



Michael Okpara
UNIVERSITY OF AGRICULTURE, UMUDIKE
Directorate of University Research Administration (DURA)
& MOUAU Extension Centre

PROCEEDINGS OF THE 2ND RESEARCH & INNOVATION FAIR & CONFERENCE

THEME:

**LEVERAGING ENDOGENOUS TECHNOLOGIES FOR THE
SUSTAINABLE DEVELOPMENT OF THE NIGERIAN OIL AND
GAS AND AGRO-ALLIED INDUSTRIES**



DATE: 26TH - 27TH FEBRUARY, 2025

VENUES:

- (1) PIUS ANYIM AUDITORIUM (OPENING CEREMONY, KEYNOTE AND LEAD PAPERS, AWARDS, CONFERENCE).
- (2) OLD MATRICULATION GROUND (EXHIBITION)

EDITORS

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DR. C. JOHN

PROF. I.E. OTUOKERE

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- National Raw Materials Research and Development Programme.
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Director-General, RMRHC



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2MRIFC

TECHNICAL SUB-COMMITTEE CHAIRMAN'S ADDRESS



I welcome you to this significant Conference on "Leveraging Endogenous Technologies for the Sustainable Development of the Nigerian Oil & Gas and Allied Industries." As the global energy sector experiences revolutionary change due to the dual imperatives of sustainability and technological innovation, Nigeria stands at a pivotal crossroads. As a nation abundant in hydrocarbon resources and human capital, our future success will hinge not just on resource availability but also on our capacity to use local knowledge, tailor technologies to indigenous requirements, and cultivate resilient, domestically developed solutions.

I am profoundly appreciative to the Director of University Research Administration, Prof. K. J. Simonyan, for my appointment as Chairman of the Technical Sub-Committee for the Second MOUAU Research and Innovation Fair/Conference. I wish to convey my sincere appreciation to the members of the Technical Sub-Committee: Dr. C. I. Oriaku, Dr. Benson Nwajiobi, Dr. Chioma Nwaobiala, Dr. Samuel Onoja, Dr. Blessing Ada Ahamefule, Dr. R.J. Nosike, Dr. J.C. Ehiem, Dr. Chisimkwo John, and Prof. G.U. Chukwu for their remarkable contributions and commitment to fulfilling the Committee's Terms of Reference. We express profound gratitude to our 30 reviewers who, despite their demanding schedules, managed to allocate time to evaluate the 84 papers submitted for the conference. Their efforts have not been in vain, as the academic quality of the submitted articles has significantly improved due to the review process. The chairmen of the technical sessions, Prof. G. Omosun, Prof. E.O. Ekundayo, Prof. C.N. Ehisianya, and Prof. G. U. Nnaji, merit acknowledgment and appreciation. We extend our sincere gratitude to our valued writers who submitted their papers, remitted payment for the conference, and meticulously rewrote their articles in accordance with the reviewers' feedback. Your involvement was essential to the conference's success.

God bless you.

Professor I.E. Otuokere

Professor of Inorganic Chemistry

Chairman of the Technical Sub-Committee

LOCAL ORGANIZING COMMITTEE (LOC) CHAIRMAN'S ADDRESS



The LOC is immensely grateful to the Pro-Chancellor and Chairman of the Governing Council, Comrade Fidelis Edeh and members of Council for their unwavering support. Immense gratitude goes to the Vice-Chancellor, Prof. M. O. Iwe and Management for their unflinching support. Immense gratitude is pertinent for our guests from far and near, our sponsors and collaborators for coming to our aid which contributed to the success of the event. Worthy of mention are the Conference participants, authors and paper reviewers who contributed to the success of the Conference. The Exhibitors were just wonderful and the LOC expresses her thanks to them for the captivating and competitive Exhibition.

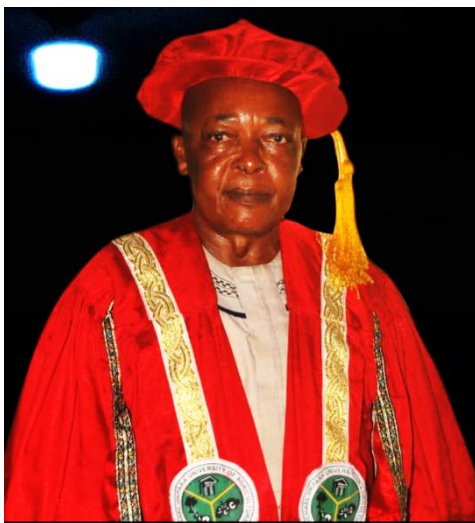
Sincere thanks goes to staff and students of the University including the Deans and Directors, HoDs, Chief Security Officer, Director of Works, Transport Officer and MOUAU Guest House. Their contributions were critical to the success of the Fair and Conference.

I wish to express my profound gratitude to the members of the Central Planning Committee (CPC), Chairpersons and members of all Sub-committees for their impressive contributions and dedication towards the achievement of a successful Fair and Conference.

Prof. Jude C. Nnaji

Professor of Analytical/Environmental Chemistry
LOC Chairman

MOUAU EXTENSION CENTRE (MEC) DIRECTOR'S ADDRESS



On behalf of the Directorate of University Research and Administration (DURA) and the Michael Okpara University of Agriculture, Umudike Extension Centre (MEC), we express profound gratitude and appreciation to the visionary and innovative Vice Chancellor of our University, Prof Maduebibisi Ofo Iwe and his Management team for creating the enabling environment that gave impetus to the packaging of the Second Research and Innovation Fair/Conference. The theme: Leveraging Endogenous Technologies for the Sustainable Development of the Nigerian Oil and Gas and Agro-allied Industries, no doubt provided ample platforms for researchers, scholars, entrepreneurs, exhibitors and professionals in diverse disciplines to showcase their unique perspectives and expertise towards finding solutions to diverse problems confronting the Oil and Gas and Agro-allied sectors in Nigeria. Our sincere appreciation goes to the Chairman of the occasion, Prof. Ogbonnaya C. Onwudike (Vice Chancellor, Rhema University, Aba, and former Vice Chancellor, Michael Okpara University of Agriculture, Umudike) as well as the Keynote Address Presenter, Dr. Felix Ogbe, the Executive Secretary, Nigerian Content Development & Monitoring Board. To the Lead Paper Presenters: Chief Raymond Isiadinso, MD/CEO, Mid-Century Agro Allied Ventures Ltd, Lagos; Dr. Ebieri Jones, Hon. Commissioner for Trade & Investment, Bayelsa State; Dr. Frank Oteiva of Indorama –Eleme Petrochemicals Ltd, Port Harcourt we say thank you. The Second Research and Innovation Fair/Conference might not have recorded the measure of success attributed to it without the roles played by members of the formidable Local Organizing Committee who worked tirelessly to ensure the success of Fair/Conference

Prof. Uchechi Apu,
Director, MOUAU Extension Centre (MEC)

DIRECTORATE OF UNIVERSITY RESEARCH ADMINISTRATION (DURA) DIRECTOR'S ADDRESS



Protocol,

It is with great pleasure and a profound sense of pride that I welcome you all to the Second Research and Innovation Fair/Conference of our University, Michael Okpara University of Agriculture, Umudike. Today, we gather once again to celebrate innovation, showcase groundbreaking research, and foster collaboration towards solving some of the most pressing challenges facing our nation.

The climate change issues have shifted attention globally to focus on renewables such as biofuels and biomass of which Agriculture is the primary source. Nigeria is richly endowed with natural resources, including oil, gas, and fertile land for agriculture. However, the country is yet to fully optimize the benefits of these resources due to a number of challenges such as:

Over-reliance on imported technology by most Nigeria's industries, which can be costly and unsustainable.

The local content of Nigeria's industries is low, resulting in limited economic benefits for the country.

The extraction and production activities have significant environmental impacts, including pollution and habitat destruction.

The theme for the research and innovation fair/conference this year, "Leveraging Endogenous Technologies for the Sustainable Development of the Nigerian Oil and Gas and Agro-Allied Industries," is both timely and strategic. It reflects our commitment as an institution to address critical sectors of our economy through research and innovation. The theme is designed to address the earlier mentioned challenges by:

- i. Promoting endogenous technologies through leveraging local innovations, expertise, and resources to develop sustainable technologies.
- ii. Enhancing local content by increasing the participation of local businesses and communities thereby retaining more economic benefits within the country; as well as
- iii. Fostering sustainable development by encouraging environmentally friendly practices and technologies to minimize their environmental footprint.

Michael Okpara University of Agriculture is well-positioned to tackle this theme, given its expertise in:

Developing sustainable agricultural practices and technologies that can be applied to the oil and gas and agro-allied industries.

Understanding the environmental impacts of the oil and gas, and agro-allied industries and developing strategies to mitigate them.

Designing and developing innovative technologies that can be applied to the oil and gas, and agro-allied industries.

The choice of this theme is not accidental. As a university, we are uniquely positioned to contribute to these industries, given our robust departments of Soil Science, Geology, Chemistry, Chemical Engineering, and others that directly interface with the oil and gas and agro-allied sectors. Over the years, our researchers have conducted groundbreaking studies in bioremediation, developed innovative technologies, and provided actionable insights that have the potential to transform this industry.

This Conference is a testament to our belief that sustainable development can only be achieved when academia, industry, government, and the community work together- a principle encapsulated in the Quadruple Helix Model, which was the focus of our first conference. This year, we take a step further by emphasizing the importance of endogenous technologies-homegrown solutions that leverage our local resources, expertise, and cultural context to drive sustainable growth.

I would like to take this moment to specially thank our amiable digital Vice - Chancellor, Professor Maduebibisi Ofo Iwe, for his unwavering support in hosting this conference for the second time. His leadership and commitment to fostering a culture of research and innovation have been instrumental in making this event a reality. Thank you, sir, for your vision and dedication to advancing the research agenda of our university.

To our Awardees and Special Guests of Honour, we are deeply honoured by your presence and celebrate your impact in our nation. Your contributions to your respective fields inspire us. To our Plenary Session facilitators and presenters, we look forward to learning from your insights during the Technical and Plenary Sessions.

Dear Conferees, it must interest you to know also that this conference is not just about presentations and discussions; it is also a platform for exhibitions, where researchers and innovators will showcase their work. I encourage everyone to explore these exhibitions, engage with the creators, and draw inspiration from their ingenuity.

As we embark on this two-day journey, I urge all participants to actively engage, share ideas, and forge meaningful connections. Let us make this conference not only interesting and educative but also a catalyst for actionable solutions that will benefit our industries and our nation.

Together, we can forge a path toward a more self-reliant Nigeria, where innovation is the cornerstone of prosperity for future generations. Let us use this platform to foster dialogue, share best practices, and generate actionable ideas that can drive real-world impact. The future of our industries depends on our ability to work together to make innovation a central pillar of development.

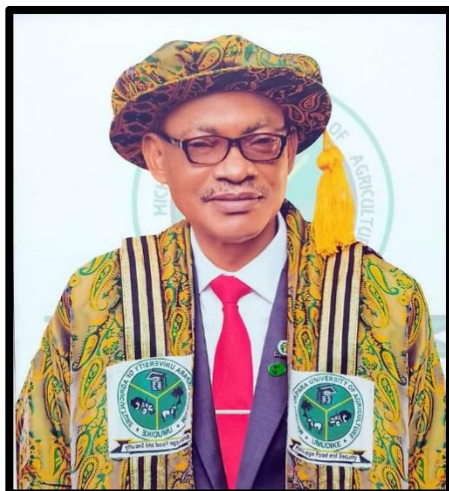
On behalf of the local organizing committee, I welcome you once again to this conference, and I look forward to the thought-provoking discussions, collaborations, and innovations that will emerge over the coming days.

Thank you, and God bless.

Prof. Kayode J. Simonyan, FNIAE

Director, Directorate of University Research Administration (DURA)

WELCOME ADDRESS BY THE VICE-CHANCELLOR



Protocol

It is my pleasure to welcome His Excellency, the Executive Governor of Abia State, Dr. Alex Chioma Otti and the Honourable Minister, Federal Ministry of Agriculture and Food Security ably represented by the Executive Secretary, Agricultural Research Council of Nigeria, the Honourable Minister, Federal Ministry of Innovation, Science and Technology, Director General, Raw Materials Research and Development Council (RMRDC), the Executive Secretary, Tertiary Education Trust Fund (TETFund) and various dignitaries to Michael Okpara University of Agriculture, Umudike (MOUAAU) for the purpose of participating in this 2nd Research Innovation Fair and Conference organized by

the Directorate of University Research Administration (DURA) on behalf of the University.

I am equally pleased to welcome to our campus the Keynote Speaker, the Executive Secretary, Nigerian Content Development and Monitoring Board as well as other lead speakers.

Let me specially welcome the Chairman of the 8th Governing Council Chairman of Michael Okpara University of Agriculture, Umudike, Comrade Fidelis Edem, other Members of Council, Senate, our awardees and other distinguished personalities who will chair sessions of the Conference. I welcome our sponsors and partners to this event.

I wish to recognize and welcome all participants, His Royal Highnesses (Ndi Eze) from our host communities and indeed, members of the University Community to this Conference.

Having welcomed all, permit me to appreciate the Director of our Directorate of University Research Administration (DURA) and the MOUAAU Extension Centre (MEC) for their commitment and patriotism in organizing this event.

Your Excellency, distinguished guests, as I said during the maiden research innovation fair, this is another demonstration of some of the efforts of my administration in reminding our researchers of the real essence of the establishment of universities and to re-awaken us to our responsibilities towards ensuring that our university remains an academic centre for research and innovation.

It is a well-known fact that since the last decades of the twentieth century, most countries, have been seeking to transform their economies from depending on primary natural resources to knowledge-based ones, thereby providing permanent sources for economic growth, and thus achieving sustainable development. By so doing, they have helped to diversify their national economic frameworks and multiply income and wealth resources of their countries.

In all the countries of the world, sustainable economic development is facing challenges posed by globalization and fierce competition. Consequently, economic development now needs creativity and innovation, hence, the need for high-skilled human resource inputs. This is where universities' roles come into action with their huge human resource assets. Research institutions are capable of producing

knowledge, creativity and innovation represented by their researches. Universities are considered a resource of economic development and the most important inputs of production processes for the knowledge-based economy in this century. They represent an integral part of the production system of innovations and technologies and transferring these to businesses and society.

This world is in an age of information and knowledge, and this has been hinged on the reliance on scientific research, creativity, and innovation. The foundations of today are laid upon the achievements of the industrial revolution followed by the information and communication revolution. Furthermore, the global openness and substantial development in the means of mobility and communications show that the innovations, achievements and inventions are not the end in themselves but to be transformed and translated into the industrial practical field, thereby achieving profits and returns. This causes the transformation into economics of knowledge as a natural outcome of the effective transformation to knowledge societies in many countries.

Accordingly, narrowing or filling the knowledge gap is the gateway to moving from backwardness to progress, whether it is economic, scientific, or cultural. It should be taken into consideration that the wealth of nations is no longer centred on natural sources of wealth such as natural resources and lands, but rather represented in knowledge. That explains how countries that lack natural resources, such as Japan, Switzerland, Denmark, and Singapore, turned wealthy because of their knowledge resources. Such countries have become among the world's richest and highest GDP per capital countries. Meanwhile, some of the richest countries in terms of natural resources, such as Russia and Brazil, are of low GDP per capita income in comparison with other major countries.

Universities have become the source of power in the knowledge-based economy of the century, as they represent an integral part of the production chain of innovations and skills and transferring them to business and society. Many universities have a lot of programmes, curricula, workshops, and mechanisms that have been developed to encourage students on creativity and innovation and improve their cognitive functions.

MOUAU is one of such universities and its core mandates as a University include teaching, research and innovation, and community services. I can say without mincing word that Nigerian universities are doing very well in teaching and training of manpower, in research and community services. The question, however, is how has our research impacted lives and changed our society for the better? Or, maybe we are just researching and publishing papers for promotion only. Such is no longer the trend.

I wish to let this audience know that in the past four years, we have made conscious efforts, building on some of the legacies of previous administrations at re-engineering and repositioning our University to make it a place where serious academic and research activities take place. In the past one year, we have organized events that buttressed our resolve to make our University a citadel of learning, a hub for entrepreneurship and research, and an institution to be recognized and respected for cutting-edge research and innovations. As a result, our researchers now have the premise of competing with others at both national and international space for research funds and competitions. I am glad to say that some have brought somethings home. We are now partnering with foreign universities on embedded AI program, smart agricultural practices, to mention a few.

I am particularly impressed with the choice of the theme for this second Research and Conference, which is: **Leveraging Endogenous Technologies for the Sustainability Development of the**

Nigerian Oil and Gas and Allied Industries. There is no better time to discuss this theme than now, when funding of universities including research has become a major challenge.

CONCLUSION

I am confident that with the array of scholars and research experts in various areas of science and technology, engineering and entrepreneurship, etc., the theme and sub-themes of this second conference will be satisfactorily addressed. I am glad to have you all here and request that you give the best you can.

On our part, we shall continue to fund research as resources become available and facilitate the attraction of research funds by both our staff and students. We have devoted a lot of efforts in opening and equipping our laboratories.

We shall continue to do so and trust that more men like Dr. Chika Ikenga, our Keynote Speaker during the Maiden Research Innovation Fair and Conference, who rebuilt our Chemistry laboratories shall emerge and come to our aid. We remain indebted to him and the National Office for Technology Acquisition and Promotion (NOTAP) that adopted our Chemistry and Chemical Engineering departmental laboratories and equipped them two years ago. We remain ever grateful.


I cannot conclude this address without mentioning the need to endow a Professorial Chair in Oil and Gas in the Department of Chemical Engineering of the University and I am convinced that the Nigerian Content Development and Monitoring Board (NCDMB) can assist the University in this regard.

Mr. Chairman, distinguished guests, Members of the University Council, Senate, staff, students and friends of the University, ladies and gentlemen, I thank you for being here for this epoch making event which we will continue to hold from time to time. I wish that the administration coming after mine will uphold and take this lecture to higher heights.


On behalf of the Senate of Michael Okpara University of Agriculture, Umudike, I welcome you all once again to the second Research Innovation Fair and Conference of MOUAU.

Thank you.

Prof. Maduebibisi Ofo Iwe, CFS,
Vice-Chancellor, MOUAU




NIGERIAN CONTENT DEVELOPMENT AND MONITORING BOARD



PRESENTATION AT MOUAU 2025.

THEME: LEVERAGING ENDOGENOUS TECHNOLOGIES FOR POLLUTION REMEDIATION AND SUSTAINABLE DEVELOPMENT OF THE NIGERIA OIL GAS SECTOR


BY THE ES NCDMB



26 FEBRUARY 2025
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NCDMB Mandate




The Nigerian Content Development and Monitoring Board (NCDMB) was established in 2010 by the Nigerian Oil and Gas Industry Content Development (NOGICD) Act of 2010 with a mandate to:

- Develop the capacity of the local supply chain for effective and efficient service delivery to the oil and gas industry without compromising standards and
- Implement and enforce the provisions of the NOGICD Act of 2010

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Provisions of the NOGICD Act on R&D



The Minister shall make regulations with requirements and targets for the growth of research and development in the Nigerian oil and gas industry

Source: Section 36 of NOGICD Act of 2010

For every project for which a plan is submitted, an operator shall carryout a programme and make expenditure, to the satisfaction of the Board, for the promotion of education, attachments training, R&D in Nigeria in relation to its work programme and activities"

Source: Section 37 of NOGICD Act of 2010

1. "The operator shall submit to the Board and update, every six months, the operator's R&D plan.
2. The R&D plan shall;

a. Outline a revolving 3 to 5 year plan for oil and gas related R&D initiative to be undertaken in Nigeria together with a breakdown of the expected expenditures that will be made in implementing the R&D plan.
b. Provide a public calls for proposals for R&D initiatives associated with the operator's activities"

Source: Section 38 of NOGICD Act of 2010

"The operator shall report to the Board on quarterly basis, with respect to R&D activities and the Board shall compare these activities to the operators R&D plan"

Source: Section 39 of NOGICD Act of 2010

Nigerian Content Levels for R&D

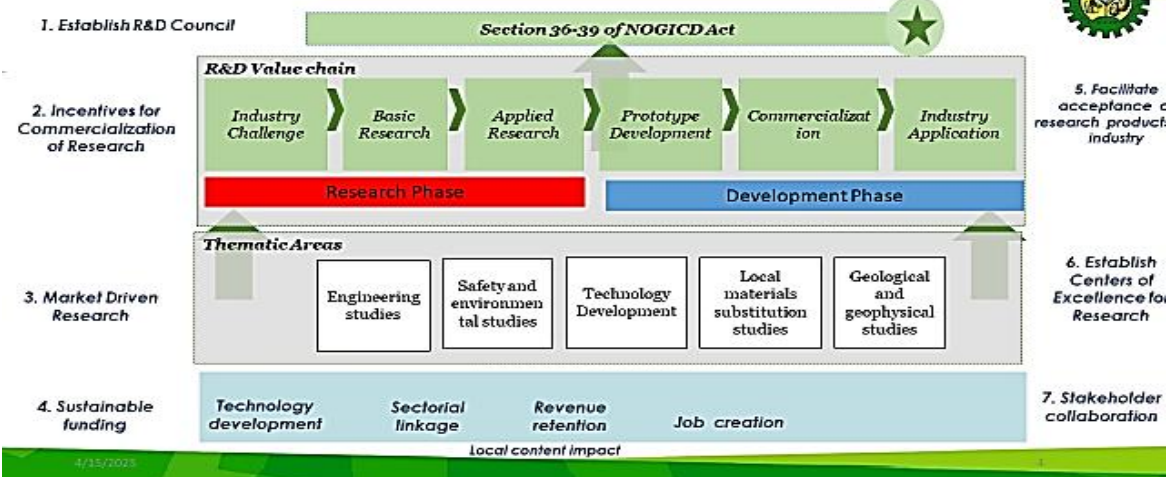
1. Engineering Studies Reservoir, Facilities, Drilling etc.	60% Spend
2. Geological and Geophysical Services	80% Spend
3. Safety & Environmental Studies	75% Spend
4. Local Material Substitution Studies	75% Spend

Source: Schedule to the NOGICD Act of 2010

Imperatives for success: [1.] Build capacity [2.] Enforce compliance

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NCDMB Research and Development Implementation Framework



Research and Innovation Culture Imperatives



System imperative



Global Engagement and Commercialization



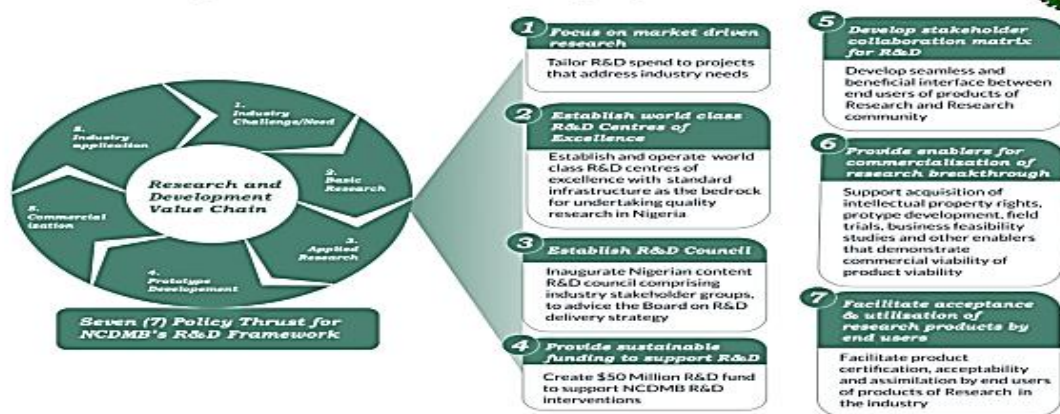
Global Engagement	Incentives for Commercialization	Long-Term Vision & Strategy
<ul style="list-style-type: none"> Foster international collaboration and partnerships Access global knowledge networks Participate in international research programs and agreements Leverage shared resources and expertise 	<ul style="list-style-type: none"> Develop mechanisms for technology transfer and startup incubation Provide incentives for researchers and entrepreneurs Allocate funding and offer industry partnerships Promote commercialization efforts within specific sectors like oil and gas 	<ul style="list-style-type: none"> Develop and update research and innovation strategies Align with long-term economic and societal goals Ensure continuity of funding and support Create a framework for fostering creativity, knowledge generation, and societal benefit

April 15, 2025

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Research and Development Framework

The NCDMB R&D framework is anchored on seven policy thrusts.....



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Research and Innovation

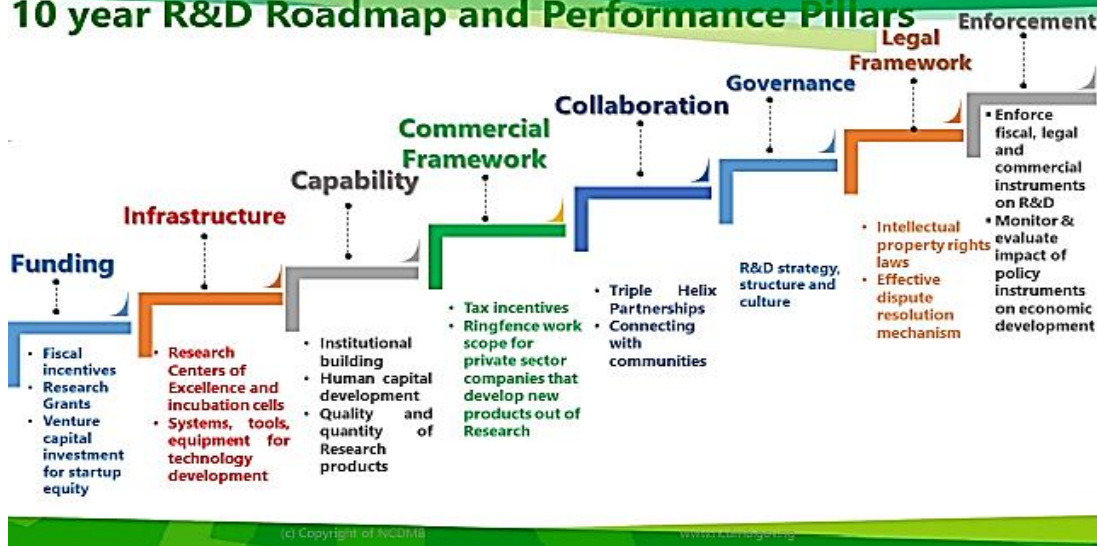
NCDMB Research Product Development Framework



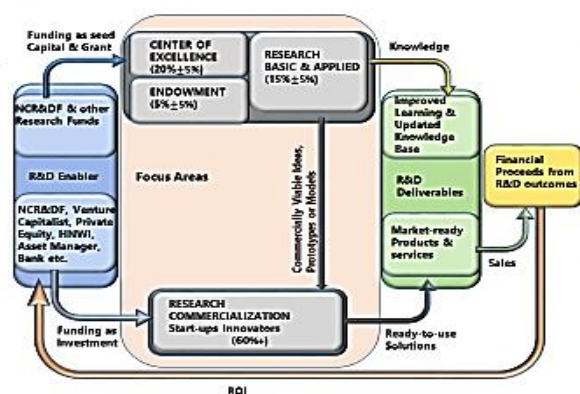
April 15, 2025

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10 year R&D Roadmap and Performance Pillars



Nigerian Content Research and Development Fund (NCRDF)



NCRDF Themes:

- Involve multiple stakeholders with deep knowledge of Research
- Attract co-funding from venture capitalist and foundations to support indigenous technology development
- Transparent selection process
- Well defined governance and KPIs

NCDMBA Sponsored R&D Centers of Excellence



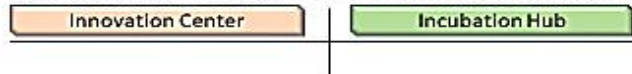


NCDMB Research and Development Success Areas

- Research and Development (R&D) Initiatives
- Training and Capacity Building
- Partnerships with Academic Institutions
- Infrastructure Development
 - Construction & Revamping of Research facilities and Centers of Excellence, laboratories, and innovation hubs
- Incubators and Startups
 - Established TIIC, a Hub for innovation and entrepreneurship,
 - 2 Cohorts with, 54 individuals & 17 at the Business Development stage

NCDMB Technology Innovation & Incubation Center(TIIC):

To be located in the NC Towers. Will include the following



Intent: To establish a **Technology Innovation and Incubation Center (TIIC)** with full complements of equipment, procedures, technicians, teaching aid, communication infrastructure, and network in fulfillment of requirements for innovation, patenting, prototyping, field validation, commercialization, and deployment of Research breakthroughs to oil and gas operations. The TIIC shall focus on providing the following services:

- a. Resource center for obtaining data on priority research needs of the oil and gas industry
- b. Low-cost transition platform for researchers to incubate their ideas to tangible products
- c. Ecosystem for innovators to think through new ideas for technology adaptation or process improvement
- d. Networking platform between researchers and investors and end-users in the oil and gas industry and its linkage sectors

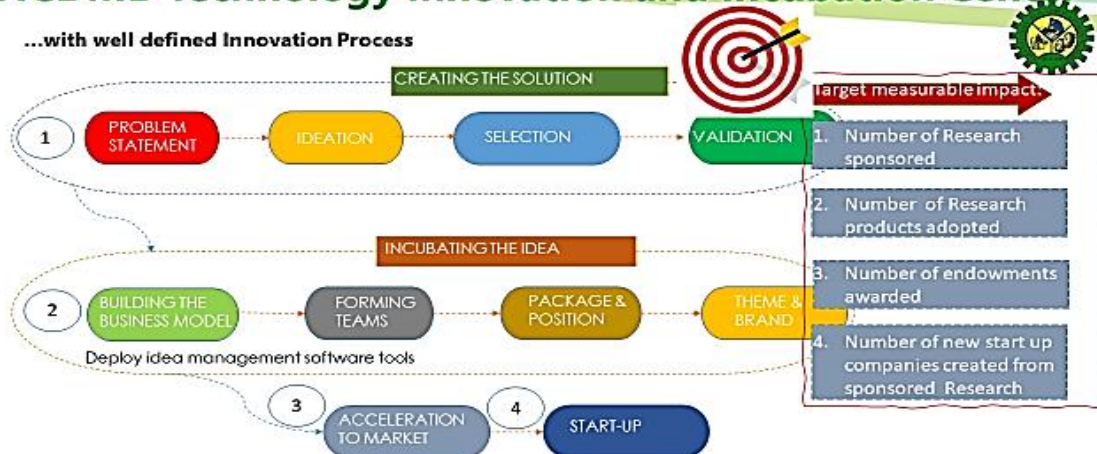


Technology Innovation & Incubation Center (TIIC)



