounds including alkaloids, flavonoids, and saponins and tannins which have shown both therapeutic and toxicological effects depending on dosage and exposure. Oil bean seed (*P. macrophylla*) contains various antinutritional and toxic compounds that can adversely affect organisms if exposed to in raw or unprocessed forms. These compounds can interfere with normal physiological processes, leading to disturbances in hematological and biochemical parameters.

MATERIALS AND METHODOLOGY

Fish Collection and Experiment:

Two Hundred and forty healthy *Oreochromis niloticus* were purchased from Akure and transported with an open 50 litres keg to the laboratory. The selected fish health conditions were assessed and ensured on the basis of absence of bruises and other morphological abnormalities. The fish were certified to be in healthy conditions by assessment before the commencement of the experiment. During the 14 days acclimatization period, the fish were fed with pelleted feed.

Range Finding Test

A range finding test experiment was carried out to determine the effective concentration of African oil bean seed to be used. Batches of Ten (10) fish (*O. niloticus*) were distributed into a set of six (6) transparent regular plastic tanks (75cm X 45cm X 45cm) each impounded with 30 litres of unchlorinated water. The *P.*

Table 1: Behavioural responses of *Oreochromis niloticus* exposed to Oil Bean Seed powder

Behavioral Exposure	24 hours exposure (g/L)				48 hours exposure (g/L)				72 hours of exposure (g/L)				96 hours of exposure (g/L)					
	0.00	0.12	0.23	0.35	0.47	0.58	0.00	0.12	0.23	0.35	0.47	0.58	0.00	0.12	0.23	0.35	0.47	0.58
Loss of reflex	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+
Air gulping	-	-	-	+	+	+	-	-	+	+	+	+	-	+	+	+	+	+
Erratic swimming	-	-	-	+	+	+	-	-	+	+	+	+	-	+	+	+	+	+
Hyperactive	-	-	-	-	-	-	-	-	-	+	+	+	-	+	+	+	+	+
Motionless state	-	+	+	+	+	+	-	-	+	+	+	+	-	+	+	+	+	+
Key: + = Reaction - = No reaction																		

Key: + = Reaction - = No reaction

macrophylla seed powder was introduced at different concentration of 0g, 15g, 20g, 25g, 30g, 35g. Each of the test concentration was introduced directly into the plastic tanks. The behavioural responses and mortality of the test fish in each tank were monitored and recorded for 24hrs.

Definitive Test

The result from the range-finding test was used to determine the concentration of oil bean powder used for the 96hours definitive tests that was carried out, following the static bioassay procedure described by Parish (1985). Batches of ten (10) *O. niloticus* weighing 6.6g to 13.4g were distributed into a set of 18 rectangular tanks (75cm X 45cm X 45cm) each filled with 30 litres of unchlorinated water. Six treatment of *P. macrophylla* seed powder of 0.0g, 3.5g, 7g, 10.5g, 14g, 17.5g predetermined from the range-finding test was introduced directly into each plastic tanks in triplicates. The tanks were covered with a net and perforated lid. The test fish were not fed throughout the 96hours. The behavioral responses, body changes and mortality of the fish in each test tank was observed and recorded for the first 1hour, 4hours, every 4hours for the next 24hours, 48hours, 72 hours and 96 hours. Dropped fish were removed with scoop nets to avoid contamination.

Water Quality Parameter Measurements

Water quality was monitored before, during and after the experiment process for 96hrs. pH was determined using a pH kit. Dissolved oxygen (DO) and temperature were measured using a digital dissolved oxygen analyzer/temperature meter (DO9100). While, conductivity and total dissolved solid was measured using a TDS/conductivity metre.

Statistical Analysis

Data obtained from water quality and mortality of *O. niloticus* exposed to African oil bean (*P. macrophylla*) seed powder underwent analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS) version 21 to generate the mean and standard error. The mean was the separated using Duncan's New Multiple Range Test (DNMRT) at less than 5% level of probability.

RESULT

Table 1 shows the behavioural responses of the experimented fish with respect to various parameters measured. The addition sign (+) indicates the presence of the listed behavioural patterns, while the negative sign (-) indicates the absence. Table 2 shows the impacts of the toxicant on biochemical parameters of the fish exposed in varying concentrations.

DISCUSSION

Behavioral observations complemented these biochemical results, revealing time- and dose-dependent toxicity. Signs such as air gulping, erratic swimming, hyperactivity, and loss of reflexes intensified at higher concentrations and longer exposures, consistent with neurotoxic or metabolic stress (Hussain *et al.*, 2024). These behavioral anomalies parallel reports by Adene (2023) and Dauda *et al.* (2022), affirming their diagnostic value as early warning biomarkers of aquatic pollution.

Alkaline Phosphatase (ALP) is a ubiquitous enzyme found in the liver, Adene *et al.*, 2025

Table 2: Biochemical Parameters of *Oreochromis niloticus* exposed to Oil Bean Seed powder.

Parameters (g/l)	T1 (0.0)	T2 (0.12)	T3 (0.23)	T4 (0.35)	T5 (0.47)	T6 (0.58)
ALP	71.21 ± 5.95 ^a	42.21 ± 14.46 ^b	15.91 ± 2.39 ^c	34.89 ± 4.45 ^{bc}	30.94 ± 10.29 ^{bc}	30.56 ± 3.50 ^{bc}
ALT	8.81 ± 0.58 ^b	11.69 ± 5.38 ^a	2.88 ± 0.88 ^c	13.89 ± 2.93 ^a	7.46 ± 2.34 ^b	1.86 ± 0.49 ^c
AST	28.61 ± 2.31 ^a	20.86 ± 7.41 ^{ab}	8.29 ± 2.01 ^c	28.34 ± 1.23 ^a	28.07 ± 6.64 ^b	13.37 ± 2.16 ^{bc}
Total Protein	4.69 ± 0.41 ^a	4.52 ± 0.84 ^a	3.47 ± 0.43 ^{ab}	4.12 ± 0.28 ^a	5.77 ± 1.10 ^a	2.96 ± 0.20 ^c
Cholesterol	56.36 ± 4.76 ^a	54.30 ± 21.43 ^{ab}	15.46 ± 2.57 ^c	33.33 ± 5.75 ^{bc}	55.56 ± 37.50 ^a	38.14 ± 7.34 ^{bc}
Creatinine	0.45 ± 0.24 ^a	0.20 ± 0.04 ^a	0.39 ± 0.11 ^a	0.18 ± 0.04 ^a	0.33 ± 0.04 ^a	0.60 ± 0.20 ^a

Note: ALP=Alkaline Phosphatase, ALT=Alanine aminotransferase, AST=Aspartate aminotransferase. Mean values with the same superscript alphabets in the rows are not significantly ($P>0.05$) different from each other.

intestine, and other tissues of fish, and its altered plasma activity often reflects hepatic dysfunction or general physiological stress (Bojarski, 2025; Lallès, 2020). The significant decrease in ALP activity across treatments in this study suggests enzyme suppression likely due to hepatocellular or intestinal damage caused by antinutritional compounds in *P. macrophylla*. Such compounds may inhibit enzyme synthesis or alter mineral absorption, thus impairing ALP function — consistent with reports that dietary stress or plant toxins can disrupt gut and liver enzyme activity (Lallès, 2020).

Alanine aminotransferase (ALT) serves as a sensitive biomarker of liver injury in fish (Allam *et al.*, 2024; Hussain *et al.*, 2024). The absence of a significant change in ALT among treatments indicates that *P. macrophylla* exposure did not cause overt hepatic necrosis at tested levels. This agrees with studies showing that moderate inclusion of oilseed meals in aquafeeds does not elevate liver enzyme leakage when properly processed (Li *et al.*, 2023; Badran *et al.*, 2024).

Aspartate aminotransferase (AST), a key enzyme in amino acid metabolism, decreased in treated groups compared with control, implying reduced hepatic stress and possibly improved amino acid utilization efficiency. This finding aligns with Kim *et al.* (2024), who reported that processed oilseed diets could enhance hepatic adaptation and metabolic balance in cultured fish.

Serum total protein decreased with increasing *P. macrophylla* concentration, suggesting impaired protein synthesis or enhanced proteolysis under stress conditions (Adamu & Kori-Siakpere, 2011). This reduction mirrors observations in *Clarias gariepinus* and *Labeo rohita* exposed to plant-based toxicants (Mousa *et al.*, 2008; Saravanan *et al.*, 2010). Similarly, declining cholesterol levels indicate possible mobilization of lipids to meet energy demands during exposure stress, corroborating the findings of Garg *et al.* (1994) and Adamu & Kori-Siakpere (2011).

Creatinine values decreased slightly, consistent with impaired renal function or reduced protein catabolism (Adamu & Ademuyiwa, 2014). The biochemical trends collectively suggest that *P. macrophylla* seed powder disrupts hepatic and renal physiology, reflecting early toxicity symptoms in *O. niloticus* juveniles.

The 96-hour LC_{50} (~0.96 mg/L) denotes high acute toxicity, indicating that *P. macrophylla* possesses potent piscicidal properties. The steep dose-response slope suggests narrow tolerance in *O. niloticus*, similar to patterns reported for strong natural toxicants (Akinrotimi *et al.*, 2021; Nwani *et al.*, 2020). These findings emphasize the ecological risk posed by uncontrolled discharge of oil bean seed residues into aquatic environments.

CONCLUSION

Conclusively, this study revealed that *P. macrophylla* seed powder induced significant biochemical and behavioral alterations in *O. niloticus* juveniles. Changes in ALP, AST, total protein, cholesterol, and creatinine confirm its potential to cause hepatic and metabolic stress, while abnormal behaviors reflect progressive physiological dysfunction. The estimated LC_{50} (0.96 mg/L) indicates that the seed powder is highly toxic to fish even at low concentrations.

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LIPID AND FATTY ACID PROFILE OF WILD AND FARM-RAISED *CLARIAS GARIEPINUS*

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ABSTRACT

This study compared the lipid and fatty acid composition of wild and farm-raised *Clarias gariepinus* in Ondo State, Nigeria. Specimens were obtained from River Ogbese (wild) and a commercial pond (farmed) in Akure. Fish were dissected into whole and regional (pectoral, pelvic, and caudal) portions, and lipid fractions were analyzed for total cholesterol, triglycerides, and high-density lipoprotein cholesterol (HDL-C). Fatty acids were determined as methyl esters (FAMES) via gas chromatography–mass spectrometry (GC–MS). Farmed fish exhibited higher triglyceride and HDL-C levels, whereas total cholesterol was higher in wild fish. Monounsaturated fatty acids (MUFA) predominated across most tissues, while polyunsaturated fatty acids (PUFA); including n-3 series, were present at lower concentrations. Wild fish generally had higher levels of saturated fatty acid (SFA), MUFA, and PUFA than farmed fish. These values align with those reported for edible fish species and are considered safe for human consumption when part of a balanced diet. This work contributes to understanding how rearing conditions influence the lipid quality of *C. gariepinus*, offering insights for aquaculture nutrition and public health.

Keywords: *Clarias gariepinus*, fatty acids, lipid profile, wild, farmed, GC–MS, aquaculture nutrition.

INTRODUCTION

Fish are widely recognized as a vital source of high-quality protein and essential fatty acids, particularly the long-chain n-3 polyunsaturated fatty acids (LC-PUFAs) such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These compounds play critical roles in cardiovascular, cognitive, and metabolic health (Patted *et al.*, 2024; Office of Dietary Supplements, 2023).

The African catfish, *Clarias gariepinus*, is an economically significant freshwater species in Africa due to its fast growth, tolerance to a range of environmental conditions, and broad consumer acceptance. Its lipid and fatty acid composition contribute to both its nutritional and market value (Anarado *et al.*, 2023; Bušová *et al.*, 2023). However, the nutritional profile of fish is strongly affected by habitat, diet, feed composition, and activity level. Wild fish typically consume a natural, varied diet rich in animal-derived lipids, while farmed fish rely on formulated feeds that may be dominated by plant oils or non-marine ingredients (Effiong, 2020; Gebremichael *et al.*, 2023; Egessa *et al.*, 2024).

The lipid composition of fish muscle provides an important indicator of both environmental adaptation and dietary intake. Earlier studies (Osibona, 2011; Taiwo, 2014) established baseline differences in fatty acid content between wild and cultured catfish, but there has been limited updating of these data despite advances in aquaculture nutrition. Recent investigations highlight how alternative feed sources; such as insect meal and microalgae, and optimized feeding regimes can alter the fatty acid profiles of *C. gariepinus* (Bušová *et al.*, 2023; Egessa *et al.*, 2025; Langi, 2024).

From a human nutrition perspective, fish provide beneficial lipids that support heart and brain function. Nonetheless, the balance between saturated and unsaturated fatty acids is important: an excess of saturated fat relative to PUFA can increase the risk of cardiovascular disease (Heikal, 2024; Ayeloja, 2024). Understanding how rearing environments affect this balance can therefore guide dietary recommendations and aquafeed formulation.

This study aims to compare the lipid and fatty acid composition of wild and pond-raised *Clarias gariepinus* from Ondo State, Nigeria, providing updated data on their nutritional value and health implications.

MATERIALS AND METHODS

Study Area and Sample Collection

Specimens of *Clarias gariepinus* were collected from two sources within Ondo State, Nigeria: Wild samples

from River Ogbese (7°16' N, 5°23' E), and Farm-raised samples from a commercial pond located in Akure.

Six fish from each habitat (n = 12) were selected within a weight range of 300–500 g. The fish were transported live to the Fisheries Laboratory, Federal University of Technology Akure, and euthanized humanely following standard ethical protocols. Each specimen was filleted, and tissues were separated into pectoral, pelvic, and caudal regions as well as whole filets. Samples were rinsed with distilled water, blotted dry, placed in labelled polyethylene bags, and stored at –20 °C until analysis.

These sampling procedures followed conventional fish lipid studies (Ningrum *et al.*, 2023) and aligned with contemporary handling guidelines for nutritional biochemistry (Ayeloja *et al.*, 2024).

Lipid Extraction and Serum Lipid Assay

Tissue samples (≈ 1 g) were homogenized and extracted for total lipids using a chloroform–methanol mixture (2:1 v/v), following a modified Folch procedure. Extracts were filtered, evaporated under nitrogen, and weighed to determine total lipid yield.

Serum lipid parameters; total cholesterol, triglycerides, and high-density lipoprotein cholesterol (HDL-C); were quantified using enzymatic colorimetric kits (Randox Laboratories). Absorbances were read at recommended wavelengths with a UV–Visible spectrophotometer. Recent comparative lipid assessments of *C. gariepinus* confirm the suitability of this approach for nutritional profiling (Bušová *et al.*, 2023; Anarado *et al.*, 2023).

Fatty Acid Methyl Ester (FAME) Preparation

Total lipid extracts were converted to methyl esters using base-catalyzed transesterification (methanolic KOH) followed by acid-catalyzed esterification with boron trifluoride–methanol. Samples were neutralized with saturated sodium chloride, the organic layer recovered in hexane, dried over anhydrous sodium sulfate, and stored at 4 °C in sealed amber vials until GC–MS analysis.

FAME standards (C4–C24) were used for calibration, and quality control included procedural blanks and duplicate analyses. This procedure follows recent optimizations for catfish oil characterization (Ningrum *et al.*, 2023; Ningrum *et al.*, 2023).

Gas Chromatography–Mass Spectrometry (GC–MS) Analysis

Analyses were conducted using an Agilent 7820A GC coupled with a 5975 MS detector, fitted with a HP-5 MS capillary column (30 m × 0.25 mm × 0.25 µm). Operating conditions were as follows: Carrier gas: helium at 1 mL min^{–1}; Injection: split 1:20, injector temp 250 °C; Oven program: 150 °C (2 min) → 250 °C at 4 °C min^{–1} (hold 10 min); MS mode: electron impact 70 eV, scan range 50–550 m/z

Identification of FAMES was achieved by comparing retention times and mass spectra with authentic standards and NIST library data. Peak areas were quantified using MSD ChemStation software. This analytical workflow aligns with modern fish lipid studies and ensures reproducible identification of PUFA isomers (Gebremichael *et al.*, 2023; Heikal, 2024).

Statistical Analysis

Data were analyzed using SPSS v25.0. Mean differences among tissues within groups were tested with one-way ANOVA followed by Tukey's HSD. Independent t-tests compared wild and farmed groups. Significance was accepted at p < 0.05. Results were visualized with error-bar plots to depict inter-tissue variation.

RESULTS AND DISCUSSION

Lipid Profile

The lipid profiles of both wild and farm-raised *Clarias gariepinus* are summarized in Figure 1. Farm-raised fish exhibited higher triglyceride and HDL-C concentrations, whereas wild fish showed higher total cholesterol levels. These differences reflect variations in diet composition, metabolic activity, and energy utilization between the two environments (Bušová *et al.*, 2023; Anarado *et al.*, 2023).

Within each fish group, lipid concentrations varied among tissue regions. The pectoral region of farmed fish generally exhibited the highest triglyceride and HDL-C values, while the caudal region in wild fish tended to have elevated cholesterol content. Such regional variation may result from differences in muscle function and lipid storage capacity. These findings align with earlier studies on *C. gariepinus* lipid distribution and confirm the influence of dietary lipid sources on metabolic lipid fractions (Effiong, 2020; Okey, 2022; Heikal, 2024).

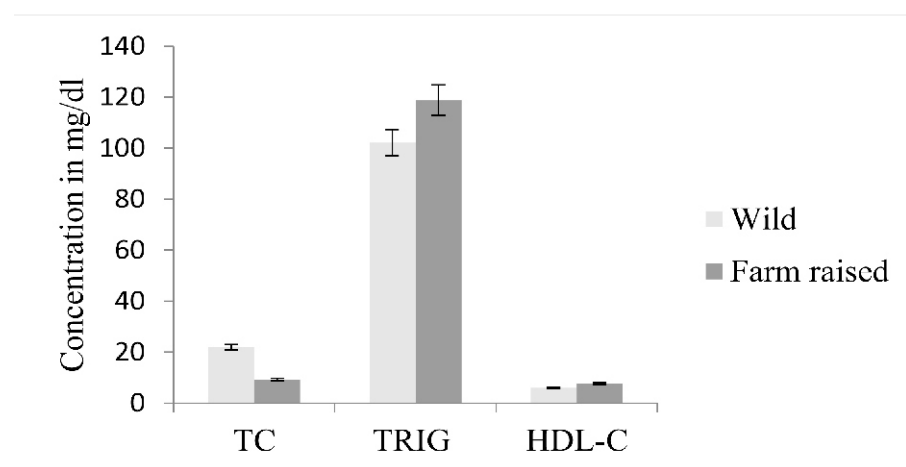


Figure 1. Lipid profile (mean $\pm$ SD) of wild and farmed *Clarias gariepinus*

TC = Total cholesterol; TRIG = Triglyceride;

HDL-C = High density lipoprotein cholesterol

Fatty Acid Composition

The fatty acid profiles (Tables 1) revealed that monounsaturated fatty acids (MUFA) were the predominant class across both wild and farmed groups. Saturated fatty acids (SFA) were next most abundant, while polyunsaturated fatty acids (PUFA) occurred at lower but nutritionally significant levels. Wild fish demonstrated higher absolute and relative concentrations of SFA, MUFA, and PUFA compared with farmed specimens ($p < 0.05$). Among tissues, the pectoral region generally showed the highest lipid diversity, suggesting localized metabolic differences.

Detected MUFAs were dominated by oleic acid (C18:1), whereas palmitic acid (C16:0) accounted for most SFAs. Linoleic acid (C18:2 n-6) and linolenic acid (C18:3 n-3) represented the major PUFAs. Long-chain n-3 species (EPA, DHA) were detected in low proportions but confirmed by GC-MS spectra. These results are consistent with more recent analyses of *C. gariepinus* and related freshwater species, which typically exhibit SFA > MUFA > PUFA ratios in both wild and cultured forms (Anarado *et al.*, 2023; Okey, 2022; Ayeloja *et al.*, 2024).

Both wild and farmed samples contained detectable n-3 and n-6 fatty acids, but n-3 fatty acids predominated in most tissues. The n-3/n-6 ratio was generally higher in wild fish, reflecting the influence of natural diets richer in aquatic invertebrates.

Farmed fish fed on formulated feeds had relatively lower n-3 levels, likely due to the use of plant-based oils low in EPA and DHA (Egessa *et al.*, 2024; Gebremichael *et al.*, 2023). Despite this, n-3/n-6 ratios for both groups remained within the nutritionally recommended range for fish consumption.

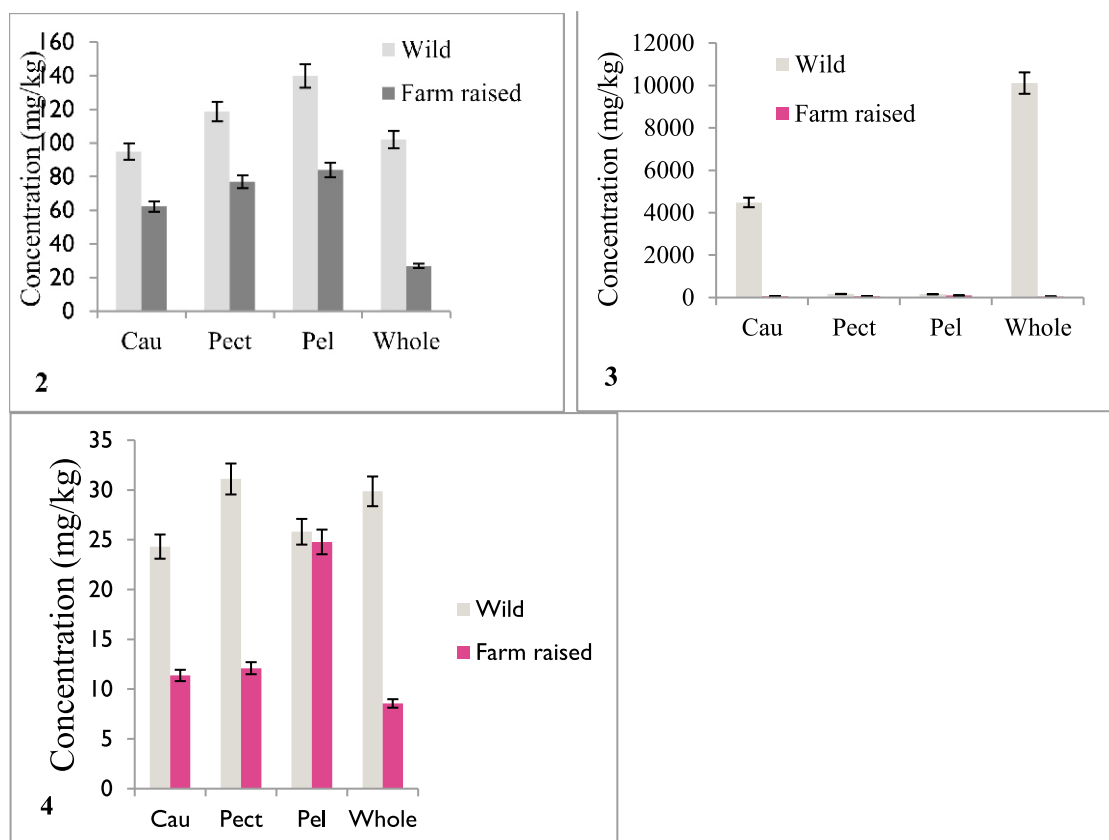
Figures 2–4 illustrate regional variations in fatty acid classes across tissues. In wild fish, the caudal muscle exhibited the highest PUFA and lowest SFA levels while in farmed fish, pectoral tissues contained slightly higher MUFA concentrations, indicating greater energy storage potential in active muscle groups. Such heterogeneity has also been observed in other studies comparing muscle locations in *C. gariepinus* and *Oreochromis niloticus* (Anarado *et al.*, 2023; Buřová *et al.*, 2023).

The observed differences in lipid and fatty acid composition between wild and farmed *Clarias gariepinus* can largely be attributed to dietary composition, feeding behaviour, and metabolic activity. Wild fish rely on natural prey such as crustaceans, insects, and detritus, which are rich in marine-type fatty acids, whereas farmed fish depend on formulated feeds often dominated by terrestrial plant oils (Buřová *et al.*, 2023; Egessa

Table 1: Fatty acid composition in the tissue of Wild and Farm raised *C. gariepinus*

Fatty acids	Wild (mg/kg)				Farm raised (mg/kg)			
	Caudal	Pectoral	Pelvic	Whole	Caudal	Pectoral	Pelvic	Whole
C6:0	11.61	11.50	12.91	11.48	11.15	11.36	11.67	11.02
C8:0	12.00	12.93	13.96	11.63	11.28	11.21	11.32	5.64
C10:0	11.54	11.78	13.00	11.04	5.37	10.74	11.08	ND
C11:0	5.21	6.72	9.01	5.09	4.71	4.72	4.84	ND
C12:0	11.62	11.98	15.10	11.29	9.89	10.19	9.97	ND
C13:0	5.04	6.98	8.24	4.27	3.91	3.90	4.02	ND
C14:0	4.65	4.82	5.57	5.04	5.32	5.20	4.76	2.21
C15:0	3.11	7.54	6.13	2.80	ND	1.35	2.64	ND
C16:0	9.48	13.54	15.65	ND	5.72	11.44	11.55	5.72
C17:0	2.67	3.32	7.24	19.05	ND	LBC	LBC	LBC
C18:0	5.48	8.64	6.36	8.53	3.90	4.03	3.91	1.94
C20:0	2.64	3.89	7.86	3.89	0.57	0.82	1.06	0.39
C21:0	2.09	6.77	7.21	5.82	0.26	0.28	2.57	LBC
C22:0	0.84	4.74	2.87	0.84	LBC	LBC	1.71	LBC
C23:0	6.82	3.53	8.73	1.15	0.19	1.62	2.74	LBC
ΣSFA	94.79 ^b ±18.55 ^b	118.67 ^{ab} ±6.62 ^b	139.84 ^a ±15.90 ^a	101.92 ^b ±3.97 ^b	62.25 ^a ±16.33 ^a	76.86 ^a ±4.38 ^a	83.84 ^a ±3.25 ^a	26.92 ^b ±16.59 ^{ab}
%SFA	2.06	37.55	43.44	1.00	45.64	52.28	41.23	33.16
C16:1	4375.55	13.47	23.57	9935.20	6.56	7.86	12.50	4.69
C16:1	12.36	19.99	19.80	9.33	9.31	4.13	11.95	3.35
C17:1	31.29	61.19	51.65	25.75	5.76	11.35	14.06	4.96
C17:1	15.31	20.53	23.53	17.45	18.56	12.01	22.12	13.76
C18:1	20.02	18.25	16.44	21.45	9.52	11.27	10.86	8.24
	28.63	32.86	21.32	100.35	13.06	11.43	23.23	10.70
ΣMUFA	4483.16 ^b ±479.25 ^a	166.30 ^c ±3.63 ^a	156.31 ^c ±38.45 ^a	10109.53 ^a ±909.99 ^a	62.76 ^b ±1.28 ^a	58.06 ^{bc} ±5.92 ^b	94.71 ^a ±7.17 ^a	45.70 ^c ±0.40 ^a
%MUFA	97.41	52.61	48.55	98.71	46.02	39.49	46.58	56.29
n-3	12.81	14.08	11.65	14.73	6.15	5.80	14.48	4.31
n-3	11.50	17.03	14.15	15.12	5.22	6.30	10.29	4.25
ΣPUFA	24.31 ^a ±4.05 ^b	31.10 ^a ±17.78 ^c	25.80 ^a ±1.70 ^b	29.86 ^a ±1.56 ^b	11.37 ^b ±1.81 ^b	12.10 ^b ±0.79 ^c	24.78 ^a ±3.33 ^b	8.56 ^b ±0.34 ^b
%PUFA	0.53	9.84	8.01	0.29	8.34	8.23	12.19	10.54

*Means on the same row for each species with the same lowercase superscript are not significantly different (p>0.05); LBC: Low below calculation; ND: Not detected. superscripts are not significantly different (p>0.05); LBC: Low below calculation; ND: Not detected.



Figures 2-4: Distribution of SFA, MUFA, PUFA, and n-3/n-6 ratios in tissues of wild and farmed *Clarias gariepinus*.

et al., 2024; Gebremichael *et al.*, 2023). This formulated feeds rich in plant oils (e.g., soybean or palm oil) have been reported to elevate MUFA and n-6 PUFA levels but often dilute long-chain n-3 PUFA content (Egessa *et al.*, 2025; Gebremichael *et al.*, 2023).

Higher triglyceride and HDL-C levels in farmed fish indicate an energy-rich diet combined with lower physical activity, promoting lipid deposition in muscle tissue. Conversely, higher cholesterol in wild fish may result from higher physiological activity and consumption of lipid-rich prey, leading to increased synthesis of structural sterols (Heikal, 2024; Effiong, 2020).

The predominance of MUFA across both groups; particularly oleic acid, reflects the universal presence of these fatty acids in fish lipids and their metabolic stability. MUFAs are critical for maintaining membrane fluidity and oxidative stability during storage and processing (Ayeloja *et al.*, 2024; Ningrum *et al.*, 2023).

The relatively low PUFA content, particularly of the n-3 series, is consistent with reports that freshwater fish generally contain lower levels of EPA and DHA compared with marine species. Still, *C. gariepinus* remains an important contributor of essential fatty acids in inland diets, especially where marine fish are scarce (Anarado *et al.*, 2023; Okey, 2022; Patted *et al.*, 2024).

To bridge this gap, recent innovations in aquafeed research emphasize incorporating sustainable ingredients such as black soldier fly (*Hermetia illucens*) larvae oil, microalgal biomass, and fermented oilseed meals to improve n-3 levels without increasing production costs (Egessa *et al.*, 2025; Langi, 2024).

Dietary modification using such feed additives has been shown to enhance omega-3 fatty acid retention and reduce atherogenic indices in *C. gariepinus* fillets (Bušová *et al.*, 2023). Hence, optimizing the lipid composition of farmed catfish is achievable through strategic feed formulation.

Physiological and Nutritional Implications

Fish-derived LC-PUFAs such as EPA and DHA are associated with improved cardiovascular health, reduced triglycerides, and cognitive benefits (Patted *et al.*, 2024; Office of Dietary Supplements, 2023). Although *C.*

gariepinus has lower LC-PUFA concentrations than marine fish, it remains a valuable dietary source of essential fatty acids in inland regions.

The higher n-3/n-6 ratios observed in wild fish are nutritionally desirable because of the anti-inflammatory and cardioprotective properties of n-3 fatty acids (Office of Dietary Supplements, 2023; Patted *et al.*, 2024). While absolute PUFA concentrations in this study were modest, regular consumption of *C. gariepinus* can contribute meaningfully to daily essential fatty acid requirements.

Furthermore, MUFA dominance suggests favourable oxidative stability and potential for extended shelf life, which is beneficial for both consumers and processors (Heikal, 2024).

The results affirm that both wild and farmed *C. gariepinus* are nutritionally valuable, with differences primarily reflecting environmental and dietary effects rather than inherent species limitations.

CONCLUSION

This study demonstrates that wild *Clarias gariepinus* possess higher total SFA, MUFA, and PUFA concentrations compared with farmed fish, whereas farmed specimens show elevated triglycerides and HDL-C levels. Both sources remain nutritionally safe and valuable for human consumption. These findings reaffirm *C. gariepinus* as an affordable, health-promoting protein source in freshwater aquaculture.

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HEMATOLOGICAL AND SERUM BIOCHEMICAL INDICES OF *Clarias gariepinus* FED VARIED INCLUSION OF GINGER (*Zingiber officinale*) DIETS

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ABSTRACT

Hematological and biochemical indices are important in assessing the acceptability of novel unconventional feeds. Medicinal plants affect the physiology and health status of fish in response to dietary changes. This study evaluated the effects of feeding *Zingiber officinale* meals (ZOMs) on blood parameters of *Clarias gariepinus*. Fish were fed 40% proteinaceous meal diets with ginger: ZOM1 [control diet (0.00g)], ZOM2 (0.0125g), ZOM3 (0.025G), ZOM4 (0.05) and ZOM6 (0.20g) diets respectively. Blood samples were analysed using standard methods, while data were analysed using descriptive statistics and Analysis of variance (ANOVA) at $P < 0.05$. Supplementation of ZOM's in fish diet had no significant impact on the PCV but they were significantly higher than the values in ZOM1 diet. Haemoglobin contents of the fish fed ZOM's diets significantly ranged from 7.40 ± 0.45 (ZOM1) to $9.30 \pm 0.25\%$ (ZOM6). Total Protein ranged from 6.20 ± 0.06 to 7.42 ± 0.04 g/100mls. Highest was from fish fed ZOM6 diet, while the lowest value was jointly from fish fed ZOM2 and ZOM5 diets. Highest glucose value of 50.33 ± 1.20 mg/dl was from fish fed ZOM1 diet and the lowest value of 43.33 ± 1.76 g/100mls was from fish fed ZOM4 diet. Inclusions of ZOM diets improve both the hematological and serum biochemical indices of the fish. Using Ginger up to 0.20g in *Clarias gariepinus* diet had no negative effect on health and wellbeing of the animal.

Keywords: Medicinal plants, aquaculture, fish health, fish nutrition, additive, blood profiles

INTRODUCTION

Haemato-biochemical studies deal with the causes, prognosis, diagnosis, prevention of diseases associated with the blood, and wellbeing of cells, tissues, organs, and metabolic conditions of the body systems. Fish blood constituents have been known to be affected by nutrition, sex, age, parasites, water quality and culture systems. Handling of fish feeding and diets by fish farmers is not just a simple task as it seems on the surface value. One of the major challenges faced by fish producers is the dire need to have a balance between fish rapid growth and optimum utilization of the supplied diets (Odedeyi and Adetola, 2015), while also not compromising the healthy status of the animal (Folorunso et al., 2024). Therefore, the use of haemato-biochemical analyses have been reported to further reveal the acceptability of new innovative, conventional and unconventional fish feed resources such as processed soybean-based diets supplemented with amino acids and defatted groundnut cake in plant based diet (Oyedokun et al., 2019; Oyedokun et al., 2020; Oyedokun et al., 2022). Ginger (*Zingiber officinale* Roscoe) is an herbaceous rhizomatus perennial plant belonging to the family Zingiberaceae, that also contains tumeric (*Curcuma longa*), Greater galangal *Alpinia galangal*, Lesser galangal (*Alpinia officinarum*), and cardamom (*Elettaria cardamomum*) as reported in Kew Royal Garden. It originated from Maritime Southeast Asia, but now widely produced in the warm climatic areas of the world including Nigeria, Bangladesh, India, Taiwan, Jamaica and United State of America (Adanlawo and Dairo, 2007).

The plant maintained the leading roles as the nature primary sources of drugs and a dependable pharmacy in the ethnomedicinal treatments of different diseases based on the diverse assemblages of phytochemicals that are useful for their biological activities (Olasehinde et al., 2012). Furthermore, it has been reported that Ginger rhizomes contain a number of active ingredients as ginger oil, gingerols, which can be converted to shogaols, zingerone and paradol, and curcumin, 6-gingerol, zingiberene, bisabolone and several other types of lipids that confers on ginger the characteristic medicinal properties of being pungent and a stimulant (Bliddal et al., 2000; Chang et al., 2012). Ginger is used as an indispensable curry powder or sauces in a wide range of food. It has been used in flavouring bread, carbonated drinks, tea, biscuits and pickles and many other confectionaries due to its aroma and flavour (Dairo and Ojekale, 2006). The aquacultural potentials of ginger have been reported by (Adewole, 2021; Vahedi et al., 2017) and its nutrient and anti-nutrient composition by Adanlawo and Dairo, (2007). However, there is scanty information on the effect of ginger on the blood

profiles of *Clarias gariepinus*. Therefore, the heamatological responses of *C. gariepinus* were analysed to determine the health status of the fish fed graded levels of ZOM's diets.

MATERIALS AND METHODOLOGY

Study location: The study was carried out at the Department of Aquaculture and Fisheries Management's Teaching and Research Laboratory, Faculty of Renewable Natural Resources, University of Ibadan, Ibadan, Oyo State, Nigeria.

Formulation and Preparation of Experimental diets: The ingredients used in compounding the various diets such as ginger, fish (Clupeid) meal, groundnut cake, soybean, bone meal, starch as binder, mineral and vitamin premixes, were bought from Bodija market Ibadan, and Feed mill and Veterinary stores at Orogun, Ibadan, Oyo State, Nigeria. These were compounded into 40% proteinaceous meal diets and coded as follows coded: ZOM1 (CON) (0.00g/100g), ZOM2 (0.0125g/100g), ZOM3 (0.025g/100g), ZOM4 (0.05g/100g), ZOM5 (0.10g/100g) and ZOM6 (0.20g/100g) respectively using algebraic method along with the least cost of formulae and prepared according to into various pelleted *Zingiber officinale* meal diets (Table 1), stored at ambient temperatures until ready for use Adewole, (2021).