NCDMB Technology Innovation and Incubation Center

...with well defined Innovation Process



AMAL TECHNOLOGIES FACILITY
Location: Idu Industrial Area, Abuja

FACILITY COMMISSIONED IN DEC. 2023



PIONEER STARTUP

.....Amal Smart Gas leak detector-incubation process

Product features

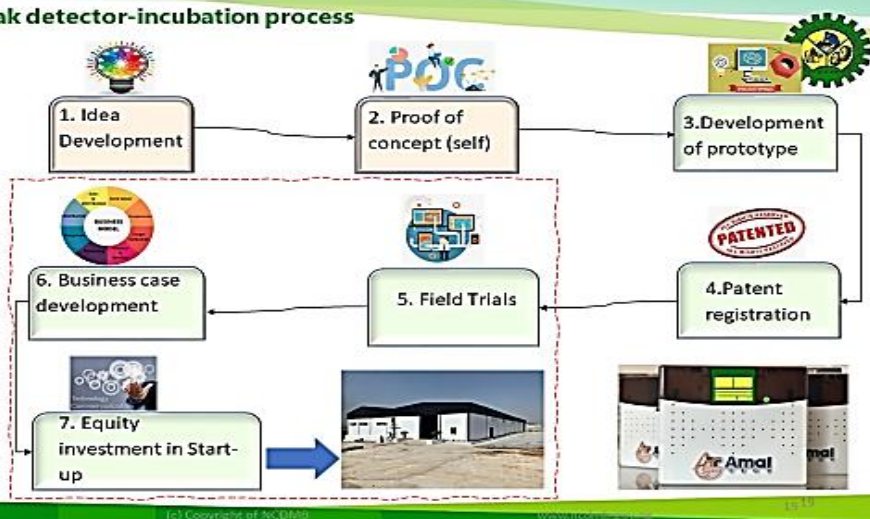
- Detects smoke and combustible gases
- SMS and Call notification
- WIFI Extender
- works with smart valve
- Simple and portable
- High sensitivity to LPG and combustible gas
- Fast response time
- Stable and long battery life
- Alarm system
- Power by DC and Internal battery
- Battery last for 10 hours in case of power outage
- Daily SMS notification to check device is working
- App
- Low battery alarm

End users

- Homes
- LPG Cylinder manufacturers
- Offices
- Schools
- Factories
- Fabrication yards
- Gas distribution Centres

Economic Impact

- 465 jobs
- Annual turnover = N9.3 billion (\$22 Million)
- Spinoffs = gas penetration, Printed Circuit Board (PCB), electric metering technology



Indigenous Innovations Supported by NCDMB

S/N	INNOVATOR	PROJECT DELIVERABLES	TRL	CURRENT ACTIVITY	ACTIVITY PROJECTION	FUNDING STATUS	REMARKS
1	KEN PAM NIGERIA LIMITED	Application of <i>Mucuna Solanrie</i> as additive in drilling fluid	4	The oil obtained from the plant has been utilized in tests to evaluate its operational efficiency in oil fields.	Strategic plan to ensure availability of the plant within the nearby communities.	Funded already	Ready for second test
2	RAPID MEDICARE	Online Telehealth care Service	7	Integrating front end and back end for the Web application	Real time testing of the web application.	Funded already	Ready for field trial
3	FEASIBILITY GIANT	Oil and Gas transmission pipeline design and Modelling	5	Modelling interphase and connecting familiar locations also concrete center connection	Populating models and defining the geometry	Funded already	Work in progress
4	SOLPAWA	Soil booster and soil conditioner.	6	The product has been tested in the operating environment, and it performs appreciably	Business development framework and market validation.	Funded already	Awaiting Approval commercialization
5	BENEMES NIG.LTD	Carbon Capture and Storage Technology.	7	Prototype has been developed, tested and demonstrated at a scale on exhaust streams of diesel and petrol engine with carbon capture of about 75% of its original carbon concentration.	Certification by relevant bodies and execution of marketing plan, upgrading from 0.075kg to 0.9kg capturing capacity.	Funded already	Work in progress

Indigenous Innovations Supported by NCDMB

S/N	INNOVATOR	PROJECT DELIVERABLES	TRL	CURRENT ACTIVITY	ACTIVITY PROJECTION	FUNDING STATUS	REMARKS
6	GLVI	Development of an Automatic fire arrestor system for transporting tankers with highly inflammable gases.	4	Developing a Demo AFAS for a Tanker Construction Company in Abuja. Where some design and fabrication errors were identified which include Sensor's detection errors and Sensor's misalignment.	Neural Network Algorithm (NNA) would be deployed to address the errors thus failure to sense and differentiate between fire and Sunlight.	Funded already	Development of prototype in progress
7	EFOCHRIST.	Automated Vantage Intelligent System (AVIS) for tackling pipeline vandalization.	5	Development of circuit board in a model's optical circuit and seismic circuit.	Calibration of prototype, Testing of prototype and collection of data.	Funded by the stakeholder.	Ready for field trial
9.	GAS 360	Tackling legacy supply chain and logistic challenges for all industries.	9.	Completed field trial.	Review of business case.	Funded already	Awaits approval commercialization of
10	AICEMR ENG'G (FUPRE).	The Automated oil and gas pipeline vandalization detection system.	4	Development of prototype	Complete prototype and test	Funded already	Work in progress

Conference Theme:

“Leveraging Endogenous Technologies for Pollution Remediation and Sustainable Development of the Nigeria Oil Gas Sector”



These involves utilizing local innovations, practices and knowledge to address environmental challenges and promote sustainability.

Strategies and approaches to consider

- ☐ Bioremediation
- ☐ Waste management innovations
- ☐ Sustainable extraction practices
- ☐ Community Involvement and education
- ☐ Regulatory and policy frameworks
- ☐ Research and development
- ☐ Monitoring and Assessment technologies
- ☐ Corporate social responsibility

By integrating these endogenous technologies and approaches, Nigerian oil and gas sector can move towards a more sustainable model that not only mitigate pollutions of our environments but also foster economics growth and community resilience. The holistic approach requires collaboration between government, industry, academia and local communities to ensure lasting impact

April 23, 2022

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At the end of this conference, the Board will be expecting some research and development proposals from MOUAU that will be leveraging endogenous technologies to remediate the environment and sustain development in the Nigeria oil and gas industry and its linkage industry for consideration.



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Opportunities for Partnership with NCDMB



NCDMB's Adopt a Faculty Initiative (AAFAC)

- An expanded view of how NCDMB can utilize the Triple Helix Model for opportunities and partnerships:
- **Research, Development and Innovation**
 - Access funding for impactful research projects
 - Address industry-specific challenges
- **Knowledge Sharing and Technology Transfer**
 - Gain insights into industry best practices through sabbaticals and interns
 - Collaborate on emerging technologies
- **Infrastructure and Equipment**
 - Provision of Physical Buildings
 - Provision of Equipment and Teaching Aids
- **Curriculum Enhancement**
 - Sponsor Curriculum and align it with industry needs
 - Sponsor Review of Existing Curriculum in existing STEM courses



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CONCLUSION: “Essentially, our work is to increase the participation of Nigerians in the oil and gas industry, to grow capacity and local capabilities that will enable more work to be domiciled in Nigeria and to improve the value of expenditure in the oil and gas industry that is retained in Nigeria and in that way increase employment, increase the well-being of Nigerians, and keep technological growth going”.



LEAD PAPER 2

CIRCULAR ECONOMY, ADMINISTRATION, GREEN ACCOUNTING AND FINANCING APPROACHES FOR SUSTAINABLE TRANSFORMATION OF EDUCATION, AGRICULTURE AND INDUSTRY

DR. EBIERI JONES

A PAPER PRESENTED AT THE PLENARY SESSION OF THE SECOND RESEARCH AND INNOVATION FAIR/CONFERENCE AT MICHAEL OKPARA UNIVERSITY OF AGRICULTURE, UMUDIKE (MOUAI) ABIA STATE HELD ON WEDNESDAY 26TH FEBRUARY, 2025 AT PIUS ANYIM AUDITORIUM.

Protocol

The ever-increasing production and consumption have continuous impact on the broader environment as there is a nexus between production and destruction. Our actions (domestic and industrial) have transgressed the environment affecting both the biotic and abiotic ecosystem. The processes either legal or illegal possess threats to the atmospheric conditions and biodiversity in form of waste and pollution.

The demand for raw materials, its extraction and processing of natural resources has resulted in Greenhouse Gas Emissions. 50% of the world current greenhouse gas emissions result from the extraction and processing of natural resources with demand for raw materials (Houten and Ishil, 2025). This presupposes that industrial development causes environmental pollution; therefore, the environment should be protected irrespective of the industrial advancement. The conflict between industrialization and environmental protection has to be resolved if the nation is to improve the living standard of its citizens.

A report from Dataphyte (2022) has shown that Nigeria generates 32 million metric tonnes of waste annually for which 2.5 million tonnes is plastic waste while the annual growth rate of waste is 2.4% annually. This suggests that waste generation will further increase in subsequent years if not managed appropriately, in view of the growth of our population and if the linear economy model is continually adopted.

Nigeria has enacted a lot of laws and regulations to guide the behaviour and attitude of entities (individual and corporate) towards the protection, prevention, administration and control of the environment. These legislations amongst others include; the Constitution of the Federal Republic of Nigeria 1999 as amended, National Environmental Standards and Regulations Enforcement Agency

(NESREA) Act 2007, Federal Solid and Hazardous Waste Management Regulations (1991), Environmental Impact Assessment Act 2004, Harmful Waste (Special Criminal Provisions) Act 2004, The Nigerian Urban and Regional Planning Act 2004, Territorial Waters Act 2004, Petroleum Industry Act 2021 etc. (Environmental Law Research Institute, 2021).

In spite of the several laws and regulations in Nigeria, her ranking in environmental performance index in waste management ranked 152nd and 174th in recycling of products out of 180 countries using a performance rate of 100 for high and 0 for the lowest performance. It scored below average in all the EPI variables used as shown in table 1.

Table 1. Nigeria Environmental Performance Index (EPI) Scores

EPI	Rank	Scores
Waste Management	152	12.70
Unsafe Sanitation	174	6.00
Recycling	171	4.70
Controlled Solid Waste	123	16.70
Ocean Plastic	124	12.70

Source: Dataphyte, (2022)

The EPI results validated an earlier study by Omole et. al. (2016) on waste management practices in Nigeria: impacts and mitigation which found that burying of waste, open – air – burning and open dumping were established to be ineffective and detrimental to public health and the environment.

Nwosu and Chukwueloka (2020) in their study to review solid waste management strategies established that the overall waste management across Nigeria is poor as most waste management authorities rely more on the traditional solid waste management strategy while waste minimization and the use of technological strategies showed minimal results in waste management.

In view of the above, it is significantly crucial to transform the nation's economy into a circular economy (CE) which has become a critical agenda in several international discourse in view of its importance in contributing towards the achievement of the 2030 Agenda of the Sustainable Development Goals (SDGs).

The SDGs that are very critical to discussions on circular economy are; Good health and well – being (SDG 3), Quality education (SDG 4), Clean water and sanitation (SDG 6), Affordable and



clean energy (SDG 7), Decent work and economic growth (SDG 8), Industry, innovation and infrastructure (SDG 9), Reduced inequality (SDG 10), Sustainable cities and communities (SDG 11), Responsible consumption and production (SDG 12), Climate action (SDG 13) and Life on Land (SDG 15) amongst others (United Nations Development Programme, 2015).

CE is a sustainable economic model that encourages the extension of the life span of materials, products and services. It is a model that has the objective to reduce waste and consumption through reuse and recycling of products by enhancing the maximum value use of the products.

The model of CE is seen as both economy – centric and environment – centric at the same time because its practice focuses on generating job opportunities, enhances economic growth, resource optimization and minimization of waste to engender healthy environment and well – being.

Rajput et.al. (2020) in their study titled circular economy in the Africa – EU cooperation – County report for Nigeria, opined that CE is an economic model that ultimately produces neither waste nor pollution by extending the life of products in use and by circulating materials at a high quality within the production system and possibly feeding them back into the biosphere to restore natural resources at the end of the product life.

The above implies that producing goods under a circular economy starts from the conceptualization of the product which requires consistent advancement in technology, retrofitting, capacity building in line with the changing technology, consistency and adherence to policies and administration, adequate funding in education, agriculture and industry, and it seeks for the overall stakeholders' support.

Oluwatayo and Ojo (2024) stated that going into circular economy will assist in the diversification of Nigeria's economy, foster inclusive prosperity, generate employment opportunities and the same time provide a healthy environment that would advance the sustainable development goals.

To buttress the significance of Circular Economy, various stakeholders and leaders across the world has set up institutions and platforms to fast-track and reshape economic activities and transit to circular economy. In Africa, the African Circular Economy Alliance (ACEA) was formed during the 23rd United Nations Conference of Parties (COP23) by the Governments of South Africa, Nigeria and Rwanda. Members of the ACEA now include Ghana and Cote d'Ivoire. The major role of the alliance is policy advisory, leadership and advocacy as well as projects and business scale up.



ACEA collaborates with other bodies such as the Platform for Accelerating the Circular Economy (PACE) a body initiated by World Economic Forum, United Nations Environment Programme and Ellen MacArthur Foundation (African Development Bank, 2025). The African Development Bank (2025) noted that the transition to fully circular economy is estimated to generate economic benefits of up to \$4.5 trillion globally in 2030. At present, activities through circular economic generates only 9% of the global economy (Houten and Ishil, 2025). This projection of \$4.5 trillion accruable economic benefit behoves that the transformation into circular economy has enormous benefits to nations including Nigeria. In Nigeria, the sectors that needs transformation are not limited to but includes petroleum, agriculture, waste recycling, education, electronics, creation of eco – industrial parks and smart cities etc.

Ude et.al. (2024) investigated impact of circular economy on economic development of Nigeria using plastic waste and organic waste recycling as independent variables and poverty rate as the dependent variable of companies from 1992 to 2022. Adopting the Auto – Regressive Distributed Lag model of data analysis established that plastic waste recycling had positive but insignificant impact on poverty rate while organic waste recycling had negative and insignificant impact on poverty rate in Nigeria. They therefore concluded that circular economy does not have significant impact on economic development of Nigeria.

Engaging in circular economy has implications for our educational, agricultural and industrial sectors to evolve in view of the accruable social, environmental and economic benefits it possesses.

The administration of CE would require a multidimensional approach that should involve a broad spectrum of stakeholders for it to achieve sustainability. This is because, it has to be a collective responsibility of all stakeholders. The key mechanisms of the administrative effectiveness and efficiency should amongst others include: consistent and coherent policies and regulations; continual stakeholders' engagements; innovation and constant improvements in technology, retrofitting; intensive capacity building and transformation of learning curriculum; monitoring, evaluation and feedback of the processes in each sector.

Therefore, the institutional framework for the administration of CE should comprise; Federal Government Ministries of Trade, Investment and Industry, Information, Culture, Finance, Environment, State relevant Ministries, business associations such as Manufacturers Association of Nigeria (MAN) and Chamber of Commerce, Agriculture and Industry, affiliation with relevant



International and African bodies, Bank of Industry, CBN and Bankers Committee, Universities, the organised private sector, NGOs and civil society etc.

The activities in engaging a circular economy influences social and environmental variables (financial or non – financial) which needs to be accounted for and reported accordingly as appropriate for all stakeholders (investors, customers, regulatory bodies, potential investors, society etc) to determine the overall performance of a business entity in view of its effect on sustainable development. This type of accounting is called Green Accounting or Environmental Accounting or Social and Environmental Accounting. The Institute of Chartered Accountants of Nigeria defines green accounting as the discovery, collecting, estimate, and analysis of the environmental cost data for better business decision making. It is described as the creation, analysis, and use of financial and non – financial data to improve corporate, environmental, and economic performance and long – term business success of businesses.

Omusuo et. al. (2022) in their study of green accounting and sustainable development in the Niger Delta region of Nigeria, using variables such as infrastructural amenities, poverty eradication, natural disasters, health care – delivery and pollution as green accounting proxies affirmed that there is a link between green accounting, sustainable development and economic stability in Nigeria.

Agriculture, education and industry are vital variables to sustainable transformation. Consideration for the different financing approaches for sustainable transformation of agriculture, education and industry are very essential in determining the workability of these variables. Inadequate funding will stiffen the progress of the sectors and hence sustainable development.

The impact of COVID – 19 on global oil prices exposed Nigeria of the continues reliance on oil and circular economy will provide an opportunity to shift from the extraction of natural resources as the major source of revenue because it can transform an economy to create more jobs, enhance food security and serve as leverage to boost the informal sector. The concept of circular economy has not received the desired attention from private or public sectors discourse in Nigeria, there are several sectors such as Agri – food, plastic/packaging and waste management that could benefit in engaging in the principles (Rajput *et. al.*, 2020).

Rajput et.al. (2020) noted that the choice of these sectors is because they have relatively contributed to the gross domestic product (GDP), share of labour force, existence of policies and strategies for transition into CE and identification of opportunities that can achieve the CE goals.



Higher education is at centre of most countries of governmental agenda. Universities are now seen as crucial national assets in addressing many policy priorities, and as, sources of new knowledge and innovative thinking; providers of skilled labour and credible credentials; agents of growth and development; contributors to innovations; attractors of international talents and business investments; agents of social justice and mobility; contributors to social and cultural vitality; and determinants of the health and well – being of a nation, therefore, great premium should be placed on providing multiple sustainable funding of these institutions for them to reliably perform the functions of teaching, research and community service in line with the development aspirations of a nation. (Bamiro, 2012).

The African Development Bank provides financial support in nature of development finance, trade finance, loans and equity investments for economic and social development which cut across agriculture, capacity building, renewable energy finance and industrial development. In Nigeria, the Bank of Industry also provide green financing for solar powered farms, asset acquisition and replacement. Funds will be provided directly to the vendor of such asset/machinery.

The Nigerian Government, the Global Environmental Facility and UN Environment Programme launched a \$15 million circular electronics initiative in June 20, 2019 at Lagos. It was partnered by the Platform for Accelerating the Circular Economy (PACE) and World Economic Forum (World Economic Forum, 2025).

Way forward

1. Circular strategies: resource efficiency, product sustainability
2. Specialized private investment funds.
3. Public – private partner alliance
4. Consistent and coherent government policies.
5. Measurement criteria
6. Social awareness
7. Development plans on circular economy
8. Eco – Industrial Parks.
9. Smart Cities

Thank you for listening and my sincere deepest appreciation to the Vice Chancellor and management of the University.



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LEAD PAPER 2

CLIMATE CHANGE MITIGATION AND ADAPTAION STRATEGIES FOR AGRICULTURAL AND INDUSTRIAL SECTORS IN NIGERIA

By

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At the Plenary Session of the Second Research and Innovation Fair/Conference of Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria on 26th February, 2025.

INTRODUCTION

Climate: Climate refers to the general weather conditions in an area over a long period. Climate is the long term manifestation of weather and other atmospheric conditions in an area with its long term evidence and/or signs.

Weather: Weather is the short term state of the atmosphere at a specific time and place in terms of precipitation (rainfall), temperature, wind, humidity, etc. Therefore the weather conditions prevalent in an area or geographical zone determines the climate of the area.

Climate change: Climate change could then be defined as long-term shifts in weather conditions of an area/location due to nature (changes in the Sun's activities, Earth movements, volcanic activities/eruptions, rainfall and flooding, etc.) and/or human activities such as industrial activities, agricultural practices, mining and crude oil explorations, wars and conflicts, domestic and life patterns. Ngigi (2009) stated that climate change is change in climate that is attributable directly or indirectly to human activities that alters the atmospheric composition of the earth that leads to global warming.

Global warming refers to increases in world environmental temperatures. It is an aspect of climate change that refers to the rise in global temperature due mainly to the increasing concentration of greenhouse gases (Methane, CO₂, NH₃, N₂O, NO₂, etc.) in the atmosphere while climate change refers to the increasing changes in the measures of climate over a long period of time including sun intensity, temperature, precipitation, humidity, etc. Some scientists have attributed climate change mainly to global warming and therefore considers climate change as the most important environmental problem and challenge facing our world. The signs of climate change include:



- ❖ Temperatures are rising world-wide due to greenhouse gases trapping more heat in the atmosphere.
- ❖ Droughts are becoming longer and more extreme around the world.
- ❖ Tropical storms becoming more severe due to Warmer Ocean water temperatures.
- ❖ As temperatures rise, there is less snowpack in mountain ranges and polar areas and the snow melts faster.
- ❖ Overall, glaciers are melting at a faster rate.
- ❖ Sea ice in the Arctic Ocean around the North Pole is melting faster with the warmer temperatures.
- ❖ Permafrost is melting, releasing methane, a powerful greenhouse gas into the atmosphere.
- ❖ Sea levels are rising, threatening coastal communities and estuarine ecosystems.

CAUSES OF CLIMATE CHANGE

Elementary geography told us four to five decades ago that the climate changes about every 14 years. That could have been when weather conditions were more stable, and effects or consequences of industrial and other human activities were either not being felt, beginning to show up or pretended not to exist. But presently, our climate could be said to be changing within a much shorter period. Climate change has been constant on earth as could be seen in our geological/geographical records while the increased rate and magnitude of the change is what is of great concern humans. There could be two broad major causes of climate change – natural and human activities.

A. Natural:

- Variations in the solar radiations received by earth.
- Movement within and around the earth's crust.
- Alterations/shifts in the earth's rotation and revolution that leads to change in pattern of seasons.
- Natural activities like currents and waves in oceans, seas and large water bodies.
- Other natural phenomena known and unknown (spiritual) to man.

B. Human Activities:

Humans appear to be directly responsible for a greater percentage of global warming through increase in the production of greenhouse gases (methane, CO₂, N₂O, NH₃, and NO₂). Human activities that could cause or lead to climate change include:



- I. Industrial Activities – Fumes from industrial machines, industrial wastes, chemical wastes into the environment, rivers and atmosphere, noise from industrial machines, etc.
- II. Mining Activities – Soil degradation, use of explosives and chemicals, dusts of mineral elements (limestone, granite, potash, lead, etc.)
- III. Crude Oil Production – Fracking, oil spillage, gas flaring, off-shore drilling, oil spillage into rivers, seas and oceans, etc.
- IV. Use of Fossil Fuels – Use of fossil fuels to power motor vehicles, industrial machines, electricity generators/plants, coal power plants, etc.
- V. Agricultural Activities – Bush burning, use of herbicides and pesticides, inorganic fertilizers, animal production, deforestation, overfishing
- VI. Landfills and Waste Management – Organic wastes decompose to produce methane gas, discharge from food industries into rivers and streams, poor human waste disposal.
- VII. Consumption Patterns and Habits – Most common in developed countries due to economic growth and encouragement of people to consume goods and services.
- VIII. Poverty – High level poverty in Nigeria has resulted in citizens, especially the lower/poor class to lose respect for the environment (environmental abuse). This includes indiscriminate waste disposal into rivers, disregard for proper environmental care, extensive use of firewood in domestic cooking, increasing deforestation, etc.
- IX. Government Economic and Socio-political Policies – Subsidy removal from kerosene and cooking gas, poor electricity supply, emphasis on inorganic fertilizer for crop production, poor rail and water transport services (leading to over-reliance on road vehicles for transportation) all encourage human activities that lead environment degradation and abuse.

EFFECTS OF CLIMATE CHANGE

1. **High Environmental and Ambient Temperatures** – The most significant effect of climate change is the increase in environmental temperatures and consequent increase in ambient temperature. Increase in greenhouse gases increases global environmental temperatures. As has been observed in each decade since the 1990's has been hotter than the preceding ones, causing hotter days and nights, heat waves, wildfires, and increase in heat-related sicknesses.



2. **Drought** – Water availability is reduced, especially in water-stressed regions (deserts), affecting agriculture (crop and animal production), desertification and human lives and livelihood. Droughts could cause destructive dust and sand storms that could send tons of sand across nations and regions increasing desert encroachment.
3. **Severe Storms** – Today we hear of many destructive storms (wind and water) in many regions of the world; a situation that was rare many years back. Intense storms are a consequence of increased global environmental temperature as they cause ocean temperature to rise. This causes typhoons, tropical storms, cyclones and hurricanes that destroy homes, communities and infrastructure with attendant deaths and economic losses.
4. **Loss of Species** – Wildfires and forest fires are caused by high environmental temperatures and extreme weather that threatens species survival. Also during flooding, invasive pests and illnesses are threats due to climate change. It has been estimated that the world is losing species at a rate of 1000 times faster than in any other time in human history with about 1 million species at risk of extinction in the next few decades.
5. **Declining Food Production** – Agricultural production is the most negatively impacted by climate change. Adverse weather conditions negatively impact on crop, animal and fisheries production. Heat stress also diminishes water, forages and grasslands affecting grazing, herding and hunting.
6. **Poverty** – Climate has been known to increase the poverty level in regions and countries. Wildfires and floods have destroyed livelihoods, homes, villages and communities. Excessive heat makes it difficult to work, grow food crops and produce animal products. In some cases, farmers have lost up to 60% of their animal herd due to lack of water, pushing such people to extreme poverty. It has been estimated that weather-related conditions have displaced about 23.1 million people on average each year, with many more left vulnerable to poverty.
7. **Diseases** – It is believed by health scientists that climate change and changing weather patterns are responsible for increased health challenges, expanding diseases and increased animal and human deaths. Climate change adversely impacts health and human lives through threats to the essentials of good health like clean air, safe drinking water, food and nutrition, security, proper shelter and conducive living environment. The impacts of climate change and heat waves on health include cardiovascular diseases such as stroke, heart disease, asthma, chronic obstructive pulmonary disease and lung cancer.



CLIMATE CHANGE MITIGATION AND ADAPTATION

Climate change mitigation and adaptation are strategies to address the effects of climate change. Mitigation reduces the amount of greenhouse gases emitted into the atmosphere, while adaptation adjusts to the effects of climate change. Both strategies are necessary to address climate change.

MITIGATION

- **Reducing emissions:** Actions to reduce or prevent greenhouse gas emissions from human activities.
- **Using renewable energy:** Replacing fossil fuels with clean energy sources.
- **Improving energy efficiency:** Conserving energy and making homes and transportation more efficient.
- **Protecting ecosystems:** Protecting and restoring forests and other critical ecosystems.
- **Changing land use:** Removing carbon dioxide from the atmosphere and changing how land is used.

ADAPTATION

- **Adjusting to current effects:** Adjusting to the current effects of climate change.
- **Preparing for future effects:** Adjusting to the future effects of climate change.
- **Improving water management:** Improving water storage and use.
- **Managing land:** Managing land to reduce wildfire risks.
- **Building defenses:** Building stronger defenses against extreme weather like floods and heat waves.
- **Practicing regenerative agriculture:** Planting crop varieties that are more resistant to drought and practicing regenerative agriculture.

CLIMATE CHANGE MITIGATION

Nigeria is one of the countries that is highly exposed to the effects of climate change. These effects include extreme weather conditions, variations in temperature and rainfall patterns, devastating winds, over-flowing river banks, etc. These effects usually lead to perennial flooding especially of coastal communities, destruction of farms and agricultural lands, food insecurity, desertification and drought mainly in northern Nigeria, erosion of shorelines in coastal areas and displacement of



human and animal populations. These may also result in socio-economic impacts like communal conflicts, inter-tribal conflicts/wars, violence and general insecurity.

Agrarian rural and poor communities appear to be more susceptible to climate change effects because they are mainly engaged in rain-fed subsistence agriculture with all its features.

The poor segment of the society therefore are more vulnerable to climate change because they depend on nature for their daily lives. They may also resist mitigation measures against climate change if such strategies may threaten their livelihood and survival. For example, poor people in Nigeria continue to use firewood to cook and for other domestic purposes even with the knowledge that cutting trees for firewood encourages deforestation. Climate change also causes poor crop yield and harvest, and also poor animal growth and performance.

MITIGATION MEASURES

A. Agriculture

i. Crops

- Climate-smart agriculture.
- Reduction in the use of inorganic fertilizers and increase in the use of organic fertilizers.
- Zero burning of crop fields, crop residues and forests.
- Change of irrigation systems from sprinkler to drainage type.
- Tree planting and use of cover crops.
- Mechanization of rice and other crop production activities.

ii. Animal

- Proper feeding of animals (poultry and livestock) with good quantity and quality feeds.
- Feeding low energy and low crude protein diets.
- Reduction in animal manure and proper manure handling and storage.
- Reduction in CH₄ (methane) in animal houses and environments.
- Inclusion of feed additives (enzymes, prebiotics, probiotics, organic acids, antioxidants, phytogenic, etc.) in animal feeds.

iii. Waste Management

Nigeria presently has a very poor waste management system. The government, citizens and the general public are very important in the mitigation of greenhouse gas emissions from wastes. Waste management should involve:

- Waste recovery and collection



- Waste sorting
- Recycling
- Reuse

These four would lead to waste reduction in the environment, landfills, and reduced greenhouse gas emissions. Animal wastes are used to produce biogas as domestic farm and industrial fuel. Proper sorting and recycling of waste recovers and conserves resources and funds. I wish to point out that some Asian countries (Malaysia, Singapore, and Thailand) import waste, sort, recycle and export the products even to Nigeria.

iv. Industry

The Nigerian industrial sector is pivotal in the nation's economy but faces significant challenges due to climate change. Implementing effective adaptation and mitigation strategies can enhance resilience, reduce environmental impact, and promote sustainable growth.

Industries in Nigeria should regulate the amount and quality of hazardous gasses, chemicals and fumes released as waste into the environment during their production and processes. This is to avoid acid rain, water pollution and other dangerous consequences. Cement and quarrying industries should develop and adopt technologies that could collect and or re-inject the heavy dust fumes they generate, like it obtains in Israel and other developed countries. Crude oil spillage and gas flaring at offshore, on-shore and oil flow stations should be stopped as they have devastated the environment of oil-producing communities in Nigeria.

v. OTHERS

- Legislative instruments (laws)
- Legal jurisprudence/climate litigation
- Fiscal measures/ climate financing (tax CO₂)

ADAPTATION TO CLIMATE CHANGE

Agriculture in Nigeria has remained rural, subsistence, and smallholder in nature with low capacity to acquire improved inputs, crop varieties, fertilizers, herbicides, pesticides, etc.), and other factors of production. Animal and crop farmers therefore usually adopt resilient strategies to cope with and/or reduce climate change vulnerability. These strategies include:

i. Crop



- Adjusting planting date/schedules – This allows farmer to plant during favorable weather conditions that could result in improved yields, better harvest and reduced losses from adverse weather conditions.
- Crop diversification – Mixed cropping rather than mono-cropping (single crop) reduces climate-related risks, enhances resilience against climate variability, diseases, and pests. It also improves farmers income and wellbeing.
- Planting improved crop varieties that are early-maturing helps reduce the risk of crop failure thereby ensuring food security during changing weather and climate conditions.
- Sustainable land management – Zero tillage, cover cropping, and agroforestry maintain soil health and reduce soil erosion. These improve soil fertility, enhance water retention and contribute to carbon sequestration.
- Water management – Efficient water management through rainwater harvest and good irrigation practices help optimize water use and ensures consistent crop production during droughts and other times of water scarcity.
- Use of organic fertilizers and soil amendments – Organic fertilizers and compost manure improve soil structure and fertility. This reduces greenhouse gas emissions associated with inorganic chemical fertilizers.
- Training - Farmers education and training provides them with knowledge about climate change impacts, sustainable practices and early warning signs.

ii. **Animal**

Animal farmers in Nigeria face significant challenges due to climate change, including heat stress, water scarcity, and feed shortages. To effectively adapt to and mitigate these impacts, several strategies can be employed:

- Provision of Adequate Housing for Livestock - Constructing well-ventilated and shaded housing for animals to protect them from extreme weather conditions. Proper housing reduces heat stress in livestock, improving their health and productivity. It also minimizes disease outbreaks that can arise from exposure to harsh environmental conditions.
- Improved Feeding Practices - Implementing strategies such as indoor feeding during adverse weather and utilizing drought-resistant forage crops. This approach ensures a consistent food supply during dry spells and reduces competition for resources, ultimately enhancing animal health and productivity.
- Diversification of Livestock Species - Engaging in the rearing of multiple species of livestock that are better suited to changing climatic conditions. Diversification can spread risk and improve



resilience against climate-related disruptions, as different species may have varying tolerances to environmental stresses.

- Use of Drought-Tolerant Breeds - Adopting livestock breeds that are more resilient to heat and drought conditions. Drought-tolerant breeds can maintain productivity under challenging conditions, reducing losses associated with climate variability.
- Water Conservation Techniques - Implementing rainwater harvesting systems and efficient water management practices. These techniques ensure a reliable water supply for livestock, especially during dry seasons, thus supporting animal health and reducing mortality rate.
- Regular Health Monitoring and Veterinary Care - Establishing regular health checks and vaccination schedules for livestock. Proactive health management helps detect diseases early, ensuring better survival rates and productivity despite climate stresses.
- Training and Capacity Building - Providing education on climate change impacts and sustainable farming practices. Empowering farmers with knowledge enables them to make informed decisions regarding adaptation strategies, improving overall resilience.
- Engagement in Climate Information Systems - Utilizing weather forecasting services to plan farming activities accordingly. Access to timely weather information allows farmers to make better decisions about breeding, feeding, and managing livestock during extreme weather events.
- Integration of Crop-Livestock Systems - Combining crop production with livestock rearing to optimize resource use. This integration enhances soil fertility through manure application while providing additional income sources for farmers, thus improving overall farm resilience.
- Participating in Cooperative Groups - Joining cooperatives or associations focused on livestock farming. Cooperatives can provide shared resources, collective bargaining power for purchasing feed or veterinary services, and access to training programs on sustainable practices.

INDUSTRY STRATEGIES

Here are some key strategies:

- Transition to Renewable Energy - Industries can invest in renewable energy sources such as solar, wind, and hydropower to reduce reliance on fossil fuels. This transition lowers greenhouse gas emissions, decreases operational costs over time, and enhances energy security. It aligns with Nigeria's commitment to achieving net-zero emissions by 2050-2070 under the Climate Change Act.
- Improving Energy Efficiency - Upgrading machinery and adopting energy-efficient technologies can significantly reduce energy consumption in industrial processes. Increased energy efficiency leads to lower energy costs and reduced carbon footprints, contributing to both economic savings and environmental protection.



- Implementing Circular Economy Principles - Adopting practices that focus on recycling, reusing materials, and minimizing waste in production processes. This approach reduces resource consumption and waste generation, leading to a more sustainable industrial ecosystem while also creating new business opportunities.
- Enhancing Waste Management Systems - Developing comprehensive waste management strategies that include recycling, composting, and proper disposal of hazardous materials. Effective waste management minimizes environmental pollution and can recover valuable materials for reuse, thus supporting sustainability goals.
- Strengthening Climate Governance and Policy Frameworks - Engaging with government policies such as the National Climate Change Policy (NCCP) and Nationally Determined Contributions (NDC) to align industrial practices with national climate goals. Compliance with these frameworks can enhance corporate reputation, attract investment, and ensure access to financial incentives for sustainable practices.
- Capacity Building and Training Programs - Providing training for employees on sustainability practices, climate change impacts, and adaptation strategies. Educated employees are better equipped to implement sustainable practices within their operations, leading to improved efficiency and innovation.
- Research and Development (R&D) for Sustainable Technologies - Investing in R&D to develop new technologies that reduce emissions and enhance sustainability in industrial processes. Innovation can lead to more efficient production methods, lower costs, and reduced environmental impact while positioning companies as leaders in sustainability.
- Engagement with Stakeholders - Collaborating with government agencies, NGOs, and communities to develop shared goals for sustainability. Stakeholder engagement fosters a collective approach to addressing climate challenges, enhancing resilience through shared resources and knowledge.
- Carbon Pricing Mechanisms - Implementing carbon taxes or trading systems as part of a broader strategy to internalize the costs of carbon emissions. Carbon pricing encourages industries to reduce emissions by making it economically beneficial to adopt cleaner technologies.

SUMMARY

- ❖ Climate change is a natural global phenomenon that has been accelerated and exacerbated by human activities.
- ❖ The main aspect of climate change is global warming which is rise in global temperatures due mainly to increasing concentrations of greenhouse gases (Methane, CO₂, NH₃, N₂O, NO₂) into the atmosphere.



- ❖ Nature and human activities (mainly agriculture, industries and waste management) are responsible for the present effects and consequences of climate change.
- ❖ Mitigation measures such as climate-smart agriculture, environmental friendly crops and animal production practices, poverty reduction, proper waste management procedures, environmentally friendly industrial production processes and adequate government policies are needed to mitigate the impact of climate change.
- ❖ Adaptation measures required or already in existence to adjusting to climate change impacts include adjustment in crops and animal production practices, water management, sustainable land use, public enlightenment about climate change and training.

RECOMMENDATION -

The government of Nigeria should as a matter of urgency formulate socio-economic and political policies and programmes that could ensure environment protection and stem the rising tide of climate change.

Institutions such as Universities, Ministries and Agencies should improve education, enlightenment and advocacy for the protection of environment.

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LEAD PAPER 3

SUSTAINABILITY & INDUSTRIAL CHEMICALS PRODUCTION (PLASTICS PRODUCTION AS A CASE STUDY)

BY

DR. OTEIVA MOKIE-FRANK FCSN, MICCON, CA

INTRODUCTION

The chemical process industry includes those manufacturing facilities whose products are: Chemical reactions between organic materials, or inorganic materials. The extraction, separation, or purification of a natural product (with or without the aid of chemical reactions). The preparation of specifically formulated Industrial Chemicals. With the help of Biotechnology process, we can manipulate micro-organisms such as bacteria and fungi at the genetic level to produce new tailor-made strains that can produce a multitude of chemical products.

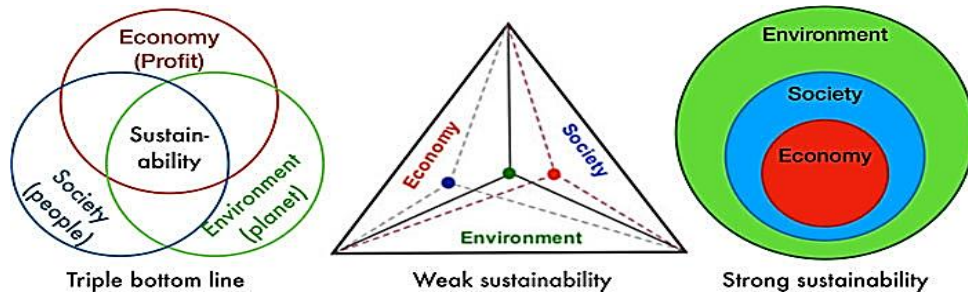
SUSTAINABILITY

The term sustainability was first used in relation to forest management in Europe in the 18th century, but it was only in the late 1980s that the ideas of **sustainability and development** were connected. The Brundtland Commission defined **sustainable development** as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Especially since the first United Nations (UN) conference on environment and development in Rio in 1992, there have been a plethora of definitions, academic commentaries, and policy initiatives.



PILLARS OF SUSTAINABILITY

Sustainability - ability to exist and develop without depleting natural resources for the future. Sustainability - social goal for people to co-exist on Earth over a long period of time. Sustainability usually has **3 Dimensions (or Pillars)**: Environmental, Economic and Social (3Ps – Planet, People and Profits/Prosperity) BUT POLITICS has been added to it making it 4Ps.



- Sustainability - Often viewed as a long-term goal, focusing on maintaining a balance for future generations. i.e. a more sustainable world.
- Sustainable Development (SD) - The many processes and pathways to achieve it. i.e. sustainable Education and training, Research and Technology transfer.



ENVIRONMENTAL SUSTAINABILITY (PLANET)

The responsible management of natural resources to fulfill current needs without compromising the ability of future generations to meet theirs.

It is concerned with the reduction of carbon footprints, non-decomposable packaging, water usage, wasteful processes as part of a supply chain. These processes can often be cost-effective, and financially useful as well as important for environmental sustainability. Reducing negative impacts on the environment would improve environmental sustainability.

ECONOMIC SUSTAINABILITY (PROFITS/PROSPERITY)

Economic sustainability (Profits/Prosperity) is probably the simplest form of sustainability. To be economically sustainable, a business must be profitable and produce enough revenues to be continued into the future. The challenge with this form of sustainability is achieving an equilibrium.



Rather than making money at any cost, companies should attempt to generate profit in accordance with other elements of sustainability.

Economic development can indeed reduce hunger or energy poverty. This is especially the case in the least developed countries. That is why Sustainable Development Goal calls for economic growth to drive social progress and well-being. Its first target is for: "at least 7 percent GDP growth per annum in the least developed countries". However, the challenge is to expand economic activities while reducing their environmental impact.

Recently, the UN issued The Sustainable Development Goals as its main aims for the successful achievement of a better and more sustainable future. They address global challenges to sustainability. The 17 Goals include sustainable economic growth, no poverty, zero hunger, clean water and sanitation, affordable and clean energy, and responsible consumption and production, and it is hoped that they will be reached by 2030.

SOCIAL SUSTAINABILITY (PEOPLE)

Social sustainability (People) is about treating employees fairly and ensuring responsible, ethical, and sustainable treatment of employees, stakeholders, and the community in which a business operates. Social aspect of sustainability takes into consideration human welfare, rights and liberties, workplace atmosphere, and more.

POLITICAL SUSTAINABILITY (POLITICS)

Unfortunately, political sustainability is rarely identified as one of the pillars of sustainability. In democratic countries, sustainability principles and their implementation are well-accepted, but this is not the case in totalitarian regimes. Although the four pillars of sustainability act as an interdependent system, if sustainability of the environment product is to be achieved, every one of the pillars must be in harmony with each other.

Political sustainability refers to governments taking actions to comprehensively address sustainability as well as individuals pushing for governments to take those actions.

Political sustainability refers to the ability of a political system or government to maintain stability, continuity, and effectiveness over time.

THE GLOBAL INDUSTRIAL CHEMICALS PRODUCTION CHALLENGE

- Industrial Chemical Producers enjoy making things. Modern life is delivered through the furniture, goods, clothes, cars, medicines, etc., that are the output of industrial production.
- To many people, these products magically appear in shops while the system that creates them is hidden and mysterious.
- To others, Industrial Production is simply a giant machine that pollutes.
- For those of us close to production, we know that, jobs have been created, jobs that have helped lift billions from poverty. By using our relentless focus on innovation and productivity, we have made our products accessible to those billions.



- We also now know that, each time we make a product, we are degrading the air, soil, water and people we rely on.
- And the vast scale of global production is pushing that degradation close to, or over, environmental and social sustainability.

THE NEED FOR SUSTAINABILITY IN CHEMICAL PROCESSES

- **Environmental Protection:** The chemical industry is responsible for significant environmental degradation through pollution, habitat destruction, and resource depletion. By prioritizing sustainable practices, such as the use of renewable resources and minimizing emissions, industries can mitigate their ecological footprints.
- **Regulatory Compliance:** Governments and international bodies are increasingly enacting stringent regulations aimed at reducing environmental impacts. Companies that adopt sustainable strategies not only ensure compliance but can also avoid potential penalties and enhance their reputations.
- **Market Demand:** Consumers are becoming more environmentally conscious and prefer products manufactured using sustainable processes. Businesses that integrate sustainability into their operations can capture new market segments and improve customer loyalty.
- **Economic Benefits:** Sustainable practices often lead to greater efficiency and reduced costs over time. Innovations that cut waste and improve resource management can result in significant savings. As noted by the chemist and environmentalist

“What we are doing to the forests of the world is but a mirror reflection of what we are doing to ourselves and to one another.” – Mahatma Gandhi

- **Resource Security:** As non-renewable resources become scarcer, relying on sustainable alternatives ensures long-term viability for industries. This transition is crucial for preventing economic instability associated with resource shortages.

IMPACT OF INDUSTRIAL CHEMICALS PRODUCTION ON THE ENVIRONMENT (ENVIRONMENTAL SUSTAINABILITY)

IMPACT OF INDUSTRIAL CHEMICALS PRODUCTION ON HUMANS (SOCIAL SUSTAINABILITY)

SUSTAINABLE PRACTICES TO MITIGATE IMPACTS OF INDUSTRIAL CHEMICALS PRODUCTION

This approach emphasizes designing processes that reduce or eliminate the generation of hazardous substances.

1. **Prevention of waste:** It is better to prevent waste than to treat or clean up waste after it has been created.
2. **Atom economy:** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.



3. Less hazardous chemical syntheses: Whenever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Designing safer chemicals: Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. Solvent-free reactions: Auxiliary substances (solvents, separation agents, etc.) should be avoided wherever possible and innocuous when used.
6. Energy efficiency: Energy requirements should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. Renewable feedstocks: A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. Reducing derivatives: Unnecessary derivatization (blocking group, protection/deprotection, etc.) should be minimized or avoided if possible, as these steps generate additional waste.
9. Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Designing for degradation: Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. Real-time analysis for pollution prevention: Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.
12. Inherently safer chemistry for accident prevention: Substances and the form of substances produced should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

5C'S APPROACH TO MEETING CLIMATE CHANGE TARGETS

(Consolidate, Curb, Create, Compensate & Circulate)

Consolidate - Industrial facilities should produce with a low-carbon intensity. This should not only support emissions mitigation by displacing higher-carbon intensity fuels but also ensures access to secure & affordable energy.

Curb – Industrial facilities should focus on undertaking measures to reduce emissions and enhance efficiency across their assets and operations by employing best-in-class and energy-efficient technologies.

Create – Industrial facilities should focus on establishing a position in the low-carbon energy business by increasingly developing a renewable energy portfolio & producing lower-carbon products.

Compensate - Industrial facilities should focus on developing carbon capture capacity & infrastructure to capture, utilize & store CO₂ from our operations

Circulate - Industrial facilities should focus on proactively minimizing waste production & optimizing resource use. Circularity will enable companies to recycle & repurpose waste & avoid additional emissions.



WASTE RECYCLING

- **Waste recycling:** _ any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes.
- **The 5R's** - Today, the concept of the 5R's in waste management advocates: **REFUSE, REDUCE, REUSE, RECYCLE & ROT**

CHEMISTRY IN SUSTAINABILITY

1. **Paper Recycling**—Chemistry plays a role in determining chemicals such as surfactants and hydrogen peroxide for processing pulp in paper recycling.
2. **Metal Recycling** – Chemical analysis determines the composition of scrap metals, thermodynamics of the metallurgical processes.
3. **Glass Recycling** – Chemistry helps us understand the chemical composition of waste glass and how it can be processed to a new glass product.
4. **Plastic Recycling** – Chemistry is important in understanding the polymer conversion process, condition and product.
5. **Organic Waste Recycling**- Composting, involves decomposing organic materials, such as food scraps and yard waste, into nutrient-rich compost.

BENEFITS OF SUSTAINABLE INDUSTRIAL CHEMICALS PRODUCTION

Environmental safety; Minimizes potential harm to the environment; Avoids harming people who handle the chemicals; Reduces waste -reducing the number of steps in a synthesis process can reduce the amount of waste created; Saves time and energy -reducing the number of steps in a synthesis process can save time and energy; Climate-friendly -renewable raw materials can help reduce greenhouse gas emissions and mitigate climate change; Local employment -using renewable raw materials locally can create jobs in rural areas; Resource efficient -renewable raw materials can help avoid waste and reduce the need for fossil fuels; Immediate action -real-time analysis allows for immediate action to reduce or eliminate harmful emissions; Compliance -real-time analysis helps ensure compliance with environmental standards; Sustainable practices -real-time analysis promotes sustainable practices by helping industries respond quickly to pollution events; Cost savings -energy efficiency can help reduce energy bills for consumers and businesses; Environmental benefits -energy efficiency can help reduce air pollution and greenhouse gas emissions; Economic development -energy efficiency can help businesses improve their bottom lines and provide economic development benefits; Improve efficiency -sustainable catalysis aims to improve the efficiency of resource utilization; Reduce environmental impact -sustainable catalysis aims to reduce the impact of chemical processes on the environment; Reduce or eliminate the use of hazardous substances; Promote safer alternatives for the environment and humans; Design chemical products that are effective but have little or no toxicity

Why is SUSTAINABILITY important? Protects Ecosystems, Wildlife and the Environment generally. Reduces Incineration. Reduces the Need to Harvest New Materials. Conserves Natural Resources such as forest and trees, fossil fuel. Saves Energy and Money. Reduces Carbon

Emissions. Improve collaboration. Creates Jobs for example sorters, drivers, mechanics, technicians. Supports the Transition to Circular Economy.

SOLUTIONS FOR SUSTAINABILITY (Green Chemistry Vs. Circular Chemistry)

Green chemistry supports the linear economy model, i.e. take-make-use-dispose approach.

Circular chemistry, addresses, the circular economy, which involves a closed-loop, waste-free approach.

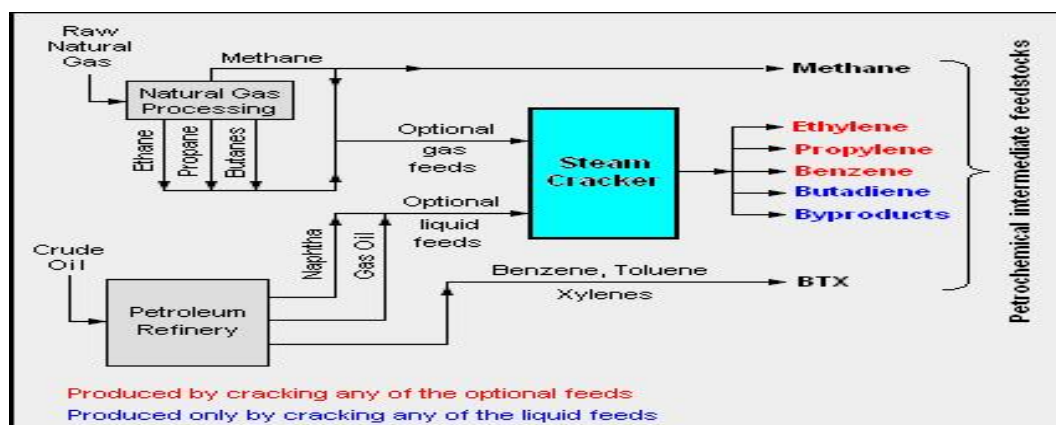
BENEFITS OF SWITCHING TO CIRCULAR ECONOMY

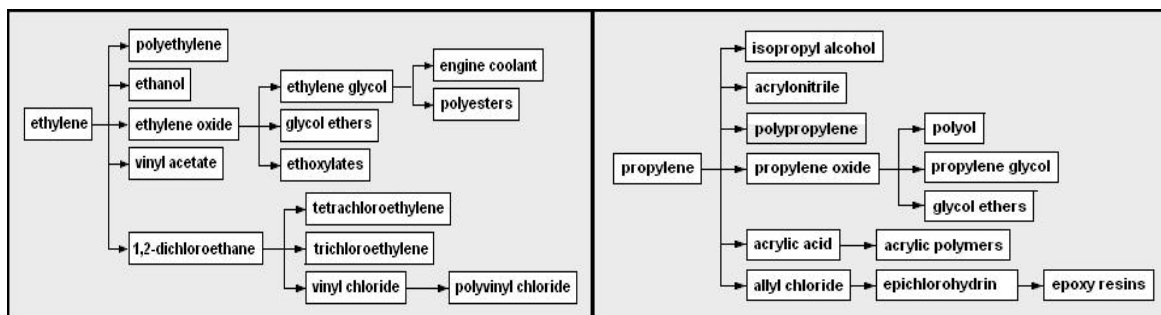
- ☐ Protects the Environment and Human Health
- ☐ Increases the generation of new added value
- ☐ Reduces raw materials dependence
- ☐ Creates jobs and saves consumer's money
- ☐ Improves the Ecosystem
- ☐ Cuts down on greenhouse gas emissions

PETROCHEMICALS – LINEAR ECONOMY – FROM UPSTREAM TO DOWNSTREAM

The prefix "petro-" is an arbitrary abbreviation of the word "petroleum"; since "petro-" is Ancient Greek for "rock" and "oleum" means "oil". Petrochemicals are chemical products derived from petroleum products (Naphtha, NGL, C2/C3). The classes of Petrochemicals that are most common are Olefins and Aromatics. The olefins include ethylene and propylene while the aromatics include benzene, toluene and xylene isomers (BTX). Olefins are the basis for polymers and oligomers used in plastics, resins, fibers, elastomers and lubricants.

BASIC BUILDING BLOCKS OF PETROCHEMICALS





Polymer or Plastics?

Plastics = Polymers + Additives

Polymer is a structural molecule which comprises of long chains and has a high molecular weight. It is formed through a chemical process known as polymerization. Polymer is made up of repetitive units called monomers that are bound together by covalent bonds. The chain could be of same monomer or different monomers

Plastics are typically polymer of high molecular weight and may contain other substances to improve performance and/or reduce cost.

CHALLENGES AND PROSPECTS

Challenges

- **Economics (High Initial Costs)** - The economics of translating some catalytic routes to market can be challenging. Implementing sustainable practices often requires substantial upfront investment in new technologies, processes, or materials. Many companies may be hesitant to allocate funds for these changes without assurance of immediate returns, limiting their willingness to innovate.
- **Identifying competitive products** - Identifying which molecular products are competitive to produce at scale can be challenging.
- **Regulatory Uncertainty** - Constantly evolving regulations can create confusion and reluctance among industry players to adopt sustainable practices. Companies might be wary of investing in sustainability if future regulations could render their methods obsolete.
- **Lack of education or limited Awareness** on sustainability - A lack of understanding about the principles and benefits of sustainable practices can impede progress. Chemists and industry professionals may not be sufficiently trained in green chemistry concepts, leading to resistance to change.
- **Competing Priorities** - Organizations often prioritize short-term profitability over long-term sustainability goals. The pressure to deliver immediate financial results can lead to decisions that neglect environmental considerations.

Future

- ✓ There is a growing impetus to explore new catalytic concepts.



- ✓ There is a need to improve the interpretability of machine learning algorithms.
- ✓ There is a need to shift to a circular model that considers the entire life cycle of products.

ENVIRONMENTAL MANAGEMENT

Industries in Nigeria should have a robust Environmental Management System (EMS) in place that is, ISO 14001:2015 certified. The EMS apply to all industries current and planned activities and their standards, procedures and guidelines should be intricately designed to align with their mission statement, ensuring the preservation of ecosystems and minimizing impacts on the environment.

There should be corporate standards in place for environmental risks and requirements related to site preparation works for new capital projects, abandonment at the end of life of assets and the remediation and restoration of land.

As part of EMS, industries should have corporate standards for the management of water resources, requirements for air quality monitoring using Continuous Emission Monitoring Systems (CEMS) and guidelines to monitor and report GHG and pollutant emissions impacting air quality.

Environmental Action

As a responsible corporate citizen, Industries should recognize the importance of safeguarding and preserving Nigeria's natural resources and acknowledge the urgent need to address environmental challenges, such as the depletion of resources and loss of biodiversity. Through these actions and collaborations, industries can contribute to a more sustainable future for Nigeria and the world at large.

PROTECTING LOCAL NATURAL RESOURCES – AIR, WATER AND LAND

Air quality - Maintaining a healthy atmosphere and reducing air pollution is crucial for promoting the well-being of society and local communities. Understanding the significance of managing emissions and air pollutants in ensuring good air quality is key. Air quality indicators are crucial to evaluate air-related impacts and management strategies. Together with GHG emissions measurements, these air quality indicators serve as a mechanism for tracking any company's climate change and ambient air quality performance.

Water management – Recognizing the challenges operating in a region with high water stress. Any responsible organization should be dedicated to identifying and implementing solutions that enhance water use efficiency and conservation. Commitment to protecting freshwater resources and restoring ecological balance in marine environments should be embedded in industries environmental policies. Developing sustainable solutions that minimize impact on water resources while maintaining operational excellence is vital. Prioritizing water conservation and efficiency measures, helps towards creating a more sustainable future for our communities. Industries should explore innovative approaches to conserve freshwater resources and maintain ecological balance, while striving to achieve their operational goals.

Waste management – Waste should not be viewed as a burden, but rather as a potential resource. Industries vision should shift from waste management to resource management. See the waste generated across Industrial operations as a valuable renewable resource. Industries, communities



and government goal is to follow the waste hierarchy of preferred waste management options, which prioritizes waste prevention, product reuse, material segregation and recycling, resource and energy recovery and proceeds with safe disposal. This approach helps to reduce environmental impact and contributes to mitigating global warming.

Biodiversity - Biodiversity plays a crucial role in community's heritage, culture and future. It provides the foundation for food security and sustainable agricultural development by supplying essential resources such as food, medicine, clothing, housing, energy and raw materials. Nigeria's National Biodiversity Strategy and Action Plan 2016-2020. This revised NBSAP guides the conservation and sustainable utilization of biodiversity, access to genetic resources and the fair and equitable sharing of the benefits arising from their utilization. It is an important document that provides information on biodiversity and their threats and analyzes institutional and legal frameworks that govern biodiversity issues in our country.

RECOMMENDATIONS

- ❑ **Humanity would not last** if we do not make changes right now to sustain ourselves in the future. Because of that, political sustainability depends on issues like environmental and social sustainability. **However, sustainability in those issues won't be accomplished without political sustainability. Our governments vitally need to address the many aspects of sustainability if they want to continue to exist.**
- ❑ **Sustainability Education:** Improve sustainability science literacy at every level of society—from informal education of consumers, citizens and future scientists, to the practitioners of the field, and the businesses that use and sell these products.
- ❑ **Promote incorporation of sustainability concepts**—into curricula, particularly in chemistry and chemical engineering.
- ❑ **By voting, protesting, lobbying, petitioning, and campaigning,** we can pressure the government to implement sustainability solutions, which will have a much more widespread impact than personal sustainability lifestyle changes.

CONCLUSION

The chemical industry plays a crucial role in modern society, but it also has a significant impact on the environment and human health. To address these challenges, the industry is working to develop more sustainable practices, including cleaner production processes, safer chemicals, and greater worker and community safety. Also, by investing in sustainable practices, chemical companies can both meet growing consumer demand for sustainable products and build long-term value.

Educational initiatives focused on sustainability are gaining traction (support). As universities and organizations emphasize sustainable science in their curricula, the next generation of scientists will be better equipped to tackle the looming challenges of environmental degradation and resource scarcity. In closing, the landscape of sustainable industrial chemistry is evolving, driven by an urgent need to harmonize chemical production with environmental stewardship. By focusing on these emerging trends, industries can foster a culture of sustainability that embraces innovation while addressing the critical challenges of our time.



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REVIEWERS OF SUBMITTED PAPERS FOR THE SECOND MOUAU RESEARCH AND INNOVATION FAIR AND CONFERENCE

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18	Dr. Mmaduabuchi U. Uzoegbu	Dept of Geology, MOUAU
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24	Dr. Kalu Kalu Igwe	College of Veterinary Medicine, MOUAU
25	Dr. Lebe A. Nnanna	Dept. of Physics, MOUAU
26	Dr. Everestus Obinwanne Eze	Dept. of Mathematics, MOUAU



COMMUNIQUE OF THE SECOND RESEARCH AND INNOVATION FAIR/CONFERENCE OF MICHAEL OKPARA UNIVERSITY OF AGRICULTURE, UMUDIKE, ABIA STATE

Preamble. The Directorate of University Research Administration (DURA), in collaboration with the MOUAU Extension Centre (MEC), Michael Okpara University of Agriculture, Umudike, successfully organised and hosted the 2nd Research and Innovation Fair/Conference held on 26th and 27th February 2025 at Anyim Pius Anyim Auditorium, Michael Okpara University of Agriculture, Umudike, Abia State. The conference brought together leading experts, policymakers, researchers, and industry stakeholders to deliberate on the theme, *"Leveraging Endogenous Technology for the Sustainable Development of the Nigerian Oil and Gas and Agro-Allied Industries."*

The event was graced by the presence of the Executive Governor of Abia State represented by his deputy which reaffirmed the state's commitment to research, innovation, and sustainable industrialization. The special guest of the fair/conference was Arc. Sunny S. T. Echono, the Executive Secretary of the Tertiary Education Trust Fund (TETFund), whose presence underscored the importance of education and research in national development.

Key Presentations:

1. **Keynote Address:** Engr. Felix Omatsola Ogbe Executive Secretary, Nigerian Content Development & Monitoring Board, who was ably represented by Mr Jonathan Njoku, delivered the keynote address. He called for the establishment of R & D Council, comprising the Government, Industries and Academia, who will ensure that funded Research Outcomes must be utilised for Industrial Operations, provide incentives for Researchers and ensure local Patronage. He advocated for Market- driven Researches which are Government approved, with outcomes ready to be deployed in operations. He further highlighted on Research Roadmap, Global Engagement & Collaboration and Product Characterisation along end -user needs.
2. **Plenary Session:** The plenary session was chaired by **Prof. Nnanyelugo Martin**, Director/CEO of the Raw Materials Research and Development Council (RMRDC), Abuja. His presentation provided insights into the role of local raw materials in industrial development and the need for policy support to enhance local content utilization.
3. **Lead Speakers:**
 - **Chief Raymond Isiadinso (MD/CEO, Mid-Century Agro-Allied Ventures Limited)** spoke on "Climate Change Mitigation and Adaptation Strategies for the Agricultural and Industrial Sectors of Nigeria." He highlighted the threats posed by climate change and proposed actionable strategies for resilience and adaptation.
 - **Dr. Ebieri Jones (Hon. Commissioner for Trade, Industry and Investment, Bayelsa State)** presented on "Circular Economy, Administration, Green Accounting, and Financing Approaches for Sustainable Transformation of Education, Agriculture, and Industry." He emphasized the need for a shift from a linear economy to a circular model, promoting sustainable resource management.
 - **Mr. Mokie-Frank Otevia (Indorama Eleme Petrochemicals Limited)** discussed "Sustainability and Industrial Chemicals Production: Plastics Production as a Case Study." His presentation underscored the necessity of sustainable industrial processes and innovation in petrochemical production.