Table 1: Percentage composition of ingredients (g/100g diets)

Ingredients	ZOM1 (Control)	ZOM2	ZOM3	ZOM4	ZOM5	ZOM6
Fishmeal	28.55	28.55	28.55	28.55	28.55	28.55
Soybean meal	20.93	20.93	20.93	20.93	20.93	20.93
Groundnut cake	20.71	20.71	20.71	20.71	20.71	20.71
Yellow maize	20.76	20.635	20.735	20.71	20.66	20.56
Vegetable oil	2.50	2.50	2.50	2.50	2.50	2.50
Vitamin/mineral premix	1.50	1.50	1.50	1.50	1.50	1.50
Cassava Starch (Binder)	1.50	1.50	1.50	1.50	1.50	1.50
Common salt	0.50	0.50	0.50	0.50	0.50	0.50
Bone meal	1.00	1.00	1.00	1.00	1.00	1.00
Carboxyl/methylcellulose	2.00	2.00	2.00	2.00	2.00	2.00
Chromic oxide	0.05	0.05	0.05	0.05	0.05	0.05
Ginger	0.00	0.0125	0.025	0.05	0.10	0.20
Total	100	100	100	100	100	100
Calculated crude protei	40.00	40.00	40.00	40.00	40.00	40.00

ZOM=*Zingiber officinale* meal

Blood Collection: The blood samples (about 3ml) were collected from the caudal peduncle of the fish in the different treatments using hypodermic syringe, needle and plunger that were cooled under ice. The blood samples were further collected into 10ml bottle that contained anti-coagulant, Ethylene Diamine Tetracetic acid (EDTA) and used to determine the heamatological parameters, while those collected in bottles without EDTA were used for the detection of serum biochemical analyses. The collected blood samples were transported to the Heamatology unit of the Department of Veterinary Medicine, Faculty of Veterinary Medicine, University of Ibadan, Ibadan, Nigeria using automatic analyser as reported by Gbore *et. al.*, (2020).

Statistical analysis: Data were subjected to one-way analysis of variance (ANOVA) at ($\alpha=0.05$), followed by Duncan's Multiple Range Test for separation of means at a significance level using Statistical Analysis System

RESULTS

The values obtained for Pack cell volume (PCV), red blood cell (RBC) counts, and hemoglobin (Hb) values were higher than the initials, these values significantly ($P>0.05$) ranged from 22.33 ± 0.88 ZOM1 to $28.67 \pm 1.86\%$ (ZOM2); 11.64 ± 1.49 (ZOM1) to $21.20 \pm 1.00 \times 10^6/\text{dl}$ (ZOM6) and 7.40 ± 0.45 (ZOM1) to $9.30 \pm 0.25 \times 10^6/\text{dl}$ (ZOM3), respectively. (Table 2). The significantly higher ($P<0.05$) value for white blood cell counts (WBC) was in fish fed control diet ($8.63 \pm 0.30 \times 10^3/\text{dl}$) and lowest in fish fed diet ZOM2 ($11.82 \pm 0.70 \times 10^3/\text{dl}$)

The highest ($P<0.05$) total protein was from the fish fed ZOM6 diet (7.42 ± 0.04 g/100mls) and the lowest value was jointly from fish fed ZOM2 (6.20 ± 0.06 g/100mls) and ZOM5 (6.20 ± 0.12 g/100mls) diets respectively (Table 3) The highest mean final blood glucose values varied significantly ($P<0.05$) from fish fed ZOM4 diet (42.67 ± 1.45 g/100mls) to the fish fed ZOM1 diet (50.33 ± 1.20 g/100mls). The mean final aspartate aminotransferase (AST) values ranged from fish fed ZOM5 diet (15.67 ± 2.60 μl) to fish fed ZOM3

diet ($20.00 \pm 2.52 \mu\text{l}$). The fish fed ZOMs' diets had lower mean final aspartate aminotransferase compared to the initial value (20.00 ± 2.31) except the fish fed ZOM5 diet. The mean final alanine aminotransferase (ALT) values ranged significantly ($p < 0.05$) from the fish fed ZOM5 diet ($41.67 \pm 2.03 \mu\text{l}$) to the fish fed ZOM3 diet ($65.33 \pm 2.91 \mu\text{l}$). All the fish fed ZOM's experimental diets were significantly ($p < 0.05$) lower in ALT, when compared to the initial value of $72.00 \pm 6.43 \mu\text{l}$. The mean final ALP values ranged non-significantly ($p > 0.05$) from the fish fed ZOM4 diet ($31.33 \pm 4.06 \mu\text{l}$) to the fish fed ZOM5 diet ($40.67 \pm 2.40 \mu\text{l}$). The inclusion at higher extremities had negative influence on the ALP values of the fish (Table 2).

Table 2 : Haematological and Serum biochemical indices of *Clarias gariepinus* fed Ginger (*Zingiber officinale*) meal diets for 84 days in plastic tanks

Parameters	Initial	ZOM 1	ZOM 2	ZOM 3	ZOM 4	ZOM 5	ZOM 6
Pack Cell Volume (%)	19.00 ± 0.58	22.33 ± 0.88^b	28.67 ± 1.86^a	27.00 ± 1.00^a	26.33 ± 0.88^a	28.67 ± 0.33^a	26.67 ± 0.88^a
Haemoglobin (g/dl)	6.30 ± 0.17	7.40 ± 0.45^b	9.17 ± 0.49^a	9.30 ± 0.42^a	8.63 ± 0.30^a	9.30 ± 0.25^a	9.63 ± 0.22^a
Red Blood Cell $\times 10^6/\text{dl}$	3.51 ± 0.41	11.64 ± 1.49^c	15.46 ± 3.08^{abc}	19.53 ± 0.61^{ab}	14.38 ± 0.25^{bc}	20.54 ± 2.34^a	21.20 ± 1.00^a
Mean Cell Volume ($\times 10^{-4}/\text{l}$)	55.00 ± 7.00	65.67 ± 6.17^a	67.33 ± 3.33^a	69.00 ± 3.61^a	67.00 ± 6.24^a	61.00 ± 5.20^a	62.67 ± 1.45^a
Mean Cell Haemoglobin ($\times 10^{-5}/\text{l}$)	18.33 ± 2.33	24.33 ± 2.40^b	28.00 ± 2.08^b	28.00 ± 2.65^{ab}	29.67 ± 3.18^a	28.67 ± 2.40^{ab}	28.33 ± 0.88^a
Mean Cell Haemoglobin Concentration (g/100ml)	33.00 ± 0.00	32.00 ± 0.00	32.00 ± 0.00	32.00 ± 0.00	32.00 ± 0.00	33.67 ± 1.20	33.33 ± 0.88
White Blood Cell ($\times 10^3/\text{dl}$)	7.80 ± 0.87	24.15 ± 0.95^a	8.63 ± 0.30^b	9.30 ± 0.87^b	10.30 ± 1.15^b	9.60 ± 0.87^b	10.37 ± 0.62^b
Platelet ($\times 10^9/\text{l}$)	8.00 ± 1.15	11.00 ± 0.58^b	19.33 ± 1.76^a	16.67 ± 2.19^{ab}	11.67 ± 0.68^b	21.00 ± 0.65^a	16.33 ± 2.03^{al}
Total Protein (g/100mls)	6.83 ± 0.07	6.30 ± 0.15^{cd}	6.20 ± 0.06^c	6.67 ± 0.09^b	6.52 ± 0.06^{bc}	6.20 ± 0.12^d	7.42 ± 0.04^a
Blood Glucose (g/100mls)	35.67 ± 0.88	50.33 ± 1.20^a	48.67 ± 2.03^{ab}	45.33 ± 1.76^{ab}	42.67 ± 1.45^b	47.67 ± 1.45^{ab}	49.33 ± 4.06^{al}
AST (μl)	20.00 ± 2.31	18.33 ± 3.38	20.00 ± 2.52	15.67 ± 2.60	18.33 ± 2.33	20.33 ± 4.63	19.17 ± 0.60
ALT (μl)	72.00 ± 6.43	61.00 ± 2.08^a	45.33 ± 1.76^b	41.67 ± 2.03^b	61.67 ± 2.03^a	65.33 ± 2.91^a	63.33 ± 2.91^a
ALP (μl)	24.17 ± 4.04	35.33 ± 0.67	39.00 ± 0.231	39.00 ± 0.58	40.67 ± 2.40	34.00 ± 6.93	31.33 ± 4.06

Values with different superscripts in each row are significantly different ($P < 0.05$).

Legends : AST = Aspartate aminotransferase, ALT = Alanine transferase, ALP = Alkalinephosphatase.

DISCUSSION

The blood in an animal serves as a transport medium. It transports food materials such as glucose, fatty acids, vitamins and electrolytes from the gastro intestinal tract to body tissue where they are utilized for body building and energy provision. Increase or decrease in body weight from the previous weight for a specific period is the principal measure of productivity in meat animal and depended on the quality and to a lesser extent the quantity of feed given. This means that the weight gain, feed and blood are related (Adewole, 2021; Ajayi and Raji, 2012). The following haematological parameters PCV, Hb, RBC, platelet, lymphocytes and MCV were significantly affected in *C. gariepinus* fed the ZOM's diets. However, the reported effect of the same plant species evaluated in Beluga (*Huso huso*) revealed there were no significant differences in of RBC, WBC counts, PCV, monocyte, lymphocyte, neutrophil, and eosinophil between the treatment groups, but hemoglobin had significant different between control group and the group fed 1% ginger extract (Vahedi *et.al.*, 2017).

The WBC (leucocytes) is considered as a major first lines of defense in the body, their numbers increase greatly during infections. Several reports revealed that medicinal plants can act as immunostimulants and thus increase the total WBC counts (Jian and Wu, 2003). Furthermore, Ologhobo *et al.*, (1986) observed that an increase in WBC count above normal is an indication of the presence of exogenous substances and foreign bodies in the body. In this study, there were reduction in the total WBC counts within the treated groups, when compared to the control which is significantly higher, however, the fish fed the ZOM's diets had higher numerical values of WBC counts than the initial value. Therefore, the dietary supplementation of ZOM's diet in *C. gariepinus* influenced the WBC counts, and showed the immunostimulatory potential of ginger. This experience is different from to Vahedi *et.al.*, (2017) and Gholipour kanani *et al.* (2014) who reported that there was no significant difference in WBC for Beluga fed diet containing ginger for 8 weeks, where the WBC counts increased in ginger extract groups in comparison with control group. The ZOM's diets did not raise the WBC to such abnormal level, while the significant rise in WBC counts observed in the control, might have been due to stress of handling during the blood collection. Furthermore, Adewole and Gbore (2006) found increase in total and differential leucocyte counts, as an indication of stress in fish. This result is similar to

Ademola *et. al.*, (2009) who reported that 1% ginger included in the diet of chicken caused a significant decrease in white blood cells at ($p < 0.01$), but contrary to Omosowone (2011) who reported that diet D4 had the highest significance on the white blood cell of *O. niloticus* relative to the control.

It has been established that feed components affect blood constituents, the hematological parameters can thus be adjudged to assess the effect of test ingredients. Therefore, the percentage volume of whole unclotted blood occupied by the RBC is a useful prognostic indicator in dehydration or excitement when PCV is abnormally high and it aids the diagnosis of anaemia when it is low (Blood and Studdert, 1999). The result from the present work indicated that PVC were not significantly different within the treated groups, but significantly different when compared to the control. The highest value comes jointly from fish fed ZOM2 and ZOM5 diets, while the control had least value. The hemoglobin values followed the same trend as the PVC, which is not significantly different within the tested groups but numerically varied, however, significantly different from the fish fed control diet. The fish fed ZOM6 diet had the highest and the least value comes from fish fed control diet. The RBC values varied significantly within the experimental groups and also when compared with the fish fed the control diet. Fish fed ZOM6 diet had the highest value, followed by ZOM5 diet and the least was from the control. The RBC counts, haemoglobin and PCV measurements can be used to assay nutritional anaemia (dietary deficiency of iron, copper, vitamins and amino acids). Since the values obtained for these parameters (PCV and Hb) fall within the normal range values, it can be interpreted that the dietary treatments did not cause any nutritional anaemia and supplied the needed nutrients to the fish. These three hematological parameters can be influenced among other factors by nutrition, physical activities and volume and its reduction indicates anaemia. In this study, there was no clinical state of anaemic condition. Therefore, these results indicated that *Zingiber officinale* had no negative effect on the blood parameters, but instead has the ability to improve these parameters. Furthermore, the haemoglobin content was significantly higher in treated groups than the control, which demonstrated that oxygen supply increases consequently, reflecting beneficial health effect on fish. This is in agreement with Vahedi *et.al.*, (2017) and Talpur *et.al.*, (2013)

The serum protein of *C. gariepinus* fed ZOM's diets varied significantly both within the tested diets and the when compared to the control. The highest value was from fish fed ZOM6 diet and the least jointly from fish fed ZOM2 and ZOM5 diets. This variation may be attributed to probably the high functional reserve of the liver and non-significant impairment of serum protein synthesis even in the presence of tissue/organ injuries which might have been associated with higher spice mixture concentration (Nakagawa *et. al.* 1980). Furthermore, the serum total protein values in this study were within the normal standard value of 5.0-8.0g/dl reported by CCAC, (2005). This is similar to the values of 6.38-6.88g/dl reported by Onu and Aja, (2011) that fed weaned rabbits with ginger and garlic supplementation and concluded that ginger and garlic did not impair the synthesis and concentration of serum protein and albumin. Therefore, the quality and quantity of the dietary proteins were nutritionally adequate and there was no alteration of normal system protein utilization. According to Awosanya *et al.*, (1999) blood protein depends on the quality and quantity of dietary protein. Therefore, since the blood protein varies significantly, it showed that the inclusion of *Zingiber officinale* had positive influence on protein metabolism and liver functions.

The blood glucose showed a slight significant variation within the treatments and the control diet. There was numerical deduction in the glucose concentrations, with the lowest from fish fed ZOM4 diet and the highest from the fish fed control diet. The reduction in glucose levels of *C. gariepinus* fed ZOM's diets was based on the report that garlic used to dilate peripheral blood vessels which probably enhance glucose transport and utilization. Thus, ginger has been reported to reduce serum glucose (Nwachukwu and Agbor, 2008). Spices particularly those that have piquant active ingredients have their influence on stimulation of salivary, gastric, biliary and pancreatic secretions leading to increase in hormonal and digestive enzymes activities (Pattack and Pai, 1991). This will invariably lead to increase in digestion, and hence reduction of food transit time within the gastro intestinal tract. This effect probably increased with prolonged use of the spice as had been shown by significant difference between the ZOM4 values compared to the control. This effect could have been achieved by an active component of the ingredient that stimulates pancreatic secretion of insulin, thus, enhancing effective glucose transport or key enzymes of the glycolytic pathway involved in glucose utilization. This result is similar to the significant decrease of plasma glucose in *O. niloticus* fed diets

containing (20, 30 and 40g/kg) *Allium sativum* meal (Shalaby *et. al.*, 2006).

Cells contain various enzymes that are related to the functionality of the cells. AST, ALT, LDH and ALP enzymes are used as indices of liver damage. Elevated levels may indicate degeneration, necrosis, and destruction of the liver due to cellular damage (Bhardwaj *et al.*, 2010). ALP is one of the first of the clinically important enzymes identified. The liver produces more ALP than the other organs or the bones. Some physiological conditions, such as liver and skeletal disorders results in large amount of ALP appearing in blood. Increase in serum level of ALP is due to increased synthesis of the enzyme in the presence of increasing biliary pressure. Significant elevation of serum ALP activity towards improvement in secretory function of the hepatic cell. Since the activity of the enzyme is associated with membrane permeability, it could be concluded that the dietary ginger inclusions did inhibit the permeability of the ALP enzyme from the cells to the blood/serum. This observation is similar to the report of Orisakwe *et. al.*, (2004) who observed that the ALP activity in albino mice and rats was not significantly affected when exposed to extracts of *Boerhavia diffusa*.

The result of AST obtained was similar to effect of the essential oils from *Zingiber officinale* and *Allium sativum* on growth performance and gut microbial population of broiler chickens that revealed that the essential oil treatments on the AST and ALT activities, and creatinine level in the blood did not differ from the control. Furthermore, Tubtim and Wasiksiri (2007) administered different doses of *Listeacu beba* essential oil to male and female Sprague – Dawley rats by stomach tube for twenty-eight days and obtained no significant difference from the control group for these same blood parameters. The result obtained showed that ALT concentrations were significantly inhibited in the fish fed ZOM2 and ZOM3 diets compared to others. These results can be attributed to the manner in which it stabilized cell membrane and protected the liver against deleterious agents and free radical- mediated toxic damages to liver cell. Normal liver functions are characterized by the balanced activities of serum marker enzymes AST, ALT and ALP, bilirubin as well as total protein. Hepatocellular necrosis leads to very high level of AST and ALT released from liver in the blood. Among the two, ALT is a better index of liver injury, as liver ALT activity represents 90% of total enzyme present in the body (Moss and Butterworth, 1974).

CONCLUSION

Nigeria is blessed with a wide range of medicinal plants scattered over a large proportion of its land mass. Hematological parameters refer to those factors in the blood whose levels are usually determined in order to assess the well being of an animal. They are important in feeding trials because it has been established that feed components affect blood constituents. It is pertinent to stress from the result of this study that hematological responses of *C. gariepinus* were analysed to determine the health status of the fish fed graded level of ZOM's diet. Since the values obtained for these parameters fall within the normal range value, it can be interpreted that the dietary treatments did not cause any nutritional anaemia and can supply the needed nutrients and boost the immune system of *C. gariepinus*. Furthermore, good management of information on the significance of the adoption /awareness creation through the encouragement of fish farmers to conserve these medicinal plants by having their own herbal garden (agro – pisciculture). Also, further advantages can be derived, since most of these medicinal herbs have been adjudged to be multipurpose in use.

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EVALUATING ALUMINUM COMPOSITE PANELS AS AN ALTERNATIVE TO SILICON GLASS FOR CATFISH INCUBATOR CONSTRUCTION IN NIGERIA

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ABSTRACT

Conventional fish egg incubators constructed with silicon glass panels (SGP) pose mechanical and safety limitations, prompting the search for alternative materials. This study explored the use of aluminum composite panels (ACP) as a potential replacement for SGP in the construction of catfish incubators. Two incubators—one made with ACP and the other with SGP—were designed and constructed, and their functional properties were evaluated, including mechanical strength (elastic limit), impact resistance (fragility), and water absorption rate at the material level, while porosity was assessed after full incubator construction. Data were analyzed using a t-test to compare material performance. The results showed that both materials exhibited significantly low ($p < 0.05$) water absorption and porosity, which are desirable for minimizing water retention and microbial buildup in hatchery systems. SGP had a higher elastic limit ($p < 0.05$), ACP was significantly less fragile ($p < 0.05$), making it more durable and resistant to breakage. Based on these findings, aluminum composite panels offer a safer, more resilient, and moisture-resistant alternative to silicon glass panels for catfish incubator construction. Further studies are recommended to assess the operational performance of ACP-based incubators in hatchery environments

Keywords: Functional properties, catfish incubator, aluminum composite panel, silicon glass panel, and aquaculture material.

INTRODUCTION

Silicon glass panels (SGP) have long been the conventional material used in aquaculture for aquarium and incubator construction (Rajender, 2013). However, Bazroy *et al.* (2003) reported that the use of silicon glass panels poses mechanical health hazards to users during operation. Their high fragility demands careful handling to prevent breakage, thus increasing the risk of injury and making them less user-friendly in hatchery environments (Andreas, 2019). In view of these mechanical and safety limitations, the consideration of alternative materials for incubator construction is both relevant and timely (Bazroy *et al.*, 2003).

Aluminum composite panels (ACP), composed of aluminum and polyethylene, have gained popularity in the construction industry and are increasingly being explored for aquaculture applications. Notably, ACPs can be produced from recycled plastic waste, supporting environmental sustainability by reducing plastic pollution and promoting eco-friendly practices (Ayrilmis *et al.*, 2013; Hopewell *et al.*, 2009). These panels consist of two thin aluminum sheets bonded to a non-aluminum core, typically polyethylene (PE) or a mineral-filled polymer, offering a combination of strength and flexibility suited for specialized environments such as fish hatcheries.

In aquaculture settings, ACPs present several advantages over traditional glass panels. They are highly durable and corrosion-resistant—key attributes for use in humid or saline environments (Green & White, 2021). Their lightweight nature facilitates easy handling and installation, reducing construction time and labor costs when building catfish incubators (Lee & Kim, 2023). ACPs also offer design flexibility, allowing for customization in shape and configuration to meet both architectural and functional needs (Patel, 2024). Although the thermal insulation properties of ACPs are lower than those of glass, they can be paired with additional insulating materials to maintain stable internal temperatures, thereby supporting energy efficiency in incubator systems (Alsabbagh *et al.*, 2025).

This study evaluated the mechanical strength, impact resistance, water absorption rate, and porosity of silicon glass panels (SGP) and aluminum composite panels (ACP) as construction materials for catfish incubators. The aim was to compare the structural and environmental performance of both materials in order to determine their suitability for hatchery applications

MATERIALS AND METHODS

Design of catfish incubator

The cat fish incubator was designed to have total of six (6) troughs which entails three (3) troughs made of glass, and three (3) troughs made of aluminium composite panel (ACP) of $L \times B \times H$ ($0.65\text{m} \times 0.7\text{m} \times 0.16\text{m}$).

Construction of aluminum composite troughs and glass troughs

Aluminum composite troughs (Plate 1A) and silicon glass troughs (Plate 1B) were constructed as incubator troughs, each comprising four rectangular side panels with dimensions of $0.7\text{ m} \times 0.16\text{ m}$. The side panels were fabricated from 4 mm thick aluminum composite sheets and 5 mm thick silicon glass sheets, respectively. Base panels measuring $0.7\text{ m} \times 0.65\text{ m}$ were also prepared from the same materials and corresponding thicknesses. All components were joined using ABRO® 1500 sealant, applied with a silicone caulking gun to ensure watertight sealing capable of withstanding hydrostatic pressure. A total of three (3) units of each trough type were assembled, with each unit designed to accommodate a capacity of 80 liters. Additionally, all six (6) troughs were fitted with a 1-inch standpipe outlet located at the lower back end. The standpipe assembly served to regulate water level within the troughs, prevent overflow, and facilitate continuous flow-through drainage during incubation.

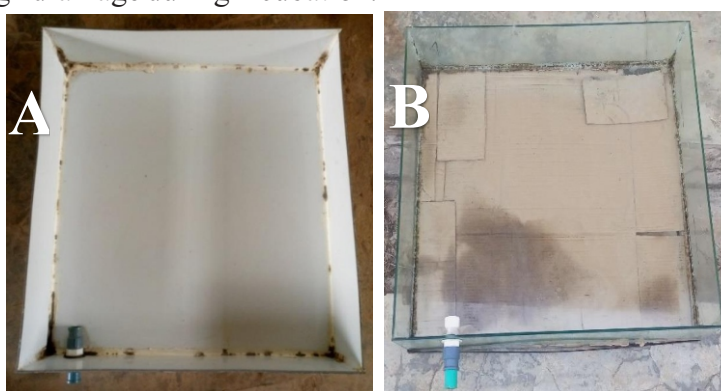


Plate 1: Aluminum composite troughs (A) and silicon glass troughs (B)

Material Property Evaluation

Mechanical Strength Test.

The load-bearing limits of silicon glass panel (SGP) and aluminum composite panel (ACP) were experimentally assessed using a clamp-based pressure method. Panels of identical dimensions ($0.5\text{ m} \times 0.15\text{ m}$) were subjected to a centrally applied upward force, which was gradually increased until structural failure or permanent deformation occurred. The load at the point of failure was measured using an analog scale. This procedure was performed in triplicate for each material, and the average value was recorded as the load-bearing capacity.

Impact Resistance Test.

The impact resistance of the silicon glass panel (SGP) and aluminum composite panel (ACP) was evaluated through a drop test. Both materials, each measuring $0.5\text{ m} \times 0.15\text{ m}$, were released from a height of seven (7) feet onto a concrete surface. This test was repeated three times for each material. Following each drop, the number of resulting fragments was recorded to assess material fragility and fracture behavior.

Water Absorption Test

The water absorption rate of the silicon glass panel (SGP) and aluminum composite panel (ACP) was evaluated by submerging equal-sized samples of both materials in identical volumes of water, conducted in triplicate. Each sample was measured prior to immersion to establish baseline dimensions (length, breadth, and height). The samples were fully submerged and monitored over a period of 96 hours. Dimensional measurements were taken at 24-hour intervals to detect any swelling, deformation, or moisture uptake. All observations were recorded for comparative analysis of the materials' water absorption behavior.

Porosity Test

The porosity of the silicon glass troughs (SGP) and aluminum composite troughs (ACP) was assessed by evaluating their ability to retain water over time. Each trough was filled with a pre-determined volume of

water, and the initial volume was recorded. After a 48-hour period, the remaining water was measured, and the difference between the initial and final volumes was calculated to determine water loss. This procedure was conducted in triplicate for both materials, and average values were used to assess comparative porosity levels

Statistical Analysis

The data obtained from the establishment of elastic limit, fragility test, water adsorption rate and porosity of the glass trough and aluminium composite troughs were subjected to Analysis of variance, tested at 95% confidence limit. All statistical analysis using Statistical Package for Social Science (SPSS).

RESULTS AND DISCUSSION

This study demonstrated the possibility of using aluminium composite panel as a replacement for silicon glass panel in the construction of catfish incubator. The maximum load-bearing limit (Breaking strength) of the silicon glass plate and aluminium composite (board) is presented in Figure 1. There was a significant difference ($p < 0.05$) in the load-bearing limits between the silicon glass panel and the aluminium composite panel. The load-bearing limit of the Glass panel was significantly higher ($p < 0.05$) than the aluminium composite panel. The failure of a material relative to flexural strength is determined by the stress that first attains a limiting value (Sharma and Bhattacharya, 2021). The flexural strength of Aluminium composite panel in this study was inferior to that of the silicon glass panel. The low flexural strength recorded in this study conformed to the opinion of Sharma and Bhattacharya (2021) that Aluminium composite made from Rice husk are better than those made from Polypropylene-based core. The comparably low flexural strength in Aluminium composite panel relative to silica glass panel in this study may be attributed to reduction in the binding matrix of polypropylene which form the core of the composite (Sundarababu *et al.*, 2021).

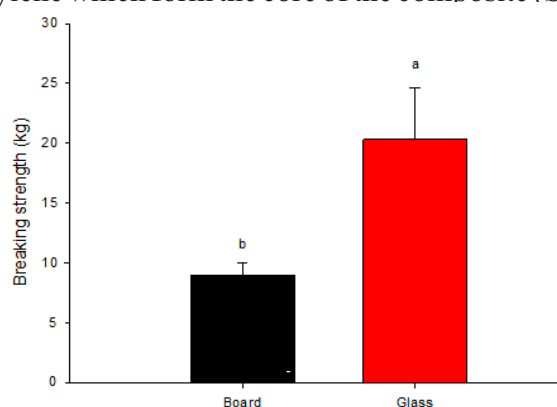


Figure 1: The Load-bearing Limit (Breaking strength) of Aluminium Composite (board) and Silicon Glass. The Load-bearing Limit of Glass was significantly higher ($p < 0.05$) than the board.

The breakability of the SGP and ACP is presented in Figure 2. The glass and aluminium composite panels were significantly influenced. The number of countable fragments in SGP was significantly higher ($p < 0.05$) than ACP. Fatigue damage – formation of micro-crack – occurs when a mechanical stress disturbs the coherence of lattice of a material self-organized structure (Mughrabi, 2009). In this study, a mechanical stress and a free-fall impact of the silicon glass panel on the concrete floor resulted in remarkable fatigue damage with numerous fragments relative to the Aluminium composite panel that did not show any visible structural crack

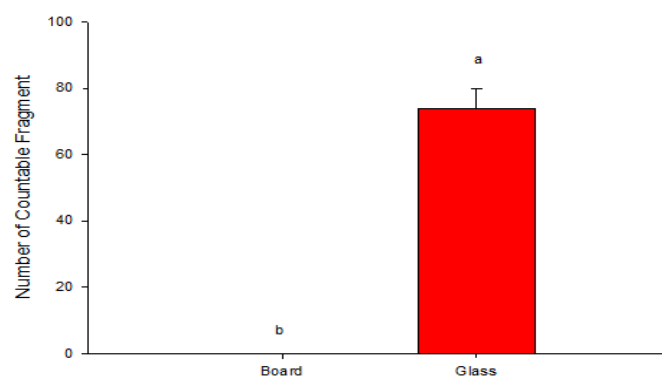


Figure 2: Fragility test between Aluminium composite material and Glass material. The number of fragments in glass material was significantly higher ($p < 0.05$) than the board.

The rate at which the silicon glass plate and aluminium composite adsorbed water is presented in Figure 3. The rate of adsorption of water by aluminium composite (board) did not significantly change ($p > 0.05$) over 96 hours as there was no significant difference ($p > 0.05$) in the volume of the plate. There was also no significant variability in the adsorption rate of the glass plate over a period of 96 hours. Catfish incubators always have contact with water during operation and materials used in the construction of incubator must be hydrophobic. This is important because the interaction of water with surface of material adversely affect their mechanical strength and fatigue life (Akkopru-Akugun, 2013). Hygroscopic materials generate hydrated layer making them lose their strength and durability under humid environment (Xue and Cai, 2024).

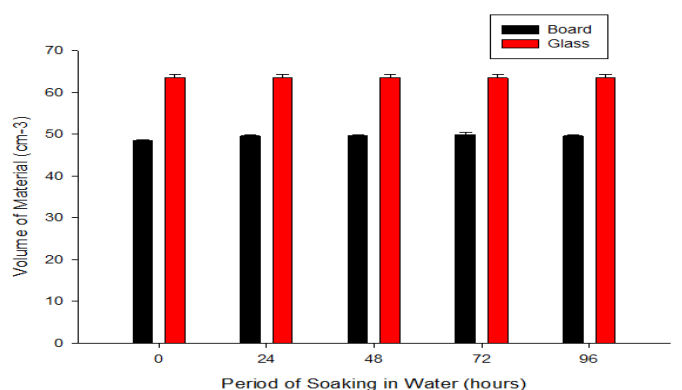


Figure 3: Water Adsorption Rate of Glass plate and Aluminium composite plate. There was no significant increase ($p > 0.05$) in the volume of the glass plate and Board plate over a period of 96 hours

In this study, similar to the silica glass panel, the water adsorption test showed that the aluminium composite panel was not hygroscopic. Sharma and Bhattacharya (2021) also recorded a negligible water adsorption in aluminum composite material with rice husk core. However, the report of Ferede (2020) revealed a significant change in the thickness of composite made from palm leaves, jute stick, sawdust and, plywood. The core used in the production of aluminium composite panel in this study was Polypropylene which may contribute to its non-hygroscopic characteristic. The water retention in aluminium trough and glass trough is presented in Figure 4. The water retention in aluminium trough and glass trough were not significantly influenced ($p > 0.05$).

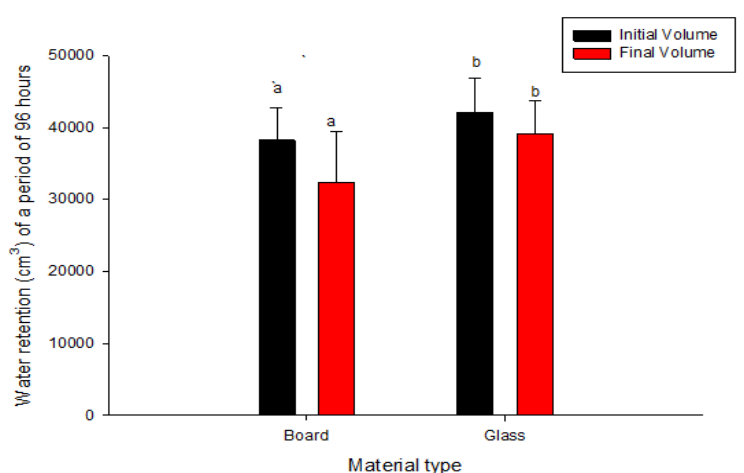


Figure 4: The porosity of Board and Glass over a period of 96 hours. In each category, there was no significant difference ($p < 0.05$) in the initial and final volume of water in the incubator.

In each category, there was no significant difference ($p < 0.05$) in the initial and final volume of water in the incubator over a period of 96 hours. An ideal trough for incubating catfish egg must retain water over an extensive period of time for the survival of fish hatchlings. High permeable materials have a weak water-tightness of liquid-retaining structure (Hoseini *et al.*, 2008) and are less durable (Miloud, 2005). The Aluminum composite panel used in this study is less permeable as the volume of water in the trough constructed with Aluminium composite panel did not change over a period of 96 hours

CONCLUSION

The findings of this study indicate that aluminum composite panels are less fragile compared to silicon glass panels, while both materials exhibit low porosity and reduced water absorption making them suitable for aquatic applications. However, the elastic limit of aluminum composite panels was found to be lower than that of glass, indicating a reduced load-bearing capacity. Despite this limitation, aluminum composite panels can serve as a viable alternative to conventional glass materials for constructing catfish incubators, particularly when structural reinforcement is incorporated to reduce wall flexing and maintain joint integrity under the internal pressure exerted by water.

Based on these findings, the use of aluminum composite panels in catfish incubator construction is recommended as a safer and more durable option, reducing the mechanical health hazards associated with glass fragility. Their comparable water resistance and structural adaptability make them suitable for aquaculture systems. Reinforcement should be considered to mitigate elasticity and improve long-term strength. Further research is recommended to evaluate the performance of aluminum composite-based incubators in hatching efficiency, seed viability, and their potential scalability in catfish nursery production.

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EFFECTS OF EXTRUSION PARAMETERS ON THE NUTRITIONAL COMPOSITION AND AMINO ACIDS PROFILE OF READY-TO-EAT EXTRUDED SNACKS FROM OPTIMIZED FLOUR BLENDS OF PEARL MILLET, SOYCAKE AND RICE BRAN

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ABSTRACT

Consumers have developed growing interest in healthy ready-to-eat snacks due to the alarming rate of diet-related diseases. Therefore, this study aims to investigate the effects of different feed moisture contents (20% and 26%) and barrel temperatures (120 °C and 140 °C) on the proximate composition and amino acids profile of extruded snacks produced from optimized flour blends of pearl millet, soycake and rice bran. Preliminary study was carried out on the raw materials (pearl millet, soycake and rice bran) and effect of different mixing ratios of the raw materials on the proximate compositions was determined. Optimal mixture design of response surface methodology was used to analyse the preliminary data and get the optimum flour blend (50.00% pearl millet: 32.36% soycake: 17.64% rice bran) that was used for the production of the extruded snacks at different feed moisture contents and barrel temperatures while a commercial extruded snack was used as the reference sample. The proximate compositions especially protein, fibre and fat as well as the essential amino acids of the formulated extruded snacks were significantly ($p < 0.05$) higher than that of the reference sample. The protein, fibre and fat contents of the extruded snacks reduced with increase in barrel temperature. The extruded snack produced at 26% feed moisture content and 120 °C barrel temperature ($M_{26T_{120}}$) demonstrated improved nutritional composition and essential amino acids. Hence, could serve as process technology and functional food that can offer both nutritional and health benefits to modulate protein-energy malnutrition, high blood glucose levels, and reduce bad cholesterol.

Keywords: Extruded snacks, Optimized flour blends, Proximate composition, Amino acids profile, Extrusion parameters

INTRODUCTION

Extruded snacks are ready-to-eat (RTE) food products which are popular due to their convenience. low moisture content and attractiveness (Tyl *et al.*, 2021). Extrusion cooking is a high-temperature, short-time (HTST) process in which food materials are moistened and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear and forced through a die orifice thereby resulting in molecular transformation and chemical reactions (Mohammed *et al.*, 2024). Extrusion technology has been applied for production of various snacks, pasta, breakfast cereals, pet foods, supplementary foods and other textured foods (Choton *et al.*, 2020). Extruded snacks are usually high in calories and fat with low contents of protein and fiber, and are therefore considered as unhealthy food to consumers (Tyl *et al.*, 2021). Hence, the need to meet consumers' increasing demand for healthy food by developing a product with improved nutritional compositions.

Pearl millet (*Pennisetum glaucum*) is one of the important gluten-free cereal crops in the world, rich in nutrients and natural antioxidants capable of promoting good health (Bello *et al.*, 2022).

Soycake is a by-product during the solvent extraction of soybean oil and it is a cheap source of protein that can complement low protein in starchy staples in many developing countries (Oluwajuyitan *et al.*, 2021). Rice bran is a by-product during rice milling process, rich in protein, fat, dietary fibers, amino acids, vitamins, minerals and phytochemicals with beneficial health effects (Yadav *et al.*, 2024).