Observations and Resolutions:

1. The conference recognized the importance of leveraging indigenous technology for sustainable development in the oil and gas and agro-allied industries.
2. There is an urgent need for increased investment in research and development to foster innovation in local industries.
3. Climate change remains a significant threat to Nigeria's agricultural and industrial sectors, necessitating proactive mitigation and adaptation measures.
4. The adoption of a circular economy approach can enhance sustainable industrialization, reduce waste, and optimize resource use.
5. Stronger collaboration between academia, industry, and government is essential for translating research findings into practical solutions.
6. Sustainable industrial chemical production, particularly in the petrochemical sector, should be prioritized to reduce environmental impact and enhance efficiency.
7. There is a need for government policies and incentives to support homegrown technological solutions and innovations in the Nigerian oil and gas and agro-allied industries.

Conclusion. The Second Research and Innovation Fair/Conference of Michael Okpara University of Agriculture, Umudike, successfully provided a platform for meaningful discourse on the role of endogenous technology in national development. The university remains committed to fostering research and innovation that will drive sustainable industrial and economic growth in Nigeria. Stakeholders are encouraged to implement the resolutions from this conference to achieve long-term benefits for the oil and gas and agro-allied industries.

Recommendations:

- **Establishment of R&D Council:** Implement the proposed R&D Council to ensure effective utilization of funded research outcomes.
- **Market-Driven Researches:** Encourage market-driven researches that are government-approved and have outcomes ready to be deployed in operations.
- **Collaboration and Partnerships:** Foster collaboration and partnerships among academia, industry, and government to promote sustainable development.
- **Capacity Building:** Provide training and capacity-building programs for researchers and professionals to enhance their skills and knowledge.
- **Sustainability:** Emphasize sustainability in all aspects of research and innovation, aligning with the United Nations' SDGs.



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CONFERENCE PAPERS

SUB-THEME 1:
Role of Local Content
Development and
Capacity Building in
promoting Sustainable
National Development



ORGANOLEPTIC AND MICROBIAL EVALUATION OF FOOD PRODUCTS PROCESSED WITH LOCALLY FABRICATED FOOD GRINDING MACHINES IN UMUAHIA NORTH LOCAL GOVERNMENT ABIA STATE

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Abstract

This study investigated the contamination levels of microbial presence and organoleptic properties associated with grinding machine across various locations. Four sampling locations (Ahia Eke, Isi gate, Oriegba, Ubani) and 6 food samples (soybean, millet, beans, corn, pepper, and tomatoes) were used in this study. Soybean, millet and beans were milled dry, while corn, pepper and tomatoes were milled wet. The milled samples were analysed for their microbial load, presence of indicator organisms, and organoleptic attributes and compared to control samples. The results of the microbial analysis revealed high bacterial loads, particularly in corn at Oriegba (44.3×10^4 cfu/g total aerobic count, 15.7×10^4 cfu/g total coliform count, and 39.3×10^4 cfu/g total fungal count). *Escherichia coli* was detected in multiple locations, including soybean and tomatoes at Ahia Eke and Oriegba, raising concerns about hygiene practices. Sensory (organoleptic) analysis revealed variations in taste, odour, and colour of processed food samples. Soybean from Isi Gate scored highest in taste (7.2), odour (7.8), and colour (6.8), while tomatoes from Ubani scored lowest (taste: 5.6, odour: 6.0, colour: 5.0), indicating possible contamination or spoilage. From the result obtained, the locally fabricated milling machine may need to be improved to ensure the quality of food samples.

Background to the Study

Food is considered to be the primary source of essential human micro nutrients such as copper, Nickel, Manganese, molybdenum, selenium, Cobalt, iron, and zinc. However, the intake of contaminated foods can also be a major route for entry of toxic chemicals into humans. Food toxicity occurs where food safety and quality are not rigorously monitored and sanitation measures not adequately maintained during food processing, to prevent the introduction of toxins into the food. The consumption of unsafe food is responsible for approximately 600 million cases of food-borne disease and 420,000 deaths annually (WHO, 2022) and if nothing is done to address this challenge, it could lead to more damaging cases.

Hazard analysis and critical control points (HACCP), is a food safety approach that employs systematic preventive methods to protect foods and consumers from chemical, physical, and biological hazards/contaminants. It is a system that is employed at all steps in a food chain, from



preliminary food preparation to production processes and post production handling, including raw materials, production, packaging, storage, distribution, etc. Many food regulatory agencies in several countries require mandatory application of specific HACCP programs for different foods, such as meat, juice, dairy products, infant formula, seafood, canned foods, etc., in order to ensure proper food safety to protect public health and prevent the outbreak of food-borne diseases (Awuchi *et al.*, 2021). Factors responsible for food contamination, includes chemical contaminants (e.g such as allergens, histamine, mycotoxins, toxic elements), Biological contaminants(e.g *Campylobacter*, *Brucella*,viruses, *Escherichia coli*, prions, *Staphylococcus aureus*, *Listeria monocytogenes*, protozoa, parasitic pathogens) and physical contaminants (such as bone, glass, metal, personal effects, plastic, stones, wood).

Olatunji *et al.* (2021) conducted a study assessing microbial contamination in food products processed using locally fabricated grinding machines in Nigeria. They found that the levels of contamination from *Escherichia coli* and *Salmonella* exceeded acceptable limits, highlighting the significant public health risks associated with these machines. The study reported that inadequate sanitation and cleaning practices contributed to high microbial loads, leading to potential food borne illnesses.

When these locally fabricated food grinding machines are not thoroughly cleaned and sanitized before and in between use, there is a risk of cross-contamination between different food products and this can lead to the transfer of harmful bacteria, allergens, or foreign substances from one product to another, thereby leading to food-borne illnesses or allergic reactions in consumers. Color is an important indicator of sensory evaluation and consumer preference (Gao *et al.*, 2020), which is one of the parameters checked in organoleptic tests.

The environment where the grinding takes place is also very critical, often times the surroundings are very dirty and this can cause cross contamination. Kassa *et al.*, (2020), carried out a microbial test on food products processed using locally fabricated machines. The results showed that food products had higher microbial counts compared to those processed with industrial-grade machines, especially when the local machines lacked appropriate cleaning and sterilization features. Some studies have shown that when food grinding machines are made from non-food-grade materials, like untreated wood or rust-prone metals, there is a higher risk of microbial contamination (Pati *et al.*, 2020).



Poor maintenance can lead to microbial growth and chemical leaching, resulting in health hazards for consumers. It is against this background that the present study set out to achieve the following Objectives, which are:

- i. To determine post grinding microbial load in food products processed with locally fabricated food grinding machines.
- ii. To carry out an organoleptic evaluation test on the food products processed with locally fabricated food grinding machines.

Materials and Methods

The study was carried out in four major markets in Umuahia North local government of Abia state. The markets include: Orié Ugba market, Isi Gate market, Ubani market and Ahiaéke market. Triplicate samples of six (6) foodstuffs; Maize (*Zea mays* L), Soybean (*Glycine max* L), Millet (*Pennisetum glaucum*), Beans (*Vigna unguiculata* L), Tomatoes (*Solanum lycopersicum*) and Fresh pepper (*Capsicum annum*) procured from Orié Ugba Market were grounded with locally fabricated machines in Ahia-éke Market, Ubani Market, Orié Ugba Market and Isi-gate Market. A total of 24 locally fabricated machines were considered and used to grind these foodstuffs (in triplicate). Sterile porcelain mortar and pestle was used to ground a portion of the foodstuffs (in triplicate) to serve as controls, thus giving a total of 90 ground samples. The samples were stored in dry polyethylene containers with screw caps and taken to the laboratory for analysis.

Microbiological Analysis

Media preparation

All the media employed for the enumeration of the microbial load were prepared using the method as described by manufacturers. Stipulated grams of each media were dissolved in equivalent volume of distilled water. Following preparation, they were sterilized by autoclaving at 121°C for 15 minutes after which they were allowed to cool and gel.

Nutrient Agar was used to estimate aerobic bacterial load count. MacConkey Agar, was used for the growth of enteric organisms (*coliform* bacteria) and Sabourad Dextrose Agar was used for fungal growth (mould and yeast).



Serial Dilution. One gram of each sample was in 10 millilitre peptone water and was serially diluted according to the method described by (Dhawale and La Master, 2003), by taking 1 millilitre from the stock bottle and transferring to the test tubes containing 9 millilitre of sterile distilled water.

Pour Plate

Inoculums from the 3rd dilution (10^{-3}) was plated onto NA, SDA, and MCA using the pour plate technique. One ml of the diluted sample was aseptically transferred using pipette to sterile plastic petri dishes and sterilized and cooled NA, SDA, and MCA were poured into each plate, allowed to gel and incubate at 37°C for 18-24 hours.

Enumeration of Total Bacteria Counts: Inoculum from the 3rd dilution was pour plated into nutrient agar and incubated at 37°C for 24 hours. A representation of typical colonies from well isolated colonies showing 30-300 colonies (Efiuvwevwere *et al*, 2020) were picked at random.

Enumeration of Total Coliforms

Coliform contamination level (CCL) was used as an index of sanitary quality of the samples. The inoculums from the appropriate tube were pour plated onto plates of MacConkey agar and incubated 37°C for 24 hours.

Enumeration of Total Fungal Counts: Inoculum from the 3rd dilution was pour plated onto Sabourad Dextrose Agar and incubated at 37°C for 48 hours.

Prevalence of indicator Organisms (*E. coli* and *faecal Streptococcus*)

Escherichia coli. *E. coli* were identified through the IMViC test from thermo tolerant *coliforms*. Briefly, suspected colonies from thermo tolerant *coliforms* were selected and subcultured on Nutrient Agar at 37°C for 24 hours. Positives colonies were transferred into Levine Eosin Methylene Blue Agar (EMB) (France), which was incubated at $37 \pm 1^\circ\text{C}$ for 24 hours. Colonies with green metallic sheen were considered to be *Escherichia coli*.

Faecal Streptococcus. This was identified by culturing the foodstuffs on a Bile Esculin Agar. White or light yellow colour colonies that are typically small, circular and entire with black or dark brown pigment of escharine hydrolysis around the colonies were selected and subcultured on Nutrient Agar at 37°C for 24 hours. Pure cultures grown on Nutrient Agar were subjected to further

confirmatory tests. Colonies that were negative to catalase test, grows in 6.5% salt solution and also grows at 45°C was considered to be *faecal streptococcus*.

Organoleptic Evaluation

Organoleptic evaluation of the foodstuffs grounded using locally fabricated machines compared to the control (grounded with sterile porcelain mortar and pestle) was carried out using a 9-point Hedonic scale as described by Iwe *et al.* (2007). 10 semi-trained panelists from the department of Environmental management and Toxicology, Michael Okpara University of Agriculture, Umudike were used. The 9-point Hedonic scale ranges from extremely like (9) to extremely dislike (1). Samples were presented in identical coded plates. Each sample was evaluated for colour, taste and odour.

RESULTS AND DISCUSSION

The table below shows the result of the Microbial Analysis that was carried out on six selected food products, at different locations.

Table 1: Effect of locally fabricated milling machine on the microbial load of selected food samples at different locations.

Samples	Locations	Total aerobic bacterial count (cfu/g) x10 ⁴	Total coliform count (cfu/g) x10 ⁴	Total fungal count (cfu/g) x10 ⁴	E. coli	Faecal Streptococcus
Soybean	Ahia Eke	13.0 ^c	3.0 ^c	12.3 ^b	+	+
	Isi gate	8.0 ^d	2.67 ^c	5.34 ^c	+	-
	Orie Ugba	33.3 ^a	11.34 ^a	26.67 ^a	+	+
	Ubani	22.0 ^b	7.67 ^b	15.3 ^b	-	-
	Control	4.34 ^d	0 ^c	5.3 ^c	-	-
Millet	Ahia Eke	3.0 ^b	0 ^b	3.7 ^b	-	-
	Isi gate	1.7 ^b	0 ^b	4.3 ^b	-	-
	Orie Ugba	16.7 ^a	3.3 ^a	14.7 ^a	+	-
	Ubani	15.3 ^a	4.7 ^a	13.0 ^a	-	-

Beans	Control	0.34 ^b	0 ^b	2.7 ^b	-	-
	Ahia Eke	8.7 ^b	2.3 ^b	7.0 ^b	+	-
	Isi gate	6.7 ^b	1.7 ^b	5.7 ^b	-	-
	Orie Ugba	24.7 ^a	10.0 ^a	17.3 ^a	+	-
	Ubani	21.0 ^a	9.0 ^a	16.7 ^a	-	-
Corn	Control	1.3 ^c	0 ^c	2.0 ^c	-	-
	Ahia Eke	28.0 ^c	6.3 ^b	24.7 ^b	+	-
	Isi gate	22.7 ^d	9.3 ^b	19.3 ^b	+	+
	Orie Ugba	44.3 ^a	15.7 ^a	39.3 ^a	+	+
	Ubani	39.3 ^b	14.7 ^a	34.3 ^a	-	-
Pepper	Control	8.0 ^c	0 ^c	6.67 ^c	-	-
	Ahia Eke	17.0 ^b	3.3 ^{bc}	12.3 ^b	-	-
	Isi gate	15.3 ^b	6.0 ^b	16.0 ^b	-	-
	Orie Ugba	31.7 ^a	14.0 ^a	26.7 ^a	+	-
	Ubani	30.3 ^a	11.7 ^a	25.7 ^a	-	-
Tomatoes	Control	3.3 ^c	0 ^c	3.6 ^c	-	-
	Ahia Eke	26.0 ^c	2.67 ^c	21.3 ^b	+	+
	Isi gate	28.0 ^c	9.0 ^b	20.7 ^b	-	-
	Orie Ugba	36.3 ^a	14.0 ^a	32.3 ^a	+	+
	Ubani	41.3 ^a	16.7 ^a	36.0 ^a	-	-
	Control	9.0 ^d	0 ^c	7.3 ^c	-	-

Values are mean of triplicate observation. Values on the same column for each food sample with different superscripts are significantly different ($p \leq 0.05$)

Table 2 shows the results of Organoleptic evaluation carried out on six selected food samples to determine its taste, odour and colour, against a control.

Table 2. Effect of locally fabricated milling machine on the organoleptic attributes of selected food samples at different locations

Samples	Locations	Taste	Odour	Colour
	Ahia Eke	6.6 ^c	7.2 ^{bc}	6.2 ^{ab}



Soybean	Isi gate	7.2 ^b	7.8 ^{ab}	6.8 ^a
	Orie Ugba	7.8 ^a	6.4 ^d	5.4 ^b
	Ubani	6.2 ^c	6.8 ^{cd}	5.8 ^b
	Control	7.4 ^a	8 ^a	7 ^a
	Ahia Eke	7.0 ^{ab}	7.6 ^{ab}	6.6 ^{ab}
Millet	Isi gate	7.5 ^a	8.1 ^a	7.1 ^a
	Orie Ugba	6.4 ^b	7.0 ^b	6.1 ^b
	Ubani	6.5 ^b	7.1 ^b	6.1 ^b
	Control	7.6 ^a	8.2 ^a	7.2 ^a
	Ahia Eke	7.0 ^{ab}	7.6 ^{ab}	6.6 ^{ab}
Beans	Isi gate	7.4 ^a	8.0 ^a	7.0 ^a
	Orie Ugba	6.0 ^c	6.6 ^c	5.6 ^b
	Ubani	6.4 ^{bc}	7.0 ^{bc}	6.0 ^{bc}
	Control	7.6 ^a	8.2 ^a	7.2 ^a
	Ahia Eke	6.6 ^{bc}	7.2 ^{abc}	6.2 ^{ab}
Corn	Isi gate	7.0 ^{ab}	7.6 ^{ab}	6.6 ^{ab}
	Orie Ugba	6.2 ^{cd}	6.8 ^{bc}	5.8 ^{ab}
	Ubani	5.8 ^d	6.4 ^d	5.4 ^b
	Control	7.4 ^a	8.0 ^a	7.0 ^a
	Ahia Eke	7.0 ^{ab}	7.6 ^{ab}	6.6 ^{ab}
Pepper	Isi gate	6.6 ^{bc}	7.2 ^{bc}	6.2 ^{ab}
	Orie Ugba	6.8 ^{bc}	7.4 ^{ab}	6.4 ^{ab}
	Ubani	6.2 ^c	6.8 ^c	5.8 ^b
	Control	7.5 ^a	8.1 ^a	7.1 ^a
	Ahia Eke	5.8 ^b	6.4 ^b	5.4 ^b
Tomatoes	Isi gate	5.2 ^b	5.8 ^b	4.8 ^b
	Orie Ugba	5.6 ^b	6.2 ^b	5.2 ^b
	Ubani	5.6 ^b	6.0 ^b	5.0 ^b
	Control	7.6 ^a	8.2 ^a	7.2 ^a



Values are mean of the panelists score. Values on the same column for each food sample with different superscripts are significantly different ($p \leq 0.05$).

Discussion

The results of the microbial analysis of the food samples suggest that the locally fabricated milling machine introduces microbial contamination to food samples. For instance, microbial analysis of food products processed with locally made machines has shown higher counts of *Escherichia coli*, *Salmonella*, and *Listeria monocytogenes* over time (Ibraheem et al., 2020). The results of this study indicate that the microbial load of the selected food samples was higher in samples from Orié Ugba and Ubani compared to Ahia Eke, Isi gate, and the control samples. This could be attributed to the poor sanitation and hygiene practices in Orié Ugba and Ubani, which may have led to contamination of the food samples.

It could also have been as a result of open milling areas in Orié Ugba and Ubani which exposes the milling machines to dust, airborne microbes, and cross-contamination from multiple food sources. High humidity and temperature in these areas may also promote microbial proliferation (Berghofer et al., 2003). The high microbial load in Tomatoes and Pepper can be attributed to their high moisture content, making them more prone to microbial spoilage (Tournas, 2005). Dry foods like Millet and Soybean had lower microbial counts, aligning with previous research showing that low-water activity inhibits microbial growth (Beuchat, 1981). According to a study by Oyewole and Odunfa (2017), the use of poorly maintained milling machines can lead to contamination of food samples and there's serious need for regular microbial testing and compliance with international food safety standards to mitigate the risks of contamination. Government regulations and food safety authorities play a critical role in enforcing these standards for both locally fabricated and industrial machines (Alakali et al., 2020).

The presence of *E. coli* and *Fecal Streptococcus* in the milled food samples is a serious food safety concern, indicating potential fecal contamination and poor hygiene in the milling process. They also opined that if water used for cleaning the machine or food materials is contaminated, it can introduce pathogenic microorganisms (WHO, 2015). The fact that some machine operators do not following proper hygiene by washing their hands after using the toilet, could be a source of contamination (Mensah et al., 2002). The non-hygienic state of Orié Ugba and Ahia Eke milling



environment may expose food to airborne contaminants and cross-contamination from other food products or surfaces (Tournas, 2005).

Orie Ugba had the highest contamination, likely due to high human traffic, exposure to dust, and unsanitary milling practices. Ubani had the least contamination, suggesting better hygiene practices or more effective milling machine cleaning, while, the moderate contamination in Ahia Eke and Isi Gate indicate inconsistent hygiene measures.

The data obtained for the organoleptic attributes clearly indicate that milling with the locally fabricated machines negatively affected the organoleptic properties of food samples. The control samples, which were not milled using the machine, had significantly better taste, odour, and colour compared to the milled samples.

Conclusion

The results demonstrate that milling with a locally fabricated machine introduces significant microbial contamination, particularly *E. coli* and *Fecal Streptococcus*, which are strong indicators of fecal contamination and poor hygiene. Orie Ugba and Ahia Eke showed the highest contamination levels, while control samples were free of any contamination, proving that the milling process itself is the primary source of microbial introduction.

The result of the organoleptic test confirm that milling with a locally fabricated machine negatively affected the organoleptic quality of food by reducing taste, odor, and color scores. The control samples consistently had the best sensory attributes, proving that the milling process itself is the primary cause of deterioration.

The fact that the results varied significantly in the different markets, at different locations, utilized in this study is an indication that milling conditions vary across locations, possibly due to differences in hygiene, machine maintenance, and environmental exposure.

Recommendations

Based on the results of this study, the following recommendations are made:

1. To prevent food-borne illnesses, proper hygiene practices, routine sanitation of milling equipment, and better food handling techniques must be enforced by the State Government.



This will ensure safer food products and reduce health risks associated with microbial contamination.

2. Environmental agency of the State Government should enforce strict sanitation protocols for cleaning milling machines using disinfectants like chlorine-based solutions or hot water.

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MINERAL AND PHYTOCHEMICAL COMPOSITION OF BISCUITS PRODUCED FROM FLOUR BLENDS OF WHEAT, ACHA AND TAMBA

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Abstract

Biscuits are ready-to-eat nutritious baked snacks that are available in different shapes and sizes. One of the problems that militate against food security in developing countries such as Nigeria is postharvest losses and underutilization of locally cultivated food crops. Finger millet, locally known as Tamba (*Eleusine coracana*) and Hungry rice or Acha (*Digitaria exilis*) are staple cereal grains indigenous to Northern parts of Nigeria. Biscuit samples were produced from five proportions of flour blends of Wheat, Acha and Tamba; (90:10:0; 90:0:10; 80:0:20; 80:20:0; 75:15:15) using standard methods. A 100% wheat flour served as the control. The biscuit samples were evaluated for their mineral and phytochemical composition. The results of the mineral contents ranged from 23.56-30.52 mg/100g, 52.32–65.22 mg/100g, 45.62–59.44 mg/100g, 28.72–35.72 mg/100g for sodium, phosphorus, potassium and magnesium respectively. While the phytochemicals ranged from 0.05- 0.20 mg/100g, 0.01- 0.12mg/100g, 0.21–0.42mg/100g, 0.17-0.38 mg/100g, for phenol, tannin, flavonoid and alkaloids respectively. The results of this study showed that the mineral and phytochemical contents of these biscuits samples makes their flour blends good tools in the production of as snacks and baked products with vital nutrients.

Keyword: wheat, tamba, brown acha, mineral components, phytochemicals, biscuits

Introduction

Biscuits are nutritious, low moisture ready-to-eat snacks produced in different shapes and sizes from unleavened dough. They are consumed among all age groups in many countries due to their creamy taste and low water activity, which defines their long shelf-life particularly in parts of the world where there is prevalence of protein and calorie deficiency. (Nwanekezi, 2013; Chauhan *et al.*, 2015; Usman *et al.*, 2015).

Wheat (*Triticum aestivum*) flour is the most versatile and principal raw material utilized in the production of baked foods. However, its cultivation is limited to some parts of the world due to the climatic conditions hence, has necessitated its importation in those parts of the world (Iwe, 2015). Consequently, a general increase in the demand for baked foods has been recorded over time which has translated to an increase in wheat importation in wheat-poor parts of the world hence, a subsequent increase in cost of baked foods (CSA, 2011; FAO, 2022). Conventionally, cookies are produced from wheat flour due to its gluten content which improves its texture (Oluwafemi and Seidu, 2017).



The dependence on wheat flour by baking industries is a major constraint in biscuit production as huge sums of money are involved in wheat importation. In 2010 alone, Nigeria spent N 635 billion (\$4.2 billion) on the importation of wheat (Momoh, 2011). The nutritional composition of baked foods is vital in meeting nutrient needs of consumers (WHO, 2010). Biscuits produced from wheat are energy-dense therefore, require additional nutrients to meet basic nutrient needs and help curb the prevalence of most deficiencies (Bruins *et al.*, 2018).

It has been reported that deficiencies of phosphorus, magnesium, potassium and other micronutrients were the causes of severe acute malnutrition in children from developing countries. (Worthley *et al.*, 2002).

Acha (*Digitaria exilis*) also known as “hungry rice” is a cereal crop of West African origin belonging to the family Graminaea (Aviara *et al.*, 2017). The white acha (*Digitaria exillis*) and brown acha (*Digitaria iburua*) are the two most prominent varieties (Aviara *et al.*, 2017). Acha is an important cereal crop of West Africa with cultural, nutritional and economic significance as it is mainly grown and cooked by women, as a special food for treats at weddings, and other ceremonies (Chinwe *et al.*, 2015). It plays an important role in household food security and income generation, having high yield and nutritional value with superior protein, carbohydrate and fibre contents compared to other cereals for households in rural areas (Animasaun *et al.*,

2023). However, despite its nutritional value and potential food applications, it is still underutilized (Glew *et al.*, 2013). They are gluten-free and are often consumed whole, therefore, are considered as health grains (Jideani, 2012). According to Ayo *et al.* (2018), Acha does not only have potentials to contribute significantly to whole grain diets, wellness, economic status improvement, and food security in developing economies, but also, contain significant amounts of micronutrients.

Tamba (*Eleusine coracana*) popularly known as “Finger millet” is a staple food in many African and South Asian countries. The grain belongs to the family Poaceae which originated in Ethiopia and the sub-family Chloridodeae (Sood *et al.*, 2016). It is also considered a helpful famine crop, as it could be stored for lean years (FAOSTAT, 2012). The seed is storable for a long period maintaining an edibility and viability for even up to 10 years if stored dry. The grain is readily digestible, highly nutritious and versatile: it can be cooked like rice, ground to make porridge or flour or used to make cakes (De Wet, 2006). Sprouted grains are recommended for infants and the elderly. Finger millet is also used to make liquor (“arake” or “areki” I Ethiopia) and beer, which



yields by-products used as livestock feed (FAOSTAT, 2012). In Plateau state and across the Guinea Savannah regions of Nigeria, finger millet is used in making local drinks “kunu” and variety of local dishes (Audi *et al.*, 2019). Finger millet exists in different cultivars: brown, light brown and white, which are found from one region to another (Devi *et al.*, 2014; Kumar *et al.*, 2016).

Finger millet grains also contain high amount of magnesium and phosphorus, which contribute to the development of body tissue and energy metabolism (Sood *et al.*, 2016; Ramashia *et al.*, 2018). Magnesium implicated for the reduction of high blood pressure, severity of asthma, frequency of migraines and the risk of heart attack (Saleh *et al.*, 2013). In comparison with other millet species, finger millet grains are more nutritious (Devi *et al.*, 2014). This research work aimed at evaluating the mineral and phytochemical composition of biscuits produced from flour blends of Wheat, Acha and Tamba.

Materials and Methods

Source of raw materials

Acha and wheat grains were purchased from Ariaria International market, Aba, Abia state. Tamba grains were procured from Gumi market in Kaduna state, all in Nigeria.

Sample preparation

Production of wheat flour

Wheat grains were processed into flour by using the method described by Peter *et al.* (2017). The wheat grains were sorted manually by removing stone, debris, extraneous materials, washed with clean tap water, drained using a plastic perforated screen, and oven dried (Gallenkemp, 300 Plus, England), at 60°C for 8h. The dried wheat grains were milled using a hammer mill (HMC-HM6630, China), sieved through 0.2mm screen to obtain resultant flour and packaged in a transparent polyethylene bag for further use.

Production of acha and tamba flour

The method described by Mbaeyi-Nwaoha and Uchendu (2016) was adopted in the production of acha and tamba flour. Acha/tamba grains were sorted, washed (in clean water) and drained of water with a perforated plastic bowl. The clean grains were oven dried (Gallenkemp, 300 Plus, England) at 50°C for 6 h, milled using hammer mill (HMC-HM6630, China) and sieved (0.2 mm meshsize) to obtain acha/tamba flour which was packaged in a polyethylene bag until needed.

Composite flour formulations



Composite flours from wheat, brown acha and tamba were formulated. The flours were blended to obtain five (5) composite samples. Each formulation was mixed using Argos food blender (XB, 9165) to obtain homogenous mixture. A 100% wheat flour served as the control. The flours obtained from wheat-acha-tamba were formulated into different ratios of five proportions: 90:10:0 (wheat-acha-tamba); 90:0:10 (wheat-acha-tamba); 80:0:20 (wheat-acha-tamba); 80:20:0 (wheat-acha-tamba); 75:15:15 (wheat-acha-tamba). A 100% acha served as the control.

Production of biscuit

The biscuit was prepared using the method described by Atinuke (2014). The ingredients used include flour (200g), margarine (100g), sugar (118g), whole egg (50ml), water (30ml), salt (3g), and baking powder (3g). The fat and sugar were creamed until light and fluffy, using Kenwood (220-240V) hand-held mixer. Egg and flour were added to the mixture, followed by water, salt and baking powder. The mixture was thoroughly kneaded into consistent dough, rolled out and cut into circular shapes of uniform thickness using a cookie cutter and baked in a pre-heated oven for 15 minutes. The hot baked biscuits were allowed to cool, packaged in low density polyethylene bags and stored in air-tight plastic containers at room temperature.

Analyses

Determination of Mineral and Phytochemical composition of the biscuit samples

The following mineral (sodium, potassium, phosphorus and magnesium) and phytochemicals (phenols, tannins, flavonoid and alkaloid) composition of the biscuit samples were determined according to the method described by Onwuka (2018).

Results and Discussion

Mineral content of the biscuit samples

The results of the mineral content of the biscuit samples are presented in Table 1.

The sodium content ranged from 23.56-30.52. There was significant difference ($P < 0.05$) in the sodium content. Biscuit sample 75:15:15 (wheat/acha/tamba) recorded the highest value while 90:0:10 (wheat/acha/tamba) had the lowest value. The same trend was observed for the phosphorus, potassium and magnesium. The highest values were recorded for biscuit sample produced from 75:15:15 (wheat/acha/tamba) while the lowest values were recorded for biscuit sample produced from 80:20:0 (wheat/acha/tamba) 90:0:10 (wheat/acha/tamba) and 100% wheat (control) for phosphorus, potassium and magnesium. The result revealed that the biscuit sample with 75:15:15

(wheat/acha/tamba) recorded highest in all the mineral (sodium, phosphorus, potassium, magnesium) evaluated. This is an indication that flours produced from brown acha and tamba possesses higher mineral content than wheat. Previous researchers have proven that cereal grains such as acha and tamba possesses high value of the minerals evaluated (Jideani and Jideani, 2011).

Table 1: Mineral composition (mg/100g) of biscuits produced from flour blends of wheat, acha and tamba

Sample				
WT:BA:TM	Sodium	Phosphorus	Potassium	Magnesium
100:0:0	24.75 ^d ±0.01	57.46 ^d ±0.03	48.41 ^d ±0.01	29.48 ^e ±0.02
90:10:0	26.42 ^c ±0.03	60.34 ^c ±0.02	52.67 ^c ±0.02	31.77 ^c ±0.01
90:0:10	23.58 ^e ±0.03	52.32 ^f ±0.03	45.62 ^e ±0.02	28.72 ^f ±0.04
80:0:20	27.43 ^b ±0.01	62.73 ^b ±0.04	54.74 ^b ±0.03	32.76 ^b ±0.02
80:20:0	26.23 ^c ±0.73	56.42 ^e ±0.02	48.43 ^d ±0.03	30.64 ^d ±0.02
70:15:15	30.50 ^a ±0.03	65.22 ^a ±0.03	59.44 ^a ±0.02	35.72 ^a ±0.02

Mean values in the same column with the same superscripts are not significantly different ($P>0.05$).

WT= Wheat flour, BA= Brown acha flour, TM =Tamba flour

wheat, Acha and Tamba; (90:10:0 ; 90:0:10; 80:0:20; 80:20:0; 75:15:15)

Phytochemical content of the biscuit samples

The phytochemical contents of the biscuit samples are presented in Table 2. There were significantly difference ($P<0.05$) amongst the biscuit samples.

The phenol contents of the biscuit samples ranged from 0.05 to 0.20 mg/100g. The control sample had the lowest value while the biscuit samples from 75:15:15 (wheat/acha/tamba) had the highest value. The phytate content is quite lower compared with results (0.19-1.63 mg/100g) obtained from a previous researcher on Acha-Tangerine peel Biscuits (Ayo *et al.*, 2022). According to Gemede *et al.*, 2014, phytates lower blood glucose response of diabetes patients by reducing the rate of starch digestion and slowing gastric emptying. The tannin content ranged from 0.01-0.12mg/100g. The lowest value was recorded for the control sample while the highest was recorded for biscuit sample produced from 70:15:15(wheat/acha/tamba). In the same trend the values obtained in this study were also lower than values (0.19-0.92 mg/100g) obtained by Ayo and others in their Acha-



Tangerine peel biscuits (Ayo *et al.*, 2022). The same trend was observed in the flavonoid and alkaloid content with the ranges of 0.21-0.42mg/100g and 0.17-0.38mg/100g respectively. It was observed that biscuit samples produced from flours containing the highest proportion of brown acha and tamba had the highest phytochemicals. The flavonoid content was higher compared with the results (0.01-0.03 mg/100g) obtained by Ayo and Gidado (2017) in biscuits produced from acha-carrot flour blends. Flavonoids are anti-oxidants, lower cholesterol, inhibit tumor formation, decrease inflammation and protect against cancer, heart disease etc (Ayo and Gidado, 2017). The result revealed that both brown acha and tamba contains higher level of phytochemicals than the control (100% wheat).

Table 2: Phytochemical composition (mg/100g) of biscuits produced from flour blends of wheat, acha and tamba

Sample WT:BA:TM	Phenol	Tannin	Flavonoid	Alkaloid
100:0:0	0.05 ^d ±0.02	0.01 ^c ±0.00	0.21 ^c ±0.02	0.22 ^c ±0.02
90:10:0	0.06 ^d ±0.02	0.02 ^c ±0.01	0.24 ^d ±0.01	0.17 ^d ±0.01
90:0:10	0.11 ^c ±0.02	0.03 ^b ±0.01	0.25 ^c ±0.01	0.23 ^c ±0.01
80:0:20	0.15 ^b ±0.01	0.03 ^b ±0.01	0.32 ^b ±0.02	0.29 ^b ±0.02
80:20:0	0.17 ^a ±0.02	0.06 ^a ±0.01	0.37 ^a ±0.01	0.32 ^a ±0.01
70:15:15	0.20 ^a ±0.01	0.12 ^a ±0.02	0.42 ^a ±0.02	0.38 ^a ±0.03

Mean values in the same column with the same superscripts are not significantly different (P>0.05).

WT= Wheat flour, BA= Brown acha flour, TM =Tamba flour

wheat, Acha and Tamba; (90:10:0 ; 90:0:10; 80:0:20; 80:20:0; 75:15:15)

Conclusion

The results of this study have revealed that biscuit samples produced from 75:15:15 (wheat/acha/tamba) contains vital minerals and phytochemicals of health benefits. Thus it is concluded that flour blends of acha and tamba will serve as good tools with vital nutrients when incorporated with wheat flour in the production of snacks and baked products.

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EVALUATING THE SUBSURFACE STRATIGRAPHY OF ITEM TOWN USING DOWNWARD CONTINUITY OF ELECTRICAL RESISTIVITY METHOD

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Abstract

Evaluation of the subsurface stratigraphy of Item town was done to establish the groundwater potential for productive borehole using downward continuity analysis of vertical electrical sounding (VES) data. Twenty-four (24) VES points were carried out using Schlumberger array configuration AB/2 = 1000m. The study area is located at longitude 5°35'E to 5°45'E and Latitude 5°44'N to 5°50'N. The area is accessible through the main roads that leads to Bende, Umuahia, Uzuakoli, Okigwe, Enugu and Aba. Results showed that at AB/2 = 1m, the area was filled with low resistive material such as shale, at AB/2 = 4m to 30m aquiferous materials were revealed in some villages like Umuokwe, Amaokai and Okoko. At AB/2 = 50m to 300m, Amaokai didn't show up any aquiferous properties. At AB/2 = 350m to 500m, no aquiferous properties were traced, the study area had very low potential for groundwater at this depth, this indicates that at depth below 238m, there is no possibility for potential water borehole as the study area has very low resistive materials. This study, therefore has shown that productive borehole should be cased between 100m to 230m depth in villages like Umuokwe and Okoko. These areas have revealed a fracture zone as the geology of the study area has showed that it will be difficult to get a potential water borehole in the area.

Keywords: Stratigraphy, Schlumberger, Groundwater, Borehole, Fracture

Introduction

Item towns which form the study area have had problems of water boreholes over the years. Enormous efforts by many agencies to provide potable water to this area have been abortive especially with Item communities underlain by the Nkporo and EzeAku shale Formation. It is worthy of note that Item area is a food producing area. The local farmers depend on surface water sources for their water needs. Source of water, particularly in dry season frequently lie at some distance from the town, and some of these are contaminated surface water sources. A typical example is the case of the Elugwu, Akanu that uses a stream as its source of water supply. There are areas in Item town where water boreholes never worked. Others town like Akanu and Okayi have histories of unproductive/failed wells. The concerted effort of the Abia State Government and other agencies to curb this problem has led to the investigation of the groundwater distribution, yield and



water quality variations of the study area as an alternative to surface water as domestic water supply to the inhabitants. Ground water importance increases as a major source of water for domestic activities. Surprisingly, less than 3% of the world's available fresh water occurs in streams and lakes (Egor, 2022), but because of large expensive surface water projects one tends to think of surface water as the most important potential source. Ground water hydrology is a relatively new science developed slowly after modern geological principles had been formulated near the end of the eighteenth century. Although shallow wells have been in use for many centuries, early concepts of the origin of ground water were curious mixtures of superstition and faulty deduction. In recent years the science of ground water hydrology has advanced significantly not only as a result of extensive hydrological data gathering but also from the explosion of research in biology, chemistry, physics and meteorology (Chinyem, 2005).

The zone constitutes the extensive Anambra-Imo River basin. Studies so far have shown that sedimentary basins generally contain enormous quantities of water. Such studies include (Freeze and Cherry, 1979; Fetter, 1980; Kehinde and Loehnert, 1989; Okereke and Edet, 2002). To realize this fact, several countries worldwide have engaged in extensive studies within their frontiers using geological/hydrogeological, geophysical or chemical data or a combination of the above, for proper identification and delineation of the water bearing units. Such studies include those of Leite and Barker, 1978; Van Overmeeren, 1989; Mbonu *et al*, 1991; Choudhury *et al*, 2001; Okereke and Edet, 2002; Lashkaripour, 2003; Eluwa *et al.*, 2019. These studies have afforded the optimization and proper management of the basins in order to enhance safe discharge and safeguarding appropriately the quality status of the water. However, most developing nations of the world like Nigeria are challenged with acute shortage of water leading to serious inconveniences to the people. Due to this menace of water shortage and in line with the UN declaration, a means of ascertaining the condition of the subsurface in respect of groundwater and its exploitation is obliged. These can be done through geophysical and geological means.

Geophysical method for determining aquifer is based on the fact that certain physical properties of the rock change considerably depending on their water contents thereby creating a physical boundary between the host rock and the water bearing strata. Such changes in physical properties interpreted by the presence of water include changes in elastic wave velocity, change in density and increase or decrease in elastic constants. It has been established that groundwater is found in pore spaces of sediments. Such sediments as sand, silt, clays are good examples. These rock bodies and sediments have their specific range of resistivity. The electrical resistivity of a given medium is

dependent on such factors such as size and porosity of which porosity is the major controls of the resistivity of rocks. Resistivity generally increases as porosity decreases and vice versa (Chinyem, 2005; Eluwa *et al.*, 2019; Quichimbo *et al.*, 2020; Egor, 2022; Zhang *et al.*, 2021).

Any rational development of groundwater requires geophysical data input among others. Low productivity of borehole already billed in the Ameke and Okoko Item areas support the prolific nature of the Ajali and Manu Formations which appears at the Southern part of the study area. This covers about 25% of the entire study area while Nkporo and Eze Aku Formations lies within the Northern part of the study area which have acute water problem occasioned by the overriding shale units to great depth. Anyway, the foregoing groundwater abstraction is being done indiscriminately without good knowledge of the distribution, geometry, safe yield and water quality variations in the different horizons; hence abandoned water scheme by various agencies has caused failed boreholes.

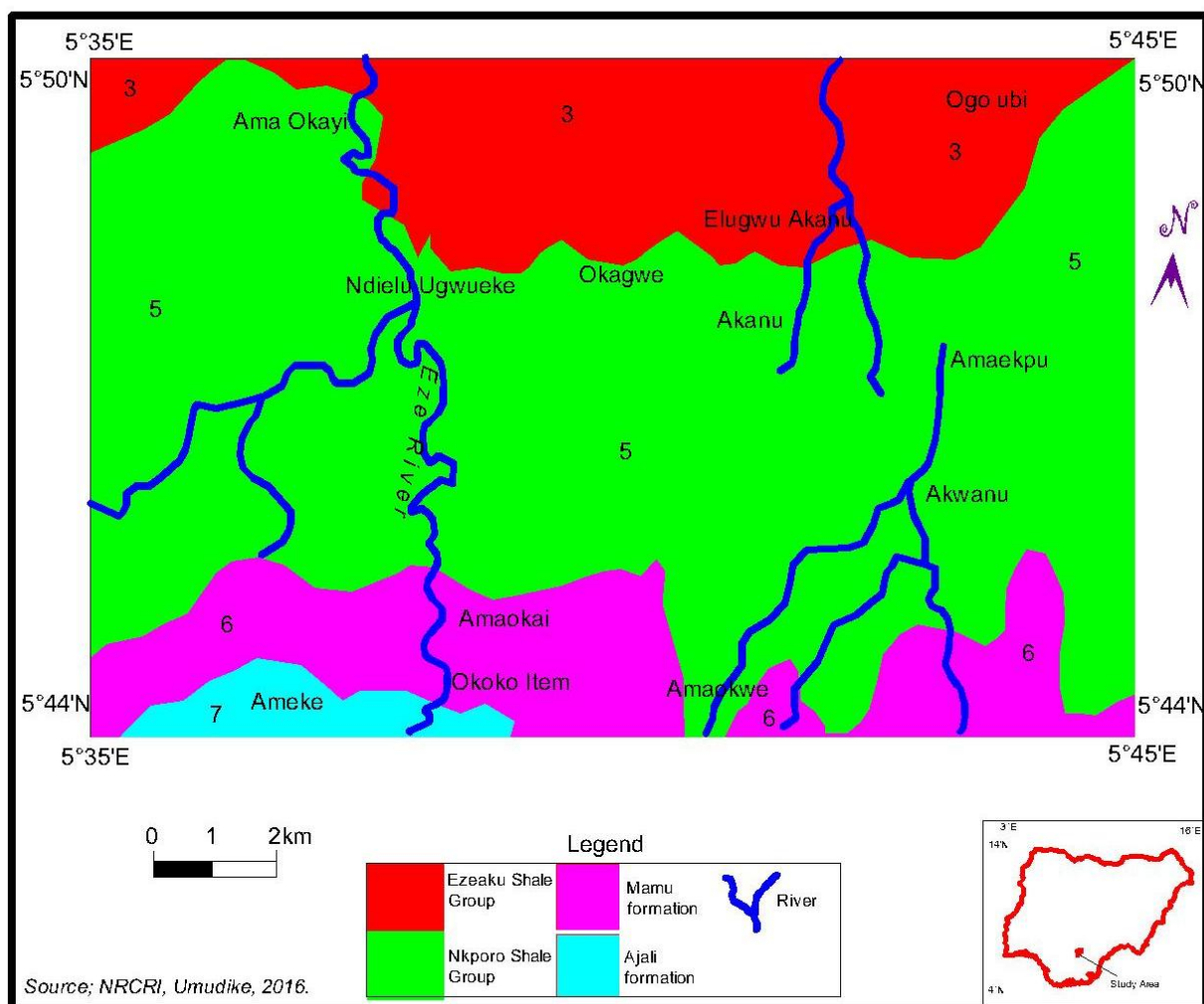


Fig 1. Geological Map of the Study Area

From Fig.1 the study area is characterized by a lot of features and flooded surface in the wet season. In high rainfall areas; they are commonly wet throughout the year (Onwuchuriba and Agbasi, 2002; Nnokwe *et al.*, 2014). The size of the watershed in the area is different from those found in other areas; the extension of the hydrological system depends on section of Item areas that is being noted. Onwuchuriba and Agbasi (2002) determined that the drainage patterns of watershed influences the density of Item environment which is defined as the ratio of length of all streams (km) to area of watershed (km²). In area were dendrite are free like branching patterns, the valley that is associated with Item extends in all directions while in watershed with trellis drainage patterns, the valleys are oriented in lines (Onwuchuruba and Agbasi, 2002).

In borehole exploration, geology and geophysics complement one another. When properly analyzed, data from geophysical investigation provide vital information on the subsurface structure. Geology on the other hand is used to extrapolate from the surface observation to what is beneath the surface. Usually geophysical interpretations are expected to fall within limits of geological probability for an area investigated. However, geophysical methods alone are capable of discovering groundwater. Nonetheless, they offer practical insights in determining subsurface conditions that are favorable to the occurrence of groundwater. In groundwater exploration, the aim of the geophysicist or geophysical investigation is to locate aquifers. The quality of good aquifer are dependent on its porosity (capacity to store water) and permeability (capacity to transmit water). Aquifers are usually found in highly permeable rocks like sandstones or fissured limestone. This is the reason for greater success in drilling boreholes in sedimentary Formation (Chukurah, 1992). A geophysical investigation of the earth's interior involves taking measurements at or near the earth's surface that are influenced by internal distribution of its properties. Electrical resistivity methods of geophysical prospecting are well established and the most important method for groundwater investigations. The electrical resistivity method is one that has been widely used because of the theoretical, operational and interpretational ease. The advantages of electrical methods also include control over depth of investigation, portability of the equipment, availability of wide range of simple and elegant interpretation techniques, and the related software etc. Direct current (D.C.) resistivity (electrical resistivity) techniques measure earth resistivity by driving a D.C. signal into the ground and measuring the resulting potentials (voltages) created in the earth. In turn, from those electrical properties we can infer the geological characteristics of the earth. The work aimed at evaluating the subsurface geology and downward continuation of rock types for possible groundwater resources

based on the resistivity survey data within the study area. This work therefore is projected to serve as a guide for future groundwater project in the study area as well as reduce the incidence of failed water boreholes. It is hoped that the water authorities in Abia State and individuals will find this work useful in planning the water supply to the communities especially as regards the siting of more boreholes. The study area covers Item towns which is in the geological drainage basin of Anambra – Imo River basin.

Materials and Method

Schlumberger array configuration was used as shown below Fig.2

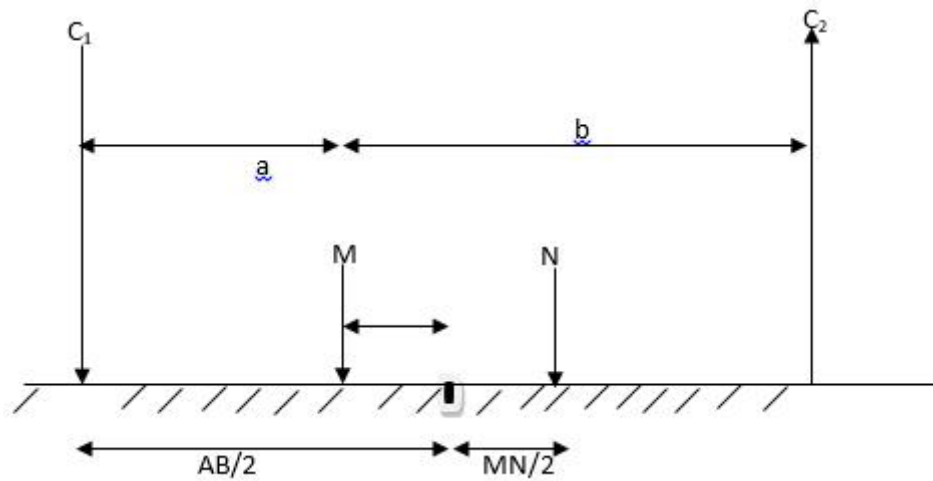


Fig: 2: Schlumberger Array

In Schlumberger array (Fig.2) the current and potential pairs of electrodes also have a common mid-point but the distances between adjacent electrodes differ so that: $a \neq b$.

The geometric factor K can be obtained, thus

$$K = \frac{2\pi}{\frac{1}{a} - \frac{b}{2} - \frac{1}{a} + \frac{b}{2} - (\frac{1}{a} + \frac{b}{2} + \frac{1}{a} - \frac{b}{2})} \quad (1)$$

$$k = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) = \left\{ \frac{[(AB/2)^2] - (MN/2)^2}{MN} \right\} \pi. \quad (2)$$

$$\rho = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) \quad \text{or} \quad \rho = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) R \quad (3)$$

The factors K in equations above are called the geometric factors and depend only on the electrode separation or intervals. R responds to the resistance of the volume of ground between the potential electrodes. If V and I are converted in millivolts and milliamperes respectively and the distances in meters, then the resistivity, ρ is obtained which is measured in Ohm-meter. It should be noted that the resistivity method in principle is based on resistivity contrast rather than an absolute resistivity values and the resistivity thus obtained are apparent resistivity of the ground. The apparent resistivity of the ground is calculated from measured resistance. In the vertical electrical sounding, variations of the apparent resistivity are measured. This is achieved by gradual increase in electrode spacing about the centre of the electrode array. The apparent resistivity data are interpreted in terms of resistivity of each layer and depth to the bedrock or other interfaces across which a strong electrical contrast exists (Chinyem, 2005; Eluwa, *et al.*, 2019; Awosika *et al.*, 2020; Eebo & Yusuf, 2021; Ademlua *et al.*, 2014; Nwobi *et al.*, 2022) ABEM SAS Terameter was used.

Field Procedure; Direct current (DC) vertical electrical sounding method was adopted in the field. The maximum spread was $AB = 1000\text{m}$. The ABEM Terameter SAS 1000 gave a direct readout of resistance (V/I). The intervals between the potentials and current electrode were increased at appropriate steps in order to obtain potential differences large enough to be measured with satisfactory precision. Twenty Four (24) vertical electrical soundings (VES) have been acquired at various sites within the study area. Schlumberger method was adopted. During the survey, DC electric current was intermittently released into the ground through the positive electrodes, anode. This passage of the current met with different degree of resistance in the earth layers. This generated potential difference. A change in potential difference in the earth varies with bed boundaries and with the presence/nature of the conducting fluid. Readings were taken at different electrode spreads and the resultant values for each distance was recorded. The data obtained were plotted as a graph of apparent resistivity against half current electrode spacing ($AB/2$) for the Schlumberger array. A useful approximation is that the depth of the interface is equal to two thirds ($2/3$) of the electrode spacing at which the point of inflection occurs (Vingoe, 1972).

Result and Interpretation

Vertical electrical sounding technique was utilized to delineate the subsurface structural stratigraphy of the study area. The investigation employed a Schlumberger array configuration. The result obtained have revealed the trace of fracture at the southern part of the area. The study area is dominated with Nkporo Formation, followed by Ezeaku and Mamu Formations. Ajali Formation was revealed at the southern part of the study area which corresponds to work published by

Onwuchiruba and Agbasi, 2002. Displayed are the results of the interpreted layer parameters from the geoelectric resistivity soundings (table 1); and the downward continuation of the resistivity values (table 2). The VES data obtained showed that the study area has average of 6 layers with resistivity values ranging from $1.42\Omega\text{m}$ to $13900\Omega\text{m}$ and depth between 0.44m to 140m . QH curve is dominant in the study area followed by HK curve.

Table 1: Interpreted Layer Parameter from Geoelectric Resistivity Sounding of the Study Area

S/N		No of layers	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	D1	D2	D3	D4	D5	D6	Curve type	Aquifer thickness h(m)	Top or Aquifer h1(m)	Aquifer ρ	bottom Aquifer h2(m)
1	ACHARA AMAEKE (1a)	6	2480	5330	514	38	288	205	0.61	1.5	4.4	16.7	97	A	HK	4.4	0	2922	4.4
2	AMAEKE	6	171	77.5	64.8	16.5	3.22	130	41	1.6	7.8	29.8	66.2	A	QH	0.61	0	157	0.61
3	NDEANYE	6	157	67.7	17.1	3.3	19.1	122	0.61	7.4	28.9	61.8	89	A	QH	2	0	205	2
4	NDIOKORO AMAEKE (1A)	6	100	205	35.8	15.7	3.49	98	0.74	2	17.3	94.8	139	A	KQH	2.7	0	112	2.7
5	AMABO OKOKO TEM	6	1170	195	439	1310	161	49.1	0.71	3.9	6.8	16.1	105	A	KQH	12.2	3.9	1170	16.1
6	NDIELU UGWUEKE	6	32.9	38.6	17.2	29.9	40.6	18.1	0.57	3.2	21.9	58.8	140	A	HQ	0.57	0	38.6	0.57
7	AMAKAYI	6	28.8	40.7	14.2	35.2	13.6	24.5	0.54	3.4	11.7	37.2	101	A	HK	0.54	0	40.7	0.54
8	OKOKO ITEM	6	1860	2900	1230	13600	5060	240	0.81	3.3	8	22.8	38.5	A	HKH	15.8	22.8	5060	38.6
9	AMANGWU	6	810	177	354	1070	185	8.3	0.44	1.7	14.2	24.2	33.8	A	HK	10	14.2	1070	24.2
10	AMABOELU OKOKO	6	273	268	1510	431	151	28.1	1.5	10.7	27.4	36.1	57.6	A	HKQ	16.7	10.7	1510	27.4
11	UMUAKPA	6	525	322	2180	1870	396	41.9	0.73	1.7	11.8	42	101	A	KQH	30.2	11.8	1870	42
12	OKAGWE	6	620	556	195	47.3	13.1	1.42	1.1	7.5	81.5	95.9	119	A	HK	7.5	0	556	7.5
13	AMAKWE	6	1110	910	72.6	45.1	14	3.8	1.4	25.3	74.6	90.6	118	A	QH	25.3	0	1010	25.3
14	AMAKAI	6	456	282	31.7	19.9	3.55	10.6	2.7	34.9	45.1	83	87	A	QH	2.7	0	319	2.7
15	AMAKWE (M1)	6	675	374	5.1	67.3	82	5.3	1.5	5.7	16.6	33.2	78.9	A	QH	5.7	0	425	5.7
16	AMAKWE (M2)	6	6170	2090	4850	32700	4240	626	64	1.1	8.4	26	41.9	A	HKQ	41.9	0	4240	41.9
17	OKAYI OKAI	6	101	69.3	23.1	8.7	37	3.05	1.5	5.2	30.8	62.7	131	A	HK	5.2	0	101	5.2
18	AKANU	6	98	9.8	3.42	1.98	24	24.9	0.91	5.3	17.4	44.4	122	A	QK	0.91	0	98	0.91
19	ELUGWU AKANU	6	88	39.6	5.66	4.01	54.5	14.6	1.1	3	28.2	51.5	122	A	H	3	0	88	3
20	AKWANU	6	128	67.2	8.3	35	44.9	77.8	37	2.8	42.7	83.8	118	A	H	2.8	0	97.6	2.8
21	AMAEKPU	6	711	91	14.8	12.3	201	23.7	1.2	3.2	30.5	47.8	82.8	A	H	1.2	0	401	1.2
22	OGO UBI	6	485	119	6.1	74.1	96	620	2.3	21.4	30.2	43	67.6	A	H	2.3	0	485	2.3
23	NDIAWA UGWUEKE	6	485	119	6.1	74.1	96	620	2.3	21.4	30.2	43	67.6	A	QH	2.3	0	575	2.3
24	NKPORO	6	234	45	12	27.9	32	345	31	2.1	20.6	102	81.1	A	QH	1.9	0	99	1.9



Table 2: Downward Continuation of the resistivity values of the study area

	LONG (°E)	LAT (°N)	1m	4m	8m	10m	15m	30m	50m	80m	100m	150m	200m	250m	300m	350m	400m	450m	500m
1	7.5847	5.7566	2608	1817	417.9	235.1	83.5	75.1	154	134.2	127.7	200.00	198	235	203	211	211	210	215.6
2	7.60035	5.7385	128	72	48	56	36	19	11	9	8.5	10.00	16	56.3	16.9	17.3	17.8	18	18.6
3	7.60815	5.77885	115.2	113.5	62.8	42.4	36	30.6	21.5	17.6	16.7	12.1	13.6	11.7	14.7	15.9	17.8	18	20.4
4	7.6155	5.7562	82.9	78.3	49.8	46.2	33.9	20.7	15.6	7	6.5	3.5	10.5	12.7	11.3	12.2	12.9	13	13.7
5	7.62304	5.74712	883.8	249	292.1	327.6	430	584	395	301.4	230.5	144.2	123	85.8	80.5	73.8	65.7	49	37.5
6	7.63368	5.7842	34.1	33.4	27.6	23.4	20.1	20.1	22.4	25.9	21.9	29.2	30.5	34.1	36.2	27.5	22.6	19	12.7
7	7.62802	5.82557	31.6	33.4	28.4	23.4	20.1	22.5	21.5	25.7	20.1	19.2	19.8	19.9	20.1	13.7	11.9	11	10.1
8	7.63368	5.74022	2000	2703	2059	2355	2840	2874	4238	5315	5182	2040	914	524	596	419	427	431	450
9	7.63566	5.73958	438.4	255.9	304.9	354.1	414	309	346	355.4	141.9	39.4	15.8	10.5	9.9	11.4	11.9	12	12.7
10	7.63851	5.73905	276.1	259.4	299	312.5	369	459	481	556.1	694.8	387.1	91.9	52.9	52.4	61.8	29.8	29	28.9
11	7.64858	5.734	545.2	730.6	1071	1218	1451	1774	1550	1646	882.1	500	290	150	100	12.7	48.6	35	24.7
12	7.64928	5.80488	614.4	582.6	349.8	517.6	415	312	153	186.5	211.8	125.7	62.5	29.4	14.5	6.7	10.6	8.7	8.4
13	7.66205	5.73937	1102	1026	902.8	878.5	862	731	428	186.5	101.4	49.6	20.1	12.7	8.1	8.1	6.8	6.9	7.1
14	7.66348	5.75143	459	402.9	332.1	312.5	300	235	284	181.6	54.7	21.2	9.4	9.2	9.9	8.3	8.1	8.9	8.6
15	7.66765	5.76343	634	505.4	314.7	165.7	138	13.4	15.8	25.9	30.2	32.4	32.7	25	19.7	18.4	14.9	11	10.6
16	7.6683	5.73663	4927	3470	4683	5209	6073	9649	1240	11407	8355	4010	2004	1487	678	32.6	27.1	22	18.5
17	7.6734	5.82385	99.9	83	54	49.5	37	21	19.1	16	14	15.6	14.9	16.2	17.8	10.5	8.9	6.1	4.8
18	7.68262	5.79885	80.1	13.5	8	6.7	4.8	3	3.6	6.6	15.5	74.6	93.2	8.3	8.7	9.4	11.5	12	12.3
19	7.68578	5.80662	86.2	35.1	11.5	11.5	6.1	6.1	6.2	8.2	18.4	76.9	95.3	9.8	7.8	18.3	19.4	20	20.4
20	7.69893	5.76782	85.8	45.7	9.2	22.6	9.4	9.2	4.6	10.5	16.1	75.2	92.8	44.2	20.7	21.8	23.2	24	27.2
21	7.70761	5.78568	737.5	173.3	24.8	26.1	17.6	16.7	22	35.2	43.1	67.8	74.4	86.4	81.9	149	175	186	200
22	7.7195	5.82817	356.4	582.6	142.3	135.5	125	42.8	49.2	37.5	36.8	20.2	126	165	125	148	151	160	167
23	7.63525	5.8096	35.4	51.1	28.7	23.7	18.7	15.4	27.3	38.5	43.6	48.5	49.2	48.6	44.8	41.4	37.6	30	27.2
24	7.76898	5.77253	414.8	545.5	237.6	84.5	37.1	29.7	47.8	65.1	33.8	19.1	141	187	149	141	106	25	48.1

The image of the downward continuation (iso-resistivity) and contour maps below displayed that majority of the study area are dominated with low resistive materials which is represented with blue/black colours. The towns includes Ndiawa Ugwueke, Okagwe, Elugwu and others, this corresponds to shale unit with relatively low resistivity. Other colours corresponds to areas with high resistive materials indicating the presence of sandy/sandstone units revealing aquiferous zones. The downward continuation of the study area has provided information on the thickness of the overburden and depth to the groundwater aquifer unit in the study area. From the VES data interpretation, it has been confirmed that VES 5,8,9,10,11,13,14 and 16 have high groundwater potential and the towns includes; Okoko, Amangwu, Amaoboelu Okoko, Amaokwe, AmaokweM2, Amaokai, Umuakpa and Amabo Okoko while other towns in the study area has very low groundwater potential. Depth beyond 200m (660feets) has impervious material which indicates non aquiferous zone (Fig.2 to Fig.11).