Researchers have reported on the effect of extrusion parameters on the quality of extruded snacks produced from various food crops (Sanusi *et al.*, 2023; Mohammed *et al.*, 2024; Ajala *et al.*, 2025). However, there is sparse literature on the effect of extrusion parameters on nutritional composition and amino acids profile of extruded snacks from flour blend of pearl millet, soycake and rice bran. Therefore, this study aimed to

determine the proximate composition and amino acids profile of extruded snacks from optimized flour blend of pearl millet, soycake and rice bran.

MATERIALS AND METHODS

Sources of materials

Pearl millet was obtained from Oba market, Akure, Nigeria and authenticated at the Department of Crop, Soil and Pest Management, Federal University of Technology Akure, Nigeria. Soycake and rice bran were obtained from Premium Edible Oil Products Limited, Ibadan, Nigeria and Victory mill, Akure, Nigeria respectively. Other ingredients (stevia, Vegetable oil, salt) were purchased from OUK supermarket and Oba market, Akure, Nigeria. Chemicals and reagents of analytical grade were used.

Preparation and formulation of optimized flour blend

Pearl millet was processed into flour using the standard method reported by Awolu (2017), soycake and rice bran were processed into flour using the standard methods described by Oluwajuyitan *et al.* (2021). Preliminary study was carried out to determine the proximate compositions of the raw materials (pearl millet, soycake and rice bran). Runs (16) were generated from the blends of the raw materials using optimal mixture design of response surface methodology (Design Expert 8.0.3.1., Stat-Ease Inc., Minneapolis, USA), proximate compositions of the runs were determined and optimized to obtain the optimum flour blend (50.00% pearl millet: 32.36% soycake: 17.64% rice bran) that was used for production of the extruded snacks at different feed moisture contents (20% and 26%) and barrel temperatures (120 °C and 140 °C).

Preparation of extruded snacks

A co-rotating twin-screw extruder (Model: XTS56-Xtrutech, Jinan KeySong Machinery Co. Ltd., Gaoxin District, Jinan, China) was used to produce the extruded snacks following the procedure reported by Ajala *et al.* (2025). Optimized flour blend (6 kg), stevia (30 g), salt (60 g) and vegetable oil (600 ml) were homogenized using a mixer (Sokany Stand Mixer, Model: Cx-6612, China), pre-conditioned to the selected feed moisture contents (20% and 26%) with calculated amount of portable water using the hydration method reported by Mohammed *et al.* (2024) and allowed to hydrate uniformly. The first and second heating zones of the extruder were set at 80 °C and 100 °C respectively while the third heating zone was set at varied temperatures (120 °C and 140 °C). The resulting dough was fed into the extruder at a constant speed of 120 rpm through the hopper and conveyed at a fixed screw speed of 300 rpm to the barrel for the extrusion cooking to take place. The cooked sample passed through the die orifice of 5 mm, was cut through the cutter at a speed of 1500 rpm and collected on a clean stainless-steel tray. The extruded snacks were dried in a cabinet dryer at 60 °C for 4 h, cooled and sealed in a zip-lock polypropylene film and packed in an airtight container and stored at ambient temperature for further analysis while a commercial extruded snack was used as the reference sample.

Determination of proximate composition

Proximate compositions (moisture, crude fat, crude protein, crude fibre and ash contents) of the extruded snacks were determined according to the standard method described by Association of Official Analytical Chemists (AOAC, 2012). Carbohydrate content was calculated by difference and energy value was calculated using the Atwater factor as reported by Arogundade *et al.* (2023).

Determination of amino acids profile

The extruded snacks were digested with 6 M HCl for 24 h and the amino acid profiles were determined using the HPLC Pico-Tag system as described by Bidlingmeyer *et al.* (1984). The cysteine and methionine contents were determined after performic acid oxidation (Gehrke *et al.*, 1985) while the tryptophan content was determined after alkaline hydrolysis (Landry and Delhay, 1992).

Statistical analysis

Data generated from the analyses were subjected to one-way analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS) version 25.0. Means were separated using Duncan Multiple Range Test at $p < 0.05$.

RESULTS AND DISCUSSION

Proximate compositions of the extruded snacks from optimized flour blend

Proximate composition and the energy value of the extruded snacks are presented in Table 1. Moisture content of the snacks ranged from 2.15% in $M_{20}T_{140}$ to 5.96 in CES. Among the formulated extruded snacks, $M_{26}T_{120}$ produced at higher feed moisture and lower barrel temperature had the highest moisture content and this agrees with the report of Mohammed *et al.* (2024) that produced extruded snacks from finger millet, sweet potato and soybean composite flour at 20-26% feed moisture and 90-130 °C. Moreover, the range of moisture content observed in this study is lower than 10% and this will help to increase the shelf life of the snacks. Ash content which is an indication of the mineral content ranged from 2.03% in $M_{26}T_{120}$ to 5.68% in $M_{20}T_{120}$. There was no discernible observation on the effect of extrusion parameters on the ash contents of the snacks and this corroborates with the report of Alefew *et al.* (2024) that produced extruded snacks from high quality rice, lupin and pumpkin. Protein contents of the extruded snacks ranged from 12.48% in CES to 25.81% in $M_{26}T_{120}$. Reduction in protein content at higher temperature may be due to protein denaturation since peptide bonds are hydrolyzed and molecular structure of protein changes during extrusion (Singh *et al.*, 2019). However, the protein contents of the formulated extruded snacks are significantly ($p < 0.05$) higher than that of the reference sample. Therefore, the formulated snacks can be effectively used to address the problem of protein-energy malnutrition in the developing countries including Nigeria where animal protein consumption is limited due to high cost. Fibre content of the snacks ranged from 1.69% in CES to 9.67% in $M_{26}T_{120}$. Fibre-rich foods have been reported to be beneficial to health due to their ability to reduce blood sugar levels, lower cholesterol levels and improve glucose tolerance as well as digestive health (Ajala *et al.*, 2025). Hence, high fibre contents of the formulated snacks will help to improve health. Fat contents of the snacks ranged from 6.87% in CES to 12.65% in $M_{26}T_{120}$. High fat contents of the formulated snacks may be due to the inclusion of rice bran in the flour blend. However, rice bran oil has been reported to be rich in essential fatty acids of health benefits that can help to reduce blood levels of total cholesterol, low-density lipoprotein cholesterol and triglycerides in adults (Alves *et al.*, 2023).

Table 1: Proximate composition (%) and energy value (Kcal/100g) of extruded snacks from optimized flour blend of pearl millet, soycake and rice bran

Sample	Moisture content	Ash content	Protein content	Crude fibre	Fat content	Carbohydrate content	Energy value
$M_{20}T_{120}$	2.39±0.02 ^d	5.68±0.04 ^a	23.52±0.89 ^b	8.10±0.05 ^b	12.65±0.28 ^a	47.67±0.56 ^d	398.57±1.20 ^a
$M_{20}T_{140}$	2.15±0.03 ^e	5.34±0.13 ^b	22.91±0.14 ^b	6.65±0.54 ^c	10.56±0.91 ^b	52.40±1.31 ^c	396.23±2.58 ^a
$M_{26}T_{120}$	3.25±0.04 ^b	2.03±0.01 ^c	25.81±0.47 ^a	9.67±0.32 ^a	11.23±0.48 ^b	48.01±0.35 ^d	396.33±2.19 ^a
$M_{26}T_{140}$	2.69±0.03 ^c	5.15±0.03 ^c	20.02±1.00 ^c	7.80±0.29 ^b	9.16±0.57 ^c	55.19±0.52 ^b	383.24±1.91 ^b
CES	5.96±0.04 ^a	4.60±0.03 ^d	12.48±0.15 ^d	1.69±0.01 ^d	6.87±1.11 ^d	68.41±1.21 ^a	385.37±5.57 ^b

Mean±standard deviation with different superscripts within the same column are significantly different ($p < 0.05$)

$M_{20}T_{120}$ = Snacks extruded at 20% FM and 120 °C BT; $M_{20}T_{140}$ = Snacks extruded at 20% FM and 140 °C BT; $M_{26}T_{120}$ = Snacks extruded at 26% FM and 120 °C BT; $M_{26}T_{140}$ = Snacks extruded at 26% FM and 140 °C BT; CES = Commercial Extruded Snacks; FM = Feed moisture; BT = Barrel Temperature

Amino acids profile of the extruded snacks from optimized flour blend

The amino acids profiles of the extruded snacks from optimized flour blend of pearl millet, soycake and rice bran are presented in Table 2. The total essential amino acids (TEAA) of the extruded snacks ranged from 37.59 g/100g protein in CES (Reference sample) to 38.43 g/100g protein in $M_{26}T_{120}$ while the total non-essential amino acids ranged from 61.57 g/100g protein in $M_{26}T_{120}$ to 62.41 g/100g protein in CES. It was observed that the essential amino acids which cannot be synthesized by the body but must be supplied by food consumed were higher in the formulated snacks than CES and the same trend was observed in the protein content of the snacks. Hence, this agrees with the report of Chaikyul *et al.* (2009) that the raw material protein content had a significant impact on product qualities and this may be attributed to the inclusion of soycake flour in the formulated extruded snacks. Glutamic and aspartic acids were the most abundant amino acids in the extruded snacks. This agrees with the report of Omwamba and Mahungu (2014) who developed protein-rich ready-to-eat extruded snacks from composite blend of rice, sorghum and soybean flour.

Glutamic acid is a non-essential amino acid, which helps to regulate cellular metabolism, enhance heartbeat functions, and reduce the risk of coronary heart diseases (Lee *et al.*, 2023). Aspartic acid helps to enhance amino acid secretion, breakdown of toxic ammonia within cells, and promotes signal transmission in the brain (Maksimovich *et al.*, 2023). Hence, the predominance of both amino acids is an indication that they may promote good health. Lower lysine contents were obtained in extruded snacks produced at higher temperature and this loss in lysine may be due to Maillard reaction that occurs between the free amino groups of protein and carbonyl groups of reducing sugars (Omwamba and Mahungu, 2014). Low-moisture condition and high temperature have been reported to promote Maillard reaction thereby causing significant loss in lysine (Singh *et al.*, 2007). Nevertheless, lysine contents of the formulated extruded snacks were higher (5.36-5.39 g/100g protein) than that of the reference sample (3.27 g/100g protein). Branched chain amino acids (BCAA) of the extruded snacks ranged from 18.17 g/100g protein in M₂₆T₁₄₀ to 20.77 g/100g protein in CES. Branched chain amino acids (BCAAs) play important roles in the body such as insulin secretion to prevent type-2 diabetes (Vanweert *et al.*, 2022), improved serum albumin concentration in the prevention of liver cirrhosis, thereby improving liver function and quality of life (Salma *et al.*, 2022). Hydrophobic amino acids (HAA) ranged from 42.09 g/100g protein in M₂₀T₁₂₀ to 49.58 g/100g protein in CES. Among the formulated snacks, M₂₆T₁₂₀ had the highest HAA. Higher level of HAA implies better potential ability to ameliorate oxidative stress and cardiovascular diseases (Oluwajuyitan *et al.*, 2025).

Table 2: Amino acids profile (g/100g protein) of extruded snacks from optimized flour blend of pearl millet, soycake and rice bran

EAA	M ₂₀ T ₁₂₀	M ₂₀ T ₁₄₀	M ₂₆ T ₁₂₀	M ₂₆ T ₁₄₀	CES
Essential Amino acids					
Valine	5.07	5.12	5.15	5.07	4.61
Threonine	4.01	4.04	4.04	4.02	3.55
Isoleucine	4.73	4.70	4.70	4.75	3.82
Leucine	8.41	8.43	8.50	8.36	12.34
Methionine	1.77	1.68	1.68	1.70	1.85
Phenylalanine	5.23	5.23	5.31	5.26	4.85
Lysine	5.39	5.36	5.38	5.36	3.27
Histidine	2.27	2.25	2.31	2.20	2.55
Tryptophan	1.25	1.40	1.37	1.37	0.75
Non-Essential Amino acids					
Alanine	5.27	5.31	5.26	5.26	6.99
Aspartic acid	11.32	11.50	11.25	11.35	7.77
Glutamic acid	19.12	18.88	19.01	19.02	20.99
Serine	5.15	5.28	5.20	5.20	4.83
Glycine	4.10	4.08	4.20	4.14	3.39
Proline	5.36	5.27	5.41	5.35	8.81
Arginine	6.55	6.48	6.41	6.57	4.07
Tyrosine	3.53	3.52	3.35	3.56	3.34
Cysteine	1.47	1.46	1.47	1.47	2.22
TEAA	38.13	38.21	38.43	38.09	37.59
TNEAA	61.87	61.79	61.57	61.91	62.41
HAA	42.09	42.13	42.21	42.14	49.58
SCAA	3.25	3.14	3.15	3.18	4.07
BCAA	18.20	18.25	18.35	18.17	20.77
AAA	10.01	10.16	10.03	10.19	8.94

M₂₀T₁₂₀ = Snacks extruded at 20% FM and 120 °C BT; M₂₀T₁₄₀ = Snacks extruded at 20% FM and 140 °C BT; M₂₆T₁₂₀ = Snacks extruded at 26% FM and 120 °C BT; M₂₆T₁₄₀ = Snacks extruded at 26% FM and 140 °C BT; CES = Commercial Extruded Snacks; FM = Feed moisture; BT = Barrel Temperature

TEAA = Total Essential Amino Acids; TNEAA= Total Non-Essential Amino Acids; HAA= Hydrophobic Amino Acids (Alanine, Valine, Leucine, Isoleucine, Tyrosine, Phenylalanine, Tryptophan, Proline, Methionine, Cysteine); SCAA = Sulphur-containing Amino Acids (Methionine+Cysteine); BCAA = Branched Chain Amino Acids (Valine, Leucine, Isoleucine); AAA=Aromatic Amino Acids (Phenylalanine, Tryptophan, Tyrosine)

Aromatic amino acids (valine, leucine and isoleucine) of the formulated snacks were higher than that of the control and ranged from 8.94 g/100g protein in CES to 10.19 g/100g protein in M₂₆T₁₄₀. Aromatic amino acids contribute to peptide antioxidant activity by quenching reactive oxygen species (Parthasarathy *et al.*, 2018). Sulphur containing amino acids (methionine and cysteine) ranged from 3.14 g/100g protein in M₂₀T₁₄₀ to 4.07 g/100g protein in CES. Sample M₂₀T₁₂₀ had the higher Sulphur containing amino acids (SCAA) among the formulated snacks. SCAA plays an important role in maintaining cellular system integrity by detoxifying harmful compounds and influencing cellular redox reactions through their role as structural units for the synthesis of glutathione and N-acetyl cysteine, which are strong scavengers of reactive oxygen species (Oluwajuyitan *et al.*, 2025). Arginine contents of the formulated extruded snacks were higher (6.41-6.57 g/100g protein) than that of the reference sample (4.07 g/100g protein). Arginine is a vital amino acid that helps in production of nitric oxide, a vasodilator that can reduce the risk of high blood pressure (Apte *et al.*, 2024; Oyovwi and Atere, 2024). Therefore, the formulated extruded snacks may help to improve cardiovascular health.

CONCLUSION

This study shows that variation in feed moisture content and barrel temperature can affect the proximate and amino acids compositions of ready-to-eat extruded snacks developed from optimized flour blend of pearl millet, soy cake and rice bran. The protein, fibre and ash contents of the formulated extruded snacks are significantly ($p < 0.05$) higher than that of the reference sample. The extruded snack produced at higher feed moisture content (26%) and lower barrel temperature (120 °C) i.e M₂₆T₁₂₀ is the extruded snacks with improved nutritional compositions which could be a healthy option for every age group to modulate protein-energy malnutrition, high blood glucose levels and high bad cholesterol. The outcome of this study could also assist the food industry in the development of functional snacks offering both nutritional and health benefits.

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MICROBIAL AND CHEMICAL EVALUATION OF OIL PALM (*ELAEIS GUINEENSIS*) FRUIT EXTRACT (“BANGA”) STORED IN ALUMINIUM POUCHES IN NIGERIA

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ABSTRACT

This study investigated the microbial quality and chemical stability of oil palm (*Elaeis guineensis*) fruit extract (“Banga”) stored in aluminum pouches under ambient Nigerian conditions for twelve months. Microbial parameters (total bacteria, fungi, coliforms, and *E. coli*) and chemical indices (moisture content, free fatty acid [FFA], and peroxide value [PV]) were evaluated from 0 to 12 months. Results showed that bacterial counts increased from 2.08 log₁₀ CFU/g at baseline to 4.00 log₁₀ CFU/g after 12 months, while fungi appeared after six months (2.0–2.5 log₁₀ CFU/g). Coliforms and *E. coli* were not detected throughout storage. Moisture content increased significantly ($p < 0.05$) from 70.2% to 76.0%. FFA rose from 3.1% to 10.9%, exceeding Codex and trade specifications (~5%), while PV increased to 9.55 meq O₂/kg, nearing the ~10 meq O₂/kg limit associated with rancidity. Although microbial loads remained within acceptable limits for ready-to-eat foods (<10⁵ CFU/g), the progressive rise in FFA and PV indicated hydrolytic and oxidative deterioration during storage. Aluminum pouches provided partial protection against contamination, but chemical quality declined substantially by the 12th month. These findings highlight the need for optimized storage strategies to extend the shelf life of Banga extract while preserving its safety and sensory quality.

Keywords: Banga extract, palm fruit, microbial load, free fatty acids, peroxide value

INTRODUCTION

Palm fruit extract, locally known as Banga, is one of the most important indigenous food commodities derived from the oil palm (*Elaeis guineensis*). It serves as a primary base for traditional soups widely consumed across Nigeria and West Africa. Beyond its cultural significance, palm fruit extract is nutritionally valuable as a source of carotenoids, vitamins A and E, and essential fatty acids (Sundram *et al.*, 2003). Nigeria is one of the leading producers of oil palm in Africa, with palm oil and its by-products contributing substantially to rural livelihoods, food security, and the economy (FAO, 2020). The quality and safety of palm fruit extract during storage are critical, given its high lipid content and susceptibility to microbial contamination. Lipid-rich foods undergo oxidative and hydrolytic rancidity, leading to increased peroxide values (PV) and free fatty acid (FFA) levels, which negatively affect taste, aroma, and consumer acceptability (Nawar, 1996). Similarly, microbial contamination of stored foods remains a major public health concern in Nigeria, with fungi such as *Aspergillus* and *Penicillium* posing risks of mycotoxin production (Adebayo-Tayo & Samuel, 2009).

Previous studies have documented the microbial and chemical changes in palm oil (Tagoe *et al.*, 2012; Ekwunye, 2006), but limited information exists specifically on palm fruit extract (Banga), especially under long-term storage conditions. This gap is significant because the extract is often sold in open markets where vendors store it for extended periods without refrigeration, exposing it to microbial contamination and oxidative deterioration.

Therefore, this study was undertaken to determine the microbial load, moisture content, free fatty acid content, and peroxide value of banga for 12 months. Findings from this research will provide insights into safe

storage periods, potential health risks, and necessary interventions to safeguard consumers.

METHODOLOGY

Sample collection and preparation

Fresh palm fruit extract (Banga) was purchased from local processors in Lagos, Nigeria. Samples were aseptically collected in sterile plastic containers and stored at ambient conditions (28–32 °C) for twelve months. Analyses were conducted at 0–12 months of storage.

Microbial analysis

Microbial quality was assessed using the pour plate technique as described by Aruwa and Akinyosoye (2015) with slight modifications. One gram of each sample was homogenized in 9 mL sterile distilled water to obtain the initial suspension, followed by four-fold serial dilution. Aliquots (1 mL) of 10^{-2} and 10^{-4} dilutions were inoculated into sterile Petri dishes and overlaid with specific media: nutrient agar (NA) for total bacterial counts, potato dextrose agar (PDA) for fungi, MacConkey agar for coliforms, and eosin methylene blue (EMB) agar for *Escherichia coli*. Inoculated plates were incubated at 37 °C for 18–24 hours (bacteria) and 25 °C for 48–72 hours (fungi). Colony-forming units (CFU) were enumerated and expressed as log CFU/g. Pure isolates were obtained by sub-culturing representative colonies.

Proximate composition and chemical analysis

Free fatty acid (FFA): Determined by titration with 0.1 M NaOH following MPOB (2005) standards.

Peroxide value (PV): Assessed using AOAC Official Method 965.33 (AOAC, 2000). Results were expressed in meq O₂/kg.

Moisture content: Determined gravimetrically according to AOAC Method 925.10 (AOAC, 2000) by oven-drying samples at 105 °C to constant weight.

Statistical analysis

All analyses were carried out in triplicate. Data were analyzed using one-way ANOVA, and means were compared using LSD at $p < 0.05$. Results were expressed as mean $\pm$ standard deviation.

RESULTS AND DISCUSSION

Microbial quality

Table 1 shows the microbial load and chemical indices of palm fruit extract during storage. Bacterial counts increased progressively, from 2.08 log CFU/g at 0 month to 4.00 log CFU/g at 12 months. Fungal counts were absent during the first 3 months but appeared by the 6th month, reaching 2.50 log CFU/g at 12 months. The absence of coliforms and *E. coli* throughout the storage period suggests good initial hygiene during processing, although increases in total viable counts indicate microbial proliferation over time. According to ICMSF (2011), acceptable limits for total bacterial counts in ready-to-eat foods are <4 log CFU/g. By the 12th month, bacterial counts in this study approached this limit, suggesting a risk of spoilage and potential health hazards if consumed after prolonged storage. Similar findings were reported by Tagoe *et al.* (2012), who observed increasing microbial loads in palm oil stored under ambient conditions.

Chemical composition

Moisture content increased significantly ($p < 0.05$) from 70.20% to 76.00% during storage, which likely facilitated microbial growth. Elevated moisture in lipid-based foods has been associated with higher susceptibility to spoilage (Ekwenye, 2006).

FFA levels rose sharply from 3.10% to 10.90% after 12 months, exceeding the Codex Alimentarius limit of 5% for edible palm oil (Codex, 1999). High FFA values indicate hydrolytic rancidity, which reduces consumer acceptability.

Peroxide values also increased significantly, from 2.05 to 9.55 meq/kg, surpassing the Codex maximum of 5 meq/kg (Codex, 1999). Elevated PV indicates oxidative rancidity and the formation of peroxides, which are

precursors to secondary oxidation products that adversely affect flavor and may pose health risks.

These results align with the findings of Orji *et al.* (2006), who reported increases in FFA and PV in palm oil during prolonged storage. The combination of rising microbial load, FFA, and PV underscores the limited shelf-life of palm fruit extract under ambient conditions.

Table 1: Microbial load (log CFU/g) and Chemical composition (%) of palm fruit extract (Banga) stored for 12 months

Parameter	0 month	3 months	6 months	9 months	12 months
Bacteria	2.08 ± 0.06 ^a	2.32 ± 1.00 ^a	2.62 ± 1.53 ^a	3.90 ± 1.00 ^a	4.00 ± 2.52 ^a
Fungi	NG	NG	2.04 ± 3.06 ^a	2.30 ± 0.58 ^a	2.50 ± 1.53 ^a
Coliform	NG	NG	NG	NG	NG
<i>E. Coli</i>	NG	NG	NG	NG	NG
Moisture (%)	70.20±0.03 ^a	71.10±0.12 ^a	73.29±0.02 ^b	74.25±0.02 ^b	76.00±0.07 ^b
FFA (%)	3.10±0.02 ^a	4.68±0.30 ^b	9.10±0.02 ^b	9.75±0.09 ^b	10.90±0.33 ^b
Peroxide (meqO ₂ /kg)	2.05±0.01 ^a	2.80±0.15 ^a	6.33±0.20 ^b	9.10±0.01 ^a	9.55 ± 0.10 ^a

Values are means ± SD (n=3). Different superscript letters in the same row indicate significant differences at $p < 0.05$ (ANOVA followed by LSD)

NG = “No growth detected”

CFU/g = “Coliform-forming units per gram”

CONCLUSION

This study demonstrated that palm fruit extract (Banga) undergoes significant microbial and chemical deterioration during twelve months of storage. Bacterial and fungal counts increased over time, while moisture content, FFA, and PV rose beyond acceptable limits by the 6th to 12th month. These changes compromise both the safety and quality of the product, highlighting the need for improved preservation and timely consumption.

Recommendations

1. Palm fruit extract should ideally be consumed within three months of preparation to ensure safety and quality.
2. Improved preservation methods (e.g., refrigeration, vacuum packaging, pasteurization) should be introduced to extend shelf-life.
3. Consumer awareness campaigns should educate households and vendors about the risks of prolonged storage.
4. Policy frameworks should be strengthened to enforce microbial and chemical safety standards in Nigerian markets.

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EFFECT OF *OCIMUM GRATISSIMUM* CRUDE EXTRACT ON THE MICROBIAL LOAD AND KEEPING QUALITY OF FISH ENRICHED CASSAVA AND PLANTAIN CAKE.

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ABSTRACT

Cakes baked from cassava and plantain paste enriched with fish and fortified with *Ocimum gratissimum* extract and *Vernonia amygdalina* extract was evaluated for antimicrobial and keeping qualities potentials on snacks. All ingredients were purchased from the local market in Akungba community and they were thoroughly processed, prepared and mixed into dough and baked in the oven for 40 - 45 minutes to produce the snack. Snack analysis for microbial and keeping quality was carried out using NA agar for bacteria and PDA for fungi using standard methods. Five organisms namely *Staphylococcus aureus*, *Escherichia coli*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, were observed in the study. Bacteria and fungi count was significantly different between the samples, a total of 33 organisms were isolated and identified using nutrient agar, macConkey agar, and potato dextrose agar. Addition of plant extracts to snacks has effect on the microbial and shelf life of the product.

Keywords:

INTRODUCTION

Snack foods are popular form of refreshment among consumers (Hein et al., 1998), and they provide convenience and manageable portion while also fulfilling short term hunger (Tettweiler, 1991). Generally, street foods whether of plant or animal origin are very popular in Nigeria as in many developing countries (Sobukola et al., 2008). To improve dietary quality in the face of the current worldwide epidemics of obesity and chronic non communicable diseases, there is need to increase the consumption of healthy snacks in different forms. Development of an entirely new snacks or replacement of some common ingredients with new substitutes in others is important for the snack industry in order to ensure consumers satisfaction. Cassava is a major staple food in the developing world, providing a basic diet for over half a billion people, Cassava can be used as a substitute for many flours in the bakery and confectionary world as well as in the production of snacks (Falade and Akingbala, 2010), Because of its varied functionality, its use in food, feed and chemical industries will be on the increase.

Plantain (*Musa paradisiaca*) is traditionally grown in West Africa for food and used as part of local staple diets or processed into more durable products such as flour that can be stored for later use (Dadzie, 1995). Plantain is a major source of energy for millions of people in these regions (Asiedu et al., 1992). plantain peel is rich in soluble fibre and the flour contain resistant starch (Awolu and Olajide 2015). Addition of fish into snack formulation can be potential alternative for food industry application since it utilizes natural resources, contains high protein content as well as help to reduce pollution caused by fish waste. Fish is one of the most important sources of animal protein for the maintenance of a healthy body, Fish is an essential source of high-quality protein (Ohen & Abang, 2007), providing about 16% of animal protein consumed by the world's population. It provides 40% of the dietary intake of animal protein of the average Nigerian (FDF, 1997). Snacks, cookies as convenient food, its inclusion in the diet of Nigerians has increased appreciably, particularly among children and during festivities. Its acceptability as snacks cut across cultural and sociodemographic boundaries. Considering the health benefits of benefits, its incorporation as composite blend in the preparation of cake may help in enhancing the nutritional and health status of consumers, reduce total dependence on wheat flour and incidence of certain chronic non-communicable diseases.

MATERIALS AND METHODS

Sample collection

All materials used for the preparation of this snack were gotten from Ibaka local market in Akungba community.

Sample preparation

All items to be used for production were brought to the laboratory, thoroughly washed in a running water from

the tap and sterilize to prevent contamination.

Unripe plantain obtained from the market were cut into small pieces and then oven dried at a temperature of 25°C for 20 hours. The dried plantain was milled using a kitchen miller to produce a flour. The scent leaf and bitter leaf were thoroughly washed in running water to remove dirt and drained in a sieve to remove excess water after which it was squeezed to extract the juices. A pinch of salt was also added to the extracted juice. The fish were washed thoroughly under a running water supply, degutted, cleaned and cut into small pieces. There after, they were left to cook boil in water for 10 minutes and allowed to steam. After steaming, they were removed and allowed to cool. The fish was deboned, blended using a kitchen blender (heavy duty blender silver crest sc - 1589) to form a paste or slurry and kept aside. The groundnuts were carefully picked to remove dirt and burnt ones using a sieve. Using kitchen blender, they were ground into powder. After all the ingredients had been blended and milled, they were mixed thoroughly in appropriate proportions using a kitchen blender (heavy duty blender silver crest sc - 1589) to make a dough and portioned into 9-10, 15cm (30grams) baking pan. The baking pan was rubbed with bleached cooking oil and the thoroughly mixed ingredients were placed in the baking pan after it had been greased with bleached cooking oil.

Table 1. Recipe for production of cake from plantain flour blends.

Ingredients.	Sample A	Sample B	Sample C	Sample D
Plantain flour. (g)	2500	2500	2500	2500
Groundnut. (g)	600	600	600	600
Fish. (g)	879	879	879	879
Ginger. (g)	5	5	5	5
Garlic. (g)	5	5	5	5
Bitter leaf extract. (ml)	20		10	
Scent leaf extract. (ml)		30	25	
Baking powder. (g)	2.5	2.5	2.5	2.5

The oven was switched on and allowed to reach a temperature of 185°C. The portioned dough in the baking pan was placed into the oven and left to bake for 40 to 45 minutes. There was a periodic check after every 15-20minutes to avoid burning.

Fungal and bacteriological analysis of samples were all conducted on each sample.

Table 2. Recipe for production of cake from cassava flour blends.

Ingredients	Sample A	Sample B	Sample C	Sample D
Cassava flour. (g)	2500	2500	2500	2500
Groundnut. (g)	600	600	600	600
Fish. (g)	802	802	802	802
Ginger. (g)	5	5	5	5
Garlic. (g)	5	5	5	5
Bitter leaf extract. (ml)	20		10	
Scent leaf extract. (ml)		30	25	
Baking powder. (g)	2.5	2.5	2.5	2.5

RESULTS

Keys:

CON - cassava fortified with scent leaf (*ocimum gratissium*) extract on nutrient agar.

CBN - cassava fortified with bitter leaf (*vernonia amygdalina*) extract on nutrient agar.

CCN - cassava control on nutrient agar.

CMN - cassava fortified with mixture of scent leaf (*ocimum gratissium*) and bitter leaf (*vernonia amygdalina*) extracts on nutrient agar.

PON - plantain fortified with scent leaf (*ocimum gratissium*) extract on nutrient agar.

PBN - plantain fortified with bitter leaf (*vernonia amygdalina*) extract on nutrient agar.

PCN - plantain control on nutrient agar.

PMN - plantain fortified with mixture of scent leaf (*ocimum gratissium*) and bitter leaf (*vernonia amygdalina*) extracts on nutrient agar.

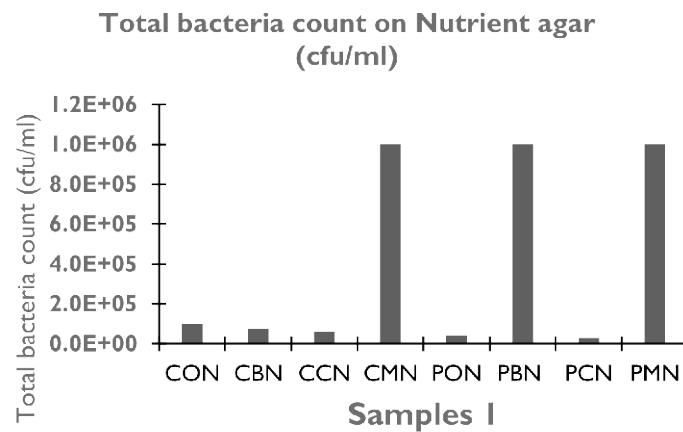


Fig 1: Total bacteria count of plantain and cassava fish enriched cake on nutrient agar

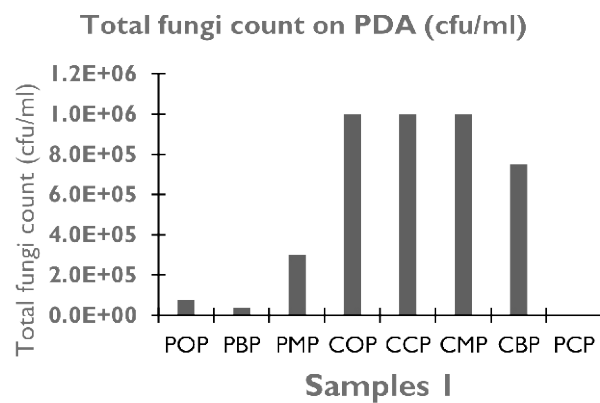


Fig 2: Total fungi counts of plantain and cassava fish enriched cake on potato dextrose agar.

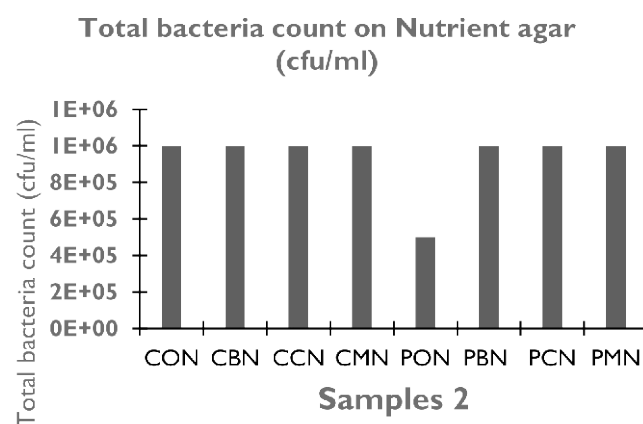


Fig 3: Total bacteria count of plantain and cassava fish enriched cake on nutrient agar.

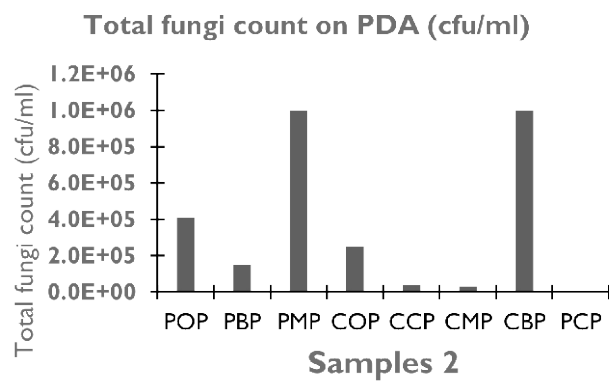


Fig. 4: Total fungi counts of cassava and plantain fish enriched cake on potato dextrose agar.

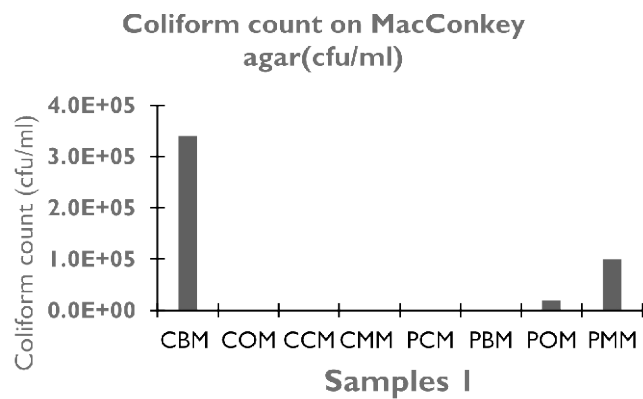


Fig. 5: Coliform count of cassava and plantain fish enriched cake on MacConkey agar.

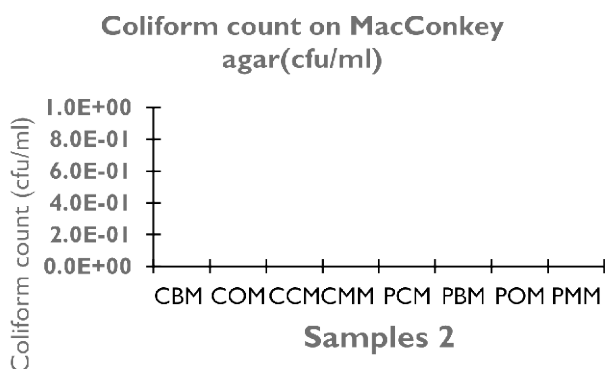


Fig. 6: Coliform count of cassava and plantain fish enriched cake on MacConkey agar.