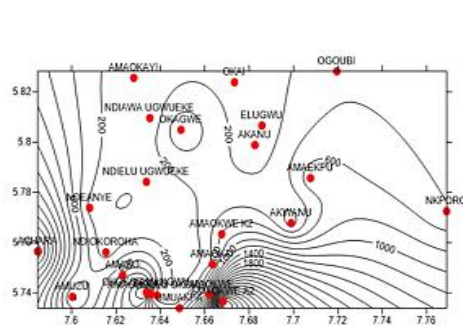


Fig 2a: Contour Map of the Downward Continuation of the Study Area AB/2 = 1m

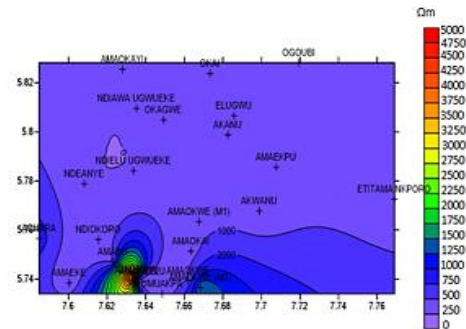


Fig 2b: Image of the Downward Continuation of the Study Area AB/2 = 1m

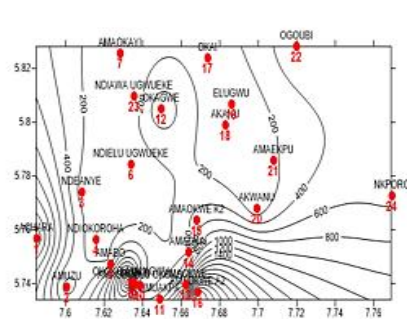


Fig 3a: Contour Map of the Downward Continuation of the Study Area AB/2 = 4m

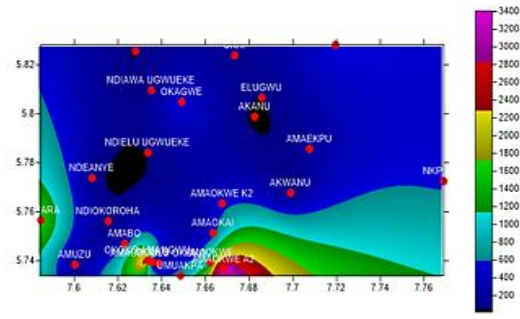


Fig 3b: Image of the Downward Continuation of the Study Area AB/2 = 4m

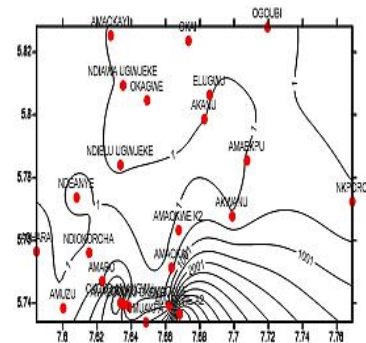


Fig 4a: Contour Map of the Downward Continuation of the Study Area AB/2 = 15m

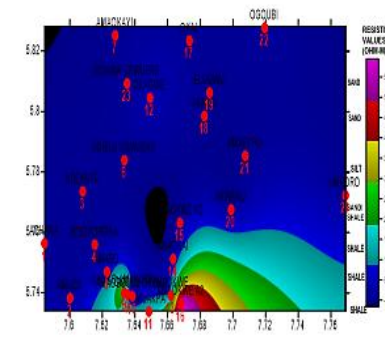


Fig 4b: Image of the Downward Continuation of the Study Area AB/2 = 15m

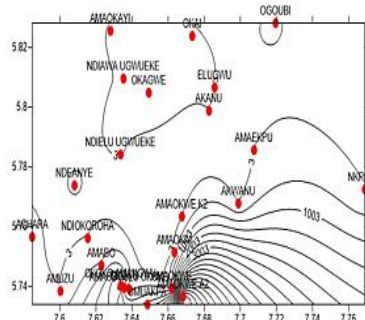


Fig 5a: Contour Map of the Downward Continuation of the Study Area AB/2 = 30m

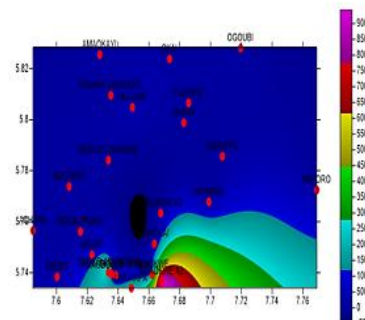


Fig 5b: Image of the Downward Continuation of the Study Area AB/2 = 30m

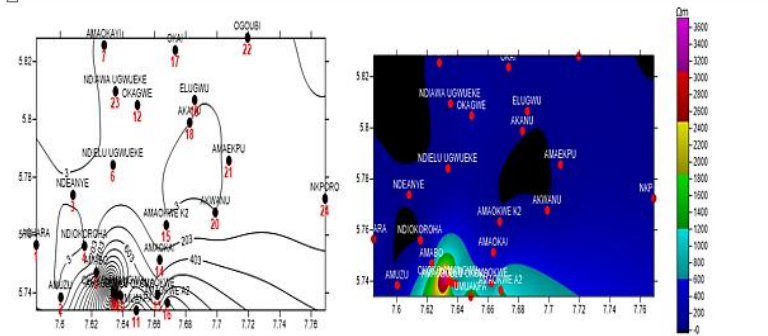


Fig.6a: Contour Map of the Downward Continuation of the Study Area $AB/2 = 50m$

Fig.6b: Image of the Downward Continuation of the Study Area $AB/2 = 50m$

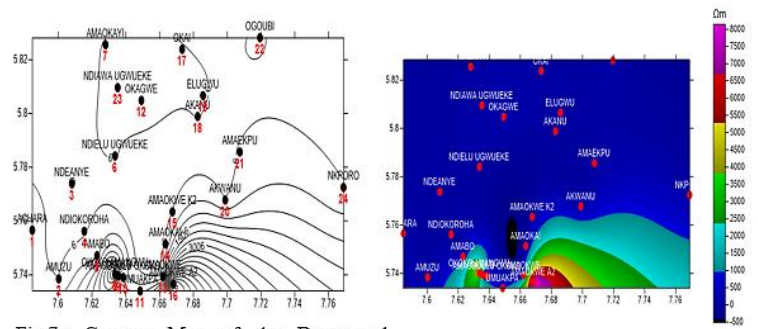


Fig.7a Contour Map of the Downward Continuation of the Study Area $AB/2 = 100m$

Fig.7b Image of the Downward Continuation of the Study Area $AB/2 = 100m$

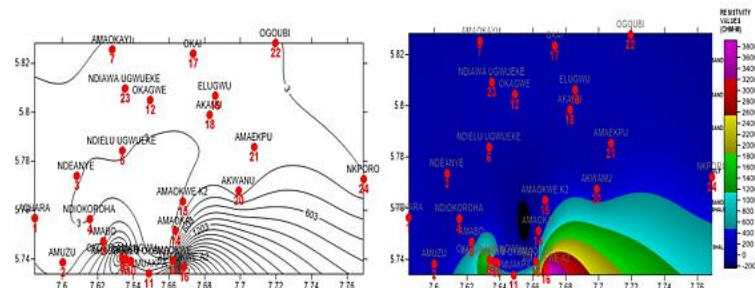


Fig.8a: Contour Map of the Downward Continuation of the Study Area $AB/2 = 150m$

Fig.8b: Image of the downward continuation of the Study Area $AB/2 = 150m$

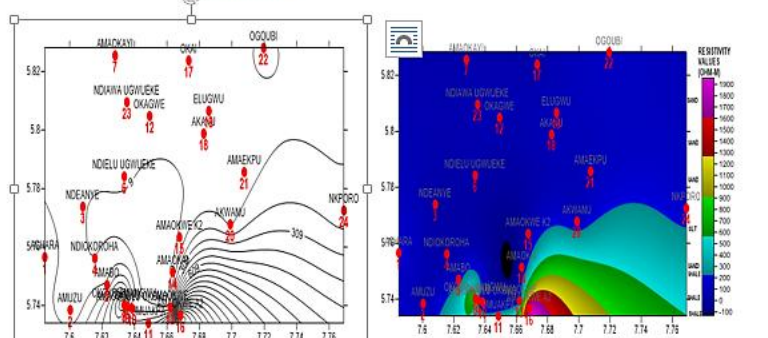


Fig.9a: Contour Map of the Downward Continuation of the Study Area $AB/2 = 200m$

Fig.9b: Image of the Downward Continuation of the Study Area $AB/2 = 200m$

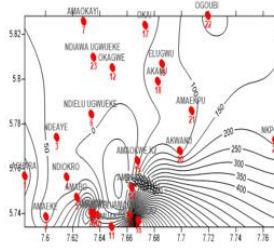


Fig.10a. Contour Map of the Downward Continuation of the Study Area AB/2=250m

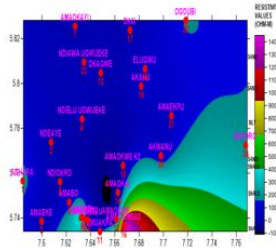


Fig.10b. Image of the Downward Continuation of the Study Area AB/2 = 250m

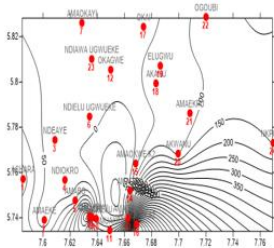


Fig.11a. Contour Map of the Downward Continuation of the Study Area AB/2 =300m

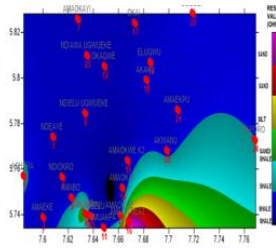


Fig.11b. Image of the Downward Continuation of the Study Area AB/2 = 300m

The downward continuation of the study area has been studied by the use of combined methodology encompassing both geological and geophysical investigations. A clear trace of Ajali sand/sandstone was observed up to the depth of 200meters. It disappears at AB/2 = 350m (233.4m) to AB/2 = 500 (334m). This indicates that beyond 200meters, impermeable materials such as clay/shale has cemented the permeable layer.

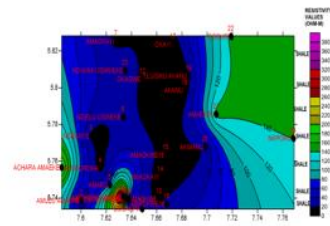


Fig.12: Image of the Downward Continuation of the Study Area AB/2 = 350m

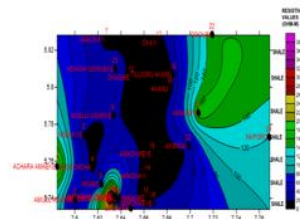


Fig.13: Image of the Downward Continuation of the Study Area AB/2 = 400m

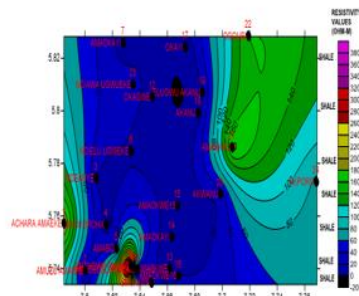


Fig.14: Image of the Downward Continuation of the Study Area AB/2 = 450m

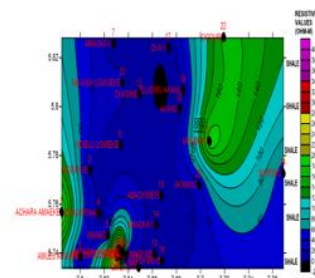


Fig.15: Image of the Downward Continuation of the Study Area AB/2 = 500m

From the 3-D image maps of the study area produced (Fig.16) below, the northern part of the study area is predominantly of shale units while some parts of southern part is made up of sandy units. The resistivity values ranges from layer 1 up to layer 17, with effective depth of 0.67m ($AB/2 = 1m$) to 333m ($AB/2 = 500m$). The areas with very low resistive materials were coloured with blue colour while other colours shows areas high resistive materials. From the 3-D image below, it revealed a fracture which is any separation in a geologic formation that divides the rock into two or more pieces. It provides permeability for fluid movement such as water. It makes good aquifers.

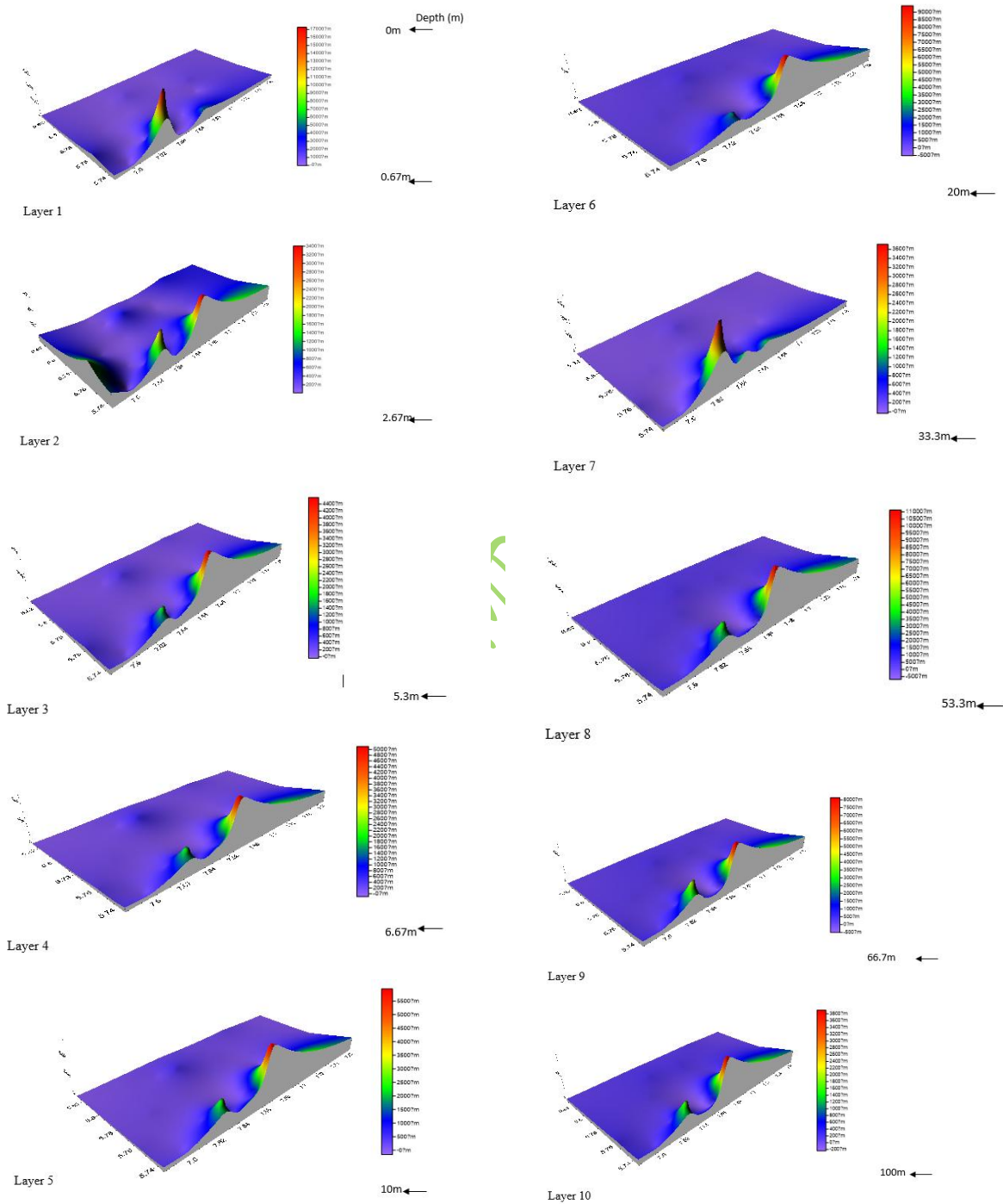
Conclusion

Based on our knowledge of the geological Formation in the study area from the geology of Nigeria supported by the observation made on the field, it is proven that the area is made up of four (4) Formation, which includes Ajali, Mamu, Nkporo and Eze-Aku Formation. Nkporo and Eze-Aku Formation outcrop at the Northern part of the study area while Ajali and Mamu Formation outcrop southward. The geophysical investigation carried out has revealed towns that has potential for groundwater borehole within the study area.

Recommendations

on due consideration and finding, it is recommended that for an effective borehole sitting, a drilling depth of about 100m (330ft) to 200m (660ft) deep borehole will thrive within the towns identified

from the work that has good potential for citing borehole. The use of a standard drilling rig capable of achieving the recommended depth and geophysical logging of the borehole before installation of casing and screens should also be done.



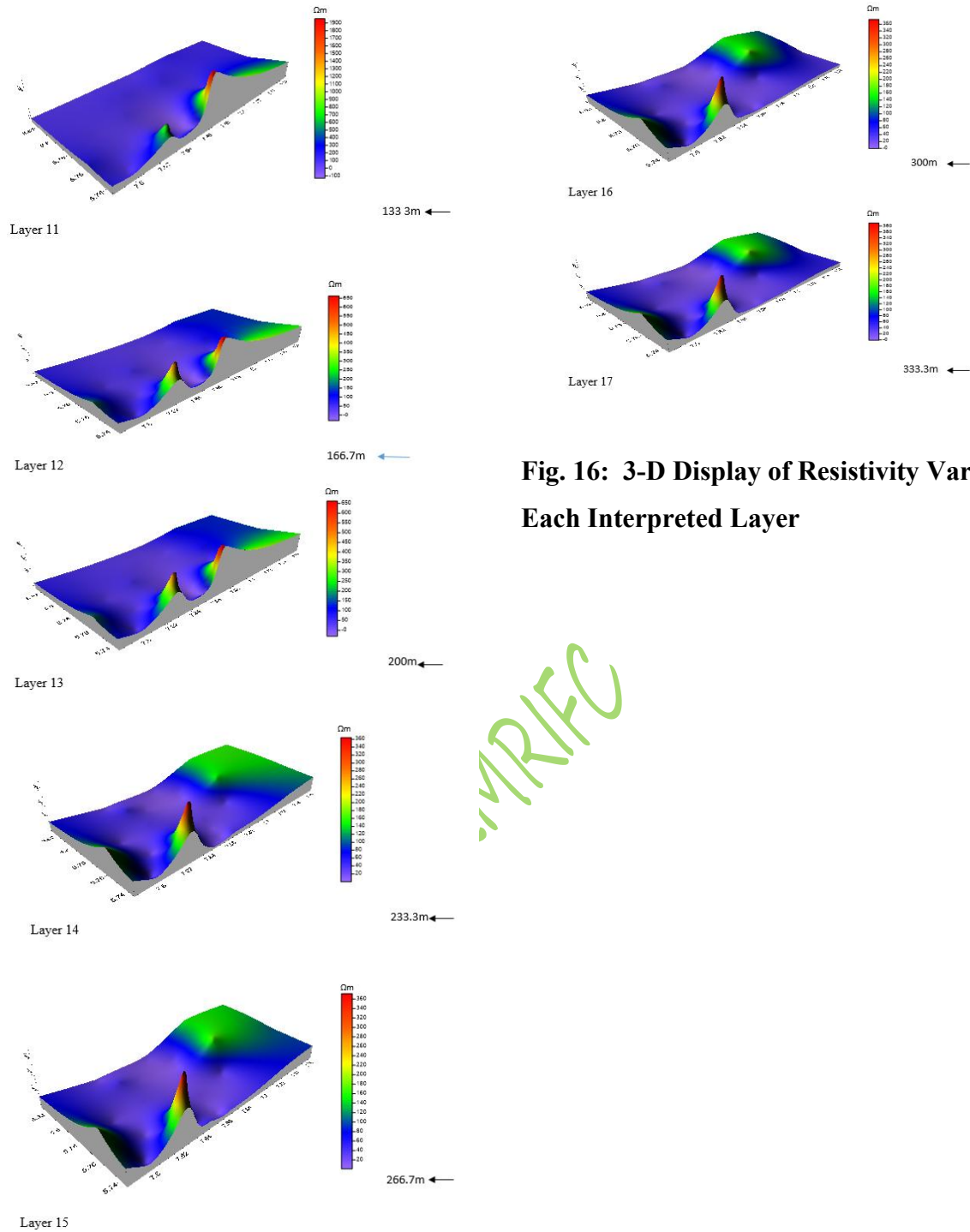


Fig. 16: 3-D Display of Resistivity Variations within Each Interpreted Layer



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THE PHYTOCHEMICAL CONSTITUENTS AND ANTIMICROBIAL PROPERTIES OF *PSIDIUM GUAJAVA* LEAVES

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Abstract

Guava Psidium guajava is a tropical plant with a wide range of medicinal applications. It belongs to the Myrtaceae family and can be used for the treatment of various diseases and ailments such as stomach aches, dysentery, vertigo, jaundice, cerebral ailments, skin infections, diabetes, diarrhea, wound healing, inflammations, and bacterial infections. This study probed the phytochemical constituents and antimicrobial properties of *Psidium guajava* leaf extract. The phytochemical constituents of *Psidium guajava* leaf revealed the presence of alkaloids (16.17 ± 0.13 mg/100 g), tannins (1.13 ± 0.05 mg/100 g), Saponins (138.6 ± 0.82 mg/100 g), flavonoids (152.83 ± 0.85 mg/100 g), phenol (1.34 ± 0.02 mg/100 g), and terpenoids (12.85 ± 0.31 mg/100 g) with flavonoids having the highest concentration and tannins the lowest. Results of the antibacterial potency of methanol extract of the leaves against selected clinical isolates determined in the agar well diffusion technique showed a concentration-dependent activity. *Escherichia coli* was susceptible/sensitive to the extract at 200 mg with an inhibition zone size of 16.5mm. At a similar concentration for *Staphylococcus aureus*, *Proteus mirabilis*, and *salmonella species*, the zone sizes were 11.0mm, 12.0mm, and 13.5mm respectively. Findings from this study showed that the minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) values of the extract against the isolates ranged between 12.5mg/ml to 100mg/ml. Therefore, these findings support the traditional use of *Psidium guajava* leaves in folk medicine and provide a scientific basis for their potential development as natural remedies for infectious diseases.

Keywords: *Psidium guajava*, Antimicrobial, Phytochemical constituents, *Myrtaceae*

Introduction

Guava, scientifically called *Psidium guajava* L. is a popular plant cultivated for its fruit and



medicinal applications. *Psidium guajava* belongs to the family Myrtaceae, class Magnoliopsida, phylum Magnoliophyta [11]. Guava are native to America stretching from southern Mexico to



northern South America, but they have been cultivated in several other nations with tropical and subtropical temperatures, enabling global production including, India, China, Nigeria, Pakistan, Indonesia, Bangladesh, Thailand, Brazil, Philippines, Egypt and so on [9]. Additionally, guavas are cultivated in southern Europe, particularly in Greece and the Costa del Sol near Málaga, Spain. Since the mid-1900s, guavas have been produced commercially in these countries, and their cultivars have multiplied. Among the several species of guava grown commercially, apple guava and its cultivars are the most commonly traded internationally.

Materials and Methods

Leaves of *P. guajava* were collected from the vicinity of the College of Physical and Applied Sciences, Michael Okpara University of Agriculture, Umudike, Abia State, air-dried for thirty days, milled into a powdered form, then preserved in an airtight container prior to analysis.

Quantitative Phytochemical Determination

Determination of Alkaloids

Alkaloids were determined by the gravimetric method described by Haborne [4]. About 5.0 g of the sample was dispersed in 50 ml of 10 % acetic acid solution in ethanol. The mixture was shaken and allowed to stand for 4 hours before it was filtered with Whatman No. 42 filter paper. The filtrate was evaporated to one-quarter of its original volume. The alkaloids were precipitated by adding two drops of concentrated NH_3 solution and then filtered using a weighed filter paper. Thereafter, the precipitate was washed with 1 % NH_3 solution. The precipitate was then dried in the oven at 60°C for 30 minutes and reweighed. Alkaloid content was calculated and expressed as shown below.

$$\% \text{ Alkaloid} = \frac{W_1 - W_2}{\text{Weight of Sample}} \times \frac{100}{1}$$

Where W_1 = weight of empty filter paper and W_2 = weight of paper + precipitate.

Determination of Tannins

The amount of tannins was determined by the method described by Van-Burden and Robinson [13]. A 0.5 g of ground sample was dissolved in 50 ml of distilled water contained in 250 ml conical flask. This was stirred using magnetic stirrer for 1 hour, with 5 ml of filtrate dispensed into a 50 ml volumetric flask. A measured weight of tannic acid (0.1 g) was dissolved in 100 ml of distilled water and 5 ml of the tannic acid solution pipetted out into 50 ml volumetric flask. A blank sample was set up by using 5 ml of distilled water. One (1) ml Folin- Dainas reagent was put in each and 2.5 ml of sodium carbonate (saturated Na_2CO_3) solution added. Fifty (50) ml distilled water was

added to dilute the mixture, and the absorbance of the dark color, which developed, was measured in a spectrophotometer after incubation at 25 °C for 90 minutes. The absorbance was measured at a wavelength of 760 nm with a reagent blank at zero.

$$\% \text{ Tannin} = \frac{AT \times VF \times DF}{AS \times VE \times WS} \times 100$$

Where, AT = Absorbance of tannic solution; AS = Absorbance of sample solution; VF = Total volume of filtrate; VE = volume of extract analyzed; DF = Dilution factor; WS = Weight of sample.

Determination of Saponins

Determination of saponins was done by the double solvent extraction gravimetric method of Harborne [4]. A weight of 5.0 g of the sample was mixed with 50 ml of 20 % aqueous ethanol solution and incubated for 90 minutes at a temperature of 55°C with constant agitation. After that, the mixture was filtered through Whatman No. 42 grades of filter paper. About 50 ml of the ethanol solution was used for the re-extraction of the residue for 30 minutes. The extracts were pooled together and weighed. The combined extract was reduced to about 40 ml by evaporation and then transferred to a separating funnel and equal volume (40 ml) of diethyl ether was added to it. After agitation, there was partition and the aqueous layer was re-extracted with the ether after which its pH was reduced to 4.5 with dropwise addition of dilute NaOH solution. Saponin in the extract was taken up in successive extractions with 60 ml and 30 ml portions of butanol. The combined extract (precipitate) was washed with 5 % NaCl solution and evaporated to dryness in a previously weighed evaporation dish. The saponin was then dried in the oven at 60°C (to remove any residual solvent) cooled in a desiccator and re-weighed. The saponin content was calculated as shown below:

$$\% \text{ saponin} = \frac{W_2 - W_1}{W} \times \frac{100}{1}$$

Where W = Weight of sample used; W_1 = Weight of empty evaporating dish; W_2 = Weight of dish + saponin extract

Determination of Flavonoids

Flavonoids were determined as described by Boham and Kocipal [2]. The sample (100 g) was extracted repeatedly with 100 ml of 80 % aqueous methanol at room temperature. The whole



solution was filtered using the Whatman No 42 filter paper. The filtrate was transferred into a crucible and evaporated to dryness over a water bath and then weighed.

$$\% \text{ Flavonoid} = \frac{\text{Weight of the dried extract}}{\text{Weight of the sample}} \times 100$$

Determination of Phenols

This was determined by the Folin-Ciocalteu spectrophotometer method [1]. The total phenol was extracted in 200 mg of the sample with 10 ml concentrated methanol. The mixture was shaken for 30 minutes at room temperature. The mixture was centrifuged at 500 rpm for 15 minutes and the supernatant (extract) was used for the analysis. 1 ml portion of the extract from each sample was treated with equal volume of Folin-Ciocalteu reagent followed by the addition of 2 ml of 2 % Na_2CO_3 solution. Meanwhile, standard phenol solution was prepared and diluted to a desired concentration. 1 ml of standard solution was also treated with the Folin-Ciocalteu reagent and Na_2CO_3 solution. The intensity of the resulting blue colouration was measured (absorbance) in a spectrophotometer at 560 nm wavelength. Measurement was made with a reagent blank at zero. The phenol content was calculated using the formula below

$$\% \text{ Phenol} = \frac{100}{w} \times \frac{A_u}{A_s} \times \frac{c}{1} \times \frac{v_t}{v_a}$$

Where, W = Weight of sample; A_u = Absorbance of test sample; A_s = Absorbance of standard phenol sample; C = Concentration of standard phenol sample; V_t = Total extract volume; V_a = Volume of extract analyzed

Determination of Terpenoid

0.8g of plant sample was taken in a test tube and 10ml of methanol was poured in it. The mixture was shaken well and filtered to take 5ml of the plant extract was introduced into a 10ml curvette and the absorbance was taken in a UV Spectrophotometer at the wavelength of 538nm [95%(V/V) methanol will be used as blank]. For the standard curve 200 μL of previously prepared linalool solution in methanol was added to 1.5 ml Chloroform and serial dilution was done [dilution level- 100mg /200 μL Linalool conc.]. In the case of serial dilution total volume of 200 μL will be made up by addition of 95% (V/V) methanol. A plot of the calibration curve was done and the actual



concentration of the sample was determined from the calibration curve as they correspond to the concentration line.

Screening of the extracts for antibacterial activity

0.4g of the crude extract was reconstituted in 2ml of Dimethyl sulphoxide (DMSO) to obtain extract concentration of 200mg/ml. This was serially diluted in 2-folds to obtain the following lower extract concentrations: (100, 50, and 25) mg/ml. The activity of the crude extract was determined using agar well diffusion techniques [6]. An 18hour old standardized inoculum (corresponding to 0.5McFarland turbidity standard) of each test bacterial isolate was inoculated on dried surface of Mueller-Hinton agar by spreading with a sterile cotton swab to achieve a confluent growth. The inoculated plates were allowed to dry after which wells were punched on the agar using a sterile standard 6mm cork borer. Subsequently, 50 μ l of different concentrations of the extract was separately introduced into the different wells that have been labeled accordingly using a micropipette. Equal volume of DMSO as well as gentamicin (antibiotic) was introduced into the well bored in the centre of the plate as negative and positive control respectively. This procedure was repeated in duplicate for all the test organisms, and allowed to stay for 30min on the bench after which they were incubated for 24hour at 37°C. At the end of incubation, observed zones of inhibition were measured and recorded to the nearest millimeter.

Determination of Minimum Inhibitory Concentration (MIC) of *P. Guajava* using Broth Dilution Technique

The Minimum inhibitory concentration (MIC) of the plant extracts on the test isolates were determined by the broth dilution method. Extract concentration (100mg/ml) was further diluted in a 2-fold serial dilution to obtain the following concentrations: 50, 12.5, 6.25, 3.12, 1.56 and 0.78mg/mL. 1ml stock solution of the plant extract 100mg/ml was diluted in sterile test tube containing 0.95ml of Mueller Hinton Broth (MHB) to obtain further dilution. Serial dilution techniques were employed by transferring 1ml from the first test tube to the second test tube and from the second to the third. This was continued to the seventh test tube from where 1ml was discarded to give concentration of 50, 25, 12.5, 6.25, 3.12, 1.56 and 0.78mg/ml. Another test tube was also prepared in a similar way containing MHB and inoculated with standard suspension (50 μ l) of the test organisms and incubated at 37°C overnight. This served as a control tube. After incubation, growth of the organisms in form of turbidity in each tube was checked. The minimum dilution (concentration) of the extracts completely inhibiting the growth of each organism was taken as the MIC for the organism tested.