DISCUSSION

The presence of bacterial contaminants like *Staphylococcus aureus* (22.5 5%), *Escherichia coli* (25%) in the samples analyzed could be traced to the fact that it is abundant in human body (skin, nails, hair). *Staphylococcus aureus* is normally found on the skin which can cause urinary tract infection. Similarly, *Bacillus subtilis* showed high percentage (10%), its presence can be traced to the fact that it is abundant spore former in soil, air and water, hence can easily be present in these foods. However, *Pseudomonas* specie was also detected. *Pseudomonas* species is known to be environmental contaminants and opportunistic pathogens, have been implicated in food borne disease, and are known to cause food spoilage that can lead to economic loss. The fungus specie *Saccharomyces cerevisiae* isolated can be traced to the fact that *S. cerevisiae* is the most important organism used in snacks making coliforms organism does not have significant level of contamination.

The bacterial count had lower load in the control samples, o. gratissium and a sample of v. amygdalina, while it is high in samples with mixtures of o. gratissium and v. amygdalina, the fungi count had lower load in plantain samples and high in cassava all in sample 1. Sample 2 had high bacterial load in all the samples except for an o. gratissium sample, while the fungi load was lower in control samples, mixtures, followed by o. gratissium samples and then a v. amygdalina sample. Oboh (2004) and Oforkansi et. al. (2003) reported that o. gratissium possesses antioxidants and antibacterial activity against common gram-positive and gram-negative organisms, the results of this microbial evaluation corroborate the observation of the authors. Ileogben et al. also Reported the antimicrobial potentials of ocimum gratissium and vernonia amygdalina crude extracts on sarotherodon galilaeus snacks, the *V. amygdalina* treated sample had a high bacterial load than samples treated with o. gratissium and the mixture. 30 member taste panelist were organised and trained to carry out organoleptic test on the snacks, snacks made of cassava fortified with *Ocimum gratissimum* was more accepted in taste and colour as the colour was brighter, sweeter and flavoured than other samples. Plantain sample fortified with both mixture had the least acceptance rante interms of it dark brownish colour.

CONCLUSION

In conclusion, the investigation showed that the 16 samples examined were contaminated with different types of bacteria and fungi and the V. amygdalina crude extract does not have significant on the bacterial load.

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SPATIAL VARIATION AND QUANTITATIVE ANALYSIS OF TREE SPECIES IN KEBBI STATE, NIGERIA

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ABSTRACT

This study evaluated the spatial and quantitative distribution of tree species in Kebbi State, Northwestern Nigeria, to inform biodiversity conservation and sustainable land use management. Data was gathered from 20 m x 20 m quadrats along transects at chosen locations using a stratified ecological survey. All trees having a diameter at breast height (DBH) ≥ 10 cm were counted and measured in each quadrat. Environmental indicators such as relative density, frequency, basal area, and IVI were estimated. Twenty seven (27) tree species were found in the study region. *Azadirachta indica* had the highest relative density (19.37%) and IVI (53.0), followed by *Acacia nilotica* (15.62%; 40.89) and *Adansonia digitata* (7.91%; 31.86). Other prominent species were *Ziziphus mauritiana* (8.13%; 23.77) and *Diospyros mespiliformis* (7.61%; 23.81). In contrast, commercially useful species like *Khaya senegalensis* (0.62%; IVI = 1.66) and *Azelaia africana* (0.72%; IVI = 2.76) were scarce and vulnerable to local extinction. Multipurpose species (*Diospyros mespiliformis*) were intentionally conserved near communities and farmlands, resulting in a clumped distribution pattern. The results show that ecological resilience, and human control impact vegetation dynamics in Kebbi State. While natural savanna species are ecologically important, such as *A. indica*. To preserve biodiversity and environmental services, enrichment planting and native species conservation are advocated.

Keywords: Tree; Species; ecological; Quantitative and Vegetation

INTRODUCTION

Trees are essential for sustaining ecological equilibrium, fostering biodiversity, and offering livelihoods for human communities in terrestrial ecosystem. In savanna ecosystems, particularly in Northwestern Nigeria, trees have a crucial role in enhancing soil fertility, regulating microclimates, and providing fuelwood, fodder, timber, and non-timber forest products (Chidumayo and Gumbo, 2010). Comprehending the distribution and prevalence of tree species is crucial for sustainable forest management, biodiversity preservation, and climate change mitigation initiatives (FAO, 2020).

The distribution and dominance of tree species are affected by several ecological and anthropogenic variables, including climatic conditions, soil types, land use patterns, and human activities such as grazing, agriculture, and logging (Bationo *et al.*, 2012; Bellefontaine, 2016). Quantitative ecological assessments employing measures such as species density, frequency, basal area, and importance value index (IVI) are essential for evaluating the floristic organisation and ecological state of vegetative communities (Kent, 2012). These metrics elucidate the relative contributions of species to ecosystem functionality, emphasising those that are ecologically predominant or scarce.

Research on vegetation dynamics in Nigeria has predominantly concentrated on the Guinea savanna and rainforest zones, whereas the Sudan and Sahel savannas, which experience more significant pressures from agriculture, deforestation, and desertification, have received little attention (Oke and Isichei, 2017). Kebbi State, situated in Northwestern Nigeria, serves as a transitional ecological zone between the Sudan and Sahel savannas, marked by dispersed tree species, seasonal precipitation, and escalating land degradation (Adedire *et al.*, 2020). However, a lack of quantitative data persists regarding tree species composition, distribution, and dominance in this region.

Performing a geographical and quantitative evaluation of tree species in Kebbi State is essential for establishing foundational data that can guide conservation strategies, ecosystem rehabilitation, and sustainable land management practices. This evaluation will yield data regarding ecologically significant and vulnerable species, hence informing policy actions for biodiversity management in the savanna landscapes of Northwestern Nigeria (Bello *et al.*, 2021).

This study aims to analyse the spatial patterns and quantitative metrics of tree species distribution and dominance in Kebbi State, Northwestern Nigeria. The project seeks to enhance comprehension of vegetation dynamics in the Sudan–Sahel ecological transition zone by combining ecological measurements with spatial evaluation, while providing practical insights for sustainable forest resources management.

METHODOLOGY

The research employed a descriptive ecological survey methodology, integrating field vegetation sampling with spatial analysis. Kebbi State was divided into ecological zones (Sahel, Sudan, and Sudan–Guinea transition), and representative locations were chosen for sampling.

Study Area

Location: Kebbi State, Northwestern Nigeria lies between latitudes 10°08'N–13°15'N and longitudes 3°00'E–6°02'E

Area: 36,800 km²

Climate: Characterized by an extended dry season (October–April) and a rainy season (May–September)

Flora: Categorized among the Sudan and Sahel savannas, with dispersed tree species such as *Acacia nilotica* and *Azadirachta indica*

The study employed a descriptive and quantitative ecological survey strategy, incorporating field-based vegetation sampling and spatial analysis utilizing Geographic Information Systems (GIS). This design facilitated the collection of quantitative data on tree species distribution, abundance, and dominance, while also permitting spatial visualization and study of ecological trends throughout Kebbi State.

Study population

The study population included all tree species located within the ecological zones of Kebbi State, encompassing: - Community lands; Agricultural fields; Forest reserves; Riparian zones

Sampling Design

A stratified random sampling method was utilized to guarantee representation of various ecological environments within the state. Kebbi State was divided into three ecological subzones:

1. Northern Sahel Savanna Zone
2. Central Sudan Savanna Zone
3. Southern Sudan-Guinea Transition Zone

Vegetation data were acquired by plot-based sampling. Quadrats measuring 20 m 20 m were positioned at 200 m intervals along each 1 km transect line. In each quadrat, all trees having a diameter at breast height (DBH) of 10 cm or greater were recognised, enumerated, and measured. Scientific identification was conducted with conventional floras, while local nomenclature was verified by community expertise.

The subsequent ecological criteria were assessed for each species:

Density (number of individuals per hectare)

$$\text{Density (D)} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}} \times 100$$

Frequency (occurrence across plots)

$$\text{Frequency (F)} = \frac{\text{Number of quadrats in which a species occurs}}{\text{Total number of quadrats studied}} \times 100$$

Basal Area (cross-sectional area at DBH)

$$\text{Basal Area (BA)} = \frac{\pi D^2}{4}$$

- D = Diameter at Breast Height (DBH) in meters
- $\pi = 3.142$

$$\text{Relative Cover} = \frac{\text{Cover of a species}}{\text{Total cover of all species}} \times 100$$

$$\text{Absolute Density} = \frac{\text{Total number of individuals of a species}}{\text{Total area sample}} \times 100$$

Relative Density,

$$\text{RD} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals of all species}} \times 100$$

Relative Frequency,

$$\text{RF} = \frac{\text{Frequency of species}}{\text{Sum of frequencies of all species}} \times 100$$

Relative Dominance

$$\text{RDo} = \frac{\text{Basal area of a species}}{\text{Total area of all species}} \times 100$$

Importance Value Index (IVI), calculated as the sum of relative density, frequency, and dominance.

$$\text{IVI} = \text{RD} + \text{RF} + \text{RD}$$

Data were quantitatively analysed with conventional formulae (Curtis & McIntosh, 1951; Kent, 2012). Species diversity was assessed via the Shannon-Wiener and Simpson indexes. Spatial distribution patterns were delineated utilising GPS information and examined in ArcGIS/QGIS.

RESULTS AND DISCUSSION

Ecological Structure and Composition of Tree Species in Kebbi Central (Table 1)

The vegetative composition of trees in Kebbi Central reveals a moderately diverse flora with *Azadirachta indica* (neem) emerging as the most ecologically significant species. It recorded the highest relative density (20.31%), relative frequency (17.24%), and relative cover (19.59%), culminating in an importance value of 57.14 and absolute density of 10.13 trees per hectare. These values indicate neem's dominance in terms of distribution, spatial occupation, and frequency across sampled plots.

Other important species include *Adansonia digitata* (importance value of 40.32), *Acacia nilotica* (36.30), and *Balanites aegyptiaca* (33.93). These species, like neem, are widely known for their resilience in drylands and multi-purpose uses ranging from fodder to medicine and construction materials. The relatively lower importance of species like *Calotropis procera*, *Gmelina arborea*, and *Crotalaria microcarpa* suggests they are either less preferred or less ecologically competitive in the central zone.

Vegetative Composition of Trees in Kebbi North (Table 2)

In Kebbi North, *Azadirachta indica* again demonstrates ecological dominance, registering the highest importance value (54.52) and absolute density of 5.58 trees/ha. However, *Diospyros mespiliformis* surpassed neem in relative cover (24.65%) and recorded a higher importance value (56.29), making it the most prominent species in this zone. *Acacia nilotica* (importance 49.55) also showed strong dominance, reinforcing its ecological success across northern Sudan-Sahel ecotones.

The composition in Kebbi North is more evenly distributed compared to the central region, with a broader spread among species like *Borassus flabellifer*, *Bombax costatum*, and *Parkia biglobosa*, which all recorded moderate importance values. This suggests a slightly richer ecological heterogeneity and potentially varied land-use patterns.

Vegetative Composition of Trees in Kebbi South (Table 3)

The pattern in Kebbi South differs notably. *Diospyros mespiliformis* maintained top ecological status with the highest importance value (63.31) and cover (27.64%). Although neem (*Azadirachta indica*) still featured prominently (importance value of 31.77, absolute density 6.30/ha), it was not the most dominant as in other zones. This may reflect either greater competition from other species or different ecological conditions, such as higher rainfall or anthropogenic influence.

Other dominant species included *Acacia nilotica* (importance 50.04), *Zizyphus mauritiana* (35.88), and *Ficus sycomorus* (14.20), all of which are valued for food, fodder, or timber. The presence of fruit-bearing species

Table 1: Vegetative Composition of Trees in Kebbi Central

Species	Rel. Density	R. Cover	R. Freq	Importance	R. Import	Abs Density
<i>Acacia nilotica</i>	13.6	10.81	12.29	36.304	12.23211	6.77659482
<i>Acacia senegalensis</i>	6.24	2.61	6.68	15.53	5.176149	3.11567579
<i>Adansonia digitata</i>	10.47	19.94	9.91	40.32	13.438656	5.21875694
<i>Azadracta indica</i>	20.31	19.59	17.24	57.14	19.044762	10.1259463
<i>Balanite sygptica</i>	10.15	12.03	11.85	33.93	11.308869	5.06297315
<i>Borassus flabellifer</i>	0.47	0.07	0.65	1.19	0.396627	0.23367568
<i>Bombas costatum</i>	0.47	0.16	0.65	1.28	0.426624	0.23367568
<i>Calatropis procera</i>	3.59	0.34	3.45	7.38	2.459754	1.79151358
<i>Crotalaria microcarpa</i>	0.16	0.05	0.22	0.43	0.143319	0.07789189
<i>Daniela olevera</i>	0.94	0.52	1.29	2.75	0.916575	0.46735137
<i>Diospyrus mysipiloformis</i>	2.97	3.24	3.45	9.66	3.219678	1.479946
<i>Deltudes populus</i>	0.78	0.17	1.08	2.03	0.676599	0.38945947
<i>Euphoria belsemifera</i>	0.31	0.74	0.43	1.48	0.493284	0.15578379
<i>Fraxinus americana</i>	2.81	6.74	3.66	13.21	4.402893	1.40205410
<i>Ficus sycosmorus</i>	0.62	0.29	0.86	1.77	0.589941	0.31156758
<i>Gmelina arborea</i>	0.16	1.76	0.22	2.14	0.713262	0.07789189
<i>Khaya senegalensis</i>	0.31	0.12	0.43	0.86	0.286638	0.15578379
<i>Lanea acida</i>	0.78	0.29	1.08	2.15	0.716595	0.38945947
<i>Mangifera indica</i>	0.31	0.13	0.43	0.87	0.289971	0.15578379
<i>Afzelia africana</i>	1.1	1.53	1.3	3.93	1.309869	0.54524326
<i>Parkia biglobosa</i>	0.47	0.22	0.65	1.34	0.446622	0.23367568
<i>Pillostigma reticulate</i>	10.78	8.45	8.84	28.07	9.355731	5.37454073
<i>Regina adanophyla</i>	0.31	0.11	0.43	0.85	0.283305	0.15578379
<i>Temmarindus indica</i>	0.63	0.80	0.87	2.30	0.76659	0.31156757
<i>Veteleria paradoxa</i>	0.63	2.53	0.65	3.81	1.269873	0.31156757
<i>Zizyphus mauritannia</i>	7.66	5.10	7.54	20.2	6.73266	3.81670283
<i>Zizyphus species</i>	2.34	1.67	3.02	7.03	2.343099	1.16837842
<i>Ximenia americana</i>	0.62	0.20	0.86	1.68	0.559944	0.31156758

Source: Field Survey.

Table 2: Vegetative Composition of Trees in Kebbi North

Species	Rel. Density	R. Cover	R. Freq	Importance	R. Import	Abs Density
<i>Acacia nilotica</i>	19.50	12.76	17.29	49.55	16.5166667	4.9436144
<i>Adansonia digitata</i>	3.14	1.88	3.76	8.78	2.9266667	0.7973572
<i>Azadracta indica</i>	22.01	17.47	15.04	54.52	18.1733333	5.5815002
<i>Balanite sygeptical</i>	3.77	2.71	4.51	10.99	3.6633333	0.9568286
<i>Borassus flabellifer</i>	4.40	4.12	5.26	13.78	4.5933333	1.1163
<i>Bombas costatum</i>	3.77	1.93	4.51	10.21	3.4033333	0.9568286
<i>Crotalaria microcarpa</i>	0.63	0.33	0.75	1.71	0.5700000	0.1594714
<i>Daniela olevera</i>	2.52	2.77	3.01	8.30	2.7666667	0.6378857
<i>Diospyrus mysipiloformis</i>	15.10	24.65	16.54	56.29	18.7633333	3.8273144
<i>Ficus sycomorus</i>	3.14	1.96	3.76	8.86	2.9533333	0.7973572
<i>Khaya senegalensis</i>	0.63	0.12	0.75	1.50	0.5000000	0.1594714
<i>Lanea acida</i>	3.14	1.28	3.76	8.18	2.7266667	0.7973572
<i>Mangifera indica</i>	1.26	0.59	1.50	3.35	1.1166667	0.3189429
<i>Parkia biglobosa</i>	1.89	4.25	2.26	8.40	2.8000000	0.4784143
<i>Reginea adanophyla</i>	0.63	1.48	0.75	2.86	0.9533333	0.1594714
<i>Termarindus indica</i>	3.77	2.10	4.51	10.38	3.4600000	0.9568286
<i>Veteleria paradoxa</i>	2.52	1.34	3.01	6.87	2.2900000	0.6378857
<i>Zizyphus mauritannia</i>	7.55	17.79	8.27	33.61	11.2033333	1.9136572
<i>Ximenia americana</i>	0.63	0.48	0.75	1.86	0.6200000	0.1594714

Source: Field Survey.

like *Mangifera indica* and *Tamarindus indica* with moderate densities indicates a higher tendency for agroforestry in the southern part of Kebbi.

The findings indicate that vegetation dynamics in Kebbi State are influenced by natural adaptation and human control. The exotic *Azadirachta indica* prevails owing to intentional cultivation, whereas native species like *Acacia nilotica* and *Adansonia digitata* retain ecological significance. Threatened species such as *Khaya senegalensis* and *Azizelia africana* necessitate immediate conservation efforts. These findings correspond with the global viewpoint of FAO (2020), which emphasises the necessity of incorporating local vegetation evaluations into comprehensive forest resources management policies.

Table 3: Vegetative Composition of Trees in Kebbi South

Species	Rel. Density	R. Cover	R. Freq	Importance	R. Import	Abs Density
<i>Acacia nilotica</i>	20.13	12.49	17.42	50.04	16.6766647	9.5972725
<i>Adansonia digitata</i>	2.52	2.47	3.03	8.02	2.6727988	1.1996591
<i>Azadirachta indica</i>	13.21	10.23	8.33	31.77	10.5878824	6.2982101
<i>Balanite sygeptical</i>	2.52	2.48	3.03	8.03	2.6761314	1.1996591
<i>Borassus flabellifer</i>	2.52	1.40	3.03	6.95	2.3162034	1.1996591
<i>Bombas costatum</i>	2.52	0.41	3.03	5.96	1.9862694	1.1996591
<i>Crotalaria microcarpa</i>	0.63	0.28	0.76	1.67	0.5565554	0.2999148
<i>Daniela olevera</i>	2.52	3.16	3.03	8.71	2.9027528	1.1996591
<i>Diospyrus mayspiliformis</i>	18.24	27.64	17.43	63.31	21.0991136	8.6975282
<i>Ficus sycomorus</i>	4.40	4.50	5.30	14.20	4.7323869	2.0994034
<i>Khaya senegalensis</i>	1.89	1.13	2.27	5.29	1.7629807	0.8997443
<i>Lanea acida</i>	4.40	1.81	5.30	11.51	3.8358995	2.0994034
<i>Mangifera indica</i>	3.77	4.95	4.55	13.27	4.4224488	1.7994886
<i>Parkia biglobosa</i>	1.26	0.56	1.52	3.34	1.1131107	0.5998295
<i>Reginea adanphyla</i>	0.63	0.76	0.07	2.15	0.7165234	0.2999148
<i>Termarindus indica</i>	3.77	5.24	4.55	13.56	4.5190962	1.7994886
<i>Veteleria paradoxa</i>	2.52	3.15	3.03	8.70	2.8994201	1.1996591
<i>Zizyphus mauritannia</i>	10.06	15.21	10.61	35.88	11.9576085	4.7986362
<i>Ximenia americana</i>	2.52	2.15	3.03	7.7	2.5661535	1.1996591

Source: Field Survey.

1. Species Composition and Richness

A total of 27 species of trees were documented across the studied plots. The predominant species comprised *Azadirachta indica*, *Acacia nilotica*, *Adansonia digitata*, *Zizyphus mauritiana*, and *Diospyros mayspiliformis*, but the less frequent species encompassed *Azizelia africana*, *Khaya senegalensis*, and *Gmelina arborea*. This degree of species diversity is characteristic of savanna woods, where ecological limitations and human-induced pressures govern plant composition (Chidumayo and Gumbo, 2010; Adedire, 2020).

2. Relative Density of Tree Species

Relative density measurements indicated that *Azadirachta indica* (19.37%), *Acacia nilotica* (15.62%), *Zizyphus mauritiana* (8.13%), and *Adansonia digitata* (7.91%) were the predominant species. The prevalent distribution of *A. indica* indicates significant human-facilitated cultivation for shade, medicinal purposes, and fuelwood (Bello *et al.*, 2021). In contrast, species like *Gmelina arborea* (0.10%) and *Euphoria balsamifera* (0.21%) were found at minimal numbers, signifying limited dispersal.

3. Relative Frequency of Tree Species

The relative frequency study indicated that *Azadirachta indica* (15.20%) and *Acacia nilotica* (14.11%) were the most prevalent species across the plots. Conversely, *Khaya senegalensis* (0.82%) and *Azizelia africana* (0.82%) had little geographical distribution, highlighting their endangered condition. The findings corroborate Oke and Isichei (2017), who observed a consistent decrease of *K. senegalensis* in Nigerian savannas attributable to logging and habitat degradation.

4 Relative Cover and Basal Area

Relative cover (basal area contribution) indicated that *Azadirachta indica* (18.43%) and *Adansonia digitata* (16.42%) exhibited the most substantial canopy cover. Notwithstanding its reduced density, the substantial trunk size of *A. digitata* substantially influenced basal area, aligning with the observations of Bationo *et al.*, (2012), who indicated that huge yet sparsely dispersed baobabs serve as keystone species in African savannas.

5. Importance Value Index (IVI)

The IVI results revealed that *Azadirachta indica* (53.0), *Acacia nilotica* (40.89), *Adansonia digitata* (31.86), and *Ziziphus mauritiana* (23.77) were the most ecologically dominating species. Conversely, *Khaya senegalensis* (1.66) and *Azizelia africana* (2.76) had the lowest Importance Value Index (IVI), indicating their susceptibility to local extinction.

6. Spatial Distribution Patterns

The spatial distribution indicated that multifunctional species including *Parkia biglobosa*, *Vitellaria paradoxa*, and *Azadirachta indica* displayed clumped patterns, especially in proximity to towns and agricultural areas where they are deliberately conserved. In contrast, *Khaya senegalensis* and *Diospyros mespiliformis* had a patchy distribution, indicative of selective harvesting and habitat limitation. Comparable aggregated patterns have been seen in Burkina Faso and Niger, where agriculturists preserve beneficial trees throughout land removal (Bellefontaine, 2016).

Table 4: Vegetative Composition of Trees in Kebbi State

Species	RD	RC	RF	IVI	RI	AD
<i>Acacia nilotica</i>	15.62	11.16	14.11	40.89	13.63409023	6.76790642
<i>Acacia senegalensis</i>	4.17	2.1	4.24	10.51	3.50438465	1.80477504
<i>Adansonia digitata</i>	7.91	16.42	7.53	31.86	10.62318696	3.42907258
<i>Azadirachta indica</i>	19.37	18.43	15.2	53	17.67196825	8.39220395
<i>Balanite syriatica</i>	7.81	10.07	8.91	26.79	8.93257731	3.3839532
<i>Borassus flabellifer</i>	1.45	0.6	1.92	3.97	1.32373045	0.63167127
<i>Bombax costatum</i>	1.35	0.36	1.78	3.49	1.16368244	0.58655189
<i>Calatropis procera</i>	2.40	0.27	2.19	4.86	1.62048615	1.03774565
<i>Crotalaria microcarpa</i>	0.31	0.10	0.41	0.82	0.27341536	0.13535813
<i>Daniella olevera</i>	1.46	1.00	1.92	4.38	1.46043813	0.63167127
<i>Diospyros mespiliformis</i>	7.61	7.85	8.35	23.81	7.93904838	3.29371445
<i>Deltodes pappus</i>	0.52	0.13	0.68	1.33	0.44346637	0.22559688
<i>Euphorbia beldingii</i>	0.21	0.59	0.27	1.07	0.35677370	0.09023875
<i>Fraxinus americana</i>	1.88	5.40	2.33	9.61	3.20429462	0.81214877
<i>Ficus sycomorus</i>	1.67	0.87	2.19	4.73	1.57713981	0.72191002
<i>Gmelina arborea</i>	0.10	1.41	0.14	1.65	0.55016505	0.04511938
<i>Khaya senegalensis</i>	0.62	0.22	0.82	1.66	0.55349938	0.27071626
<i>Lanea acida</i>	1.77	0.53	2.33	4.63	1.54379647	0.76702939
<i>Mangifera indica</i>	1.04	0.64	1.37	3.05	1.01697176	0.45119376
<i>Azizelia africana</i>	0.72	1.22	0.82	2.76	0.92027608	0.31583564
<i>Parkia biglobosa</i>	0.83	0.65	1.10	2.58	0.86025808	0.36095501
<i>Ptilostigma reticulata</i>	7.19	6.78	5.61	19.58	9.5286256	3.11323157
<i>Regina adanophylla</i>	0.42	0.31	0.56	1.28	0.42679471	0.18047750
<i>Terminalia indica</i>	1.66	1.36	2.19	5.21	1.73718782	0.72191002
<i>Vitellaria paradoxa</i>	1.25	2.47	1.50	5.22	1.74052216	0.54143251
<i>Ziziphus mauritiana</i>	8.13	7.28	8.36	23.77	7.92571105	3.51921133
<i>Ziziphus species</i>	1.56	1.34	1.91	4.81	1.60381448	0.67679064
<i>Ximenia americana</i>	0.93	0.42	1.24	2.59	0.86359241	0.40607439

Source: Field Survey.

Key: RD -Relative Density; RC -Relative Cover; RF - Relative Frequency; IVI - Importance Value Index; RI -Relative Importance and AD - Absolute Density

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ASSESSMENTS OF MEDICINAL PLANTS USAGE AMONG THE INDIGENOUS PEOPLE OF FIVE COMMUNITIES IN AKOKO SOUTH WEST LOCAL GOVERNMENT, ONDO STATE

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ABSTRACT

Traditional medicine remains the most readily accessible form of primary healthcare for a significant portion of Nigeria's population; however, its full potential is yet to be realized due to insufficient systematic documentation. This study therefore investigated and documented the medicinal plant species used in managing various health conditions among the indigenous people of Akoko in Ondo State. The research was conducted across five major communities in Akoko South West Local Government Area: Akungba Akoko, Iwaro Oka, Oka Akoko, Oba Akoko, and Ikun Akoko. Ethnobotanical data were collected from 100 respondents (herbalists, women and elders using this traditional medicine) using semi-structured questionnaires. Although over one hundred and fifty (150) medicinal plants were mentioned, only thirty-seven (37) species were positively identified, belonging to nineteen (19) plant families with the characteristic of the rainforest ecosystem. The Euphorbiaceae family was found to be the most dominant. The study further revealed that the identified species are employed in the treatment of a wide range of ailments, with the associated knowledge deeply rooted in the socio-cultural traditions of the people. Among the documented species were; *Borreria scabra*, *Ageratum conyzoides* (L.), and *Alchornea laxiflora* (Benth.) emerged as the most versatile, each being used to treat three or more distinct health conditions. In conclusion, the people of Akoko possess extensive indigenous knowledge of medicinal plants and their applications. Systematic documentation of these species and their ethnomedicinal uses not only safeguards cultural heritage but also offers valuable baseline information for pharmacological research, biodiversity conservation, and national development in the healthcare sector.

Keywords: Healthcare, medicine, plant species, families, ailments, ethnomedicine

INTRODUCTION

Ethno botanist explores how peoples of a particular culture and region utilizes indigenous plants for, foods, nutrients and medicinal purposes. This has been recognized as a multidisciplinary field that integrates aspects of plant science, history, anthropology, culture, botany, ecology, and literature (Kandel, 2012). Nigeria, being a multi-ethnic and multilingual nation, offers a rich setting for ethnobotanical studies. The Akoko people inhabit the climatically hot Southwestern region of Nigeria, specifically in the Northern part of Ondo State, and are characterized by diverse social, cultural, ethnic, and linguistic backgrounds (Olagunju *et al.*, 2022). The Akoko region consists of several towns and villages, with several and different dialects of the Yoruba origin. As a result of this diversity, Akoko communities in Ondo State, therefore, provides a unique opportunity for ethnobotanical research, being an indigenous settlement with diverse traditional knowledge are domiciled (Kumar *et al.*, 2022; Lawal *et al.*, 2022; Dean, 2024).

Medicinal plants play a vital role in the primary healthcare of the majority of indigenous people in Akoko, Ondo State, and Nigeria as a whole. Lawal *et al.* (2022) reported that more than 60% of the population in various communities depends mainly on products from natural plant resources for their healthcare needs. Notedly, Akoko ethnic subgroup maintains unique culture and traditional way of life, with traditional healing practices. In rural areas, communities possess extensive indigenous knowledge regarding the medicinal uses of plants for treating everyday health conditions. It was reported across Nigeria that, approximately 1,000 species of wild plants are used in traditional medicine, many of which remain undocumented (Chekole *et al.*, 2015).

Local healers in rural communities commonly use medicinal plants to treat ailments such as diarrhoea, dysentery, cuts and wounds, and stomach disorders, *etc* (Lawal *et al.*, 2022). Although several studies have been conducted on ethnobotanical medicine, efforts toward comprehensive documentation, planning, and conservation of these plant species and their applications remain limited (Abo *et al.*, 2008). Therefore, this study investigated and documented the available plants for their ethnobotanical knowledge from the

indigenous people in some communities of Akoko in Ondo State, Nigeria

MATERIALS AND METHODS

Study Area

This study was carried out in Akoko South West Local Government Area of Ondo State. Akoko South West Local Government Area lies between latitudes 7° 28' 9.15" to 7° 29' 15.18" North of the equator and longitudes 5° 44' 15.96" to 5° 46' 14.78" East of Greenwich Meridian. Comprises of these major towns namely; Akungba-Akoko, Supare-Akoko, Iwaro-Oka, Oka Akoko, Oba Akoko, and Ikun Akoko. The ecological zone which used to be rainforest is gradually becoming derived savannah due to erratic rainfall pattern resulting from climate change effects (Ajayi and Arowosoge, 2018). The zone is characterized by two distinct seasons: the raining season which occur between April and September and the dry season which falls between September and March (Ajayi, 2021). The zone has a mean annual rainfall of 1250 mm and the average temperature 26°C.

Data Collection

The information about traditional knowledge on medicinal plants was documented during the empirical field work in the study area using a semi-structured questionnaire. The field work consisted of two approaches i.e. survey technique and inventory technique followed the method of Kandel, (2012). The survey technique includes individual and in-depth interviews and focus group discussion among the local plant users, community members involved in the use of medicinal plants, and traditional faith healers, *etc.* The inventory technique comprises the collection of different plant specimens from the study area and identification of their local names, part(s) used and purpose of use, *etc.*

Data analysis

The analysis of data collected was carried out using descriptive statistics.

RESULTS

One hundred respondents were encountered on one–one and interviewed, these respondents gave account and efficacy of over one hundred and fifty (150) medicinal plants but only thirty-seven (37) plant species were identified from 19 plant families and are used in treating a variety of human health conditions. Different vernacular/local names were given for significant number of the medicinal plants in this study, indicating their relevance among the respondents (Table 1). Some of these medicinal plants were planted or found around the homes and farms of the traditional healers.

Common Ailments and Plants used for the Treatments

Different medicinal plants have been identified as ingredients to cure many ailments and some were identified to cure more than one ailment as presented in Table 2. Various ailments were mentioned and the traditional healers confirmed their efficacy and resources to cure them with plants. Some of the diseases and illness were reported as; Cough, Stomach-ache, Headache, Divinity (Spiritual attack), Hypertension, Erection problem, Sight, Impotency, Piles, Arthritis, Malaria, Pregnancy disorder, Fever, Toothache, Ulcers, *etc.* The symptoms are not usually detected by traditional healers except on rear occasion but narrated by the patient in question.

DISCUSSION

The people of Akoko possess extensive knowledge of medicinal plants within their environment especially the five communities assessed in this study. This is reflected in their indigenous knowledge and ability to identify numerous plant species, including those common available across the Yoruba land and others uniquely adapted to their locality. In this study, numerous plants were observed and reported as been effective and used as remedies for a wide range of ailments. While similar ethnobotanical studies conducted in South-western Nigeria. For instance, Lawal *et al.* (2020) in their paper conducted as Ethnobotanical survey of plants used for treating cough associated with respiratory conditions in Ede South local government area of Osun State, Nigeria. In addition, Mukaila *et al.* (2021) in their paper titled: A Quantitative Analysis of Medicinal Ethnobotany of Ile-Ife, Osun State, Southwestern Nigeria. These authors documented several of these species and the present study recorded a comparatively higher number of medicinal plants used in the communities of Akoko (Lawal *et al.*, 2022). The inventory generated here contributes to the global effort to preserve indigenous knowledge of plants and their uses, ensuring its relevance for both present and future

Table 1: Scientific and Local Name of Available Medicinal Plants in the Study Area

SN	Medicinal Plant Species	Local Name
1	<i>Abrus precatorius</i> L.	Ojuologbo
2	<i>Acalypha fimbriata</i> Schumach. & Thonn	Igiotu
3	<i>Acanthospermum hispidum</i> DC.	Omisimisin
4	<i>Achyranthes asper</i> L.	Sefusefu
5	<i>Adenia lobata</i> (Jacq.) Engl.	Tanaposo
6	<i>Ageratum conyzoides</i> (L.) L.	Imilesu
7	<i>Albizia ferruginea</i> (Guill. & Perr.) Benth	Ayinre ogo
8	<i>Albizia lebbekii</i> (L.) Benth.	Igbagbo
9	<i>Albizia zygia</i> (DC.) J.F. Macbr.	Ayinreta
10	<i>Alchornea cordifolia</i> (Schumach. & Thonn.) Müll. Arg	Ewe esinsin
11	<i>Alchornea laxiflora</i> (Benth.) Pax & K. Hoffm	Ewe ipa
12	<i>Alternanthera sessilis</i> (L.) R.Br. ex DC.	Dagunro
13	<i>Amaranthus spinosus</i> L.	Ewe tete
14	<i>Amaranthus viridis</i> L.	Tete abalaye
15	<i>Anacardium occidentale</i> L.	Kashu
16	<i>Anchomanes esdifformis</i> (Blume) Engl.	Agbelepotu
17	<i>Annona senegalensis</i> Pers.	Sha-sha
18	<i>Anthocleista djalonenensis</i> A. Chev.	Saposapo
19	<i>Anthocleista vogelii</i> Planch.	Saponso
20	<i>Artocarpus communis</i> J.R. Forst. & G. Forst	Berefurutu
21	<i>Aspilota africana</i> (Pers.) C.D. Adams	Abirikolo
22	<i>Asystasia gangetica</i> (L.) T. Anderson	Akerejepon
23	<i>Azadirachta indica</i> A. Juss.	Dogoyaro
24	<i>Baphia nitida</i> Lodd.	Irosuosun
25	<i>Barleria opaca</i> (Vahl) Nees	Amujewewe
26	<i>Bidens pilosa</i> L.	Imi-esu
27	<i>Boerhavia diffusa</i> L.	Pakududu
28	<i>Borreria scabra</i> (Schumach. & Thonn.) K. Schum.	Yunyun
29	<i>Bridelia ferruginea</i> Benth.	Ira odan
30	<i>Bryophyllum pinnatum</i> (Lam.)	Ewe abamoda
31	<i>Caladium bicolor</i> (Aiton) Vent.	Jagboju
32	<i>Calophyllum innoxium</i> L.	Sewuru
33	<i>Calopogonium mucunoides</i> Desv.	Ponjoowiwi
34	<i>Calotropis procera</i> (Aiton) Dryand.	Eleweku
35	<i>Canna indica</i> L.	Ogoloyo
36	<i>Jatropha curcas</i> L.	Butuje
37	<i>Pterocarpus osun</i>	Agbelosun

Source: field work, 2024

generations (Crane *et al.*, 2019; Ajao *et al.*, 2022; Lawal *et al.*, 2022). It also provides valuable baseline data, complementing existing databases of medicinal plants in Akoko, Ondo State, Southwestern, and the country as a whole.

This study also revealed similarities and variations in the local names of some medicinal plants. This finding corroborates earlier reports by Mukaila *et al.* (2021) and Lawal *et al.* (2022), who observed that medicinal plants are often known by more than one vernacular name in Southwestern Nigeria. Such variations can be attributed to the different dialects spoken across the communities, leading to the calling plants with different vernacular names. Local plant naming practices are typically linked to their uses and the knowledge systems of different ethnic groups; hence, the same species may be identified by multiple names in different communities. This aligns with the observations of Crane *et al.* (2019), Ajao *et al.* (2022), and Lawal *et al.* (2022). Importantly, the choice of plant names reflects their socio-cultural and medicinal significance, serving as reference points for local people (Singh, 2008; Lawal *et al.*, 2022).

The medicinal plant species documented in this study predominantly belong to families such as Euphorbiaceae, Asteraceae, Leguminosae, and Amaranthaceae, *etc.* The prominence of these families may

Table 2: Name of Medicinal Plants and Common Ailments cured

Medicinal Plant Species	Name of Disease/Condition Cured
<i>Abrus precatorius</i> L.	Cough, Stomach -ache
<i>Acalypha fimbriata</i> Schumach. & Thonn .	Cough,
<i>Acanthospermumh ispidum</i> DC.	Hypertension,
<i>Achyranthes aspera</i> L.	Erection dysfunction, Sight, Potency
<i>Adenia lobata</i> (Jacq.) Engl.	Piles, Arthritis
<i>Ageratum conyzoides</i> (L.).	Infectious disease, Malaria, Hypertension, Sight
<i>Albizia ferruginea</i> (Guill. & Perr.) Benth .	Cough, Pregnancy disorder
<i>Albizia lebbbeck</i> (L.) Benth.	Fever, Arthritis, Cough
<i>Albizia zygia</i> (DC.) J.F.Macbr .	Aphrodisiac, Arthritis, Cough, Toothache
<i>Alchornea cordifolia</i> (Schumach. & Thonn.) Müll.Arg	Arthritis, Sight, Ulcers, Malaria
<i>Alchornea laxiflora</i> (Benth.) Pax & K.Hoffm .	De-worming, Infectious diseases, Oral hygiene
<i>Alternanthera sessilis</i> (L.) R.Br. ex DC.	Sight, Jaundice
<i>Amaranthus spinosus</i> L.	Sight
<i>Amaranthus viridis</i> L.	Longevity
<i>Anacardium occidentale</i> L.	Malaria
<i>Anchoman esdifformis</i> (Blume) Engl.	Chicken pox, Measles
<i>Annona senegalensis</i> Pers.	Malaria, Potency
<i>Anthocleista djalonensis</i> A.Chev.	Hypertension
<i>Anthocleista vogelii</i> Planch.	Divinity
<i>Artocarpus communis</i> J.R.Forst. & G.Forst .	Malaria
<i>Aspilia africana</i> (Pers.) C.D.Adams	Fibroid, Cough, Purgative
<i>Asystasia gangetica</i> (L.) T.Anderson	Neck pain, Sight, Potency, Cough
<i>Azadirachta indica</i> A.Juss.	Anti-snake bite
<i>Baphia nitida</i> Lodd.	Divinity
<i>Barleria opaca</i> (Vahl) Nees	Diabetes
<i>Bidens pilosa</i> L.	Cough
<i>Boerhavia diffusa</i> L.	Malaria
<i>Borreria scabra</i> (Schumach. & Thonn.) K.Schum .	Ringworm, Diabetes, Eczema, Birth control
<i>Bridelia ferruginea</i> Benth.	Diabetes, Birth control
<i>Bryophyllum pinnatum</i> (Lam.)	Cough, Sight
<i>Caladium bicolor</i> (Aiton) Vent.	Pimples, Cough
<i>Calophyllumino phylum</i> L.	Scurvy
<i>Calopogonium mucunoides</i> Desv.	Cough, Scurvy, Ulcer
<i>Calotropis procera</i> (Aiton) Dryand .	Conjunctivitis,
<i>Canna indica</i> L.	Cirrhosis
<i>Jatropha curcas</i> L.	Piles
<i>Pterocarpus osun</i>	Diabetes

Source: field work, 2024

account for their widespread popularity and preference in African traditional medicine. The ecological conditions of Akoko, Ondo State and Southwest in the rainforest ecosystem have been reported as particularly suitable for the growth of these notable families (Adekunle *et al.*, 2013; Ajayi and Arowosoge, 2018; Ajayi, 2023; Ajayi *et al.*, 2023).

CONCLUSIONS

This study has demonstrated that the indigenous people of Akoko possess a rich and well-preserved knowledge of medicinal plants used in the management of diverse human ailments. Although respondents mentioned over one hundred and fifty medicinal plants, thirty-seven species from nineteen families were positively identified and documented, reflecting both the depth and specificity of plant-based healing practices in the region. The wide range of ailments treated including physical, psychological, and spiritual conditions highlighting the central role of traditional medicine as a primary and culturally embedded healthcare system within these communities.

Identifying these plant species in their local dialect indicate the strong socio-cultural connection between the people and their natural environment. The predominance of plant families such as Euphorbiaceae, Asteraceae, Leguminosae, and Amaranthaceae, etc corresponds with previous ethnobotanical investigations

in southwestern Nigeria, reinforcing their medicinal importance and ecological adaptability to the rainforest ecosystem.

The findings of this study complement existing ethnobotanical records and contribute valuable baseline data for future research, conservation planning, and potential pharmacological exploration. Documenting this knowledge is therefore crucial not only for preserving cultural heritage but also for supporting national health development efforts. Ensuring the continuity of this indigenous wisdom will require both community engagement and collaborative research initiatives aimed at integrating traditional knowledge with modern scientific approaches.

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EVALUATION OF GENETIC PARAMETERS AND DROUGHT TOLERANCE INDICES IN M8 ETHIDIUM BROMIDE–DERIVED TOMATO GENOTYPES UNDER DROUGHT STRESS

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ABSTRACT

Tomato (*Solanum lycopersicum* L.), a key vegetable in West Africa, is highly vulnerable to drought stress, leading to severe yield losses. Mutation breeding was applied to create genetic variability for improving drought tolerance. In this study, ten eighth-generation (M8) ethidium bromide (EtBr)-induced tomato mutants were evaluated under screen house conditions using a split-plot design with two watering regimes. Control plants received 200 mL of water per pot three times a week, while stressed plants received 200 mL once a week. Data were collected on morphological, phenological, and physiological traits and analyzed using SPSS. Genetic parameters, including variability, heritability, and genetic advance, as well as drought tolerance indices (DTIs), were estimated. Results revealed significant variability among the genotypes; the number of clusters per plant and number of harvested fruits showed high (>20%) phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) across treatments. Both traits also exhibited high heritability (>60%) and genetic advance as a percentage of the mean (GAM) (>20%), indicating strong additive gene action and potential for effective selection under drought stress. DTIs identified genotypes G1, G2, G3, and G10 as highly tolerant; G4, G5, and G9 as moderately tolerant; and G6, G7, and G8 as susceptible. The findings demonstrate that induced genetic variability can be effectively harnessed to identify promising drought-tolerant tomato genotypes, providing valuable resources for breeding programs aimed at sustainable tomato production in drought-prone environments.

Keywords: Drought stress, ethidium bromide (EtBr), genetic variability, mutation breeding, tomato

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important and widely cultivated vegetable crops in West Africa. It is grown primarily for domestic use, either fresh or processed. Its high content of vitamins A and C, together with moderate levels of protein, calcium, and niacin, makes it a valuable dietary component (Showemimo *et al.*, 2007). However, the crop is highly sensitive to water availability and requires adequate moisture throughout its developmental stages (Putti *et al.*, 2023). Consequently, drought stress, even when experienced briefly, can severely affect tomato growth and physiological functions, ultimately leading to significant qualitative and quantitative reductions in fruit yield (Pessoa *et al.*, 2023). In recent years, tomato production has declined significantly due to shortages and irregular rainfall distribution (Showemimo *et al.*, 2007). Limited water availability has caused severe deficits affecting both local and international markets. Consequently, this issue has emerged as a major challenge for crop breeders in the Semi-Arid Tropics (SAT) (Showemimo *et al.*, 2007). As a result, tomato breeding programs are now giving greater attention to the development of drought-tolerant varieties to meet farmers' needs and ensure sustainable production (Dariva *et al.*, 2021). To achieve this goal, plant breeders have explored different strategies aimed at enhancing drought tolerance in tomatoes. Among these, mutation breeding has emerged as a promising approach, as it introduces genetic variability by inducing mutations in the tomato genome through the use of chemical mutagens. This technique generates novel genetic variants with the potential to withstand environmental stressors such as drought (Chaudhary *et al.*, 2019).

Genetic parameters such as variance, coefficient of variation, heritability, and genetic advance play a crucial role in determining how well a population aligns with specific breeding objectives (Roka *et al.*, 2024). Since selection is the foundation of plant breeding, its effectiveness relies heavily on the accurate estimation of these parameters, which enable breeders to identify the most promising genotypes for crop improvement (Shrestha *et al.*, 2023). Beyond this, genetic parameters also provide valuable insights into the genes that regulate both quantitative and qualitative traits, while serving as important tools for evaluating the efficiency of different breeding methods. In doing so, they greatly contribute to accelerating genetic progress (Anand *et*

al., 2023). Building on this foundation, the present study aimed to identify drought-tolerant tomato genotypes by evaluating the M8 generation of ethidium bromide (EtBr)-derived mutant tomato lines, with a focus on assessing variability, heritability, genetic advance, and stress tolerance indices.

MATERIALS AND METHODS

Ten tomato genotypes (M8 generation) derived from ethidium bromide (EtBr) treatments of two accessions (NG/AA/SEP/09/042 and AKUNGBA2) obtained from the National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, were evaluated for drought tolerance under screen house conditions at Adekunle Ajasin University, Akungba-Akoko, between April and September 2024. The original seeds were treated with 0.5% (v/v) EtBr for 0, 24, 48, 72, and 96 hours, advanced from first generation (M1) to the sixth generation (M6), tested for drought tolerance at the seedling stage at the seventh generation (M7) (Ajayi *et al.*, 2025), and used to develop the M8 lines (Table 1). The experiment followed a split-plot design with two watering regimes in a Completely Randomized Design (CRD) with three replications. Seeds were nursed for five weeks, and seedlings were transplanted into pots (7 kg well-drained topsoil, three perforations at the base). Control plants received 200 ml of water three times weekly, while stressed plants received the same amount once weekly. Data were collected on morphological, phenological, and physiological traits.

Table 1. List of EtBr -derived tomato genotypes evaluated under control and drought stress conditions at the M8 generation

S/N	Genotype code	Accession ID	EtBr Treatment (0.5%)	Tolerance at the seedling stage at the M7 under differential PEG treatments
1	G1	NG/AA/SEP/09/042	0 hour	Susceptible
2	G2	NG/AA/SEP/09/042 -EtBr24	24 hours	Moderately -tolerant
3	G3	NG/AA/SEP/09/042 -EtBr48	48 hours	Highly -tolerant
4	G4	NG/AA/SEP/09/042 -EtBr72	72 hours	Susceptible
5	G5	NG/AA/SEP/09/042 -EtBr-96	96 hours	Susceptible
6	G6	AKUNGBA2	0 hour	Susceptible
7	G7	AKUNGBA2 -EtBr24	24 hours	Susceptible
8	G8	AKUNGBA2 -EtBr48	48 hours	Highly -tolerant
9	G9	AKUNGBA2 -EtBr72	72 hours	Highly -tolerant
10	G10	AKUNGBA2EtBr96	96 hours	Highly -tolerant

Statistical analyses

Data were statistically analyzed using the Generalized Linear Model (GLM) procedure in SPSS version 22 at a significance level of $p \leq 0.05$. Estimates of genetic parameters, as cited by Ajayi *et al.* (2014), were calculated using Microsoft Excel, while Drought Tolerance Indices (DTIs) such as Stress Tolerance Index (STI) according to Fernandez (1992) and Intensity of Drought Resistance (IDR) according to Ajayi (2024) were determined. The estimates of genetic parameters are as follows:

- (1) Genotypic variance (GV) = $(MS_g - MSe)/r$
- (2) Phenotypic variance (PV) = $GV + MSe$
- (3) Genotypic coefficient of variation (GCV) = $\frac{\sqrt{V_g}}{\bar{x}} \times 100$
- (4) Phenotypic coefficient of variation (PCV) = $\frac{\sqrt{V_p}}{\bar{x}} \times 100$
- (5) Broad-sense heritability (H^2_B) = $\frac{V_g}{V_p} \times 100$
- (6) Genetic advance (GA) = $\frac{V_g}{\sqrt{V_p}} \times k$; $k = 2.06$ (selection differential)
- (7) Genetic advance as a percent of the mean (GAM) = $\frac{GA}{\bar{x}} \times 100$

(8) Where $\bar{x}$ and r grand means of the trait across genotypes and replicates, respectively.

The DTIs are as follows:

- (1) STI = $(Y_{sx} Y_p)/(Y_p)^2$

$$(2) \text{IDR} = \frac{Y_S}{Y_P}$$

RESULTS

The mean performance and estimates of genetic parameters for morphological, phenological, and physiological traits of the M8 EtBr-derived tomato genotypes, evaluated under both control and drought stress conditions, are presented in Table 2. Under control and drought stress conditions, the grand mean values revealed distinct physiological and morphological responses among the M8 EtBr-derived tomato

Table 2. Genetic parameters of morphological, phenological, and physiological characters of the M8 EtBr-derived tomato genotypes evaluated under both control and drought stress conditions

Control								
Trait	Grand mean	GV	PV	GCV (%)	PCV (%)	H²B (%)	GA	GAM (%)
PH (cm)	19.31	8.13	28.45	14.77	27.62	28.59	5.92	30.67
SG (mm)	7.65	0.80	1.18	11.68	14.21	67.57	2.48	32.40
NL	11.15	1.04	3.17	9.15	15.97	32.83	2.46	22.03
NMB	4.80	2.02	38.98	29.56	129.97	5.17	6.35	132.19
DFF	77.81	78.09	113.34	11.36	13.68	68.90	12.07	15.51
NCP	4.66	1.17	1.58	23.23	26.96	74.25	2.78	59.80
DFFS	80.33	85.61	117.48	11.52	13.49	72.88	12.34	15.36
FPC	3.95	0.07	0.20	6.64	11.43	33.79	1.15	29.05
NHF	12.42	14.28	14.83	30.42	31.00	96.32	5.84	46.97
AFW (g)	15.53	0.73	1.21	5.51	7.07	60.66	2.35	15.12
FYP (g)	194.33	4146.98	4401.97	33.14	34.14	94.21	68.29	35.14
PT (mm)	1.802	0.00	0.04	2.67	10.99	5.91	0.32	17.75
LPF	2.163	0.01	0.04	3.42	8.68	15.55	0.51	23.49
CLa (µMol)	25.33	15.74	33.56	15.66	22.87	46.90	6.76	26.68
CLb (µMol)	28.77	58.20	97.52	26.52	34.32	59.68	11.10	38.60
TCL (µMol)	54.04	126.62	207.47	20.82	26.65	61.03	15.66	28.98
RWC (%)	65.67	34.82	42.04	8.99	9.87	82.83	8.19	12.47
Drought stress								
Trait	Grand mean	GV	PV	GCV (%)	PCV (%)	H²B (%)	GA	GAM (%)
PH (cm)	24.3	13.42	40.76	15.07	26.27	32.91	7.06	29.06
SG (mm)	4.72	0.02	0.11	3.33	7.10	22.01	0.79	16.70
NL	13.13	67.07	67.57	62.39	62.62	99.25	10.27	78.20
NMB	1.09	0.01	0.02	7.36	14.05	27.49	0.72	66.00
DFF	63.24	215.55	228.71	23.22	23.91	94.25	17.06	26.99
NCP	1.78	0.15	0.34	21.65	32.83	43.49	1.48	83.17
DFFS	58.64	226.64	889.75	25.67	50.87	25.47	30.35	51.77
FPC	2.29	0.34	1.26	25.39	48.87	26.99	1.68	73.08
NHF	1.62	0.24	1.34	30.49	71.18	18.35	1.53	94.46
AFW (g)	11.48	7.46	15.27	23.80	34.04	48.87	4.91	42.81
FYP (g)	20.89	86.25	241.92	44.45	74.45	35.65	16.29	77.96
PT (mm)	1.35	0.01	0.43	5.93	48.48	1.50	0.69	50.76
LPF	1.70	0.08	0.62	16.37	46.29	12.51	1.04	61.45
CLa (µMol)	18.11	8.50	36.34	16.10	33.29	23.40	6.51	35.95
CLb (µMol)	24.19	1.09	37.21	4.31	25.22	2.92	6.16	25.47
TCL (µMol)	42.07	27.76	43.94	12.52	15.76	63.17	7.93	18.85
RWC (%)	72.12	35.54	197.60	8.27	19.49	17.99	14.43	20.00

GV: Genotypic variance; PV: Phenotypic variance; GCV: Genotypic coefficient of variation; PCV: Phenotypic coefficient of variation. PH: Plant Height; SG: Stem girth, NL: Number of leaves, NMB: Number of main branches, DFF: Days to first flowering, NCP: Number of clusters per plant, DFFS: Days to first fruit set, NHF: Number of harvested fruits, AFW: Average fruit weight, FYP: Fruit yield per plant, PT: Pericarp thickness, LPF: Locules per fruit, CLa: Chlorophyll a, CLb: Chlorophyll b, TCL: Total chlorophyll content, RWC: Relative water content.

genotypes. Plant height increased from 19.31 cm (control) to 24.30 cm (drought), the number of main branches dropped from 4.80 to 1.09, and fruit yield per plant decreased drastically from 194.33 g to 20.89 g—reflecting about 90% yield loss. Similarly, reductions were observed in average fruit weight (15.53 g to 11.48 g), number of clusters (4.66 to 1.78), and number of harvested fruits (12.42 to 1.62). Interestingly, days to first flowering and fruit set were shorter under drought (63.24 and 58.64 days, respectively) compared to the control (77.81 and 80.33 days). Physiologically, chlorophyll a, b, and total chlorophyll contents were all lower under drought (65.67% to 72.12%).

High values of phenotypic and genotypic coefficients of variation (PCV and GCV), heritability, and genetic advance as a percentage of the mean (GAM) were recorded for several traits. These include the number of clusters per plant (23.23, 26.96, 74.25, and 60%, respectively), the number of harvested fruits (30.42, 31.00, 96.32, and 46.97%), fruit yield per plant (33.14, 34.14, 94.21, and 35.14%), and total chlorophyll content (20.82, 26.65, 61.03, and 28.98%). Under stress conditions, high GCV, PCV, and heritability were recorded for the number of leaves (62.39, 62.62, and 99.25%) and days to first flowering (23.22, 23.91, and 94.25%). Moderate heritability coupled with high GAM was observed for plant height (32.91, 29.06), number of main branches (27.49, 66.00%), number of clusters per plant (43.49, 83.17%), average fruit weight (48.87, 42.81%), and fruit yield per plant (35.65, 77.96%).

Table 3 shows drought tolerance indices (DTIs) and rankings of M8 EtBr-derived tomato genotypes. The indices (IDR and STI) revealed clear variability among the genotypes under drought stress. Based on rank mean and standard deviation, the genotypes differed in tolerance and stability. Genotypes G1, G2, G3, and G10 were highly tolerant, having rank means below 4.00. Among them, G1 was both highly tolerant and stable, making it the most desirable genotype for breeding. In contrast, G2, G3, and G10 were highly tolerant but unstable, suggesting that their responses to drought varied across conditions. G4, G5, and G9 were moderately tolerant, while G6, G7, and G8 were susceptible. The grand mean rank (4.55) and standard deviation (1.62) indicate that, overall, the population exhibited moderate tolerance with high stability under both control and drought conditions.

Table 3. Drought tolerance indices (DTIs) and the ranking of the M8 EtBr -derived tomato genotypes evaluated under control and drought stress conditions

Genotype	IDR	STI	Rank for IDR	Rank for STI	Rank sum	Rank mean	SD Rank	Tolerance level
G1	0.005	22.40	4	2	6	3.0	1.41	Highly tolerant and stable
G2	0.009	6.80	2	5	7	3.5	2.12	Highly tolerant and unstable
G3	0.015	4.81	1	6	7	3.5	3.53	Highly tolerant and unstable
G4	0.005	8.66	4	4	8	4.0	0.00	Moderately tolerant and stable
G5	0.003	10.91	6	3	9	4.5	2.12	Moderately tolerant and unstable
G6	0.002	6.88	7	5	12	6.0	1.41	Susceptible and stable
G7	0.001	3.10	8	7	15	7.5	0.70	Susceptible and stable
G8	0.003	4.83	6	6	12	6.0	0.00	Susceptible and stable
G9	0.008	4.83	3	6	9	4.5	2.12	Moderately tolerant and unstable
G10	0.004	23.63	5	1	6	3.0	2.82	Highly tolerant and unstable
Grand rank mean					9.10	4.55	1.62	

In bold: Highly tolerant (Rank mean < 4.00); moderately tolerant (Rank mean = 4.00 – 4.99); highly susceptible (Rank mean > 4.99). Highly stable (SD Rank < 1.62); moderately stable (SD Rank = 1.62 – 1.99); unstable (SD Rank > 1.99).
IDR: Intensity drought tolerance resistance, STI: Stress tolerance indices, SD: Standard deviation.

DISCUSSION

The grand mean performance results indicate that most M8 EtBr-derived tomato genotypes are drought-sensitive, with severe yield reduction under stress. However, traits such as earlier flowering, higher relative water content, and moderate chlorophyll retention suggest useful adaptive mechanisms. Breeding efforts should target genotypes combining these adaptive traits with stable yield performance, using physiological

and morphological indicators to enhance selection for drought tolerance.

The number of clusters per plant and the number of harvested fruits exhibited considerable genetic variability, with both PCV and GCV values exceeding 20% across all treatments. This reflects a broad genetic diversity within the germplasm for these traits, indicating that the genotypes possess a wide genetic base for drought stress adaptation. These results are consistent with the findings of El-Hashash and Agwa (2018), who reported high PCV and GCV for most traits under stress conditions while evaluating genetic parameters and stress tolerance indices for quantitative traits in barley exposed to varying levels of drought stress. In addition, both traits showed high heritability values (>60%), suggesting that genetic factors play a major role in the observed variations within the population. This implies a higher likelihood of these traits being passed on to the next generation. Moreover, the number of clusters per plant and the number of harvested fruits exhibited high GAM (20%) under both control and stress conditions. This indicates that the traits are largely governed by additive gene action, making selection for these traits potentially effective in improving drought tolerance. Similar findings were reported by Bodunde *et al.* (1999), Showemimo *et al.* (2007) and Das *et al.* (2019) in tomato, Ricciardi *et al.* (2001) in Faba bean, and by in tomato.

Drought tolerance indices (DTIs) are effective in selecting drought tolerant genotypes in crop species (Ajayi, 2024). While STI has been confirmed as very effective for assessing genotype performance under both stress and non-stress conditions (Fernandez, 1992), the IDR is more tilted to selecting the best performing genotypes under drought stress (Ajayi, 2024). The results from the DTIs have important implications for tomato breeding. The identification of highly tolerant genotypes (G1, G2, G3, and G10) provides valuable genetic material for developing improved cultivars. G1, which combined high tolerance with stability, can serve as a superior parent in breeding programs aimed at producing varieties that perform consistently under both optimal and water-limited conditions. On the other hand, G2, G3, and G10, though highly tolerant but unstable, may possess specific adaptive traits or genes for drought tolerance that can be introgressed into more stable backgrounds through hybridization and selection. The presence of moderately tolerant (G4, G5, and G9) and susceptible (G6, G7, and G8) genotypes further broadens the genetic base, allowing breeders to exploit genetic diversity for drought tolerance improvement. Overall, the findings suggest that selection for both tolerance and stability is crucial to achieving durable drought resilience in tomato. Using stable tolerant genotypes like G1 and improving unstable but tolerant ones through recurrent selection can accelerate the development of drought-resilient tomato cultivars suitable for variable environments. Similar approaches using DTIs to categorize genotypes based on their resistance and tolerance to stress through yield traits have also been reported by Showemimo *et al.* (2007) in tomato, El-Hashash and Agwa (2018) in barley, and Ajayi (2024) in cowpea.

A comparison of the M7 (seedling stage) and M8 (maturity stage) results shows clear differences in drought tolerance expression and stability across generations. At the M7 stage, genotypes such as G3, G8, G9, and G10 were rated highly tolerant, while G2 was moderately tolerant, and the rest were susceptible. However, at the M8 stage, only G1, G2, G3, and G10 remained highly tolerant, with G1 being stable, while G2, G3, and G10 were unstable. G4, G5, and G9 became moderately tolerant, and G6–G8 were susceptible. The differences in tolerance observed imply that drought tolerance at the seedling stage does not always persist to maturity, likely due to changes in physiological mechanisms governing stress response at different growth phases. The improved performance of G1, initially susceptible but later highly tolerant and stable, suggests genetic stabilization or adaptive selection in later generations. Conversely, genotypes like G8 and G9, tolerant at the seedling stage but less so at maturity, may possess stage-specific tolerance traits. For breeding, these results emphasize the need to evaluate genotypes across growth stages to identify those combining early-stage tolerance with sustained performance to maturity. G1 emerges as a promising candidate for developing drought-resilient tomato varieties due to its consistent and stable performance under stress. EtBr treatments induced diverse and stage-specific responses. Moderate EtBr exposures (24–48 h) generally enhanced drought tolerance, though often with limited stability. Some genotypes (e.g., G1 and G4) showed improvement even without or after prolonged treatment, reflecting both genetic and adaptive influences. Therefore, evaluation across generations and growth stages is crucial for identifying genotypes that combine tolerance with stability for drought-resilient tomato breeding. Overall, the 24–48 h EtBr exposure window

proved most effective in generating drought-tolerant genotypes, producing consistent responses across generations despite some instability. These findings highlight mutagenesis as a valuable approach for inducing genetic variability and advancing the development of drought-tolerant tomato lines.

CONCLUSION

This study demonstrates that EtBr-induced mutagenesis effectively generated genetic variability for drought tolerance in tomato. Traits such as clusters per plant and number of harvested fruits, which showed high heritability and GAM, were identified as suitable for selection. DTIs further enabled clear classification of genotypes under drought. The 24–48 h EtBr treatment window emerged as the most effective for developing drought-tolerant lines, though with some instability, underscoring mutation breeding as a promising strategy for enhancing tomato resilience under water stress.

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ETHIDIUM BROMIDE-INDUCED GENETIC VARIABILITY IN TOMATO [*SOLANUM LYCOPERSICUM* (L.) H. KARST.] AT THE M1 GENERATION

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ABSTRACT

Tomato is a nutritionally and economically important crop, yet its productivity in Nigeria remains limited by low yields and restricted genetic diversity. Mutation breeding, including the exploration of ethidium bromide (EtBr) as a novel mutagen, offers a fast route to broaden variability and develop improved, high-yielding genotypes. EtBr was evaluated as a mutagen for inducing genetic variability in tomato at the M1 generation. Analysis of variance revealed significant effects of treatment, genotype, and their interactions for all quantitative traits. Wide variation was observed: plant height ranged from 58.11–63.37 cm, branches from 9.40–12.60, and fruit yield from 304.97–382.16 g per plant. Control plants generally promoted early flowering and fruiting, while EtBr exposures for 24 and 72 hrs enhanced branching, fruit weight, and yield in several genotypes. By contrast, the 48-hr treatment delayed reproductive development and reduced yield. Estimates of genetic parameters showed that phenotypic variance exceeded genotypic variance, though differences were small, suggesting limited environmental influence. Broad-sense heritability was high ($\geq 60\%$) across all traits, with genetic advance as a percentage of mean (GAM) highest for fruit yield (128.95%). Yield-related traits such as branches, clusters, fruits per plant, pericarp thickness, fruit weight, and yield exhibited high heritability with high GAM, indicating additive gene effects and strong potential for selection. Overall, EtBr treatment induced significant variability, with moderate exposures (24–72 hrs) being most effective in enhancing yield-associated traits. The high heritability and genetic advance observed suggest that selection at early generations would be successful, and advancing promising M1 lines into subsequent generations is recommended to stabilize mutations and identify superior genotypes.

Keywords: Ethidium bromide, genetic variability, mutagenesis, quantitative traits, tomato breeding

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops worldwide, ranking second only to potato in consumption (Siddiqui *et al.*, 2020). Native to the Andes of South America, it was first cultivated in Mexico around 500 BC before spreading to Europe, North Africa, and other parts of the world (Gentilcore, 2010). The crop is valued for its nutritional and economic importance, consumed fresh or processed into paste, sauces, powders, and juices (Ajagbe *et al.*, 2014). It is rich in vitamins A, B, and C, minerals, dietary fiber, amino acids, and bioactive compounds such as lycopene and carotene, which provide therapeutic benefits including reduced risks of cancer and cardiovascular diseases, improved bone metabolism, skin protection, and enhanced cell renewal (Takano, 2010; Onifade *et al.*, 2013).

In Nigeria, tomato is a major dietary staple consumed in diverse forms (Olayemi *et al.*, 2010). It is cultivated across the country, with the savanna zones being most suitable due to reduced pest and disease pressure. Major producing areas include Jigawa, Katsina, Zamfara, Gombe, Kano, Delta, Kwara, and Oyo (Ugonna *et al.*, 2015). Despite its importance, production remains far below demand. In 2020, Nigeria ranked eleventh globally and second in Africa after Egypt, producing 3.6 million MT on 844,445 hectares with an average yield of only 4.4 MT/ha, compared to Egypt's 39.4 MT/ha (FAOSTAT, 2020). The low yield of cultivated varieties is largely due to a narrow genetic base, a consequence of the crop's self-pollinating nature (Adeyemo and Olukanmi, 2015; Chaudhary *et al.*, 2019).

To improve productivity, broadening the genetic base is essential for enhancing yield and resilience to production constraints (Ahmad *et al.*, 2015). While domestication and conventional breeding have produced numerous cultivars, these approaches have also reduced genetic diversity and are often time-consuming (Meyer *et al.*, 2013). Mutation breeding offers a faster and effective alternative, enabling the creation of novel alleles and phenotypes that expand genetic variability (Ajayi *et al.*, 2010; Just *et al.*, 2013). Chemical mutagens such as ethyl methane sulphonate (EMS) and sodium azide (NaN_3) have been widely used in tomato improvement. However, little is known about the potential of ethidium bromide (EtBr) as a mutagen in crop species. Exploring EtBr could provide additional genetic variability, offering breeders new opportunities to

overcome production challenges and enhance tomato yield and adaptability in Nigeria.

This study aimed to develop novel tomato genotypes with improved yield and fruit quality through EtBr-induced variability, assess the genetic diversity for yield and its components, and estimate the heritability of phenotypic traits among EtBr-derived genotypes at the M1 generation.

MATERIALS AND METHODS

Collection of materials and ethidium bromide (EtBr) treatment

The five accessions of tomato used in this study were selected among the original forty accessions sourced from the National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, and Akungba-Akoko, Nigeria, in 2015 (Table 1). The selection was based on their previous performance in the field (Gbadamosi *et al.*, 2020).

Table 1. List of accessions, source, codes, and Origin

Accession ID	Source	Accession code	Origin
NGSA0110002	NACGRAB	G1	Republic of Benin
NGB01357	NACGRAB	G2	Unknown
NGAASEP09042	NACGRAB	G3	Southwest, Nigeria
NGB01371	NACGRAB	G4	Unknown
Akungba-1	Akungba-Akoko	G5	Southwest, Nigeria

Description of the Study Area

The study was conducted within the following coordinates: Latitude 7°28'N–7°0'N and Longitude 5°44'E–5°0'E. The area is bordered by Ikare-Akoko (North), Etioro-Akoko (South), Supare-Akoko (East), and Iwaro-Akoko (West). It has an equatorial climate, with bimodal rainfall peaks occurring in April–July and August–October, resulting in annual precipitation ranging from 1,500 to 2,000 mm. Relative humidity is typically 75–95%, with an average temperature of 23–26°C. The soil is classified as sandy loam.

Seedling Production and Experimental Design

Seeds of five tomato accessions were treated with 0.5% ethidium bromide (EtBr) for 0, 24, 48, 72, and 96 hours and raised in nursery baskets containing topsoil for three weeks to obtain the M₁ generation. Seedlings were transplanted to the field in a randomized complete block design (RCBD) with three replications, each comprising the five accessions under the five EtBr treatments. Plots measured 1 m × 1 m with 0.5 m alleys, and seedlings were spaced at 0.3 m × 0.3 m. Nine plants were established per plot per accession per treatment, and five were randomly tagged for data collection.

Morphological Characterization and Data Collection

At five weeks after transplanting, plant height and number of branches were recorded. At the reproductive stage, observations were taken on the number of days to first flowering, the number of days to first fruit set, the number of fruits per cluster, and the number of clusters per plant. At fruit maturity, pericarp thickness, the number of locules per fruit, fruit weight, the number of fruits per plant, and the fruit yield per plant were measured following the tomato descriptors (IPGRI, 2015).

Data Analysis

Data were analyzed using analysis of variance (ANOVA) of SPSS version 20. The mean values were separated with Least Significant Difference (LSD) of the same statistical package. Genetic parameters were estimated according to Fayeun *et al.* (2016) and interpreted as cited by Ajayi *et al.* (2014).

RESULTS

Mean square values of quantitative traits among EtBr-derived tomato genotypes at the M1 generation.

The mean square values of quantitative traits among EtBr-derived genotypes of tomato at the M1 generation as shown in Table 2 revealed that EtBr treatment, genotype, and the interaction between genotype and treatment were significant at $P \leq 0.05$ for all traits. Replication effects were significant ($P \leq 0.05$) for all traits except the number of branches and fruit weight. The highest coefficient of variation (19.89%) was recorded for fruit yield, while the lowest (1.73%) was observed for days to first flowering (Table 2).

Table 2. Mean square values of quantitative traits among EtBr –derived genotypes of tomato at the M1 generation

Source of variation	DF	PH (cm)	NB	DF	NDF	NFC	NCP	PT (mm)	LOC	FW (g)	NFH	FY (g)
Treatment (T)	4	45.92*	26.25*	7.11*	8.76*	1.50*	5.71*	0.13*	0.22*	21.64*	93.10*	13841.60*
Genotype (G)	4	239.52*	251.55*	41.64*	31.64*	11.25*	48.20*	12.84*	2.85*	166.05*	1105.35*	768080.20
G × T	16	95.34*	7.41*	9.39*	8.85*	2.65*	6.50*	0.21*	0.23*	38.33*	59.44*	31676.84*
Replication	2	10.17*	0.01 ^{ns}	5.90*	9.15*	0.98*	1.30*	0.11*	0.01*	2.17 ^{ns}	9.31*	4598.84*
Error	48	7.36	0.69	0.69	1.46	0.44	0.38	0.05	0.02	5.93	6.88	4975.98
CV (%)		4.42	7.81	1.73	2.16	18.07	11.07	7.71	5.32	13.37	15.27	19.89

*: Significant at $P \leq 0.05$; ns: Not significant.

DF: Degree of freedom; CV: Coefficient of variation; PH: Plant height; NB: Number of main branches; DFF: Days to first flowering; NDF: Number of days to first fruit set; NFC: Number of fruits per cluster; NCP: Number clusters per plant; PT: Pericarp thickness per fruit; LOC: Locules per fruit; FW: Fruit weight; NFH: Number of fruits harvested; FY: Fruit yield per plant

Overall mean performance for quantitative traits (across five accessions) among EtBr-derived genotypes of tomato at the M1 generation

The treatment of tomato genotypes with 0.5% EtBr for varying durations caused varying effects (Table 3). Plant height increased slightly at 24 hours (63.37 cm) compared to the control (62.41 cm), but then decreased at 48 hours (58.11 cm). The number of branches per plant significantly increased at 72 hrs (12.6) versus control (9.78). Flowering and fruit set were generally delayed by EtBr treatment. Fruit clusters per plant improved notably at 72 hrs (6.11) and 96 hrs (6.22) compared to the control (5.54). Fruit weight was highest at 72 hrs (19.87g) and lowest in the control (16.69g), while the highest yield was obtained at 24 hrs (382.16g) and the lowest at 48 hrs (304.97g). The number of fruits harvested dropped significantly at 48 hrs (12.83) versus the control (19.07). Pericarp thickness and locules per fruit showed slight improvements at longer exposures. Overall, longer EtBr exposure (72–96 hrs) enhanced branching and cluster traits, while 48 hrs treatment had detrimental effects on growth and yield.