Determination of Minimum Bactericidal Concentrations (MBC) of *P. guajava* Extracts on Test Isolates

The MBC of the extracts was obtained by sub culturing an aliquot of the broth from tubes that showed little or no visible growth in the tests for determination of MICs. The aliquots were transferred respectively into plates containing freshly prepared nutrient plates. These plates were incubated at 37°C 24h and observed for growth. The absence of growth at the end of incubation period signifies total cell death. The minimum concentration of the plant extracts that produces total cell death was taken as the MBC.

Results and Discussion

Table 1.1: Quantitative screening phytochemical composition of Guava Leaf

Values are means \pm standard deviation of triplicate determinations

Phytochemical	Concentration mg/ 100 g
Alkaloids	16.17 ± 0.13
Tannins	1.13 ± 0.05
Saponins	138.6 ± 0.82
Flavonoids	152.83 ± 0.85
Phenols	1.34 ± 0.02
Terpenoid	12.85 ± 0.31

Results of the phytochemical determination indicated that flavonoid had the highest concentration (152.83 ± 0.13 mg/100 g), followed by Saponins (138.6 ± 0.82 mg/100 g), Alkaloid (16.17 ± 0.13 mg/100 g), Terpenoid (12.85 ± 0.31 mg/100 g), phenols (1.34 ± 0.02 mg/100 g) and lastly tannins (1.13 ± 0.05 mg/100 g).

Table 1.2 Mean Diameter Zones of Inhibition (mm) produced by extracts of *Guava* leaves against selected clinical isolates

Test Organisms	Concentration (mg/ml)			ControlGentamicin
	200	100	50	
<i>Escherichia coli</i>	16.5 ± 0.70	12.0 ± 1.41	8.0 ± 0.00	27.0 ± 1.41
<i>Staphylococcus aureus</i>	11.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	21.0 ± 0.70



<i>Salmonella species</i>	13.5 ± 0.70	10.0 ± 0.00	0.0 ± 0.00	24.0 ± 0.00
<i>Proteus mirabilis</i>	12.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	19.0 ± 0.70

Values in the table are the mean ± standard deviation from the results of two replication of each experiment.

Table 1.3: MIC and MBC values (mg/ml) of extract of *Guava* against the Isolates

Organisms	100	50	25	12.5	6.25	3.12	1.56	0.78	MIC	MBC
<i>E. coli</i>	-	-	-	+	+	+	+	+	12.5	25
<i>S. aureus</i>	-	+	+	+	+	+	+	+	50	100
<i>Salmonella species</i>	-	-	+	+	+	+	+	+	25	50
<i>Proteus mirabilis</i>	-	+	+	+	+	+	+	+	50	100

+: growth of the organism indicated by turbidity in the broth medium; - = Absence of growth of the test organism shown by no form of turbidity in the medium

As shown in Table 1.2, the crude extracts of *Psidium guajava* used in this study had appreciable anti-bacterial activity against growth of the test microorganisms with inhibition zone sizes in the range of 11.0mm to 16.5mm. *Escherichia coli* and *Salmonella species* which are Gram negative bacteria were most susceptible to the extracts when compared to *Staphylococcus aureus*, a Gram-positive species. The extract produced higher inhibitory zones for the Gram negative organisms relative to the Gram positive species (Table 1.2). The nature of the cell wall of Gram positive bacteria could have contributed to the decreased susceptibility of the *Staphylococcus aureus*. The extracts showed a concentration dependent effect against the respective test isolates. The antimicrobial activity of the extract was observed to be concentration-dependent and the activity varied with concentration against the tested pathogens as shown on Table 1.1. The extract inhibited the growth of *E. coli* at 200mg/ml concentration with a zone size of 16.5mm which reduced to 12.0mm and 8.0mm respectively for the 100mg and 50mg concentrations. This observation is in agreement with similar studies carried out by Patel *et al.*, [8] and Vinoth *et al.*, [14]. It is important to



recognize that the size of inhibition zones of extract against the respective organisms could be due to the polarity of compounds in the extract, since a more diffusible but less active extract could give a bigger diameter of inhibition than a non-diffusible but more active extract [10]. The results obtained from this study are interesting since these microorganisms are commonly involved in diarrheal diseases. Our data confirm previous results about antimicrobial activity of this plant. It has been shown that extracts of *Psidium guavaya* has significant antimicrobial activity [3]. The results of this present study also affirms earlier submission by Patel *et al.*, [7] on a *Psidium guavaya* against similar organisms.

The minimum inhibitory concentration (MIC) as shown on table 1.3 shows that the extracts could be effective even at concentrations lower than that obtained from the agar diffusion assay. It has been reported elsewhere that the rate of diffusion could affect the activity of some plant extracts as a result of slower migration on agar. At 25mg/mL, the extract of *Psidium guavaya* was still active against *Escherichia coli*. The extract had MIC values in the range of 25mg to 50 mg for *Salmonella* and between 50mg/ml to 100mg/ml for the other organisms. The antibacterial activities recorded from these plant substantiate earlier assertions that indigenous plants should be exploited in health promotion [5]. Several researchers have reported interesting antimicrobial properties of these medicinal plants in different investigations. The results of the present study reinforce the importance of the analyzed plants as a source of bioactive compounds for the treatment of diarrhea associated with the organisms used in this study. The susceptibility of the isolates to the study plant extracts implies that chemical compounds in the extracts can be further developed to fight against these resistant microorganisms [12].

Conclusion

The use of phytopharmaceuticals and herbal formulations represents a promising alternative to tackle the increasing global challenge of antimicrobial resistance. The *Psidium guajava* leaf extract shows significant antimicrobial activities against clinically relevant pathogens, including *Escherichia coli*, *Staphylococcus aureus*, *Salmonella* species, and *Proteus mirabilis*. These findings support the traditional use of *Psidium guajava* leaves in folk medicine and provide a scientific basis for their potential development as natural remedies for infectious diseases.

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DETERMINATION AND EVALUATION OF INDICATOR PROPERTIES IN INDIGO PLANT EXTRACTS {*Rothmannia whitfieldii*, *Lawsonia inermis*, *Baphia nitida(uhie)* and *Baphia nitida(odo)*}

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Abstract

The analytical potential of flower extracts is very promising as seen in its application in acid to base titrimetry. Four plants extracts were evaluated for its indicator properties. These plant extracts were *Lawsonia inermis*, *Baphia nitida (uhie)*, *Baphia nitida (odo)* and *Rothmannia whitfieldii*. 1% weight by volume of the synthetic indicators and natural indicators were prepared. The synthetic indicators were prepared from stock while the natural indicators were prepared from crushed dried leaves, stem and roots of the above mentioned plants. This was obtained by measuring precisely 1 gram of the synthetic indicators and natural indicators respectively, (phenolphthalein, methyl orange, methyl red, *Lawsonia inermis*, *Baphia nitida (uhie)*, *Baphia nitida (odo)* and *Rothmannia whitfieldii*), using a measuring balance and a petri dish on it. The measured 1 gram of each dried samples of indicators from stock was dissolved in 80mls of ethanol and diluted to 100mls with distilled water to make up 1% weight by volume of prepared indicators. These prepared indicators were used in acid to base titration. The strengths or indicator properties of these extracts were evaluated and checked if correlation points exist between natural and synthetic acid to base indicators. The results revealed, the plant extracts under investigation offered similar results with synthetic indicators. The best performance of these natural extracts as acid to base indicators was seen in strong acid to strong base titration. *Rothmannia whitfieldii* was an exception to this finding, as it maintained the same color (green) in both acidic and basic media. While other natural extracts {*Lawsonia inermis*, *Baphia nitida(uhie)*, *Baphia nitida (odo)*} met the requirements of good acid to base indicators in titration, *Rothmannia whitfieldii* failed. These plant extracts that met the requirements of good acid to base indicators can be used as substitutes to conventionally used acid to base indicators in laboratories.

Keywords: Titrants, Analyte, Equivalent point, Indicator, Endpoint, Indigo plants.

Introduction

Background of the study

Recent years, there has been a revival of the use of dyes and colours of natural origin for colouring food, pharmaceutical, cosmetic, textile product and indicators in titrimetry. This increasing demand for the material of natural origin is because of the toxic nature of many of the synthetic dyes. Amongst the natural dyes, which are becoming widely recognized throughout the world, indigo which is one of the oldest known natural dyes (Ensely *et al.*, 1983) is a derivative of the colourless glucosides of the enol form of Indoxyl, e.g Indican (indoxyl- β -D-glucoside). Indigo is formed from Indican by fermentation of plant material such as *Baphicacanthus cusia* Brem, *Indigofera*



suffruticosa Mill, *Polygonum tinctorium* palette, *Isatis Indigotica* etc., followed by air oxidation of Indoxyl (Minami *et al.*, 1996, 1997). *Isatis tinctoria* (woad) contains isatan B (Indoxyl-B-keto gluconate), as a major indigo precursor and Indican as a minor indigo precursor (Epstein *et al.*, 1967, Maier *et al.*, 1990).

It was found that Indole was precursor of indigo biosynthesis in plant, (Lu, 1986). In old leaves of the plant, precursors are broken down by hydrolases when the leaves are damaged and exposed to the air. The liberated Indoxyl is spontaneously oxidized by oxygen yielding indigo. Isatin is generated from indoxyl in an oxygen-rich environment as a side product. The condensation of Indoxyl with Isatin produce Indirubin, which is a pinky red pigment similar to indigo blue in structure. Indirubin has been isolated from the crude extract of *B. cusia* Brem (Ben, 1981) and from *P. tinctoriu* (Maier *et al.*, 1990). It is well known that plants contain, in addition to trans-indigo (indigotin blue) and tran-indirubin (iso indigotin red) certain trace compounds such as cis indigo (blue), cis-indirubin (iso indirubin, red, indigo brown (iso indigo), indigo gluten, indigo yellow and trace of flavonoids (Perkin and Bloxam, 1907).

In addition to the toxic effects of synthetic indicators on users such as diarrhea, pulmonary edema, hypoglycemia and pancreatitis, they can result to abdominal cramps, skin rash, eruptions, erythema, epidermal necrosis and environmental pollution.

This work is focused on determination and evaluation of indicator properties in extracts of *Rothmannia whitfieldii*, *Lawsonia inermis*, *Baphia nitida*(uhie) and *Baphia nitida*(odo).

Materials and Method

Plant Materials: The plant materials used include *Rothmannia whitfieldii* (leaves and seeds) *Lawsonia inermis* (leaves and seeds) *Baphia nitida* (uhie powder) and *Baphia nitida*(odo powder). While *Rothmannia whitfieldii* was gotten from Mbaise in Imo state, eastern part of Nigeria. *Lawsonia inermis* was gotten from Osun state in western part of Nigeria, *Baphia nitida*(uhie) and *Baphia nitida*(odo) were purchased at Ndoro market in Oboro; Ikwuano L.G.A; Abia state.

Reagents And Standards: Methanol (HPLC), acetone (HPLC), Anhydrous Sodium Sulphate, Deionized water, Ethanol, NaOH Sodium Hydroxide, Ammonium Hydroxide, NH₄OH, Tetraoxosulphate (VI) acid (H₂SO₄), acetic acid, phosphoric acid, hydrochloric acid, sodiumcarbonates (Na₂CO₃). The reagents were gotten from Grifeon Project Ltd. Laboratory Umuahia, Abia state.



Apparatus and Equipment; Glass wares, weighing balance, spatula, electric grinder, drooper, test tube stand, retort stand, wash bottle, Synthetic indicators: Phenolphthalein, methyl orange, methyl red.

Preparation of Synthetic Indictators (Methyl orange, Phenolphthalein and Methyl red) From Stock

Preparation of 1% weight by Volume of Methyl orange Indicator.

First, a petri dish was placed on a weighing balance and tare down. A spatula was used to measure precisely 1 gram of methyl orange powder and dissolved in 80mls of ethanol. The methyl orange powder and ethanol were mixed with the help of a spatula to make a homogenous mixture.

The homogeneous mixture of methyl orange in 80mls of ethanol was transferred into a 100mls volumetric flask with the help of a funnel. The solution in 100mls volumetric flask was filled with distilled water to the mark. The same process was applied in preparation of phenolphthalein and methyl red, (<https://pharmaguddu.com>).

Preparation of Natural Indicators {(Rothmannia whitfieldii, Lawsonia inermis Baphia nitida (uhie) and Baphia nitida (odo)}

The natural indicators were prepared the same way the synthetic indicators were prepared, except in the case of *Lawsonia inermis* and *Baphia nitida*(odo); where the masses of solutes measured was 2grams each and diluted with 80mls of ethanol. Finally, the homogenous mixture of each sample was poured into 100mls volumetric flask and distilled water was added up to the mark (100mls point).

Titration

The titration was between strong acid and strong base (HNO_3 & NaOH), (HCl and NH_3), weak acid and strong base (CH_3COOH and NaOH) and weak acid against weak base (CH_3COOH) and NH_3).

Three different molar strengths of the acids and alkalis were used; 0.1M against 0.5M and 0.5M against 1.0M. 50mls of the titrant was put in a burette, this was titrated against 25mls of the titrand. The 25mls portion of the titrand was measured with a 25mls by volume of a graduated pipette and then transferred to a conical flask, where 2 drops of the indicators was added. Titration exercise was repeated to obtain concordant titre values.

Result and Discussion

Results obtained from Titration

Titration between Strong Acid and Strong Base



Volume of pipette: 25 mls
 Volume of Burette used: 50 mls
 Concentration of acid: 1.0 M HCL
 Concentration of base: 0.5 M NaOH

Table 1.1 Results obtained from Titration

Standard indicators used	Mean values (cm ³)	Colour in acid	Colour in base	Colour at endpoint
Methyl orange	16.35 ± 0.05	Pink	Yellow	Orange
Methyl red	16.45 ± 0.10	Red	Yellow	Orange
Phenolphthalein	16.76 ± 0.10	Colourless	Pink	Colourless
Natural indicators used				
<i>Lawsonia inermis</i>	16.86 ± 0.05	Red	Yellow	Brown
<i>Baphia nitida (uhie)</i>	16.36 ± 0.15	Yellow	Brown	Yellow
<i>Baphia nitida (odo)</i>	16.43 ± 0.10	Yellow	Brown	Yellow
<i>rothmanna whit field ii (uri)</i>	Not suitable	Green	Green	N.R

Concentration of acid: 0.5 M Hcl
 Concentration of base: 0.1 M NaOH

Table 1.2

Standard indicators used	Mean values (cm ³)	Colour in acid	Colour in base	Colour at endpoint
Methyl orange	5.26 ± 0.10	Pink	Yellow	Orange
Methyl red	5.23 ± 0.10	Red	Yellow	Orange
Phenolphthalein	5.50 ± 0.05	Colourless	Pink	colourless
Natural indicators used				
<i>Lawsonia inermis</i>	5.86 ± 0.05	Red	Yellow	Brown
<i>Baphia nitida (uhie)</i>	5.63 ± 0.10	Yellow	Brown	Yellow
<i>rothmanna whit fieldii (uri)</i>	Not suitable	Green	Green	N.R
<i>Baphia nitida (odo)</i>	5.06 ± 0.10	Yellow	Brown	Yellow

**Table 1.4: Concentration of acid: 0.5 M Acetic acid against 0.1 M NaOH**

Concentration of acid: 0.5 M HCL

Concentration of base: 0.1 M NH₄OH

Standard indicators used	Mean values (cm ³)	Colour in acid	Colour in base	Colour at endpoint
Methyl orange	4.13 ± 0.05	Pink	Yellow	Orange
Methyl red	4.36 ± 0.05	Red	Yellow	Orange
Phenolphthalein	4.36 ± 0.15	Colourless	Pink	colourless
Natural indicators used				
<i>Lawsonia inermis</i>	4.76 ± 0.15	Red	Yellow	Brown

Titration between Strong Acid and Weak Base

Concentration of acid: 1.0 M HCl

Concentration of base: 0.5 M NH₄OH**Table 1.3**

Standard indicators used	Mean values (cm ³)	Colour in acid	Colour in base	Colour at endpoint
Methyl orange	10.36 ± 0.05	Pink	Yellow	Orange
Methyl red	10.33 ± 0.10	Red	Yellow	Orange
Phenolphthalein	10.06 ± 0.10	colourless	Pink	colourless
Natural indicators used				
<i>Lawsonia inermis</i>	10.76 ± 0.10	Red	Yellow	Brown
<i>Baphia nitida (uhie)</i>	3.76cm ± 0.10	Yellow	Brown	Yellow
<i>Baphia nitida (odo)</i>	5.16cm ± 0.10	Yellow	Brown	Yellow
<i>rothmanna whitfieldii (uri)</i>	Not suitable(NS)	Green	Green	No result (NR)



<i>Baphia nitida (uhie)</i>	Not suitable	Yellow	Yellow	No sharp colour detected
<i>Baphia nitida (odo)</i>	Not suitable	Yellow	Yellow	No sharp colour detected
<i>rothmanna whitfieldii (uri)</i>	Not suitable	Green	Green	N.R

Titration between Weak Acid and Strong Base

Concentration of acid: 1.0 M Acetic acid

Concentration of base: 0.5 M NaOH

Table 1.5

Standard indicators used	Mean values (cm ³)	Colour in acid	Colour in base	Colour at endpoint
Methyl orange	17.10 ± 0.15	Pink	Yellow	Orange
Methyl red	16.33 ± 0.15	Red	Yellow	Orange
Phenolphthalein	15.76 ± 0.15	Colourless	Pink	Colourless
Natural indicators used				
<i>Lawsonia inermis</i>	15.33 ± 0.10	Red	Yellow	Brown
<i>Baphia nitida (uhie)</i>	15.16 ± 0.10	YELLOW	Brown	Yellow
<i>Baphia nitida (odo)</i>	15.23 ± 0.10	Yellow	Brown	Yellow
<i>rothmanna whitfieldii (uri)</i>	Not suitable	Green	Green	N.R

Table 1.6:

Standard indicators used	Mean values (cm ³)	Colour in acid	Colour in base	Colour at endpoint
Methyl orange	6.20 ± 0.10	Pink	Yellow	Orange
Methyl red	5.60 ± 0.15	Red	Yellow	Orange
Phenolphthalein	5.60 ± 0.10	Colourless	Pink	Colourless
Natural indicators used				
<i>Lawsonia inermis</i>	6.60 ± 0.10	Red	Yellow	Brown
<i>Baphia nitida (uhie)</i>	5.60 ± 0.15	YELLOW	Brown	Yellow
<i>Baphia nitida (odo)</i>	5.10 ± 0.10	Yellow	Brown	Yellow
<i>rothmanna whitfieldii (uri)</i>	Not suitable	Green	Green	N.R

Titration between Weak Acid And Weak Base



Concentration of acid: 1.0 M Acetic acid

Concentration of base: 0.5 M NH_4OH

Table 1.7

Standard indicators used	Mean values (cm^3)	Colour in acid	Colour in base	Colour at endpoint
Methyl orange	16.46 ± 0.20	Pink	yellow	Orange
Methyl red	9.86 ± 0.15	Red	yellow	Orange
Phenolphthalein	9.33 ± 0.20	Colourless	Pink	Colourless
Natural indicators used				
<i>Lawsonia inermis</i>	22.70 ± 0.20	Red	yellow	Brown
<i>Baphia nitida (uhie)</i>	2.90 ± 0.20	YELLOW	brown	Yellow
<i>Baphia nitida (odo)</i>	2.00 ± 0.20	Yellow	brown	Yellow
<i>rothmanna whitfield ii (uri)</i>	Not suitable	Green	Green	N.R

Concentration of acid: 0.5 M Acetic acid

Concentration of base: 0.1 M NH_4OH

Table 1.8

Standard indicators used	Mean values (cm^3)	Colour in acid	Colour in base	Colour at endpoint
Methyl orange	9.70 ± 0.20	Pink	Yellow	Orange
Methyl red	4.40 ± 0.15	Red	Yellow	Orange
Phenolphthalein	4.90 ± 0.15	Colourless	Pink	Colourless
Natural indicators used				
<i>Lawsonia inermis</i>	16.00 ± 0.20	Red	Yellow	Brown
<i>Baphia nitida (uhie)</i>	Not suitable	YELLOW	Yellow	N.R
<i>Baphia nitida (odo)</i>	Not suitable	Yellow	YELLOW	N.R
<i>rothmanna whitfield ii (uri)</i>	Not suitable	Green	Green	N.R

Discussion



The results obtained in Table 1.1 revealed, in strong acid and strong base titration (1.0 M HCl against 0.5 M NaOH), the average titer values of methyl orange, methyl red and phenolphthalein were 16.35 cm², 16.45cm² and 16.76cm² respectively.

While *Lawsonia inermis* showed a titer value of 16.86 cm², *Baphia nitida (uhie)* showed the titer value of 16.36 cm², *Baphia nitida (odo)* had a titer value of 16.43 cm², and *Rothmannia whitfieldii* was not suitable for this titration as it maintained green colour in both acidic and basic media. This result indicated that *Lawsonia inermis* dye compared favorably with phenolphthalein while *Baphia nitida (uhie)* compared favorably with methyl orange and *Baphia nitida (odo)* compared favorably with methyl red, but in Table 1.2, at concentration of 0.5 M HCl against 0.1 M NaOH, the flower extracts under investigation are comparable to methyl orange, methyl red and phenolphthalein.

In Table 1.5, weak acid against strong base titration, (1.0 M acetic acid against 0.5 M NaOH), the result revealed methyl orange with average titre value of 17.10 cm², methyl red with 16.33 cm² and phenolphthalein with 15.76 cm², while *Lawsonia inermis* had average titre value of 15.33 cm², *Baphia nitida (uhie)* had a titre value of 15.16 cm² and *Baphia nitida (odo)* had a titre value of 15.23 cm². *Rothmannia whitfieldii* remains unsuitable in this titration. From this result, *Lawsonia inermis*, *Baphia nitida (uhie)* and *Baphia nitida (odo)* compared favorably with phenolphthalein than methyl orange and methyl red. From Table 1.6, the titration of 0.5 M acetic acid against 0.1 M NaOH revealed that *Baphia nitida (uhie)*, *Baphia nitida (odo)* compared favorably with phenolphthalein and methyl red. While *Lawsonia inermis* compared favorably with methyl orange. This reaction also occurred more rapidly than that of 1.0 M of acetic acid against 0.5 M of NaOH.

In strong acid against a weak base titration (Table 1.3), at concentration of 1.0 M HCl against 0.5 M of ammonium hydroxide, the evaluation showed average titre value of methyl orange at 10.36 cm², methyl red was 10.33 cm² and phenolphthalein with 10.06 cm², while *Lawsonia inermis* was 10.76 cm², *Baphia nitida (uhie)* was 3.76 cm², *Baphia nitida (odo)* was 5.16 cm² and *Rothmannia whitfieldii* maintained this same color in both acidic and basic media. Only *Lawsonia inermis* measured up with the synthetic indicators in the titration of 1.0 M HCl against 0.5 M ammonium hydroxide. The reaction of 0.5 M HCl against 0.1 M ammonium hydroxide reached equivalent point more rapidly. In weak acid against weak base titration (1.0 M acetic against 0.5 M ammonium hydroxide), methyl orange had an average titre value of 16.46 cm², methyl red had 9.86 cm² and phenolphthalein had 9.33 cm². Whereas *Baphia nitida (uhie)*, *Baphia nitida (odo)* and *Lawsonia inermis* did not have concordant titre values with the synthetic indicators. Same finding was



applicable in the titration of 0.5 M acetic acid and against 0.1 M ammonium hydroxide. Literature survey also revealed, that similar works carried out on flower of *rosa indica* and *hibiscus rosa sinensis* (Bhagat, 2008); *ipomoeabiloba* (Abbas, 2012), also suggested that flower extracts could be alternatives to standard indicators in acid to base titrations. The changes in the colors of the plant extracts when mixed with various substances with different p H levels are attributed to the presence of various phytochemicals such as; anthocyanin, betalains, chlorophyll, carotenoids and flavonoids(Kapilraj *et al.*, 2019; Zheng *et al.*, 2022)

Conclusion

In a nutshell, the result showed that the dye extracts under investigation have excellent analytical potential, as demonstrated by its application in acid based titrimetry, in which it performed best in strong acid to strong base titration with a sharp and clear colour change. The colour change was not sharp with weak acid and weak base.

The sharp contrast between their colour in acid and base made the pigment suitable for use as acid – base indicators. Out of the four plant extracts prepared, *Lawsonia inermis*, *Baphia nitida(uhie)* and *Baphia nitida (odo)* extracts can serve as suitable indicators in acid to base titrimetry involving strong acid and strong base, strong acid and weak base, weak acid and strong base. These plant materials are readily available and the extraction procedure is simple. The excellent performance, precise and accurate results of these extracts in acid – base titrimetry make the extracts ideal replacement for presently available synthetic indicators. Thus, the use of natural indicators in acid – base titration are more beneficial because it's economical, pollution free, inert, easy to prepare, readily available and gives accurate results.

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THE LIBRARIAN: INFORMATION MANAGER FOR ENDOGENOUS DEVELOPMENT: MICHAEL OKPARA UNIVERSITY OF AGRICULTURE EXAMPLE

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Abstract

Librarians play a crucial role as information managers in fostering endogenous development by facilitating access to knowledge, preserving indigenous resources, and promoting research and innovation. This study examines the role of librarians in supporting endogenous development at Michael Okpara University of Agriculture, Umudike. Using a case study approach, the research explores how librarians manage and disseminate information to enhance agricultural research, local knowledge preservation, and community engagement. The study highlights the significance of librarians in curating and organizing indigenous knowledge, ensuring its accessibility to researchers, policymakers, and students. It also discusses the adoption of digital tools in managing agricultural databases, open-access resources, and institutional repositories that support self-sustaining development. Findings reveal that librarians serve as knowledge mediators, bridging the gap between global information sources and local development needs. Challenges such as inadequate funding, limited digital infrastructure, and low awareness of the importance of information management were identified. The study recommends improved funding, capacity-building programs, and technological advancements to enhance library services. Ultimately, this research underscores the librarian's role in driving sustainable development through effective information management, thereby contributing to agricultural innovation and national growth.

Keywords, librarian, information manger, endogenous, development.

Introduction

Every discipline has local content relevance. The essence of education is to acquire knowledge to solve human need locally within the immediate environment or community as well as the society at large. Endogenous means something produced, originating or growing from within. Education must be home grown and library has a singular mission which is information provision for human need. Every education institution has library whose mission is to provide information materials relevant to the education curriculum.

Every development is driven by information or knowledge. Decision, plans, policies, inventions, innovations, ideas stem from information or knowledge. Development simply means making something bigger, better and more satisfying. Information makes it achievable and Librarians are readily available to serve the literate and non-literate with information that will help them be productive and achieve their goals in life. Hence Library has types namely: Special, Public,



National, Academic and School. Each has specific audience that it serves. Information need, determines the type of library the information seeker will go to in order to get the appropriate or relevant information that answers or provides solution to the information seeker's need. It is obvious that libraries are indispensable education resources, literate and non-literate enjoy endogenous relevance of libraries cum librarians.

Education in Nigeria is endogenously crafted as presented in National Policy on Education starting from the maiden edition of 1977 to the current 6th edition of 2013. The philosophy states that the "education maximizes the creative potentials and skills of individual for self-fulfillment and general development of the society". The goals of education in Nigeria include: "total integration of the individual into the immediate community, the society and the world." The specific goals of education in Nigeria include: promotion of functional education for skill acquisition, job creation and poverty reduction".

The philosophy and goals are clearly endogenous. Nigeria citizens need to be educated for their individual and community development and this of course will impact the society at large. The Nigeria philosophy of education recognizes the importance of library for this education to be achievable. Hence it made provision for school library, reading clubs, community libraries and academic libraries. Every citizen has library provision made in the Nigerian philosophy of education cum National Policy on Education as to get relevant information for development.

Librarians being professionals trained through the discipline librarianship are the only qualified personal for information management to meet the information need of the citizens. Information is power is an axiom but getting the right, current and relevant information for one's need is the most important secret for any development to be achievable.

Endogenous approach to librarianship in Nigeria

The earliest library schools in Nigeria were established on this thrust – that is meeting Nigeria/Africa needs. This is evidence in Saleh (2011) cited by Onyenachi and Akidi (2016) thus:

Library schools in Nigeria began based on Lancour (1958) and Sharr (1963) reports on library needs of West Africa and Northern Nigeria respectively. The First two library schools in Nigeria were Institute of Librarianship at the University College Ibadan in 1959 after the UNESCO seminar



that was organized in 1953 at the University College Ibadan (now University of Ibadan; and Ahmadu Bello University Zaria in 1968 respectively”)

Librarianship: Core to Information Provision for Human Fulfillment .

The library services and uses expatiated by Onyenachi *et al.* (2024) make clear that librarianship being an indispensable discipline and profession that fulfills educational essence in every society addresses information need of the people every time in all environment. Hence it is a dynamic field for information provision and dissemination of knowledge (information management) for human sustainable development starting from local needs as well as library and information science. It is like vehicle that carries the changes in the society from the point of origination to the point of application for individual and society consumption for sustainable development. By implication, every information one gains are for a purpose which is application to meet need. Hence information gained, if not put to use (applied) is total waste. Library and information's thrust is to make information available to information seekers for them to meet their need. The Librarian is the person that serves every information seeker the relevant information through which the seeker gains knowledge which he applies to meet his need.

No change from the local to the world at large can exclude librarianship cum librarian because information makes, keep and sustains man. Hence, Onyenachi and Akidi (2016) maintain that the discipline whose singular responsibility is information service cannot be relegated anywhere and at any time by any individual or society.

The curriculum for the training of the personnel is vested with every readiness for change because the thrust cum worth of the profession is meeting the information need of the people for endogenous development and beyond. The course content covers areas such as: information delivery through oral, print and non-print (electronic) media; rural information delivery (extension services); entrepreneurship; translation services; research methods with emphasis on traditional information management systems and community attitudes; buttressing the relevance of endogenous education cum information,

Olajide (2013) points out that education the world over is considered a strong weapon for change, bedrock of national development and an instrument for national reconstruction. In educational institutions, libraries are established, manned by librarians to serve information seekers with relevant knowledge which they utilize and gain knowledge to meet needs. According to Okoro and



Aurobi (2011) relevant education curriculum fulfill triplication of education which are; individualization, localization and globalization. They explain this to mean that Nigeria curriculum must be based on local values, sustainable global knowledge and technology to support the development of the community and individuals as local citizens. The outcomes of this curriculum is that Nigeria education will develop a local person, an individual that will be relevant locally and of course, globally.