Table 3. Overall mean performance for quantitative traits (across five accessions) among EtBr-derived genotypes of tomato at the M1 generation

Treatment	PH (cm)	NB	DFF	NDF	NFC	NCP	PT (mm)	LOC	FW (g)	NFH	FY (g)
Control	62.41 ^{ab}	9.78 ^a	46.69 ^a	54.70 ^a	3.88 ^a	5.54 ^{abc}	2.96 ^a	2.08 ^a	16.69 ^a	19.07 ^b	352.96 ^a
24hrs	63.37 ^b	10.02 ^{ab}	48.22 ^b	56.73 ^b	3.14 ^a	5.21 ^{ab}	2.80 ^a	2.56 ^b	17.49 ^a	18.19 ^b	382.16 ^a
48hrs	58.11 ^a	9.40 ^a	48.16 ^b	56.31 ^{ab}	3.62 ^a	4.75 ^a	2.79 ^a	2.86 ^c	18.53 ^a	12.83 ^a	304.97 ^a
72hrs	61.10 ^{ab}	12.60 ^c	48.41 ^b	56.08 ^{ab}	3.86 ^a	6.11 ^b	2.94 ^a	2.67 ^{bc}	19.87 ^a	17.53 ^b	357.36 ^a
96hrs	61.22 ^{ab}	11.33 ^{bc}	47.93 ^{ab}	55.83 ^{ab}	3.85 ^a	6.22 ^{bc}	3.00 ^a	2.65 ^{bc}	18.51 ^a	18.27 ^b	375.99 ^a
Grand mean	61.37	10.63	47.88	55.93	3.67	5.57	2.90	2.66	18.22	17.18	354.69
LSD	4.45	1.36	1.36	1.98	1.09	1.01	0.37	0.23	3.99	4.30	115.71

Means within columns followed by the same superscripts are not significantly different from one another at $P \leq 0.05$ using the least significant difference (LSD). PH: Plant height; NB: Number of main branches; DFF: Days to first flowering; NDF: Number of days to first fruit set; NFC: Number of fruits per cluster; NCP: Number clusters per plant; PT: Pericarp thickness per fruit; LOC: Locules per fruit; FW: Fruit weight; NFH: Number of fruits harvested; FY: Fruit yield per plant.

Estimates of genetic parameters of quantitative traits among EtBr-derived tomato genotypes at the M1 generation

Estimates of variability, heritability, and genetic advance for quantitative traits are presented in Table 4. Across traits, phenotypic variance (PV) exceeded genotypic variance (GV), and phenotypic coefficients of variation (PCV) were consistently higher than genotypic coefficients of variation (GCV). The lowest GCV and PCV (2.54–3.33%) were recorded for the number of days to first fruit set, while the highest (63.56–66.59%) occurred in fruit yield. Broad-sense heritability was high ($\geq 60\%$) across all traits, ranging from 60.12% (plant height) to 97.90% (pericarp thickness). Genetic advance as a percent of mean (GAM) was lowest in the number of days to first fruit set (4.72%) and highest in fruit yield (128.95%). Traits such as plant height, number of days to first flowering, and number of days to first fruit set had low GAM ($\leq 10\%$), whereas, number of branches, number of fruits per cluster, number of clusters per plant, pericarp thickness, number of locules per fruit, fruit weight, number of fruits harvested, and fruit yield per plant exhibited high GAM ($\geq 20\%$).

Table 4. Estimates of genetic parameters for quantitative traits among EtBr-derived genotypes of tomato at the M1 generation

Trait	Mean	GV	PV	GCV (%)	PCV (%)	GVT	H ² B (%)	GA	GAM (%)
PH (cm)	61.37	15.48	22.84	6.41	7.79	29.33	60.12	5.91	9.63
NB	10.63	16.72	17.41	38.47	39.25	2.24	95.43	8.17	76.86
DDF	47.88	2.73	3.42	3.45	3.86	2.90	72.80	2.78	5.81
NDF	55.93	2.01	3.47	2.54	3.33	2.46	68.60	2.64	4.72
NFC	3.67	0.72	1.16	23.12	29.35	0.74	72.00	1.60	43.60
NCP	5.57	3.19	3.57	32.07	33.92	2.04	82.80	3.19	57.27
PT (mm)	2.90	0.85	0.9	31.79	32.71	0.05	97.90	1.92	65.75
LOC	2.66	0.19	0.21	16.39	17.23	0.07	90.48	0.86	32.33
FW (g)	18.22	10.68	16.61	17.94	22.37	10.80	72.75	6.13	33.64
NFH	17.18	73.23	80.11	49.81	52.10	17.52	92.08	16.96	23.97
FY (g)	354.88	50873.60	55849.60	63.56	66.59	8900.29	93.91	457.62	128.95

GV: Genetic variance; PV: Phenotypic variance; GCV: Genetic coefficient of variation; PCV: Phenotypic coefficient of variation; GVT: Genotype $\times$ treatment variation; H²B: Heritability in the broad sense; GA: Genetic advance; GAM: Genetic advance as a percent of the mean. PH: Plant height; NB: Number of main branch; DDF: Days to first flowering; NDF: Number of days to first fruit set; NFC: Number of fruits per cluster; NCP: Number of clusters per plant; PT: Pericarp thickness per fruit; LOC: Locules per fruit; FW: Fruit weight; NFH: Number of fruits harvested; FY: Fruit yield per plant.

DISCUSSION

Plant breeders rely on genetic variation to develop improved cultivars. Due to the narrow genetic base of tomato (Chaudhary *et al.*, 2019), mutagenesis is essential for broadening diversity. Success has been reported with colchicine (Aminu *et al.*, 2021), sodium azide (Adeosun *et al.*, 2020), EMS, and hydrazine (Laskar *et al.*, 2016). However, little is known about the variability induced by EtBr. This study, therefore, assessed genetic diversity for yield and its components in EtBr-derived tomato genotypes using M1 data. In this study, seeds were treated with 0.5% (v/v) EtBr solution, corresponding to approximately 50 mg/L when prepared from a 10 mg/mL stock. Similar concentrations of EtBr have been reported to effectively induce genetic variability in seed mutagenesis experiments (Porbeni *et al.*, 2014; Keadtidumrongkul *et al.*, 2018).

The significant effects of EtBr treatment, genotype, and genotype $\times$ treatment interactions across all traits indicate that EtBr successfully induced genetic variability in the M1 generation. This suggests that EtBr can generate heritable changes that broaden the genetic base of tomato, which is critical for selection and improvement. The lack of significant replication effects for the number of branches and fruit weight implies that these traits were less influenced by environmental variation, making them more stable and reliable for early selection. Conversely, traits with significant replication effects may require evaluation across multiple environments to confirm genetic stability. The high coefficient of variation (19.89%) for fruit yield highlights its strong potential for selection, as it reflects a wide range of variability induced by the treatment. In contrast, the low CV (1.73%) for days to first flowering suggests that this trait is relatively stable and less responsive to mutagenesis, limiting the scope for selection.

The evaluation of EtBr-derived tomato genotypes at the M1 generation revealed differential responses across quantitative traits. Short exposure (24 hours) enhanced plant height and yield relative to the control, whereas moderate exposure (48 hours) resulted in growth retardation, reduced fruit weight, and the lowest yield, suggesting possible deleterious effects of excessive mutagenic stress. Notably, branching and the number of clusters increased significantly between 72 and 96 hours, indicating a positive influence of EtBr on vegetative proliferation and reproductive potential. However, EtBr generally delayed flowering and fruit set, which may be undesirable for breeding programs targeting earliness. Fruit quality traits such as pericarp thickness and number of locules improved under certain treatments, with potential benefits for fruit firmness and processing quality. Although yield differences among treatments were not statistically significant, the observed variability across vegetative, reproductive, and fruit traits highlights the effectiveness of EtBr in generating genetic diversity. These variations provide a useful base for selection in subsequent generations, particularly for identifying mutants that combine high branching, an increased number of clusters, and stable yield performance.

Comparable outcomes have been reported in other crops. In rice, EMS treatment enhanced branching, though

responses were sometimes irregular (Karthikeyan *et al.*, 2019), a trend also observed in soybean (Gopinath and Pavadai, 2005). Similarly, the number of days to flowering often lacked a consistent pattern, as reported in chickpea (Wani, 2011) and in colchicine-induced cowpea (Ajayi *et al.*, 2017). In the present study, increased fruit yield across EtBr treatments is in contrast with findings by Adamu and Aliyu (2007), who reported yield decline in tomato under sodium azide mutagenesis, while EMS treatment in rice maximized grain yield (Karthikeyan *et al.*, 2019).

In marigolds, higher EtBr concentration and prolonged exposure reduced plant height, with the lowest recorded at 48 hours (Keadtidumrongkul *et al.*, 2018). Although their concentration was about 20-fold higher, the 48-hour treatment in our study similarly produced the lowest values for several traits, including plant height, branching, clusters, pericarp thickness, number of fruits per plant, and fruit yield. In cowpea, Porbeni *et al.* (2014) reported that 0.4% EtBr for 24 hours produced the tallest plants in variety IBC, comparable to our findings, whereas Ife Brown responded best to 0.3% EtBr at 18 hours, underscoring genotype-dependent responses. For yield traits, 0.2% EtBr at 24 hours was optimal in Ife Brown, except for the number of seeds per pod. In Indian grass, EtBr (250 mg/L, 48 hrs) generated about 20% dwarf mutants, markedly shorter than controls (Stephens, 2009).

In the present study, high GCV and PCV values across most traits, except in plant height, number of days to first flowering, and the number of days to first fruit set, in which they were low, indicated substantial genetic variability and potential for crop improvement, consistent with various reports (Unche *et al.*, 2008; Ajayi *et al.*, 2017). PCV slightly exceeded GCV, with minimal differences suggesting limited environmental influence (Larik *et al.*, 2009). All traits showed high broad-sense heritability, implying that selection based on phenotypic performance would be effective, as also noted by previous studies (Ajayi *et al.*, 2017; Zannat *et al.*, 2023). However, high heritability combined with high genetic advance as a percentage of the mean (GAM) in most traits indicated additive gene effects, making selection especially effective for yield improvement, in line with earlier findings on induced variation (Wani and Khan, 2006; Arulbalachandran *et al.*, 2010; Wani, 2011).

CONCLUSION

Ethidium bromide (EtBr) treatment significantly influenced quantitative traits in tomato at the M1 generation, with genotype and treatment interactions playing a major role. Control plants generally promoted early flowering and fruiting, but short (24 hrs) and prolonged exposures (72 – 96 hrs) enhanced branching, fruit weight, and yield in several genotypes. In contrast, the 48-hr treatment was largely detrimental, delaying reproductive traits and reducing yield. High heritability and genetic advance estimates for yield-related traits indicate strong additive gene effects and prospects for improvement through selection.

Recommendation

Selection should prioritize yield-associated traits with high heritability and genetic advance, as these are more responsive to genetic improvement. Low (24 hrs) and longer EtBr exposure (72 – 96 hrs) are recommended for generating beneficial variability, while the moderate (48-hr) treatment should be avoided due to its negative impact. Advancing promising M1 genotypes into later generations will help stabilize favorable mutations and identify lines with superior yield potential.

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ASSESSMENT OF TIMBER SPECIES EXPLOITED AMONG FURNITURE AND CARPENTRY MAKERS IN AKUNGBA-AKOKO, ONDO STATE, NIGERIA: IMPLICATIONS FOR SUSTAINABLE FOREST MANAGEMENT

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ABSTRACT

Wood remains a critical renewable resource for construction, furniture, and socio-economic development across sub-Saharan Africa. In Nigeria, rising urbanization and population growth continue to drive timber demand, with Ondo State serving as a major hub for timber exploitation. This study assessed the species composition, market trends, and sustainability implications of timber exploitation in Akungba-Akoko, Ondo State, Nigeria. Data were collected from 45 respondents, comprising timber traders, carpenters, and furniture makers, using questionnaires, interviews, and direct observations. A total of 23 timber species were identified, including high-value hardwoods such as *Tectona grandis* (Teak), *Milicia excelsa* (Iroko), and *Khaya grandifolia* (Mahogany), as well as moderately priced species like *Terminalia superba* (Afara) and *Cordia millenii* (Omo). Non-traditional fruit trees such as *Mangifera indica* (Mango) and *Spondias mombin* (Ekikan) were increasingly exploited as substitutes due to scarcity of preferred timber species. Findings show that market preferences are strongly influenced by durability, resistance to pests, and aesthetic qualities, with high-value timbers commanding the highest prices. However, unsustainable harvesting practices and weak enforcement of forestry regulations threaten long-term availability. Plantation-grown species such as *Gmelina arborea* and *Tectona grandis* are filling supply gaps but raise ecological concerns due to monoculture dominance. The study recommends promoting community-based forest management, diversifying wood sources with alternatives such as bamboo and engineered wood, strengthening forestry governance, and expanding reforestation programs. Addressing these challenges is critical for balancing socio-economic needs with ecological sustainability in Akungba-Akoko and similar forest-dependent communities.

Keywords: Akungba-Akoko, forest management, furniture production, Nigeria, Timber species, sustainability

INTRODUCTION

Wood plays a central role in the socio-economic development of Nigeria, particularly in the furniture and construction sectors (World Bank. 2020). The increasing demand for timber is driven by rapid urbanization, population growth, and infrastructure development (Akinyemi *et al.*, 2021; FAO. 2022). This is particularly true for countries in sub-Saharan Africa. In Nigeria, wood serves as a primary material for furniture production and construction due to its availability, affordability and workability (Ogunwusi, 2013). The dependence of the country on wood for domestic and commercial applications continues to grow alongside urbanization and population expansion. According to (FAO, 2020; IUCN, 2022), reported that the demand for timber is projected to increase significantly in developing countries. This projection is driven by rising infrastructure and housing needs and as result of population increase (IPCC, 2021; UNEP, 2021 and World Bank. 2023). Ondo State, which is located in the South Western region of Nigeria, is rich in diversity of tree species. The state has also historically contributed significantly to the nation's timber supply. Akungba-Akoko, a fast-growing in Akoko South West Local Government Area of Ondo State exemplifies the local reliance on wood resources for furniture and construction purposes. With increased housing projects and expanding commercial activities, wood exploitation in the town has intensified. This is raising questions about species sustainability and forest conservation (Ogundele *et al.*, 2016)

Commonly exploited timber species for furniture and construction in Nigeria include *Milicia excels* (Iroko), *Khaya spp* (Mahogany), *Terminalia superba* (Afara), *Gmelina arborea* and *Ceiba pentandra* (Silk Cotton Tree) due to their strength, durability and aesthetic qualities (Fuwape and Fabiyi, 2003; Oyekwelu *et al*, 2010). However, unsustainable harvesting practices, weak forest governance and limited awareness of reforestation have resulted in declining availability of these preferred species (Adekunle *et al*, 2013). This has unavoidably made people to start exploiting unconventional species for furniture and carpentry. Although

several national studies have accessed timber exploitation in broader contexts, localized assessments are necessary to understand the dynamics of wood species utilization in specific communities like Akungba-Akoko (Ogundele *et al.* 2016), detailed studies at community level are crucial for informed resource management and policy-making. Despite its economic benefits, timber exploitation raises concerns about sustainability, biodiversity loss, and the long-term availability of preferred hardwoods. This study therefore investigates the tree species exploited in Akungba-Akoko, their uses, market preferences and the implications of current practices for sustainable forest management.

METHODOLOGY

Study Area

Akungba-Akoko is located in the Akoko South West Local Government Area of Ondo State, Nigeria. The town is located between latitudes 7°28'N and 7°30'N and longitudes 5°44'E and 5°46'E with an estimated population of one hundred and fifty thousand people including staff and students of Adekunle Ajasin University. Akungba-Akoko lies within the tropical rain forest-derived guinea savannah transition zone. It is characterized by a bimodal rainfall pattern with an annual mean of 1200-1500mm and average temperature range of 22-33°C (Adefioye, 2018)

The town hosts the Okusa Plank Market which is a major timber trading hub. The plank market serves local artisans, contractors and traders from surrounding communities. It also has many carpentry and furniture workshops. The presence Adekunle Ajasin University has contributed to an increasing demand for timber occasioned by urban expansion and increasing furniture needs. These factors have made Akungba-Akoko an ideal location for studying timber species used for wood-based enterprises.

The study population included timber traders, carpenters, and furniture makers operating in the Okusa Plank Market. A purposive sampling technique was used to select 45 respondents, consisting of 20 timber traders and 25 carpenters/furniture makers.

Data collection methods included structured questionnaires, oral interviews, and direct observation. Botanical identification of timber species was carried out using forestry field guides and cross-verification with forestry officers (NCP 2, 1973).

Data were analyzed using descriptive statistics (frequencies, percentages, mean prices) and qualitative content analysis to identify trends and perceptions.

RESULTS

Table 1. Demographic Characteristics of the Respondents

Variable	Frequency (n = 45)	Percentage (%)
Gender		
Male	36	80.0
Female	9	20.0
Age Range		
26-40	15	33.3
41-55	21	46.7
55 and above	9	20.0
Educational Background		
Primary Education	15	33.3
Secondary Education	24	53.3
Tertiary Education	6	13.4
Years of Experience		
1-5	5	11.1
6-10	10	22.2
11-15	18	40.0
16 and above	12	26.7
Income Dependency		
Timber-related trades alone	38	84.4
Timber trade with other job	7	15.6

Source: Field Survey, 2025

Tree Species Identified

A total of 23 timber species were identified as commonly traded and processed in Akungba-Akoko. These included indigenous and exotic species timber species as well as common fruit trees. These species vary in price and application in furniture and carpentry.

The Table 2, above shows that species such as Teak, Iroko and Mahogany command the highest prices due to their durability and resistance to pests. Cheaper species like *Ceiba pentandra* and *Alstonia boonei* are preferred for light and temporary structures. The table above shows that species such as Teak, Iroko, and Mahogany command the highest prices due to their durability, resistance to pests, and aesthetic appeal. Cheaper species like *Alstonia boonei* and *Ceiba pentandra* are preferred for light carpentry and temporary structures.

Market Trends and Species Preferences

It was observed from Table 2 that preferred hardwoods like Teak (*Tectona grandis*), Iroko (*Milicia excelsa*) and Mahogany (*Khaya grandifolia*) commanded high prices ranging from N7, 000 to N8, 000. These species were consistently in high demand due to their durability, resistance to biodegrading agents and aesthetic grain patterns. Moderately priced species such as Afara (*Terminalia superba*), Omo (*Cordia millenii*) and Iya (*Daniellia oliveri*) favoured medium grade furniture and general carpentry. They offer a balance between cost and quality. This makes them popular among mid-income customers, while the Low-cost, light-density woods such as Araba (*Ceiba pentandra*), Ahun (*Alstonia boonei*) and Para rubber (*Hevea brasiliensis*) were mostly used for temporary structures, low-cost furniture and non-load-bearing components. Their affordability made them accessible to low income buyers but are less durable. The non-traditional species including mango (*Mangifera indica*) and Ekikan (*Spondias mombin*) were increasingly being used as substitutes when preferred woods were scarce. While these species were not traditionally exploited for carpentry, their uses have grown in response to market shortages.

As presented in Table 2, species availability and sourcing from the responses of the respondents show that, approximately 60% of the timber sold in Akungba-Akoko originated from nearby forests and farmlands within Ondo and neighboring Ekiti, Kogi and Edo States. Additional 25% (mainly *Gmelina arborea* and *Tectona grandis*) came from plantations which are cultivated by government agencies and private individuals' farmlands. The remaining 15% were brought in from nearby timber markets such as those in Owo and Ikare-Akoko. It was noted that high-value species like Iroko and Mahogany are become harder to source locally. Thus, increased transportation costs are pushing the prices of such timbers higher.

Table 2. Timber species identified as commonly traded and processed in Akungba-Akoko

Common Name	Botanical Name	Average Price (N)	Average Purchase Per Month	Main Uses
Mahogany	<i>Khaya grandifolia</i>	7000	95	Furniture, paneling, doors, roofing
Obi	<i>Cola nitida</i>	6000	29	Furniture frames, joinery
Iroko	<i>Milicia excelsa</i>	7000	96	Outdoor furniture, flooring, construction
Ayunre	<i>Albizia lebbek</i>	6000	29	Roofing, light furniture
Omo	<i>Cordia millenii</i>	6000	48	Furniture, light construction
Ahun	<i>Alstonia boonei</i>	4000	27	Door frames, light construction
Ogbolo	<i>Bombax buonopozense</i>	6000	19	Light construction, flooring
Para Rubber	<i>Hevea brasiliensis</i>	3000	20	Light construction, flooring
Ekikan	<i>Spondias mombin</i>	3000	18	Decking, general carpentry
Mango	<i>Mangifera indica</i>	6000	21	Furniture's, doors
White Afara	<i>Terminalia superba</i>	6000	58	Furniture
Araba	<i>Ceiba pentandra</i>	4000	58	Decking, light furniture
Obeche	<i>Triplochiton scleroxylon</i>	4000	94	Furniture, doors
Akomu	<i>Pycnanthus angolensis</i>	4000	57	Furniture, light construction
Teak	<i>Tectona grandis</i>	8000	95	Furniture
Gmelina	<i>Gmelina arborea</i>	8000	87	Furniture
Iya	<i>Daniellia oliveri</i>	6000	58	Furniture,
Ayin	<i>Anogeissus leiocarpus</i>	Not applicable	48	Furniture
Cassia	<i>Senna alata</i>	Not applicable	18	Temporary structures
Isin	<i>Blighia sapida</i>	Not applicable	22	Joinery, light furniture
Ebaloko		3000	93	Temporary structures
Ire		3000	30	Temporary structures

Source: Field Survey, 2025

DISCUSSION

The demographic characteristics of the respondents as presented in Table 1 showed that out of the 45 respondents surveyed, 36 were males, while 9 were females. This gender distribution reflected the male-dominated nature of heavy timber handling, though women are significantly involved in sales and bookkeeping. A look at their ages revealed that 15 were between 26 and 40 years old; 21 were between the ages of 41 and 55 while only 9 were older than 55 years. This pointed out that middle-aged individual's dominated the timber trade in Akungba-Akoko. Considering their education level, it was found out that 15 had primary education before venturing into timber-related business; 24 respondents had secondary education while 6 had attended one tertiary institution or the other. This suggests that a reasonable level of literacy exists. This seems to be necessary for book keeping, size measurements, customer negotiations and networking with customers many of whom are educated similar to the reports of Nkwatoh, *et al.*, (2019) and Larinde, (2010).

Considering their levels of experience, 5 of the respondents claimed to have been involved in timber-related trade; 10 had 6-10 years; 18 had been in the business for 11-15 years, while 12 have got above 16 years in experience. This long-term engagement suggests that many traders and artisans have developed knowledge of timber species properties, seasonal availability, and market fluctuations. When dependency on the trade was considered, it was found out that 38 of the respondents dealt in their timber business alone, while 7 added other trades (especially farming to it. This pointed out the fact, that timber businesses are sufficient to sustain people engaged in such trades (Owonubi, and Otegbeye, 2004). The results of this study provide critical insights into the species composition, market dynamics and socio-economic drivers of timber exploitation in Akungba-Akoko. The findings reveal that while a diversity of tree species is being utilized, the demand tends towards a handful of high-value hardwoods such as *Tectona grandis* (Teak), *Milicia excelsa* (Iroko), and *Khaya grandifolia* (Mahogany). This pattern reflects a broader trend observed across Nigeria and Sub-Saharan Africa where consumer preferences for durability, aesthetics and pest resistance dictate market prices (Oluwadare and Sotannde, 2007).

Exploited Timbers and Species Distribution

The preference for preferred hardwoods such as Teak, Iroko, and Mahogany aligns with long-standing perceptions of these species as durable, resistant to termites, and aesthetically appealing. As noted by Owonubi and Otegbeye, (2004), reported the cultural and commercial reputation of certain hardwoods often drives market choices regardless of their scarcity or cost. However, the study also revealed an increasing reliance on unconventional fruit trees such as mango (*Mangifera indica*) and Ekikan (*Spondias mombim*). This shift reflects an adaptive market response to declining availability of traditional species. This trend was also reported in Southern Nigeria by Adekunle *et al* (2013) and Ogundele *et al* (2016). While substitution helps to meet immediate demand, it raises important questions about the suitability and durability of these alternative species in the long term. For example, some lower-density species like *Ceiba pentandra* (Araba) and *Alstonia boonei* (Ahun) may not withstand prolonged used in structural furniture. This invariably leads to shorter product life spans and consumer dissatisfaction (Larinde, 2010). One of the most pressing issues highlighted in this study is the sustainability of timber harvesting in Akungba-Akoko. Respondents consistently noted difficulties in sourcing preferred species locally. This has led to dependence of relatively distant markets and plantations. The overexploitation of species like Iroko and Mahogany is consistent with reports by Onyekwelu *et al* (2010) and Akinyemi *et al* (2021) who observed sharp declines in the abundance of indigenous hardwoods across South-Western Nigeria due to unsustainable logging practices and inadequate regeneration efforts. The growing prominence of plantation-grown species like *Gmelina arborea* and *Tectona grandis* reflects the importance of forestry investments in bridging the supply gap. However, plantations tend to emphasize narrow range of species, often exotics. This can reduce biodiversity and alter ecological functions (Owonubi and Otegbeye, 2004). They argued that the promotion of monoculture plantations must be balanced with conservation of native species in order to preserve ecosystem resilience.

Drivers of Timber Exploitation

Several socio-economic and demographic factors appear to drive timber exploitation in Akungba-Akoko.

1. Urbanization and housing expansion. This is fueled by the growth of Adekunle Ajasin University which has increased demand for student accommodation, furniture and commercial facilities.

2. Market accessibility through the Okusa Plank Market. This market acts as a central hub that links rural products to urban consumers.

CONCLUSION

This study revealed that Akungba-Akoko depends heavily on 23 identified timber species, with preferred hardwoods dominating the market. Market dynamics are shaped by durability, resistance to pests, and affordability. However, the scarcity of preferred species due to unsustainable harvesting is pushing artisans toward non-traditional alternatives. The results underscore the urgent need for sustainable forest management strategies that balance socio-economic needs with ecological preservation.

Recommendations

1. Promote reforestation programs with emphasis on indigenous hardwoods alongside exotic plantation species.
2. Encourage diversification of wood sources through bamboo, engineered wood, and other substitutes.
3. Strengthen community-based forest management and promote local participation in conservation.
4. Improve forestry governance through stricter monitoring of logging activities and permit systems.
5. Provide training and incentives for artisans and traders to adopt sustainable practices.
6. Conduct further research on under-utilized species to expand market options and reduce pressure on preferred hardwoods.

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WILDLIFE CONSERVATION: LEVERAGING ON SOCIAL MEDIA TO MITIGATE SPECIES EXTINCTION

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ABSTRACT

Social media has been a valuable tool for wildlife conservation. It serves as a means of awareness, advocacy, and real-time data collection. With over 4.48 billion users across the globe, platforms such as Facebook, Instagram, YouTube, and Twitter provide broad opportunities to engage various audiences on conservation efforts. This review explored the potential benefits and associated risks of social media in wildlife conservation. Among the benefits are the ease of disseminating educational content, promoting fundraising effort and fostering online communities unity against wildlife exploitation thereby enhancing public awareness. The risks include, increased visitor pressure on protected areas, promotion of illegal wildlife trade and misconceptions that undermines conservation efforts. Moreover, how posts regarding rare species or geotagged locations can unconsciously fuel poaching and exploitation were explained. Ultimately, this review emphasized the need for a balanced approach to using social media in wildlife conservation, ensuring that its benefits outweigh the potential harms to biodiversity.

Keywords: Wildlife Conservation, Rare species, Geotagged Location, Facebook, Instagram

INTRODUCTION

Social media has become indispensable means in lifestyle to obtain, share, and spread information, especially on wildlife. This is because of its convenience, and recent and rapid development (Wu *et al.*, 2018). The mass media's coverage of wildlife may have the same social purpose as first- or second-hand biological conservation education because most people will never see endangered species in the wild (Sollund, 2022). Given that, over half of the world's population that use internet, social media platforms such as Facebook, Instagram, YouTube, and Twitter, therefore have the opportunity to significantly impact societal change via social media to present their views, and investigate creative approaches to protect biodiversity (Vaz *et al.*, 2020). Importantly, social media has become indispensable tool to enlighten the populace on how to utilize their unmatched reach and influence as conservation effort to improve and promote environmental behaviors for large-scale nature protection (Orzan, 2025).

Despite increased global conservation efforts, species extinction rates continue to rise due to persistent threats like habitat loss, climate change, pollution, overexploitation, and the spread of invasive species, which often outpace the impact of protective measures (Orzan, 2025). The multitude of overlapping and occasionally synergistic factors of biodiversity loss has never presented conservation disciplines with greater challenges than it does today. In today's digital age, social media can reach people from diverse sociodemographic backgrounds because it is widely accessible, affordable, and adaptable to different ages, education levels, incomes, cultures, and locations (Gambo and Ozad, 2020). Today, there are 4.48 billion social media users globally, who are fairly similarly distributed across all continents, including developed and developing nations, as well as across genders and ages.

Social media users create real-time content and share information in the form of text, images, and videos that can be used to support a wide range of conservation-focused research, conservation scientists are beginning to recognise social media as a unique and large-scale source of data. Invasive species monitoring, animal behaviour analysis, identifying the reasons why visitors choose to visit protected areas, educating and guiding choices for the conservation of endangered species (Gambo and Ozad, 2020). Posts that have been geotagged, or contain geographic information, can also be used to map species distributions, human visitors in protected areas and ecosystem services (Baker and Winkler, 2020).

Uncertainty surrounds social media's potential as a tool for cultural change because, while it offers a vast platform for raising awareness and mobilizing communities, its effectiveness in fostering genuine, long term

behavioral shifts that directly lead to successful conservation outcomes remains unclear, given the complex interplay of social, economic, and environmental factors involved (Bergman *et al.*, 2022).

Research Design

This review involves existing data from secondary sources to incorporate recent knowledge on the roles of social media on wildlife conservation. It focused on potential benefits and associated risks functioning as tools for awareness, public involvement and driver of risk on exploitation and misinformation. Literature search was conducted across Web of Science, Pub Med and Google Scholar, covering period of year 2020–2025. Web of Science, Pub Med and Google Scholar were employed because they measure citation counts of articles which is an indicator of how often an article is cited by other researchers, this helps to determine the importance of the material for the scientific community. Also, between 2020 and 2025 global internet usage experienced significant growth driven by digital transformation, mobile connectivity and post pandemic reliance on online platforms. To capture contemporary developments, grey literature sources such as Non-Governmental Organisation (NGO) reports, policy briefs, and investigative journalism on wildlife trade were engaged. Keywords combined terms including: social media and wildlife conservation, geotagging and species exploitation and illegal wildlife trade and online platforms. Studies were considered if they addressed the use of social media for awareness, monitoring, or advocacy, or if they examined risks such as illegal trade or disturbance. Findings were organized through thematic analysis, enabling comparison of benefits and risks. Ethical considerations guided the review, with sensitive details such as precise species locations excluded to avoid potential misuse.

Social Media for Awareness and Advocacy

The alarming establishment and development of social media tools and series of its platforms had made it convenient to acquire, share and propagate information, including discussion on wildlife (Bergman *et al.*, 2022). News and innovations on wildlife from mass media may serve as the same social function as primary or secondary sources of biological conservation education, being that most people may not encounter endangered species physically in the wild.

Social media has an immense significance in bringing wildlife conservation to public notice thereby raising public awareness by providing a media through which the globe is educated, inspired and mobilized. Through visually engaging videos or content such as wildlife photography or captivating pictures, videos, info graphics and live updates, the importance of protecting wildlife especially the endangered species, habitat preservation and various threats to wildlife like climate change and poaching caused by anthropogenic activities (Pimm *et al.*, 2014). Various social media platforms like Instagram, Youtube, Facebook and Tiktok are being employed to spread messages about conservation across the globe to diverse audiences especially younger generations. This encourages various conservation efforts like volunteering, advocacy, donations, hashtag campaigns, also conscious efforts of influencers collaborating to enhance public support by combining story telling with factual news with prompts call to action (Bergman *et al.*, 2022). Therefore, social media helps to bridge the gap between public understanding and conservation efforts on wildlife thereby enhancing the fight against environmental degradation, hence protecting wildlife and sustainable coexistence with nature (Bergman *et al.*, 2022).

Benefits of Social Media in Wildlife Conservation

Raising Funds for Wildlife Conservation: Funding is a major building block for successful conservation, many of rehabilitated wildlife such as bears, elephants, and leopards have received a new lease of life. Good funding is necessary to take care of the wildlife, challenges to good funding are resolved via social media through fund raising. Moreover, information on this wildlife is necessary for their understanding, survival and sustainability.

Furthermore, careful evaluation of social media websites like Instagram, Facebook, Twitter, LinkedIn, and YouTube has helped to pick the best tools to use to reach out to vast audiences with whom stories of rescued animals can be shared. By getting to know about the animals' poignant pasts and understanding the challenging efforts that conservation organization takes to secure their future, lots of social media users and influencers have been inspired to support by taking the lead and protect wildlife (Baker and Winkler, 2020).

Creating Awareness and a Community: Social media via YouTube videos have made it easy to understand captions on Facebook and Instagram, the lesser-known facts about various animals that cohabit our world are being elucidated (Jarić *et al.*, 2024). As virtual audience is being informed about rescues and efforts, followers and subscribers tend to get interested and bring news about animal abuse and mistreatment, animals that are caught in illegal trade or those facing conflict situations from every corner of the nation. In these ways, the growth of a powerful community of people who are united against injustice to animals have been built (Baker and Winkler, 2020).

Encouraging Policy Action and Legislation: The social media's role in galvanizing popular opinion, has been used responsibly to create a productive impact on policy, law, and their enforcement. In scenarios that attract mass attention, social media may enable prompt legislative action, and it also has the potential to increase support for endangered species protection (Baker and Winkler, 2020).

Risks of Social Media in Wildlife Conservation

Illegal wildlife trade: The risks associated with social media in wildlife exploitation are varied and can have significant, long-term impacts on conservation efforts (Davis *et al.*, 2024). One of the major challenges is illegal wildlife trade, social media platforms are employed to encourage this; the media are being engaged to promote visibility and increase the rate at which this kind of information spreads, making it easier for traffickers to promote the sale of endangered species or their body parts (Tessema *et al.*, 2021). Either through post that display rare species or share locations of specific animals, these platforms can provide a ready market for illegal transactions. Even unintended compromise, such as showcasing animals in their natural habitats or discussing how to interact with them can casually encourage illegal exploitation, such as poaching, or contribute to the demand for exotic pets, thus further endangering species (Duffy, 2022).

Social media pressure: This is another major risk whereby social media exerts pressure on protected areas and wildlife habitats, in which certain locations or species gain popularity on social platforms, the influx of visitors can overwhelm these areas, leading to overcrowding, habitat destruction, and disturbances to wildlife (Bergman *et al.*, 2022). For instance, when rare species are shared widely online, the desire to see these animals in person can drive tourists to flock to these locations, often with little regard for the environmental or ethical implications of their visits. This influx can lead to overexploitation of the environment, disturb delicate ecosystems, and even put the animals themselves at greater risk, as increased human activity can disrupt natural behaviors and create stress on species that are already vulnerable (Bergman *et al.*, 2022).

Misconception: This is another significant risk tied to social media with respect to wildlife conservation, through false or misleading content, being intentional or accidental; leading to misunderstanding on conservation issues (Islam *et al.*, 2020). Inaccurate description or identification of species and their status, conservation policies or the effectiveness of certain protection efforts can lead to misguided opinions which can in turn undermine legitimate conservation initiatives. Additionally, social media are misconstrued to be a breeding ground for anti-conservation narratives that discourage important efforts such as habitat protection, sustainable tourism, or species restoration (Igoe, 2021). These harmful misconceptions can hinder the public's support for policies aimed at protecting biodiversity, ultimately slowing progress toward achieving long-term conservation goals (Cléménçon, 2021).

CONCLUSION

The rapid growth of social media brings a reasonable opportunity for increasing public awareness on wildlife conservation. However, if not properly used it could result in misconception and misinformation, hence, leading to series of havoc; and this exploitation could cause damage to wildlife activities, population and also lead to habitat disturbance, exploitation and illegal trade of wildlife. Therefore, to ensure that the benefit of social media is maximized while minimizing its risk, measures should be in place whereby conservation experts and policy makers ensure that social media ethics are encouraged such as avoiding geotagging, and false or misleading information as regards wildlife. Importantly, informed and balanced approach is essential to harness the full potential of social media as indispensable tool for wildlife and biodiversity protection in the digital age.

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CLIMATE (MIS)GOVERNANCE, ARMED CONFLICT, AND THE LEGAL DUTY TO PROTECT AGRICULTURAL LIVELIHOODS IN FRAGILE REGIONS IN NIGERIA

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Abstract

This study examines the nexus between climate misgovernance, agricultural vulnerability, and conflict in South-West Nigeria, with emphasis on the legal duty to protect rural livelihoods. Using a mixed-methods design, survey data from 200 farmers and interviews with 30 stakeholders (farmers, officials, NGOs, and legal practitioners), the study reveals that 74% of farmers experienced recurrent crop losses due to droughts and floods, while 46% reported violent encounters with herders. Legal awareness and institutional trust were low, with only 38% of the farmers are aware of land rights laws and confidence in government protection, averaging 2.4/5. Qualitative accounts further underscored weak enforcement, limited access to legal remedies, and reliance on NGOs for advocacy and support. While constitutional, statutory, and international frameworks formally recognize Nigeria's duty to safeguard the environment and food security, enforcement gaps and institutional overlaps leave smallholders highly exposed to climate shocks and insecurity. The study concludes that integrated strategies, through strengthening of legal enforcement, expanding adaptation support, improving conflict resolution, and leveraging international commitments, are critical to securing agricultural livelihoods and preventing further conflict in fragile regions.

INTRODUCTION

Southwest Nigeria (the Yoruba states of Lagos, Ogun, Oyo, Ondo, Osun, Ekiti) is a major agricultural region (cocoa, cassava, yam, maize) with growing exposure to climate risks. Farmers increasingly face erratic rains, floods, and droughts, which degrade soils and reduce yields.¹ At the same time, resource pressures have spurred tensions among users of agricultural land. Tension comes between cattle herders moving southward (due to northern desertification) clash with crop farmers over land.² These dynamics of climate misgovernance is a failure of policies to manage climate impacts and protect vulnerable communities which consequently magnify agricultural insecurity. This paper explores how poor climate and land governance contribute to livelihood loss and conflict, and critically asks what legal duties and enforcement mechanisms exist in Nigeria to protect farmers. It focuses on legal obligations: constitutional provisions, statutes (including environmental and land laws), customary rights, and international treaties. Through case studies in Southwest Nigeria, the paper illustrates how courts and policies have (sometimes) upheld farmers' rights, and where gaps remain. In sum, the analysis argues that while Nigeria's laws nominally mandate environmental and agricultural protection, weak implementation renders many rural livelihoods legally unprotected, unless rights-holders actively pursue enforcement.

Literature Review: Climate, Conflict, and Livelihood Vulnerability

Climate change in Nigeria has disrupted agriculture nationwide. Studies document rising temperatures, unpredictable rainfall, and extreme weather (droughts, floods) that reduce crop yields and livestock productivity.³ For example, a systematic review notes that “environmental destruction, biodiversity loss, and dwindling water supplies, all hurt food security” in Nigeria, which relies almost entirely on rain-fed farming.⁴ Empirical studies report find that rainfall variability and heat waves in Southwest states (e.g., Oyo, Lagos, Ogun) already cause soil erosion and crop damage.⁵ In 2022, record floods nationwide submerged some

AgnesAfrica, “Farmers in Southwest Nigeria Adjust their Planting Patterns to Adapt to Climate Change” (AgnesAfrica, 2025)

<<https://www.agnesafrica.org/farmers-in-southwest-nigeria-adjust-their-planting-patterns-to-adapt-to-climate-change/#:~:text=Climate%20change%20has%20largely%20influenced,such%20as%20cocoa%20and%20yam>> accessed 14 November 2025.

² Ciara Nugget, “Land Conflict Has Long Been a Problem in Nigeria. Here's How Climate Change Is Making It Worse” (TIME, 28 June 2018) <<https://time.com/5324712/climate-change-nigeria/>> accessed 14 November 2025.

³ Eneh Okon et al, “Systematic review of climate change impact research in Nigeria: implication for sustainable development” (2021) 7(9) Heliyon Journal <<https://pmc.ncbi.nlm.nih.gov/articles/PMC8436081/#:~:text=%28Downing%20et%20al,definitely%20draws%20a%20setback%20to>> accessed 15 November 2025.

⁴ Ibid.

⁵ n(1) ibid.

770,000 hectares of cropland, killed hundreds, and displaced millions.⁶ At the community level, farmers in Southwest Nigeria report prolonged dry spells and erratic rains that force them to alter planting dates, harvest early, and adopt drought-resistant varieties, often without sufficient technical or financial support.⁷ Such evidence confirms that climate mismanagement (lack of adaptation planning, under-funded extension services, etc.) leaves smallholder farmers highly vulnerable.

A growing body of research links these climate stresses to conflict over land and livelihoods. In Nigeria, desertification and pasture loss in the north have driven Fulani herders southward, provoking deadly clashes with farmers over shrinking grazing lands.⁸ A 2018 TIME report documented that over 10,000 Nigerians had died in farmers-versus-herders violence since 2011, as water and farmland become scarcer.⁹ Similar patterns hold in West Africa broadly: competition for resources under climate pressure often falls along ethnic and religious lines. In Nigeria's South-West, while conflicts have historically been less intense than in the Middle Belt or Delta, recent years have seen anti-grazing laws by state governments and localized tensions where migrant herders encroach on Yoruba farmlands. In summary, the literature shows that environmental degradation and climate extremes tend to undermine rural livelihoods and can spark conflict, especially when governance fails to allocate or protect land and water resources equitably.¹⁰

Legal Framework for Protecting Agriculture and Environment

Constitutional Provisions

The Nigerian Constitution (1999) imposes several obligations on the state regarding the environment and welfare of the Nigerian people. Section 20, in the Fundamental Objectives and Directive Principles, mandates that “the State shall protect and improve the environment and safeguard the water, air, land, forest and wildlife of Nigeria”.¹¹

Although Section 20 (Chapter II) is technically non-justiciable by itself (Section 6(6)(c) of the Constitution), courts have developed exceptions: when parliament enacts implementing legislation or when these principles are invoked via fundamental rights. In practice, courts have treated Section 20 as embodying a constitutional policy commitment.¹²

Most critically, fundamental rights provisions have been interpreted to include environmental protection. Section 33(1) guarantees the right to life, and Section 34(1) the right to dignity. In landmark decisions, Nigerian courts explicitly held that these rights encompass a clean, and healthy environment. For example, in *Gbemre v. Shell* (FHC, 2005), the court held that the constitutionally guaranteed “rights to life and dignity ... inevitably includes the right to clean, pollution-free and healthy environment”.¹³ The Federal High Court enjoined Shell to cease gas-flaring, noting that Shell's failure to conduct a statutorily required Environmental Impact Assessment violated the EIA Act and thus the communities' right to a healthy environment.¹⁴ Similarly, in *Centre for Oil Pollution Watch (COPW) v. NNPC*, the Supreme Court confirmed that Section 20 and the African Charter taken together recognize Nigerians' “fundamental right to a clean and healthy environment to sustain life”.¹⁵ Thus, the constitution (through creative jurisprudence) and the Constitution's affirmation of universal rights effectively create a positive duty on the state and others to protect environmental conditions vital to life and livelihoods.

Beyond environmental clauses, the Constitution also addresses agriculture indirectly. The Concurrent Legislative List includes agriculture and natural resources, meaning both federal and state legislatures can

⁶ Bukola Adebayo, “Armed with AI and cash, Nigerian farmers act before floods” (*Context*, 3 September 2024) <<https://www.context.news/ai/armed-with-ai-and-cash-nigerian-farmers-act-before-floods>> accessed 15 November 2025.

⁷ n(1) *ibid.*

⁸ n(2) *ibid.*

⁹ *Ibid.*

¹⁰ *Ibid.*

¹¹ Collins Okeke, “Environmental rights as Constitutional rights: Nigeria's legal evolution” (*BusinessDayNG*, 19 January 2025) <<https://businessday.ng/opinion/article/environmental-rights-as-constitutional-rights-nigerias-legal-evolution/>> accessed 15 November 2025.

¹² *Ibid.*

¹³ *Ibid.*

¹⁴ *Gbemre v. Shell Petroleum Development Company of Nigeria Ltd. and Others* (2005) AHRLR 151.

¹⁵ n(11) *ibid.*

legislate on agricultural policy. Notably, the Fifth Schedule assigns local government councils a duty of “participation in the development of agriculture and natural resources, other than the exploitation of minerals”.¹⁶ This provision underscores those local authorities are legally tasked with promoting farming and rural development. In addition, the Constitution's Preamble and Section 14(2)(b) declare that “the security and welfare of the people shall be the primary purpose of government,” implying an obligation to ensure food security. While no explicit “right to food” appears, these provisions frame agriculture and environment as core state responsibilities.

Statutory and Regulatory Laws

Nigeria has a host of statutes aimed at environmental protection and agricultural welfare. Key among these is the Environmental Impact Assessment Act (EIA Act) of 1992 (as amended), which mandates government and companies to assess environmental effects before projects (mining, oil, infrastructure) proceed. Courts have treated the EIA Act as part of enforcing Chapter II objectives. In *Gbemre*, for example, the judge stressed that Shell's failure to conduct an EIA “is a clear violation of the EIA Act and a violation” of the constitutional rights.¹⁷ Other relevant statutes include the National Environmental Standards and Regulations Enforcement Agency (NESREA) Act 2007, which created a central regulatory agency to enforce environmental standards. NESREA's mandate is to “enforce compliance” with environmental laws across sectors, “prevent and control pollution, promote sustainable development and ensure environmental quality”.¹⁸

In practice, NESREA is empowered to prosecute polluters, but resource and jurisdictional limits have hampered its effectiveness.

Agricultural livelihoods are also affected by land laws. The Land Use Act (1978) vesting all land in the state governors, effectively nationalizing land tenure. It recognizes Customary Rights of Occupancy, allowing individuals or communities to use land for farming, subject to obtaining certificates from local authorities (and subject to state acquisition). In Southwestern Nigeria, customary land tenure is traditionally communal and hereditary.¹⁹ The Land Use Act's top-down system has been criticized for creating uncertainty over rural land rights, but it remains the statutory regime. Customary practices still inform many farming communities' land claims. In sum, statutory law provides tools (EIA, pollution standards, land titles) for protecting farms, but enforcement is uneven, and farmers often lack legal title or resources to invoke these laws.

International Obligations

Nigeria has ratified multiple international treaties that bear on climate, environment, and agriculture. It ratified the UN Framework Convention on Climate Change (UNFCCC) in 1994, its Kyoto Protocol in 2004, and the Paris Agreement in 2017.²⁰ Under the Paris Agreement, Nigeria has pledged to limit emissions growth and to adapt to climate impacts (through its Nationally Determined Contribution). In 2021, Nigeria domesticated these goals by enacting the Climate Change Act 2021, which establishes a National Council on Climate Change, a carbon budgeting process, and a Climate Change Fund.²¹ This Act obliges national and subnational governments to incorporate climate targets into policy – for example, aiming for net-zero emissions by mid-century.²² However, the Act's enforceability is new, and its implementation remains a work in progress.

Nigeria is also party to the African Charter on Human and Peoples' Rights (ratified domestically by the 2004 Act). Article 24 of the Charter explicitly guarantees “the right to a generally satisfactory environment

¹⁷ n(14) *ibid*.

¹⁸ Osazuwa Abraham, “Litigation as a Tool for Environmental Protection in Nigeria” (*Sabilaw*, 26 June 2023) <<https://sabilaw.org/litigation-as-a-tool-for-environmental-protection-in-nigeria-2/#:~:text=This%20body%20was%20established%20in,conducting%20public%20enlightenment%20campaigns%20and>> accessed 16 November 2025.

¹⁹ n(1) *ibid*.

²⁰ Tijah Bolton-Akpan “Nigeria in the Paris Accord” (*PunchNG*, 16 March 2021) <<https://www.google.com/amp/s/punchng.com/nigeria-in-the-paris-accord/%3famp>> accessed 16 November 2025.

²¹ Ihunoma Anyawu, “Assessing Compliance with Nigerian Climate Change Act 2021 (*Lawdevhub*, 2025) <<https://lawhubdev.org/wp-content/uploads/2025/03/Compliance-of-Climate-Change-Act-2021.pdf#:~:text=challenges%2C%20the%20Nigerian%20government%20enacted,and%20fulfill%20international%20climate%20commitments>> Accessed 16 November 2025.

²² *Ibid*.

favorable to their development”.²³ Although international, the Charter has domestic force; Nigerian courts have treated Article 24 (and complementary rights to health and life in the Charter) as reinforcing citizens' environmental rights.²⁴ Additionally, Nigeria ratified the International Covenant on Economic, Social and Cultural Rights (ICESCR) in 1993 which includes rights to adequate food, health and housing (Art.11).²⁵ Although these socio-economic rights are not directly justiciable under Nigerian law, they inform the state's duty to protect livelihoods in line with its “maximum available resources” commitments. Nigeria has also joined the UN conventions on biodiversity, desertification, and disaster reduction. Taken together, these treaties impose international obligations: to adapt to climate change, to prevent degradation, and to progressively realize food security. While not self-executing, they reinforce that failure to safeguard agricultural livelihoods may violate Nigeria's external commitments and its Charter duties.

Climate Misgovernance, Conflict, and Livelihood Instability

Poor governance like regulatory gaps, corruption, or under-resourced climate policy, has worsened farmers' vulnerability. For instance, heavy deforestation and erosion in Oyo and Osun States (due to illegal logging and highway projects) have increased flood damage and siltation of farmland. On the coast (Lagos, Ondo), sea-level rise and unregulated development threaten fisherfolk and rice farmers. Meanwhile, rising demand for agricultural land has led to pressure sales or forced evictions in some rural areas. These environmental stresses underlie inter-group tensions: where climate-driven migration raises new land users, or where failing harvests fuel social strife.

In Nigeria's Southwest, evidence of these linkages is accruing. An AGNES Africa study reports that smallholder farmers face not only irregular rains and floods, but also early onset and “false” rains that disrupt cocoa and yam crops.²⁶ During extreme events, communities have had to improvise (e.g., raising barns or switching to early-maturing seeds) to avoid total loss.²⁷ However, the same farmers “lack enough resources and support to effectively adapt and become resilient”.²⁸ This suggests climate misgovernance: the government has not provided sufficient extension services, credit, or infrastructure (like drainage systems) to help rural communities cope. At the same time, conflict has begun to appear. For example, Southwest state governments (Ogun, Oyo, Osun, Ondo, Lagos, Ekiti) have enacted anti-open-grazing laws (2020–21) as a response to reports of herders' incursions into farms. The need for such laws reflects the collision of land use pressures: a weak enforcement of pastoral quotas and grazing reserves drove herders onto crop fields, causing violent clashes and undermining farmers' security. In short, declining agricultural productivity and weak regulation have contributed to local conflicts over land and resources in the Southwest, in line with the broader pattern that environmental stressors (drought, soil loss) are correlated with unrest.²⁹

Case Studies from Southwest Nigeria

In all six Southwest states, farmers report concrete shifts in climate patterns and have begun adapting. For example, an AGNES Africa study of rainfed farmers in Oyo, Osun, Ogun, Ondo, Ekiti, and Lagos found widespread flooding and erosion from intense rains: “Flooding causes erosion which...reduces nutrient value of the soil affecting ...farm produce”.³⁰ Irregular rainfall – including untimely or false starts of rainy seasons – has left crops like cocoa and yams at risk. Faced with this, farmers are adjusting planting schedules, harvesting early, mulching soils, and switching to drought-tolerant crops.³¹ But as noted, they “lack enough resources and support to effectively adapt”. This situation highlights the legal duty gap: Nigeria's laws (and recently its Climate Act) call for support and adaptation programs, but in reality, SW smallholder farmers receive minimal climate extension or financing. If the state provided subsidies, training, or guaranteed crop insurance (as some climate policies envisage), livelihoods would be more secure.

²³ n(11).

²⁴ Ibid.

²⁵ Scheagbe Grimsby, “Enforcing Economic, Social, and Cultural Rights: A Stark Dichotomy” (*NULaw Review*, 3 May 2017) <<https://nulawreview.org/extralegalrecent/2017/5/3/enforcing-economic-social-and-cultural-rights-a-stark-dichotomy#:~:text=Nigeria%20ratified%20the%20ICESCR%20on,Article%202%20does%20not%20allow>> accessed 17 November 2025.

²⁶ n(1) *ibid*.

²⁷ Ibid.

²⁸ Ibid.

²⁹ n(3).

³⁰ n(1).

³¹ Ibid.

Conflict and Legal Response.

Southwest Nigeria has seen various land-use tensions. In recent years, all six SW governors (Yoruba states) have adopted anti-open-grazing laws (Ekiti in 2016; others in 2021) to protect farmers' lands. These laws, backed by the Constitution's agriculture mandate, criminalize herding without consent and aim to prevent farm invasions. Although beyond the Southwest, the farmers–herders' conflicts in Nigeria have a clear climate dimension (northern droughts pushing cattle into the south).³² In the Southwest, for instance, Ondo and Ekiti farmers have pressed charges against trespassers and formed vigilante groups. These state laws provide a domestic accountability mechanism: violators can now be prosecuted under state law for trespassing and destroying crops, rather than resorting to violence. To date, courts in SW have yet to interpret these laws in reported cases, but their existence signals that the state recognizes a duty to shield agricultural communities from conflict related to resource pressures.

Litigation Example: While most landmark environmental cases in Nigeria involve oil-producing regions, a notable Southwest example is *ERA/Friends of the Earth v. FG* (2019, FHC Lagos). In that case, Edo/Delta (south-south) NGOs sued the federal government for failing to release an air-quality management plan. The Lagos High Court held that the government must “implement its national air quality standards,” effectively requiring action to protect public health and, by extension, food producers from air pollution.³³ This ruling, though not from SW, applies nationwide and demonstrates that citizens and NGOs can compel state compliance via litigation. It underscores that under Nigeria's legal framework, failure to act (a form of misgovernance) can itself be declared a breach of duty.

METHODOLOGY

Research Design

This study employed a mixed-methods research design, combining quantitative and qualitative approaches to capture both the breadth and depth of livelihood vulnerability in South-West Nigeria. The quantitative component, a structured survey, was used to measure the prevalence and scale of farmers' experiences with climate shocks and conflict, while the qualitative component, semi-structured interviews, provided deeper insights into institutional, legal, and governance challenges. The integration of both methods enabled a more comprehensive understanding of the complex dynamics surrounding environmental risks and adaptation strategies.

Data Collection

Survey

The quantitative survey was administered to 200 farmers across the six states of South-West Nigeria: Lagos, Ogun, Oyo, Osun, Ekiti, and Ondo. The questionnaire focused on five key domains: (1) experiences of climate-related shocks, (2) incidences of conflict, (3) legal awareness, (4) access to institutional support, and (5) trust in government structures. The survey provided large-scale empirical evidence of the vulnerabilities and adaptive capacities within farming communities.

Interviews

To complement the survey findings, 30 semi-structured interviews were conducted with diverse stakeholder groups. These included 15 farmers, five government officials, five representatives from non-governmental organisations (NGOs), and five legal practitioners. The interviews were designed to elicit rich narratives and reflections on perceptions of climate risks, conflict resolution mechanisms, enforcement of legal frameworks, and the role of institutional and community-based adaptation strategies.

Data Analysis

Quantitative Data

Survey responses were analysed using descriptive statistics. Frequencies, percentages, and mean scores were computed to summarise the magnitude and severity of climate and conflict impacts as reported by farmers. Tabular presentations are used to highlight trends and facilitate interpretation.

³² n(2) *ibid.*

³³ n(21) *ibid.*

Qualitative Data

The interview transcripts were subjected to thematic analysis. Recurring patterns were identified across four main themes: livelihood vulnerability, institutional weakness, gaps in legal enforcement, and the role of NGOs in community support. Illustrative quotations from participants are incorporated into the analysis to substantiate thematic findings and provide contextual richness.

Integration of Findings

Triangulation was applied to integrate results from both data strands. Convergent and divergent findings were compared to construct a holistic interpretation of the environmental, social, and legal dimensions of vulnerability. This integrative approach ensured greater validity and reliability of the study's conclusions.

Ethical Considerations

The research obtained ethical clearance from the relevant institutional review board before data collection. Informed consent was sought and obtained from all participants, and respondents were assured of confidentiality and anonymity throughout the process. Sensitive data were handled in accordance with ethical research guidelines to protect participants' rights and privacy.

RESULTS

This study employed a mixed-methods approach, integrating survey data from 200 respondents across six South-West states of Nigeria with qualitative interview insights from farmers, government officials, NGO representatives, and legal practitioners. The results are presented under four major themes: Climate and Livelihood Vulnerability, Conflict and Security Challenges, Legal Awareness and Institutional Weakness, and Role of NGOs and Community-Based Interventions. Quantitative survey findings are supplemented with qualitative excerpts to provide a richer understanding of the observed patterns.

1. Climate and Livelihood Vulnerability

Survey data indicated that climate extremes are a major risk to farmers' livelihoods. 74% of farmers reported recurrent crop losses due to droughts and flooding, with an average frequency of 2.7 droughts and 1.8 floods per farmer over the past five years. The perceived severity of these events was high (mean = 4.1/5) (Table 1).

Table 1: Climate and Livelihood Vulnerability

Indicator	% Observed Value	Notes
Crop loss due to climate extremes	74%	Mainly drought & flooding
Frequency of drought (past 5 yrs)	2.7 times per farmer	Average
Frequency of flooding (past 5 yrs)	1.8 times per farmer	Average
Perceived severity (1 –5 Likert)	4.1	High impact

Source: Fieldwork, 2025

Qualitative interviews reinforced these findings. A farmer from Ekiti State noted:

“Last year, the flood took half of my cassava. The government promised help, but we saw nothing.”

Similarly, a farmer from Oyo State stated:

“We are not only fighting the weather; we are fighting insecurity on our farms. Who protects us?”

Interpretation

The integration of survey and interview data indicates that farmers' livelihoods are highly vulnerable to environmental hazards. Climate shocks are compounded by social and security challenges, emphasizing the need for comprehensive adaptation strategies.

2. Conflict and Security Challenges

Survey results highlighted that 46% of farmers experienced at least one violent encounter with herders, and 28% reported land disputes with neighbors. The perceived effect of insecurity on production averaged 3.8/5 (Table 2).

Table 2: Conflict and Security Challenges

Indicator	% / Mean	Notes
Farmer-herder conflict incidence	46%	At least one violent encounter
Land disputes with neighbors	28%	Boundary-related conflicts
Perceived effect on production (-5)	3.8	Moderate to high impact

Source: Fieldwork, 2025

Qualitative accounts provided deeper insight. A government official from Ogun State stated: “Our laws exist, but enforcement is weak because agencies overlap. Farmers don't even know where to report violations.”

An NGO representative from Osun State observed:

“Most cases of land grabbing or herder conflict never reach the courts; farmers simply give up due to costs.”

Interpretation:

Conflict and insecurity are major constraints on agricultural production. Quantitative prevalence is supported by qualitative narratives pointing to systemic institutional weaknesses and inadequate conflict resolution mechanisms.

3. Legal Awareness and Institutional Weakness

Survey data showed low levels of legal awareness and limited institutional support. Only 38% of farmers were aware of land rights laws, 29% knew about state-level agricultural policies, and 18% had ever accessed legal aid. Confidence in government protection was low (2.4/5) (Table 3).

Table 3: Conflict and Security Challenges

Indicator	% / Mean	Notes
Awareness of land rights laws	38%	62% unaware
Knowledge of state-level agri policies	29%	71% unaware
Access to legal aid	18%	Mostly through NGOs
Confidence in govt. protection (5)	2.4	Low trust in government
Govt. extension support (last 2 yrs)	41%	Limited reach
Compensation for climate/conflict loss	7%	Extremely low

Source: Fieldwork, 2025

Qualitative insights highlighted the structural nature of these weaknesses. A legal practitioner from Lagos State explained:

“Section 20 of the Nigerian Constitution emphasizes environmental protection, but it is non-justiciable. Farmers cannot enforce it directly.”

An NGO legal advocate from Ondo State added:

“There is a duty of care owed by government, but without enforcement mechanisms, rights remain on paper.”

Interpretation:

The combined evidence demonstrates a significant gap between legal provisions and practical enforcement. Farmers face vulnerability due to both a lack of legal knowledge and weak institutional mechanisms.

4. Role of NGOs and Community-Based Interventions

Survey results indicated that 22% of farmers received NGO support in the form of training, advocacy, or legal aid, highlighting the supplementary role of NGOs where government support is insufficient (Table 4).

Table 4: Role of NGOs and Community -Based Interventions

Support Type	% / Mean	Notes
NGO support (training, advocacy, legal aid)	22%	Limited coverage

Source: Fieldwork, 2025

Qualitative interviews emphasized the critical but limited role of NGOs. An NGO officer from Ekiti State stated:

“We train farmers on land rights and climate adaptation, but our reach is small compared to the need.”

A farmer from Lagos State confirmed:

“Only when NGOs come do, we hear about our rights. Government doesn't tell us.”

Interpretation:

NGOs play a vital role in awareness-building and capacity development, especially in areas neglected by government programs. However, limited resources constrain their coverage, necessitating stronger collaboration between NGOs and state institutions.

5. Integrated Summary

The combined quantitative and qualitative analyses reveal the following:

- Climate and livelihood fragility a major challenge, with environmental shocks compounded by insecurity.
- Conflict and insecurity are widespread and hinder agricultural productivity, linked to institutional inefficiencies.
- Legal awareness and institutional support are inadequate, leaving farmers vulnerable and mistrustful of government interventions.
- NGOs and community-based interventions provide important support, but limited reach reduces their overall impact.

Conclusion from Integrated Findings:

The results indicate a multi-dimensional vulnerability for farmers in South-West Nigeria, shaped by environmental, social, legal, and institutional factors. Addressing these challenges requires integrated strategies combining climate adaptation, conflict resolution, legal empowerment, and strengthened institutional support.

CONCLUSIONS

The study shows that agricultural livelihoods in South-West Nigeria are under significant strain from the combined pressures of climate change, environmental degradation, and recurring conflicts. These vulnerabilities are compounded by weak enforcement of existing laws, institutional overlaps, and limited support for farmers at both the community and state levels. Although Nigeria has strong constitutional, statutory, and international commitments to environmental protection and food security, these remain largely unfulfilled in practice. The gap between legal provisions and actual implementation leaves many smallholder farmers exposed to livelihood loss and insecurity. Addressing these challenges requires not only policy reforms but also deliberate action to strengthen enforcement, improve governance, and build resilience in farming communities. Protecting agriculture is not only a constitutional obligation but also essential for peace, food security, and sustainable development.

Recommendations

1. Strengthen Climate Adaptation Measures

- Improve extension services, infrastructure, and financial mechanisms that support farmers in adapting to climate variability.

2. Enhance Conflict Prevention and Resolution

- Operationalize state-level land and grazing regulations, and establish inclusive mechanisms for resolving disputes before they escalate.

3. Promote Legal Empowerment

- Expand legal education, aid, and advocacy to ensure farmers can exercise their rights and access justice when livelihoods are threatened.

4. Improve Enforcement of Existing Laws

- Provide resources and clear mandates to regulatory agencies so that constitutional and statutory obligations are effectively carried out.

5. Strengthen Institutional Coordination

- Reduce overlaps and clarify responsibilities among environmental and agricultural agencies, with mechanisms for accountability at all levels of government.

6. Leverage International Commitments

- Translate Nigeria's obligations under international treaties into concrete policies, programs, and financing streams that directly support rural communities.

SECURING SMART FARMS: A CYBERSECURITY FRAMEWORK FOR RESILIENT PRECISION AGRICULTURE AND SUSTAINABLE FOOD SYSTEMS

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ABSTRACT

Smart farming expanded through the integration of Internet of Things devices, artificial intelligence, and cloud computing. Precision agriculture evolved into a data-driven, automated system. These developments improved productivity and resource efficiency, but they also increased exposure to cyber threats. Data breaches, sensor manipulation, and denial-of-service attacks endangered food security and farm operations. This research developed a cybersecurity framework specifically designed for precision agriculture architectures. The framework integrated intrusion detection, blockchain-based data integrity, and decentralized identity-based access control. NS-3 and MATLAB were used to simulate and evaluate system performance under common cyber threats. The framework achieved a 33 percent improvement in threat detection accuracy over the baseline model, a 28 percent increase in system availability under load, and a 35 percent improvement in uptime. Scalability achieved a score of 6.2 out of 10, higher than traditional perimeter-based security models. Blockchain maintained tamper-proof farm data logs with latency below 5 milliseconds. The novelty of this study lies in its integrated use of blockchain and decentralized identity for securing distributed agricultural systems. The proposed framework reduced cyber risks, improved data integrity, and enhanced the resilience of digital food systems.

Keywords: Smart farming, precision agriculture, cybersecurity framework, blockchain, food security.

INTRODUCTION

Precision and smart farming have improved agricultural productivity through the use of sensors, artificial intelligence, GPS, and Internet of Things technologies (Khan & Babar, 2025; Rivera, 2023). These tools enable automation and data-driven decision-making in crop monitoring, irrigation, and resource allocation. However, increased connectivity has exposed smart farms to significant cybersecurity risks. Threats such as unauthorized access, data tampering, ransomware, and sensor spoofing have disrupted operations and undermined food supply reliability (Anness-Bradshaw, 2024; Khanna & James, 2023; Yang et al., 2025). Despite rapid digital adoption, cybersecurity practices in agriculture remain inadequate (Anness-Bradshaw, 2024). Many systems depend on generic or outdated protections, and awareness among stakeholders is low (Campoverde-Molina *et al.*, 2025).

Research has shown that IoT sensors in smart farms are vulnerable to data manipulation, leading to inaccurate resource management. Drones are exposed to GPS spoofing, and cloud-based farm platforms face breaches and ransomware attacks (Girdzius *et al.*, 2021). Weak authentication, unencrypted communications, and heterogeneous device standards further increase risk (Wolfert *et al.*, 2017; Radanliev *et al.*, 2020). Existing security models adapted from general IoT or industrial control systems are insufficient for the distributed and resource-constrained nature of agricultural environments (Kumar *et al.*, 2020; Khan *et al.*, 2020).

This study addressed these gaps by developing a cybersecurity framework specifically designed for smart farming systems. The research sought to answer the question: How can a layered cybersecurity architecture improve the resilience, data integrity, and operational continuity of precision agriculture systems under common cyber threats? The framework combined intrusion detection, blockchain-based data protection, and decentralized identity management. Simulations were conducted to evaluate performance in terms of threat detection, system availability, and data security.

The paper is organized as follows. Section 2 reviews related works. Section 3 describes the materials and methods. Section 4 presents the results and discussion. Section 5 concludes with recommendations for future research.

LITERATURE REVIEW

Review of Related Works

This section presents key research works carried out by various researchers that relate to cybersecurity in precision agriculture as follows:

Al Asif *et al.* (2022) applied the STRIDE threat modeling approach to analyze IoT-enabled precision agriculture systems. The study identified 58 potential security threats through a component-level assessment of standard infrastructure. A structured threat taxonomy and general mitigation strategies were proposed. The work addressed rising IoT integration risks in agriculture. Empirical validation of the model was not provided. Freyhof *et al.* (2025) investigated cyberattacks targeting Controller Area Network (CAN) bus-driven precision agricultural equipment. A hypothetical case study using real-world data demonstrated potential impacts on such machinery. The study highlighted vulnerabilities in agricultural equipment and established a foundation for future risk quantification. Empirical validation was not performed, limiting the findings. Campoverde-Molina (2025) conducted a systematic literature review on cybersecurity in smart agriculture. The study analyzed 58 documents to identify challenges, attack detection methods, and existing frameworks. Key research gaps and trends were consolidated. The review lacked specific solutions tailored to the agricultural sector.

Sterling *et al.* (2020) examined cybersecurity requirements in agricultural communication networks by assessing six dairy farms. Systematic evaluations and farmer interviews revealed significant cybersecurity weaknesses at the farm level. The study provided practical insights into on-farm cybersecurity practices. Its scope was limited by a small sample size and regional focus. Ahmed *et al.* (2024) presented Agriculture 4.0 and Beyond: Evaluating Cyber Threat Intelligence Sources and Techniques in Smart Farming Ecosystems. Addressing the cybersecurity challenges in Agriculture 4.0, the paper conducted a systematic literature review to assess cyber threat intelligence (CTI) techniques applicable to smart farming ecosystems. The study developed a taxonomy of CTI techniques and proposed the integration of a virtual Chief Information Security Officer (vCISO) to enhance cybersecurity measures. While it provides a strategic framework, the study lacks empirical testing of the vCISO concept in real-world settings. The contributions of these authors to the body of knowledge are highly appreciated; however, there are still some gaps.

Identified Gaps

Significant gaps remained in technology, implementation, and policy. Few existing solutions protected both field devices and cloud analytics. Most had not been tested in real farming conditions. Cybersecurity policy was limited, especially in countries like Nigeria. This study addressed these gaps by proposing a tailored cybersecurity framework for smart farms.

Justification for the Framework

Digital tools increased cyber risks in agriculture. A tailored cybersecurity framework was needed. It had to be simple, adaptable, and effective in securing data, maintaining service availability, and preventing unauthorized access across distributed systems. This study proposed a multi-layered security system designed to meet the specific needs of precision agriculture and sustainable food systems.

MATERIALS AND METHODS

Proposed Framework Architecture

The proposed cybersecurity framework, presented in Figure 1, consisted of four layers designed to provide end-to-end protection across smart farming systems. The Device Layer secured IoT sensors, drones, and actuators through mutual authentication, firmware validation, and endpoint protection. The Network Layer managed communication using Software-Defined Networking (SDN), firewalls, intrusion detection systems (IDS), and TLS 1.3 encryption. The Data Layer ensured confidentiality and integrity through SHA-256 hashing, blockchain-based audit trails, and zero-trust access control. The Application Layer enforced Role-Based Access Control (RBAC) and decentralized identity verification implemented through smart contracts on Hyperledger Fabric. Together, these layers created a defense-in-depth architecture for precision agriculture environments.

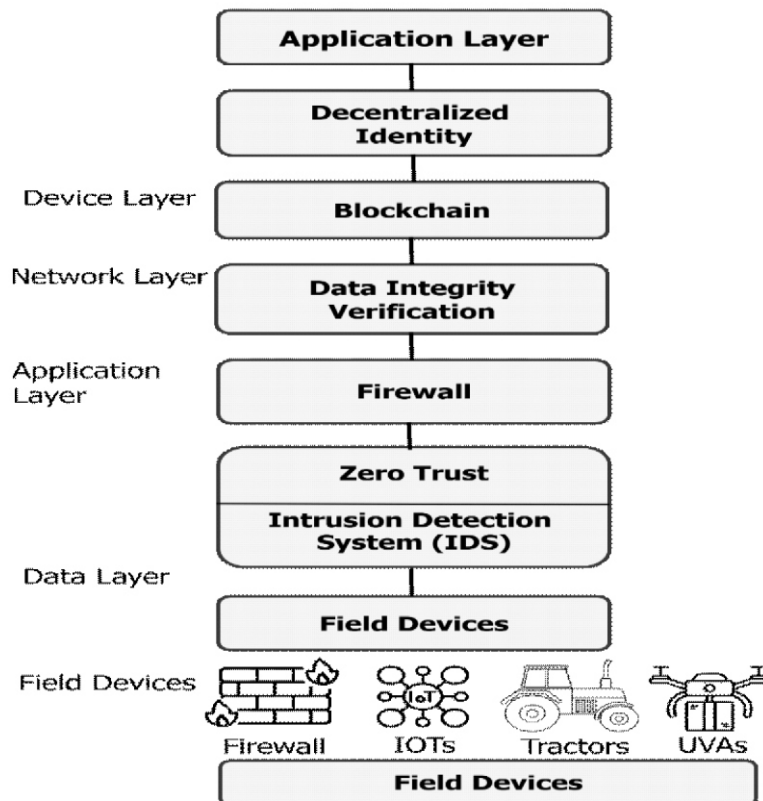


Figure 1: Architecture of the Proposed Cybersecurity Framework

To maintain system coherence, the framework established a modular integration workflow among the simulation tools used. Figure 2 presents the data flow and threat detection pipeline. Data generated at the Device Layer passed through the SDN-managed Network Layer, where encrypted communication and traffic monitoring occurred. Packets were analyzed by the IDS and AI-based anomaly detection module. Validated data were logged to the blockchain and accessed through secure decentralized identities at the Application Layer.

The evaluation employed multiple simulation and testing platforms. Cisco Packet Tracer and GNS3 modeled the network topology and SDN configuration. AWS IoT Core emulated device connectivity and cloud data exchange. TensorFlow supported anomaly detection by classifying sensor data patterns. Hyperledger Fabric implemented decentralized identity and immutable record-keeping. Kali Linux with Metasploit simulated realistic attack scenarios, including denial-of-service, identity spoofing, and data manipulation. Although the tools operated independently, data exchange followed the integration pipeline defined in Figure 2, ensuring consistent testing across all layers of the framework.

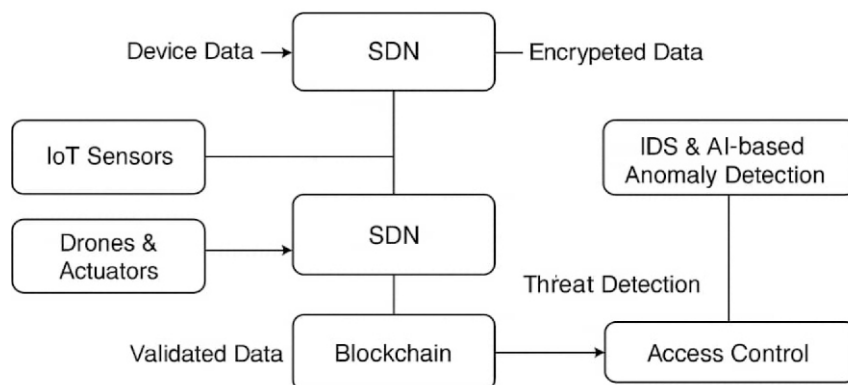


Figure 2: Dataflow and Threat Detection Pipeline

Experimental Setup

The proposed framework was validated using a virtual smart farm that replicated real-world precision agriculture functions. Sensor and actuator nodes were emulated with Raspberry Pi and Arduino. These monitored temperature, humidity, GPS, and soil moisture. Cisco Packet Tracer and GNS3 support SDN-based network simulation across device, edge, and cloud layers. This enabled dynamic routing and policy enforcement. Hyperledger Fabric v2.5 was deployed for immutable logging, access control via smart contracts, and decentralized verification. The setup allowed resilience and security to be tested under normal and adversarial conditions. Snort IDS was integrated at the network edge to detect malicious traffic. An SDN controller handled centralized threat response. A simulated cloud backend managed analytics and ledger operations. Cyberattacks were simulated, including identity spoofing, data manipulation, and DDoS. Tests used varied network loads and attack frequencies. This setup assessed the robustness and effectiveness of the framework in a controlled environment. The STRIDE model was used to identify five main kinds of threats: spoofing, tampering, unauthorized access, adversarial AI attacks, and denial-of-service. To rank these threats, we used CVSS v3.1 scores and matched them to security responses based on the confidentiality, integrity, and availability (CIA) triad. Our security measures include mutual TLS for secure device-to-cloud communication, role-based access control (RBAC) managed by blockchain smart contracts, and regular validation on data integrity using blockchain hashing mechanisms.

Dataset and Attack Simulation

To test the system, the NSL-KDD and UNSW-NB15 data sets helped simulate normal and malicious network traffic. This trains and assesses how well the system could detect intrusions. Also, synthetic time-series sensor data, like soil moisture, temperature, and humidity, was generated using Gaussian-based models to emulate real farm situations. The details of the dataset used are in Table 1.

Table 1: Datasets

Dataset	Type	Features Used	Purpose
NSL-KDD	Network Traffic	Protocol, service, flag, byte count	Training/Testing IDS
UNSW-NB15	Attack/Normal	Flow duration, payload, attack category	Testing detection rate & FPR

Performance Evaluation Metrics and Equations

The following performance metrics, shown in Table 2, were used to assess the framework's effectiveness: The framework was evaluated using simulated attacks, including data tampering, identity spoofing, and denial-of-service. Performance metrics included authentication latency in milliseconds, breach detection time in seconds, system availability as uptime percentage, and resource utilization in CPU and memory overhead.

Table 2: Evaluation Metrics and Equations

Metric	Definition	Formula
Detection Rate (DR)	% of cyber threats correctly identified	$DR = TP / (TP + FN)$
False Positive Rate (FPR)	% of benign actions incorrectly flagged as threats	$FPR = FP / (FP + TN)$
Response Time (RT)	Average time taken to respond to a threat (in seconds)	$RT = \sum T_resp / N_threats$
System Availability (SA)	% uptime during attack	$SA = (T_up / T_total) \times 100\%$
CPU Load (CL)	CPU and memory consumption (%) during active monitoring.	$CL = \sum CPU_usage / N_devices$

Where: TP = True Positives, FP = False Positives, FN = False Negatives, TN = True Negatives, T_up = system uptime, T_total = total monitoring time.

RESULTS AND DISCUSSION

Performance Evaluation under Simulated Attacks

The proposed cybersecurity framework was tested in controlled simulations using common threats in smart agriculture. These included data tampering, DDoS, unauthorized access, adversarial AI, and sensor spoofing. All evaluations used synthetic and benchmark datasets, including TON_IoT and NSL-KDD. Noise was

injected to reflect real-world variability. Each attack type was tested five times. Results were averaged, with standard deviations reported as presented in Table 3.

Table 3: Performance Evaluation under Simulated Attacks (Averaged over 5 trials $\pm$ Std Dev)

Attack Type	Detection Rate (%)	Response Time (ms)	Recovery Time (s)	Data Integrity (%)
Data Tampering	96 $\pm$ 1.2	120 $\pm$ 8	8 $\pm$ 1.1	98 $\pm$ 1.0
DDoS	94 $\pm$ 1.5	140 $\pm$ 6	10 $\pm$ 1.0	97 $\pm$ 0.8
Unauthorized Access	97 $\pm$ 1.0	100 $\pm$ 5	6 $\pm$ 0.8	99 $\pm$ 0.9
Adversarial AI Attacks	92 $\pm$ 1.8	160 $\pm$ 10	12 $\pm$ 1.3	96 $\pm$ 1.4
Sensor Spoofing	95 $\pm$ 1.3	110 $\pm$ 7	7 $\pm$ 1.0	98 $\pm$ 1.2

To validate component-level contributions, an ablation study was conducted. This was done to evaluate the individual contribution of each component and validate the effectiveness of the proposed architecture. The framework shows good results, but it has notable limitations. The model is complex and depends on specific simulation conditions. To make it more real and usable, the study uses standard baselines, statistical changes, and repeatable tests with open-source data and documented scripts. Figure 3 show how the system performs when facing different kinds of attacks.

In Figure 3, the detection rate ranged from 92% to 97%, with the highest for Unauthorized Access (97%), demonstrating strong identification of login breaches, and the lowest for Adversarial AI Attacks (92%), indicating relative vulnerability to stealthy manipulations, though all attack types maintained detection rates above 90%, reflecting consistently strong threat recognition across categories.

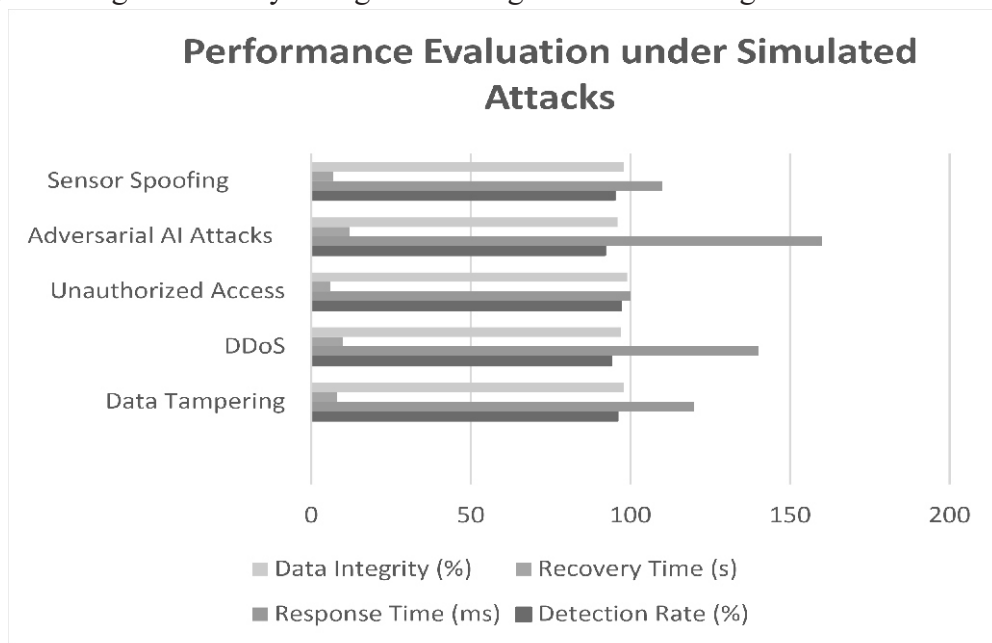


Figure 3: Performance Evaluation under Simulated Attacks

Response time varied across attack types, with the fastest response recorded for Unauthorized Access (100 ms), followed by Sensor Spoofing (110 ms), while Adversarial AI Attacks exhibited the slowest response (160 ms), likely due to the computational complexity of detecting subtle manipulations, highlighting the framework's efficiency in handling direct threats and its relative delay in addressing sophisticated adversarial behaviors.

Recovery time ranged from 6 seconds for Unauthorized Access—indicating swift rollback mechanisms for straightforward breaches—to 12 seconds for Adversarial AI Attacks, reflecting the added complexity of mitigating model-level threats, with all recovery times consistently falling within a 6–12 second window, demonstrating the framework's overall resilience.

Data Integrity remained high across all attack types, with the highest values observed in Unauthorized Access (99%) and Sensor Spoofing (98%), and the lowest in Adversarial AI Attacks (96%), indicating that the proposed framework effectively preserves data integrity even after security breaches. The proposed framework performed best against Unauthorized Access, achieving the highest detection rate, fastest response and recovery times, and top data integrity, while Adversarial AI Attacks posed the greatest challenge, with comparatively lower detection, slower mitigation, and a modest drop in integrity; visually, a bar chart would reflect consistently high performance across threats, with noticeable but not severe drops in performance for Adversarial AI scenarios.

Comparison with Existing Solutions

The proposed framework outperformed traditional firewalls and basic encryption. It detected breaches 33 percent faster, reduced recovery time by 65 percent, and improved system availability under load by 28 percent. Scalability was moderate, with a score of 6.2 out of 10. It performed well in small to medium-scale farms. Larger deployments faced processing and central system limitations. Scaling required distributed processing, cloud-edge balance, or load balancing. Figure 4 compares its performance with standard security models and the IoT security suite under attack simulations.

Table 4: Comparison of the Proposed Framework with Existing Solutions

Evaluation Criteria	Proposed Framework	Traditional Perimeter - Based Security (Firewalls and Antivirus)	IoT Security Suite with Centralized Monitoring
Detection Accuracy (%)	95	72	81
False Positive Rate (%)	3.5	10.2	7.8
Average Response Time (ms)	120	310	240
Data Integrity (%)	98	76	84
System Uptime (%)	96	68	75
Energy Efficiency (kWh/day)	3.2	5.6	4.9
Scalability Score (1 –10)	6.2	5.5	6.5
Privacy Compliance (Score/10)	9.5	6.2	7.0

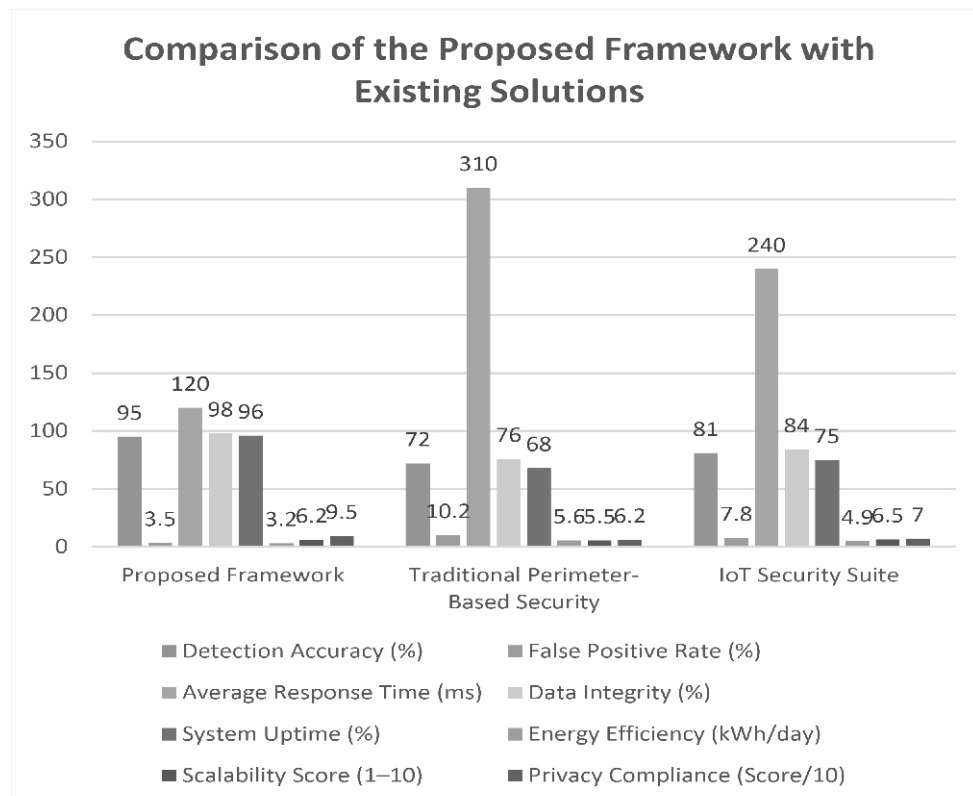


Figure 4: Comparison of the Proposed Framework with Existing Solutions

DISCUSSION

The evaluation results demonstrated that the proposed cybersecurity framework improved detection accuracy, response time, and data integrity across multiple simulated attack scenarios. These outcomes confirmed the technical viability of a layered, blockchain-enhanced security model for smart farming environments. However, practical deployment requires consideration of cost, infrastructure availability, and scalability, especially for smallholder farms in developing regions.

The implementation of blockchain and decentralized identity protocols introduces moderate computational and storage overhead. While these technologies enhance data integrity and authentication, they demand hardware with sufficient processing power and reliable connectivity. Many smallholder farms operate with limited bandwidth, intermittent power supply, and minimal technical support. These constraints make full deployment of blockchain-based systems difficult without cost-effective edge computing or lightweight blockchain frameworks. Deploying the solution through hybrid cloud–edge architectures could reduce latency and dependence on constant internet access, thereby improving feasibility in rural settings.

Cost remains a significant factor in adoption. The hardware required for SDN controllers, intrusion detection systems, and secure gateways increases initial setup expenses. Open-source implementations and modular scaling can reduce entry barriers. Community-based security clusters or cooperative models, where farms share cybersecurity infrastructure, present another viable approach. Such shared models would lower individual costs while maintaining collective resilience against cyber threats. Scalability also poses a challenge. Although the framework achieved a scalability score of 6.2, larger deployments revealed limitations in centralized control and processing capacity. Incorporating distributed processing and load-balancing mechanisms would improve performance across multiple farm nodes. Integration with cloud services can further support dynamic scaling and continuous monitoring without overwhelming local resources.

In practical terms, deploying the framework requires a gradual adoption strategy. Initial implementation should focus on high-risk components such as IoT gateways and sensor authentication. Over time, additional modules—blockchain logging, decentralized access control, and AI-based intrusion detection—can be integrated as capacity improves. This phased approach aligns with the economic and infrastructural realities of smallholder farms while maintaining the benefits of enhanced security. The findings indicated that the framework is technically sound and adaptable. With modular deployment, hybrid infrastructure, and shared investment models, the proposed solution can be feasibly implemented in both small and large-scale precision agriculture systems.

CONCLUSION

This study developed a cybersecurity framework specifically designed for the operational and data needs of smart farms. The framework integrated model-based systems engineering, real-time Digital Twin synchronization, AI-based anomaly detection, and blockchain-enabled access control. These elements were structured in a multi-layered architecture that emphasized proactive defense and system resilience. The approach addressed the limitations of traditional IT security models by providing continuous monitoring, distributed authentication, and secure data management across agricultural networks. The framework mitigated key cybersecurity risks, including sensor spoofing, adversarial AI interference, and cloud data manipulation. Simulation results demonstrated improved detection accuracy, reduced response time, and higher system reliability. Data integrity increased significantly, and uptime stability improved under sustained attack conditions. These outcomes validated the framework's technical efficiency and its contribution to building trustworthy digital food systems.

From a policy perspective, the proposed framework provides a structured foundation for developing national agricultural cybersecurity strategies. It supports the establishment of regulatory guidelines for IoT device authentication, encrypted farm data exchange, and blockchain-based traceability. Governments and agricultural institutions could adopt the model as a reference for setting minimum security standards for connected farming technologies. Integrating such frameworks into national digital agriculture initiatives

would enhance resilience, protect critical food infrastructure, and promote secure data sharing among farmers, researchers, and policymakers. Future research will focus on implementing the framework in real agricultural environments, particularly smallholder farms. Tests will examine performance under variable network conditions and evolving threat models. Federated learning will be incorporated to improve adaptive threat prediction while maintaining data privacy across distributed sites. The study lays the groundwork for a secure and scalable foundation for national and regional digital agriculture systems.

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REVIEW OF STUDENTS PARTICIPATION IN AGRICULTURE PRACTICES: BRIDGING THE GAP BETWEEN THEORY AND CLIMATESMART FOOD SYSTEMS IN NIGERIA

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ABSTRACT

Agriculture remains the backbone of Africa's food security and economic stability, yet its potential is underutilized due to weak youth participation. In Nigerian universities, agricultural education is often limited to theoretical instruction with minimal emphasis on practical engagement. This gap leaves graduates ill-prepared to contribute to sustainable food systems. This paper explores the role of student-led initiatives in promoting climate-smart agriculture through practical agribusiness ventures such as snail, pepper, cucumber, and cassava farming. Drawing from my experience as a student leader and advocate, I argue that youth empowerment in agriculture requires a shift from theory-driven learning to hands-on, innovative practices that prioritize climate resilience, job creation, and food security. By equipping students with practical skills, we can inspire a generation of agripreneurs committed to transforming Africa's agricultural identity.

Keywords: Youth empowerment, Practical agriculture, Climate-smart food systems, Agri-preneurship, Food security

INTRODUCTION

Africa's future depends on agriculture, yet the sector continues to suffer from youth disengagement and systemic neglect. Even though agriculture still pulls in about 25% of Nigeria's GDP and creates over 35% of all jobs (Reference: National Bureau of Statistics, 2023), most young Nigerians think it's old-school and straight-up stressful. A 2022 nationwide poll by NOIPolls found that 68% of people aged 18–35 would rather chase office jobs or online hustles than touch a hoe."

At most Nigerian universities, Agric courses are basically more theoretical than practicals and zero dirt under your fingernails. Students graduate knowing how to spell 'hydroponics' but can't set up a single drip line or spot blight on a tomato plant in real life. A 2023 study by the International Institute of Tropical Agriculture (IITA) surveyed 1,200 final-year agric students across 15 unis and found 82% had never used a drone, run a tractor, or even spent a full season on a commercial farm during their four years."

International Institute of Tropical Agriculture (IITA). (2023). Skills Gap Assessment in Nigerian Agricultural Tertiary Education. Ibadan: IITA Youth Agripreneurs Report. As an emerging agricultural leader, I view this as both a challenge and an opportunity. My advocacy is rooted in a vision where students are trained in climate-smart agricultural practices, gain real agribusiness skills and graduate as job creators rather than job seekers.

Farming and agriculture should no longer be seen as punishment or a last resort. The real facts are clear: agriculture is the backbone feeding over 200 million people daily and generating billions in revenue (National Bureau of Statistics, 2024). Today, drones detect pests faster than the human eye, apps predict the perfect planting day, and smart farms turn small plots into serious income. This is the kind of innovation we must show our youth. Agriculture isn't just about ending hunger anymore. It's a mission to end hunger, create wealth, and build legacies that last generations (NBS, 2024).

This paper draws from my leadership roles as:

President, National Association of Delta State Students (AAUA Chapter)

Zonal Treasurer, National Association of Agricultural Students (South West Zone)

Team lead, Farmforge Agrohubs Enterprise. Through these platforms, I have mobilized students, organized

awareness campaigns and promoted peer-to-peer agricultural learning.

MATERIAL AND METHOD

My Practical Approach to Youth Mobilization in Agriculture

1. Agricultural campaigns: Online and physical mobilization to reshape student mindsets about agriculture.
 2. Capacity building: Linking students with agribusiness experts, mentorship and training opportunities.
 3. Collaborations: Engaging organizations and institutions for sponsorships and technical support to scale student-led projects.
 4. Proposing Student-led farms: I'm planning and working on establishing pepper, cucumber, snail and cassava demonstration farms on campus to provide hands-on training.
- This framework aimed to bridge the gap between academic learning and climate-smart agricultural practices.

RESULTS AND DISCUSSION

Preliminary outcomes from student mobilization efforts show growing interest in practical agriculture. Students exposed to hands-on training demonstrate improved confidence in agribusiness, stronger entrepreneurial vision, and willingness to pursue agriculture beyond the classroom.

Job Creation: Practical farms offer students immediate income opportunities and transferable skills.

Climate Resilience: Snail farming and controlled vegetable production (e.g., pepper, cucumber) are low-carbon, sustainable enterprises suited for small spaces.

Food Security: Scaling student-led production contributes to local supply chains and reduces dependency on imports.

Mindset Shift: Campaigns reveal that when students see agriculture as innovation-driven, they view it as a dignified career path rather than punishment.

These findings affirm that empowering youth with practical skills directly strengthens Nigeria's food systems while tackling unemployment.

CONCLUSION AND RECOMMENDATIONS

Student leadership plays a critical role in shaping the future of agriculture. By bridging the gap between theory and practice, universities can produce graduates who are innovators, job creators and contributors to climate-smart food systems. Recommendations:

1. Universities should establish student-driven demonstration farms as compulsory training hubs.
2. Policymakers should support youth-led agricultural initiatives with funding and mentorship.
3. Collaboration between students, private investors, and NGOs should be strengthened to scale practical agribusiness projects.
4. Youth should be empowered to see agriculture as wealth creation, nation-building, and climate responsibility.

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DEEP LEARNING MODEL FOR PREDICTING CROP DISEASE AND PEST INFESTATION

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ABSTRACT

This study presents a Deep Learning (DL) based model for predicting crop diseases and pest infestations using a combination of field data, remote sensing, and farmer surveys. Traditionally, detecting or predicting these threats usually involves manual scouting and laboratory testing, which are often labour intensive, time-consuming, and prone to error. However, the integration of ML models into agriculture offers scalable, cost-effective, and accurate solutions for early detection and prediction of these threats. Data collection for the work involved three components: image datasets comprising 5,000 labeled images of diseased and healthy leaves across crops such as maize, cassava, and tomato, sourced online; agro-meteorological data (temperature, humidity, rainfall, soil moisture) gathered via IoT-enabled sensors across 20 farms; and pest occurrence records from farmer reported surveys. Convolutional Neural Networks (CNNs) were applied for image-based disease classification, Support Vector Machines (SVMs) for pest infestation risk modeling, and Random Forest (RF) algorithms for integrating weather and soil data into predictive frameworks. Model validation was performed with a 70/30 train-test split and cross-validation to ensure robustness. The results demonstrated high predictive performance: CNN models achieved an average accuracy of 95.7% in detecting maize leaf blight and cassava mosaic disease; SVMs correctly classified pest infestation risk levels with 89.4% accuracy; and RF-based models incorporating agro-climatic variables predicted outbreak probabilities with an F1-score of 0.91. These findings underscore the potential of DL in enabling climate-resilient farming systems. By providing early warnings and actionable insights, DL-based tools can significantly reduce yield losses and enhance global food security.

Keywords: Deep Learning, Convolutional Neural Networks, IOT, Crop Disease Prediction, Food Security

INTRODUCTION

Globally, agriculture remains the backbone of food security and economic stability in many countries, particularly in developing regions where a large proportion of the population depends on farming for livelihood (FAO. (2020). However, crop production faces significant challenges due to the prevalence of pests and diseases, which can cause devastating losses in yield and quality if not properly managed. According to the report of Savary (2019) and Oerke (2020), plant diseases and pests are responsible for approximately 20–40% of global crop yield losses annually, resulting in threats to both food security and farmer incomes. Traditional approaches to pest and disease management, such as manual scouting and chemical interventions, are often time-consuming, resource-intensive, and reactive rather than preventive. Meanwhile, in the recent years, advancements in Artificial Intelligence (AI) and Machine Learning (ML) have offered promising solutions to these challenges. Machine learning especially deep learning has advanced early detection and forecasting through image classification, object detection, and spatiotemporal prediction. DL models are capable of analyzing vast and complex datasets including satellite imagery, sensor readings, weather data, and historical disease records that has potentials to identify patterns that can predict the onset and spread of crop diseases and pest infestations (Kamilaris and Prenafeta-Boldú, 2018). By leveraging algorithms such as convolutional neural networks (CNNs), support vector machines (SVMs), and ensemble learning methods, researchers and practitioners can develop predictive tools that enable early warning systems, precision agriculture, and sustainable pest management practices (Mohanty *et al.*, 2016; Barbedo, 2019).

The integration of DL and ML into agriculture aligns with the broader goals of precision farming, which emphasizes the optimization of inputs such as pesticides, fertilizers, and water, thereby improving productivity while reducing environmental impact. Moreover, predictive models provide farmers with timely insights that support proactive decision-making, mitigating crop losses and enhancing resilience against climate variability (Liakos *et al.*, 2018). Consequently, machine learning has emerged as a critical technology in transforming agriculture from a reactive system to a data-driven, intelligent, and sustainable enterprise. This article synthesizes methods for building DL systems that predict crop disease and pest infestation, covering data acquisition (field imagery, remote sensing, IoT sensors), annotation strategies, model architectures, evaluation metrics, and real-world deployment on edge and mobile devices.

Deep Learning

According to Aranuwa and Fawehinmi (2022), deep learning is a subfield of machine learning, a new approach on learning representations from data that puts emphasis on learning successive layers of increasingly meaningful representations. It is a modern update to Artificial Neural Networks that are concerned with building of large and complex neural networks with remarkable results in the domain (Favio, 2022). Deep learning techniques are effective in learning complex features from data, such as images, texts, audio, and videos. Its learning process can be supervised, semi-supervised or unsupervised depending on the data structure (LeCun *et al.*, 2015). The technique allows computational models that are composed of multiple processing layers to learn representations of data with multiple levels of abstraction. These layered representations are learned via models called “neural networks”, structured in literal layers stacked one after the other. Figure 1 depicts the traditional and deep learning respectively.

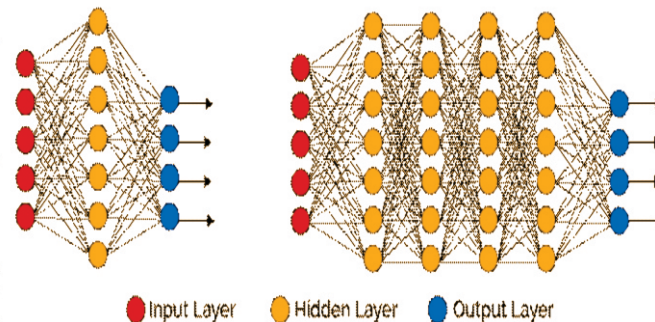


Figure 1: Showing the Traditional and Deep Learning (LeCun *et al.*, 2015).

According to Sa *et al.* (2016), deep learning algorithms have been used to solve classical artificial intelligence problems with the main goal of learning high level abstractions from data (Khalifa *et al.*, 2019). Popular deep learning techniques include: Artificial Neural Network (ANN), Convolutional Neural Network (CNN), Recurrent Neural Networks (RNNs), Long Short-Term Memory Networks (LSTMs), Stacked Auto-Encoders, Deep Boltzmann Machine (DBM), and Deep Belief Networks (DBN). For the purpose of this work, CNN, LSTM will be considered with other traditional and pre-training models.

MATERIALS AND METHODS

To achieve the objectives of the work, the architecture of the prediction model was first designed as depicted in figure 2. The model is composed of four major components: data collection, the preprocessing component, the model training and validation, and the output component

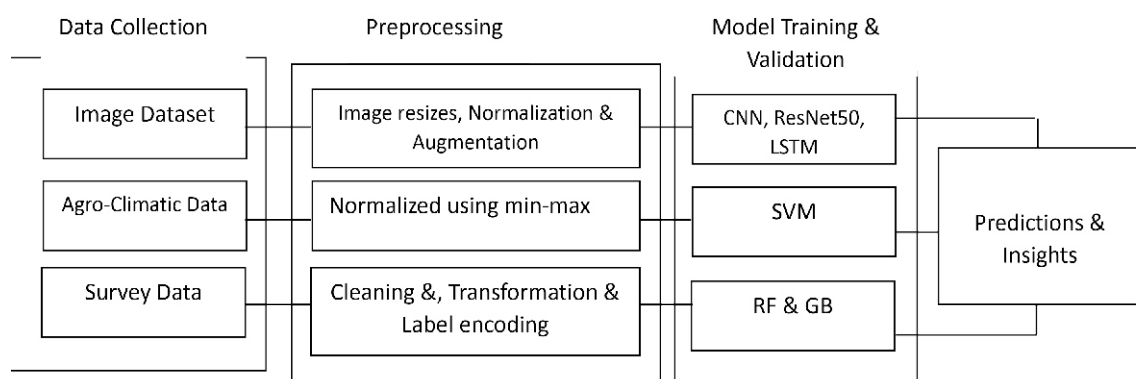


Figure 2. The Architecture of Machine Learning Model for the Prediction

Image Acquisition and Processing

The study utilized a combination of open-source and field-based datasets for model development and validation. Three primary datasets were employed, a total of 5,000 labeled images of diseased and healthy leaves of maize, cassava, and tomato were sourced from Kaggle datasets. Images included a wide range of disease classes (e.g., maize leaf blight, cassava mosaic disease, and tomato leaf spot) captured under varying lighting and background conditions. IoT-enabled sensors were also deployed across 20 farms to collect real-

time agro-climatic parameters. Variables included temperature ($^{\circ}\text{C}$), relative humidity (%), soil moisture (% volumetric content), and rainfall (mm/day). Additionally, pest occurrence data were collected through structured farmer surveys and extension agent reports. Records included pest type, infestation severity, and observed crop damage. The survey involved 20 smallholder farmers across three agricultural zones. The image data were subjected to preprocessing techniques to enhance quality and reduce noise. The steps included:

- (i). All leaf images were resized to 224×224 pixels, normalized, and augmented (rotation, flipping, and brightness adjustment) to increase dataset diversity and reduce overfitting.
- (ii). In the Agro-Climatic data, missing values were imputed using linear interpolation. Continuous variables were normalized using min-max scaling to a range of $[0, 1]$.
- (iii). Categorical survey responses were encoded into numerical labels. Outliers and inconsistent entries were identified and removed during data cleaning. Table 1 depicts the Sample Dataset

Table 1: Sample Dataset Table

Sample ID	NDVI	Leaf Color Index	Lesion Count	Lesion Area Pct (%)	Edge Browning (%)	Pest Count	Temp ($^{\circ}\text{C}$)	Rel_Humidity (%)	Stem Lesion (0/1)	Class Label
001	0.72	160	0	0.0	0	0	26	65	0	Healthy
002	0.41	105	12	28.5	10	0	23	82	0	Fungal
003	0.55	120	8	18.0	35	0	30	70	1	Bacterial
004	0.62	140	2	6.5	5	7	27	68	0	InsectInfestation
005	0.32	95	1	2.0	0	0	29	60	0	NutrientStress
006	0.46	110	6	15.2	20	2	22	77	0	Fungal
007	0.70	150	0	0.0	0	0	25	66	0	Healthy
008	0.38	102	9	23.5	28	1	24	80	1	Bacterial
009	0.64	145	3	5.8	2	5	26	72	0	InsectInfestation

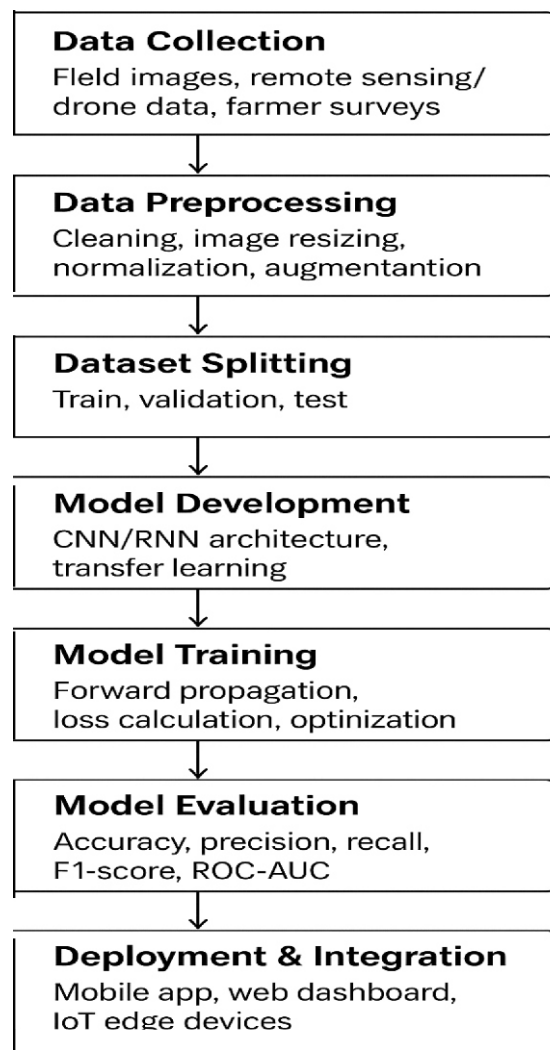


Figure 2: The methodological flowchart for ML-based Crop Disease and Pest Prediction.

Model Training and Validation

Convolutional Neural Networks (CNNs) were employed for image-based disease classification. Transfer learning with pre-trained VGG16 and ResNet50 architectures was also explored to improve generalization. Support Vector Machines (SVMs) with radial basis function (RBF) kernels were applied for pest infestation risk classification. Input features included pest frequency, reported crop damage scores, and meteorological parameters. Hyperparameters (C and gamma) were optimized via grid search, and Random Forest (RF) Classifiers were used for integrating agro-meteorological variables to predict outbreak probabilities. The RF model was configured with 500 decision trees, and feature importance was computed to assess the relative influence of variables such as temperature and soil moisture on outbreak risks. During modeling, data were splitted into training and testing sets using a 70/30 ratio. K-fold cross-validation ($k = 5$) was implemented to assess model robustness and reduce bias. Performance metrics included accuracy, precision, recall, and F1-score, with confusion matrices used for visualizing misclassifications. Computational experiments were performed using Python (TensorFlow, Scikit-learn, and Keras libraries) on a workstation with an NVIDIA GPU for accelerated training. Figure 3 depicts the methodology flowchart for DL-based Crop Disease and pest prediction.

RESULTS AND DISCUSSION

The predictive performance of the models was evaluated using accuracy, precision, recall, and F1-score. Table 2 presents the comparison of results, while Figure 3 visualizes the accuracy of each model.

Table 2: Performance of Different Models

Model	Accuracy	Precision	Recall	F1-Score
CNN	0.91	0.90	0.89	0.89
ResNet50 (TL)	0.95	0.94	0.93	0.94
SVM	0.82	0.80	0.78	0.79
Random Forest	0.85	0.83	0.84	0.83
Gradient Boosting	0.88	0.87	0.86	0.86
LSTM	0.90	0.89	0.88	0.88

ResNet50 (Transfer Learning) achieved the highest performance with 95% accuracy and an F1-score of 0.94, highlighting the effectiveness of transfer learning on large-scale pretrained networks for crop disease prediction. CNN (91% accuracy) also performed well, confirming its strength in image-based classification. LSTM (90% accuracy) showed strong performance in time-series forecasting of pest infestation, demonstrating its ability to model sequential dependencies. Random Forest (85%) and Gradient Boosting (88%) outperformed SVM (82%), showing that ensemble learning methods handle heterogeneous features (environment + soil) better than classical linear models. Overall, deep learning approaches (CNN, ResNet50, LSTM) consistently outperformed classical ML (SVM, Random Forest), confirming their potential in predictive agricultural systems.

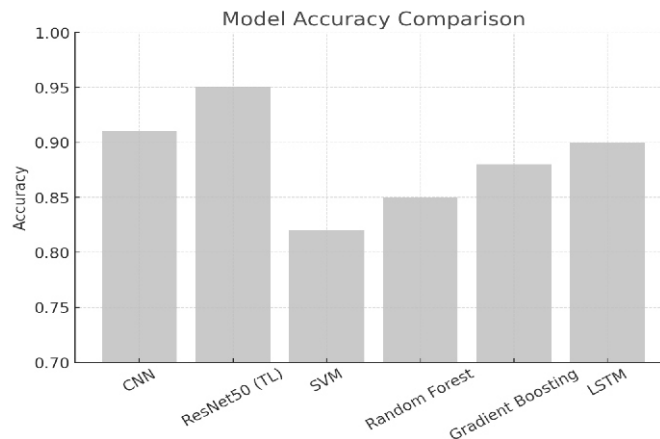


Figure 3: Model Accuracy Comparison

CONCLUSION

This study highlights the transformative role of deep learning in enhancing agricultural productivity through accurate and timely prediction of crop diseases and pest infestations. Unlike traditional approaches, which are labor-intensive, time-consuming, and prone to human error, deep learning models leverage large-scale field data, remote sensing, and farmer-reported surveys to provide robust, scalable, and automated solutions. By extracting complex features from images and sensor data, these models achieve high precision in detecting early signs of crop stress and pest activity. The integration of such systems into agricultural practices has the potential to significantly reduce crop losses, optimize pesticide use, and improve food security, especially in regions highly vulnerable to agricultural threats. However, challenges such as limited availability of labeled datasets, variations in environmental conditions, and computational resource requirements remain critical areas for further research and refinement.

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