Okoro and Afurobi maintain that the relevance of education is relevance to culture of the community it serves. They equally posited that “relevant curriculum is that curriculum hat endows its learners with appropriate knowledge, skill and attitude which enables them harness resources (material and human) in order to improve their quality of life and their environment.

Disco (1997) in Onyenachi and Akidi (2016) sharing same view over the need to serve the entire citizens with relevant information for sustainable development says “the ultimate education is the public” the public here means members of the community in general who have varying interest, background, psychology, and capabilities. He clarifies that many of such human traits are culturally determined and therefore librarianship cum librarian, despite the universal application of the service delivery, should address the specific cultural situations (endogenous). Hence, the content, orientation and application should be dictated by the socio-cultural environment in which the immediate community will benefit.

Library and Information Science Graduates (Librarians) of Michael Okpara University of Agriculture Umudike (MOUAU) as Endogenous Information Manage in Agriculture.

According to Ononogbo (2014), the Library and Information Science Department of MOUAU started in November 2012. The bold initiative secured for this university a place in the annals of history as the first agriculture-based university to successfully establish a library school and mount a degree programme in Library and Information Science (LIS). This makes the Department a pioneer of a kind. The National Universities Commission (NUC) in early 2011, gave the Federal Universities of Agriculture approval to start programme outside agriculture and agriculture-related fields.

Agriculture ideally is endogenous discipline, Library and Information Science is endogenous too as the philosophy that established it in Nigeria in 1959. University College Ibadan (Now University of Ibadan) and Ahmadu Bellow University Zaria 1968 clearly stated the Bachelor’s degree offered in



Library and Information Science MOUAAU, being a programme offered in an agriculture-based university, the curriculum has a sprinkling of courses to reflect the institution's mission of boosting agricultural productivity.

Graduates of this programme (Librarians) are trained to supply the expertise/support for agriculture-based researches, as well as disseminate latest research findings to end users of agriculture-based information. In order to give vent to this inter-disciplinary approach to the training of LIS professionals (Librarians) students, in addition to core library and information science, they take up agricultural courses such as Agronomy, Plant Health Management, Plant Science and Biotechnology and Zoology and Environmental Biology.

Among the objectives of library and information programme in MOUAAU is to "raise generations of professionals who will be well equipped to serve as information and knowledge providers (managers) to reinforce the efforts of national researches/researchers in agricultural, science and technology in the attainment of national goals and policies" (Ononogbo, 2014). The librarians, managing information either as employed personnel in an organization, or self-employed (entrepreneur) they are equipped in overall mission of boosting agricultural productivity and turning various aspects of agriculture into big and lucrative businesses. The librarians would supply the expertise in support of agriculture-based researches as well as disseminate latest research findings to end-users of agriculture-based information, too wit, processing industries, produce market operators, rural farmers and other agricultural based information seekers are beneficiaries.

Conclusion

No society can exist without endogenous knowledge. This endogenous knowledge makes librarians managers and disseminators of information for the development of human philosophy and education. It is highly essential. Libraries play a role in making resources available for both literate and non-literate of the society, thereby contributing to the goals and development of education in general.

Recommendations

- The library as an institution should be promoted to serve and disseminate information to various users.



- The librarians should be trained in such a way to facilitate knowledge dissemination in oral, print and non-print (electronic, media; rural information management system)
- Nigeria education policy and curriculum should be designed to accommodate local values, suitable global knowledge and technology to support the development of the community and individuals s local citizens.

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EFFECT OF STRESS ON COGNITIVE PERFORMANCE

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Abstract

This paper provides detailed information about the effects of stressors on cognitive performance, which is an important area of research. It also discusses the exposure to and significance of stressors, the availability of stress mediators, and the behavioral, physical, and psychological effects of stress. The body's long-term stress hormone, cortisol, has been shown to adversely impact immunological, cognitive, and reproductive systems in addition to being essential for initiating a prompt and effective stress response. The level of stress, its cause, and its length have all been found to be important variables in defining the cognitive impacts of stress. To identify the impacts of stress, it is also necessary to consider the specific cognitive operations (such as implicit or explicit memory, long-term or working memory, goal-directed learning, or habit learning) and information processing stages (such as learning, consolidation, and retrieval). Stress has a variety of effects on cognition, operating more slowly through glucocorticoids and more quickly through catecholamines. Whereas glucocorticoids biphasically modify synaptic plasticity over hours and also induce longer-term changes in dendritic structure that endure for weeks, catecholamines operate through beta adrenergic receptors and also affect the availability of glucose. Long-term stress causes neuronal loss, especially in the hippocampal region. Contrary to the theory that stress-induced catecholamine effects on emotionally charged memories involve structures like the amygdala, recent research indicates that glucocorticoid and stress-related cognitive impairments involving declarative memory are likely related to changes they effect in the hippocampus. The unidimensional inverted-U hypothesis has been a widely adopted method for explaining the relationship.

Introduction

The term "stress" was originally used in the engineering field to describe the real physical strain applied to a structure and to illustrate the ratio of applied force on a material to the cross-section area over which the applied force is acting. It wasn't until 1936 that Selye expanded the definition of stress beyond the engineering field to include living things (Selye H., 1998). After exposing a rat to a stressor, he observed a typical syndrome that was unrelated to any physical damage. Based on this, he proposed that three independent elements are associated with any given stressor, which are the brief alert reaction, the lengthier resistance stage, and the weariness that results from the adrenal cortex shrinking and the glucocorticoid level falling below normal (Selye H., 1998). The World Health Organization defines stress as a normal human reaction that encourages us to deal with threats and difficulties in our surroundings and our lives. Stress can be defined as a condition of anxiety or mental strain brought on by a challenging or constrained circumstance (WHO, 2023).



Temporary stress typically has no or little effect on our physical or mental health, but prolonged exposure can hurt our well-being and make it difficult for anyone to unwind. It can also cause a wide range of emotions, such as irritability and anxiety. Excessive levels of stress can also impair our cognitive function and make it harder for us to focus. (WHO, 2023). The mental activity or process that occurs in the brain when information is gathered through sense, thought, and experience is referred to as cognition, according to the Cambridge Dictionary, it also defines cognition as the mental processes connected to the intake and storage of information, as well as how the information can be used to direct our daily behavior. These processes include thinking, attention, learning, language, perception, and memory. Memory is more than just a means of absorbing and storing information from our immediate surroundings; it also depends on factors like the context in which information is presented, our prior experiences, and our blood sugar levels. Even a tiny amount of stress could negatively impact several areas of cognition and change memory information. Some of these effects may be linked to reversible changes in the morphology of hippocampal neurons, according to recent research. One area of the brain specifically intended for memory and learning is the hippocampus (Bryce *et al.*, 2018). In addition, prolonged stress exposure can impair hippocampus neurons irreversibly and impair cognitive function in older people. According to a prior (McEwen *et al.*, 1995), the endocrine mediators of stress respond in a way that makes the impact on hippocampal function and cognition clear. Physical and psychological stressors cause the sympathetic nervous system to release the catecholamines norepinephrine and adrenaline, and the adrenal gland to release glucocorticoids. The ratio of these neuromodulators' secretions varies depending on the degree of stress exposure. The first wave responses to stress were represented by the catecholamines part and the glucocorticoid part of the responses. One of the most important and useful mechanisms that humans possess is the ability to respond to stress (Ross *et al.*, 2020). Short-term responses to stress are governed by hormones; when norepinephrine and adrenaline are released, the body dilates its blood vessels, inhibits digestion, increases heart rate, and turns off functions that are not necessary for escaping the danger. Long-term stress is caused by the steroid hormone cortisol, which is released to activate glucose and shut off additional energy-wasting biological processes.

The broad term "cognition" refers to a range of activities that work with information and modify brain representations to elicit an appropriate response. According to Keeler *et al.*, (2011), they include a variety of memory, language, executive control, perceptual, and attention processes.



Research on the effects of stress on cognitive function is not confined to any one discipline; rather, it encompasses a variety of fields, from animal neuroscience to perceptual psychology. The relationship between a person's level of stress or stress arousal and their capacity to perform cognitive tasks can be thought of as a U-shaped relationship, and the Yerkes-Dodson law has limited predictive power because it is improbable that different stressors will impact cognitive function through the same nonspecific intervening state (Calabrese *et al.*, 2008). The law just illustrates the connection between stress and cognitive function in terms of content. According to empirical studies on the impact of stress on cognitive function, stressors seem to lead to changes in attentional focus, lapses in attention, and a slowing down of decision-making processes (Liu *et al.*, 2020). However, recent research suggests that physiological fluctuations in glucose availability also influence cognition. Finch *et al.*, (1997). Published a paper showing that glucose improves memory task performance in Alzheimer's patients. Catecholamines mediate the delivery of oxygen and, more importantly, glucose to the brain, which has an effect on memory.

This paper reviews the ways in which stress impacts cognitive performance in various domains of work and life. Our daily activities expose us to a variety of stressors, such as those found in the workplace, classroom, industrial, and academic environments. Our bodies are not designed to withstand prolonged stress or situations that are extremely stressful, and all forms of stress are detrimental to our health. For example, prolonged exposure to high cortisol levels can completely impair certain bodily systems that are essential for critical functions, which can result in major issues like anxiety, depression, memory and concentration issues.

Origin of stress

The origins of social stress can be traced back to a variety of social contexts, including cultures and social structures. Social stress arises from two main situations: the occurrence of a discrete event and the existence of difficulties that are relatively constant. Most life events also result in stress because humans are inherently intolerant of change. Any modification to an organism's environment or any component of it is thought to throw other parts of the organism out of balance, which then forces the other parts of the organism to readjust (Sarah, 2020)

This causes the organisms to become extremely susceptible to stress and its negative effects on the body and mind. The organisms strive to regain equilibrium, and the process of readjustment can be taxing and wearisome (Selye 1956; Cannon 1935). According to Chrousos (2009), the two main



focuses of stressful events experience the fundamental factor that drives stress in all living organisms. As a result, the influence of homeostasis as an event does not always impact stress upon people directly. Instead, it exerts the stress effects via a wider context of life strains. According to some researchers, life events are a primary cause of stress. Understanding the mechanism linking events and stress is crucial. Events themselves do not always directly impact stress; instead, they often exert their effects through broader life circumstances known as life strains. Thus, stress has two main focuses: significant events and ongoing chronic strains, which can intersect to produce stress. This interaction was first explored by Brown and Harris, 1978, who observed that life events could contribute to the onset of depression. They proposed that the negative implications of life problems are mediated through life events. This theory connects stress to both life events and ongoing strains. Another perspective, suggested by Pearlin and Lieberman, 1979, suggests that life events can either introduce new strains or intensify existing ones, leading to heightened stress levels.

Self-perception in relation to stress

Mastery and self-esteem are two major components of self-concept that are strongly linked to stress (Rajiv *et al.*, 2022). Self-worth judgments are the foundation of self-esteem, whereas mastery refers to the extent to which people feel in control of the forces affecting their lives. Individuals primarily want to safeguard and improve their sense of self. One of the most important things that causes stress in life is living through poisonous conditions. Chronic stress can accentuate one's perceived shortcomings and lack of accomplishment, exacerbating the sense of helplessness in the face of adversity (Elizabeth, 2023). This susceptibility might be the last stop on the road to stress, resulting in low self-esteem and a feeling of lost control.

Measuring the level of stress that individuals encounter cannot be based just on the severity of stressors, such as life events, ongoing role pressures, or a lowered sense of self. People frequently react differently to situations that cause stress in terms of their behaviors, perceptions, and cognitive processes, which can either help or worsen problems. The stress process is significantly influenced by these coping strategies and viewpoints, or mediators. Individuals can activate them to protect themselves (Dariotis *et al.*, 2022). Two common categories of mediators are coping mechanisms and social support. Coping methods have a direct impact on how stresses are managed, whereas social support is reaching out to and using people, groups, or organizations to deal with life's obstacles. One may argue that social support is less important in affecting the stress experience than coping techniques. Events in life can cause people's roles to shift, which over time erodes preferred



components of their self-concept and increases stress. It is essential to comprehend how stresses affect cognitive functions on its own.

U law model of stress and cognitive function

It has been determined by several studies that people who experience optimal or moderate levels of stress operate at their best cognitively (Angelidis *et al.*, 2019). The Yerkes-Dodson law is a well-known notion that stemmed from mouse tests carried out in 1908 by Yerkes and Dodson. According to the law, as work difficulty increases, the optimal stress or arousal level drops. This theory has its origins in Hebb's earlier research, which found an inverse U-shaped association between performance and arousal. Plotting such curves usually involves comparing task performance metrics, such as correct response frequency, with parameters such as noise level, electric shock strength, or hormone and neurotransmitter dosages (Shalev *et al.*, 2022).

These metrics and how they affect work efficiency are referred to together as arousal, stress, or anxiety. Different forms of stimuli can have distinct effects on cognitive performance, which is explained by the Yerkes-Dodson law, which postulates that arousal or stress affects stimuli and cognitive function differently across various organisms (Ann, 2020). Nonetheless, the law is frequently applied in a descriptive manner to summarise the link that has been found between measurements of cognitive performance and dangerous or demanding stimuli. It does not mean that one stress or arousal mechanism controls all connections. The Yerkes-Dodson law, according to some researchers, oversimplifies the relationship between stressors and cognitive function, particularly in the context of complex cognitive tasks like eyewitness recollection. They underline that these interactions are more complex than an inverted U curve alone would imply, depending on the particular cognitive performance measure employed as well as the stressor's relevance to the task. The applicability of the law has been contested, but it still poses significant concerns concerning why and how organisms respond differently to stressful or difficult stimuli in terms of performance (Strong *et al.*, 2020). The remaining sections of this essay will examine various mechanisms by which stressors are thought to either improve or worsen cognitive performance.

Stress level



Stress might be at an acute or low operational level. Being watchful, awake, and displaying conditional awareness is referred to be a low operational level of stress, and it is experienced by people in professions that require alertness, such as law enforcement and the military. An emergency situation, impending danger, a high alert state, and a circumstance involving life support can all induce acute stress. (Lewinki *et al.*, 2016)

Effect of stress and glucocorticoid on learning

Human learning and memory are inhibited by high glucocorticoid levels, as demonstrated by numerous recent research. Stress has a powerful ability to alter cognition, especially memory. The brain and adrenal glands jointly release the stress hormone glucocorticoids, which pass through the blood-brain barrier. These hormones have both fast non-genomic effects and slower genomic effects because of their strong affinity for mineralocorticoid receptors and weaker affinity for glucocorticoid receptors (Karat *et al.*, 2005). Catecholamines are also indirectly delivered into the brain through systemic stimulation of the locus coeruleus and solitary tract.

The conscious or deliberate recall of previously learned information is a component of declarative memory, commonly referred to as hippocampal-dependent memory. Acquisition, Consolidation, and Retrieval are its three primary phases. Research on how neuroendocrine stress responses impact cognition has been spurred by the notable presence of glucocorticoids in the limbic system, a region of the brain linked to behavioral and emotional reactions. Depending on when stress occurs in relation to the acquisition, consolidation, and retrieval phases of declarative memory, different effects are shown on cognition. According to research by Andreano and Cahill (2006), glucocorticoid medication or psychological physical stress around the acquisition phase can improve memory in both people and animals later. Stress has a known impact on previously consolidated material in people and animals (Buchanan *et al.*, 2006). Stress and glucocorticoid release often improve memory function throughout the acquisition and consolidation phases but lose some of their effects during the retrieval phase (Luipen *et al.*, 2007).

Hormones and neurotransmitters from two interrelated psychoneuroendocrine systems are thought to be responsible for the impact of stress on cognitive function. Research shows that several modulatory factors unique to each type of memory determine how stress affects cognitive function. Cortisol's impact on cognition also changes with concentration; elevated cortisol levels have the



ability to influence cognitive performance. According to Suor *et al.*, (2015), prolonged exposure to high cortisol levels has a deleterious effect on neurocognitive functioning and general mental wellbeing.

With a molecular weight of roughly 362 Daltons, cortisol is a tiny, lipophilic steroid. The adrenal gland secretes it into the bloodstream, where 90% of the cortisol that is in circulation attaches to globulin, a particular carrier protein with a strong affinity for cortisol. A lesser percentage attaches to erythrocytes and albumin, while the unbound fraction acts on target tissues by binding to intracellular glucocorticoid receptors (Kirschbaum and Hellhammer, 1994; Mendel *et al.*, 1989). Evidence, however, points to the possibility that cortisol attached to carrier proteins may also have some biological activity (Hammond, 1995). In some tissues, bound cortisol can be released from carrier proteins via specific cell membrane mechanisms.

Unbound cortisol is liposoluble, which makes it easy for it to diffuse through the blood-brain barrier and into nucleated cells via passive diffusion (de Kloet *et al.*, 2005; Pardridge *et al.*, 1979). Cortisol primes the organism's attentional resources and context-dependent memory, influencing mood and cognitive performance. Stress management, adaptation, and recuperation are supported by cortisol's suppressive actions. Anti-inflammatory and immunosuppressive actions are primary methods that guard against bodily harm from defense mechanism overshoot. Additionally, cortisol suppresses activities (such as growth and reproductive function) that are not necessary to meet the demands of the stressor. At low doses, cortisol has a permissive influence. Excessive cortisol levels, such as those that occur after stress exposure, can have suppressive effects. Munck and Narayfejestoth (1992) found that low affinity GRs mostly moderate suppressive acts, while high affinity MRs significantly moderate permissive actions. Several of the immediate consequences of cortisol is crucial for survival, but prolonged exposure to high levels of cortisol can be harmful. The endocrine system has negative feedback mechanisms that regulate cortisol levels by inhibiting its release. Circulating cortisol exerts an inhibitory effect on the hypothalamus and pituitary gland, reducing the release of corticotrophin-releasing hormone, arginine vasopressin, and adrenocorticotrophic hormone. Additional feedback control is mediated through hippocampal structures affecting the hypothalamus (Jacobson & Sapolsky, 1991). Animal models suggest that cortisol's impact on cognitive performance is influenced by the ratio of mineralocorticoid receptors to glucocorticoid saturation (de Kloet *et al.*, 1999). This theory aligns with the Yerkes-Dodson law, which describes an inverted U-shaped relationship between arousal and memory. It proposes that cognitive performance



improves when a high proportion of mineralocorticoid receptors and a low proportion of glucocorticoid receptors are occupied. Conversely, cognitive performance declines with significant changes in glucocorticoid receptor activity, as each receptor type operates at different but complementary stages of cognitive processing.

Research by Oitzl and de Kloet (1999) indicates that mineralocorticoid receptors are involved in attention and vigilance, while glucocorticoids are essential for memory consolidation. Studies on glucocorticoid removal and replacement support the hypothesis that the mineralocorticoid-to-glucocorticoid ratio affects cognitive performance under conditions of pharmacologically altered glucocorticoid levels. Stress-induced shifts in brain activity modulate cognitive performance (Schwabe *et al.*, 2012). Human and animal studies have shown that consistent glucocorticoid and sympathetic activation of the basolateral amygdala are necessary for cognitive modulation (Abercrombie *et al.*, 2006; de Quervain *et al.*, 2007). The effect of glucocorticoids on memory modulation occurs via noradrenergic activation of the basolateral amygdala, which is stimulated by the nucleus tractus solitarius or locus coeruleus. Human evidence suggests that the effects of glucocorticoids on consolidation and retrieval are especially pronounced for emotionally arousing stimuli (Kuhlmann *et al.*, 2005; Smeets *et al.*, 2009), and that memory modulation effects are diminished in non-arousing environments (Kuhlmann & Wolf, 2006). Concurrent glucocorticoid and noradrenergic activity is crucial for this process. Activity is considered to switch the brain into a state that prioritises consolidation at the expense of other memory processes (Roozendaal *et al.*, 2008; Roozendaal *et al.*, 2004). During this 'memory formation mode' cognitive functions such as attention, encoding, and consolidation of events relevant to the under stress, the brain prioritizes immediate stress responses while suppressing other cognitive functions such as memory retrieval and working memory (Schwabe *et al.*, 2012). Lupien *et al.* (2002) found that impaired declarative memory due to glucocorticoid depletion could be restored with glucocorticoid replacement. A study using hydrocortisone infusion demonstrated a dose-response, U-shaped relationship with impaired working memory. Additional evidence from psychosocial stress studies indicates that significant elevations in cortisol impair cognitive performance, while low levels of cortisol can either have no effect or enhance performance (Schoofs, Wolf, & Smeets, 2009; Andreano & Cahill, 2006). The mineralocorticoid receptors/glucocorticoids ratio hypothesis suggests that cognitive performance under stress is influenced by the time of day relative to the glucocorticoid circadian rhythm. Cortisol elevations in the morning, when glucocorticoid levels peak, should impair performance



more than elevations in the afternoon trough. A review of studies administering pharmacological glucocorticoids supports this hypothesis (Het *et al.*, 2005). Exposure to psychosocial stress has been shown to impair performance in the morning but not in the afternoon (Maheu *et al.*, 2005). However, this evidence is primarily related to declarative memory, and other studies have reported impaired performance in the afternoon and modulation of cognitive performance independent of the time of day (Smeets, 2011).

Explicit Memory Originally,

The effects of long-term stress on memory, specifically hippocampal-related memory tasks, have been well researched for more than 20 years. Early studies (McEwen *et al.*, 2001) demonstrated significant alterations in hippocampus morphology because of chronic stress, which served as the impetus for our study. The shape of the hippocampus is altered by chronic stress, and the length of stress exposure is a key factor in determining how it impacts explicit memory. Studies on rats have indicated that chronic stress lasting three to six weeks causes deficits, although stress lasting ten to thirteen days straight can enhance spatial learning on tasks like the Morris water maze and the radial arm maze (Gouirand *et al.*, 2005).

The length of stress exposure affects how chronic stress affects hippocampus anatomy and spatial memory. The influence of chronic stress on explicit memory in healthy individuals is not well-documented, mainly because repeated stress exposure of people in experimental investigations is fraught with ethical issues (Lupien *et al.*, 2007). Indirect evidence for this role comes from the observation that people with low self-esteem—a characteristic associated with elevated stress reactivity—have smaller hippocampus volumes (Pruessne *et al.*, 2005). Furthermore, Lupien *et al.*, (2007), discovered a negative correlation between hippocampus volume and explicit memory task performance in older persons with elevated plasma cortisol levels over time. Furthermore, a recent study by Aisen *et al.*, (2000), found a link between the rate of chronic stress exposure and glucocorticoid levels and a decline in neuropathology and cognition in people with Alzheimer's disease. The data gathered from research on neuropsychiatric disorders associated with stress have confirmed in hard form the connection between cumulative stress exposure and a decline in hippocampus function in humans. Therefore, stress exposure amount can essentially have an impact on hippocampus function reduction.

Implicit Memory



Chronic stress promotes fear conditioning, and concurrent morphological data in the basolateral and medial amygdala demonstrate that stress produces synaptic remodeling, spinogenesis, and increased dendritic branching in addition to heightened anxiety (Sandi *et al.*, 2001). (Roozendaal and others, 2009). Crucially, elevated anxiety-like behavior is only brought on by chronic stress regimens that promote dendritic atrophy in the basolateral amygdala. This illustrates the specificity of stress-induced enhancement of fear conditioning to cognitive domains. High levels of acute stress are often compared to chronic stress in terms of how they affect different learning forms: implicit memory is strengthened while explicit memory is weakened. This is significant since the processes triggered by acute and chronic stress are quite different, as per Chaouloff *et al.*, (2011). Acute stress is primarily influenced by glutamatergic systems, whereas chronic stress involves a wider variety of substances, such as other neurotransmitters, signal transduction pathways, neurotrophic factors, and epigenetic modulators (Sandi *et al.*, 2011). One molecule connected to the behavioral effects of chronic stress is neural cell adhesion molecule (NCAM), a glycoprotein implicated in cell-cell contact and activity-dependent synaptic rearrangements.

Methodology to investigate effect of stress on cognitive function

In the quest to understand stress processes, one of the most challenging issues is defining and measuring stress itself (Epel *et al.*, 2018). Stress is a broad term encompassing various manifestations, leading to significant conceptual ambiguity. The confusion largely arises from disagreements on what outcomes can be considered the "real" manifestation of stress. Generally, stress is understood as an organism's response to conditions perceived as harmful, either consciously or unconsciously (Britannica, 2024). However, there is less consensus on where this response is most evident: in a single cell, an organ, the entire organism, or across biochemical, physiological, or emotional functions. It could be manifested in systems like the endocrine, immune, or cardiovascular systems, or in particular physical and psychological diseases. The methods used in research heavily influence the observed manifestations of stress. For example, household sample surveys often rely on verbal reports. Consequently, these surveys are limited to signs of stress that people are aware of and cannot include unconscious signs or those requiring complex and costly laboratory assays (Epel *et al.*, 2018). Surveys also focus on naturalistic stress antecedents rather than those that can be artificially manipulated. Additionally, researchers must decide whether to treat stress as a situational state or a global trait. Job stress, for example, can be considered distinct from marital stress, and both differ from a global condition of the organism that remains constant

across various social roles and situations. An established experimental methodology has been used to examine the short-term effects of stress on cognitive function; this strategy is depicted in the picture below.

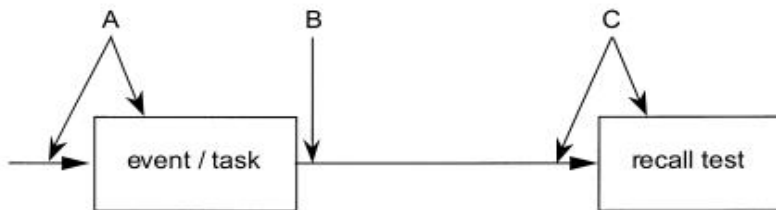


Figure 1: Illustrating experimental effect of stressor on cognitive performance

The figure illustrates three scenarios: (A) a stressor is imposed just before or during an event or task, (B) a stressor is imposed after an event or task, and (C) a stressor is imposed before or during the recall of an event or task, or any combination of these scenarios. Performance on the original task or recall test is used to gauge the stressor's influence. Using a recall test to gauge performance after a stressor is applied at point A is a typical experimental design. Although this approach tells us how certain stimuli affects learning and memory, it is unable to identify the different underlying mechanisms causing these effects (Bronbey, 2021). By introducing stressors during a task (point A) and monitoring attention shifts, the effects of stressors on attention are investigated. By delivering stressors at point B and assessing recall performance, the effect of stressors on memory consolidation following an event is examined. Stressors are presented at point C, and memory performance is assessed in order to examine the consequences on recall ability.

Heat Stress

An environmental chamber with temperatures varying from 26 to 50°C was used to manage heat in numerous research (Cramer *et al.*, 2022). The impact of heat on attention and processing speed activities varied. While metrics like accuracy or the frequency of accurate detections tended to decrease in comparison to temperate settings, reaction times frequently improved or stayed unchanged under moderate heat stress. A rise in the performer's arousal level correlated with an increase in ambient or core body temperature, which enhanced performance. But as the temperature rose above a certain threshold, performance started to deteriorate as the heat and arousal levels increased Based on Provins. Compared to less stimulating jobs like easy mental tasks, tasks that



require more mental energy, such dual tasks, and exhibit performance declines at lower temperatures (Matteo *et al.*, 2024). According to recent studies, heat depletes attentional resources by competing for them and eventually impairing performance.

Factor influencing performance in the heat

It's critical to pinpoint the different elements influencing the range of conclusions on the impacts of heat stress. The complexity of the activity appears to be a significant effect, as more complicated tasks like tracking, multitasking, and attentiveness appear to be more susceptible to heat stress than simpler tasks like mental transformations and reaction times (Kendra, 2023). Individual skill level is another important element. Hancock argues that highly competent operators are more resilient to heat stress because they have developed automated methods for doing tasks that they have overlearned, which keeps the connection between stimuli and reactions intact even in stressful situations. Longer exposures typically result in declines in cognitive performance in stressful circumstances, therefore exposure duration also matters. Even so, brief exposures—up to eighteen minutes—have been associated with better performance when doing two tasks at once. Although the relationship between gender variations in heat stress and cognitive function has not received as much research, Wyon *et al.* imply that women may be able to withstand heat stress better when performing activities involving short-term memory. Furthermore, it has been discovered that incentives can momentarily lessen the consequences of heat stress. Research indicates that in comparison to low incentive situations, greater incentives—such as surpassing goal scores, sharing findings, and verbally encouraging someone—improve performance under heat conditions. The long-term viability of these effects in regular working environments is still unknown, though. Differing results are sometimes a result of methodological variations throughout studies (Reed *et al.*, 2021). For example, exposure to temperatures as high as 90°F (32.2°C) did not affect performance in cognitively demanding vigilance tasks when individuals could work in pairs and self-regulate work/rest times. By allowing participants to take breaks during heat exposure, this intermittent task performance helped to lessen the negative impacts of heat stress on vigilance performance.

Impact of heat stress on cognitive performance

Numerous scientists have attempted to provide a methodical explanation for how heat affects cognitive function. There are now two primary tendencies that are not mutually exclusive (Xin, 2021). The first tendency is that the sort of cognitive work being performed determines how heat



affects cognitive performance. Wing's exponential curve, which defined a thermal tolerance limit without making a distinction between work kinds, was used in an early attempt in the US to create a heat stress norm for unimpaired mental function. Subsequent attempts, however, have distinguished clearly depending on the type of activity in order to define exposure limits or delineate the effects of thermal stress on cognitive performance. It has been discovered that tasks requiring less attention are less susceptible to heat stress than tasks requiring more attention.

The pursuit of a connection between the effects of heat stress and deep body temperature is the second trend. In reference to vigilance performance, Hancock contended that the performer's thermos physiological state is the primary predictor of performance. Hancock identified three fundamental thermal states of the human body that characterize operator efficiency in hot conditions after reevaluating numerous studies (Hancock, 2020)

1. **Dynamic state:** The deep body temperature rises over the normative comfort threshold because of the applied thermal stress. Under this condition, heat gradually builds up in the body and eventually causes a breakdown in performance.
2. **Hyperthermic state:** There is evidence to imply that when a person has a consistent increased body temperature, their effectiveness as a watchkeeper increases.
3. **Stable state:** Vigilance performance is not impacted since the external thermal load is not high enough to raise deep body temperature. 29.4°C (85°F) is the maximum ambience exposure level that causes no change in deep body temperature. Lind's upper bounds for the "prescriptive zone" and the "thermal equilibration zone" accord with this.

According to Pitts *et al.*, (2023), no comparable attempts have been made to link the performer's thermos physiological condition with other categories of cognitive activities, such as dual tasks, basic mental tasks, and more complicated cognitive tasks.

Stress Effects on Different Memory Contribution

Stress has been shown to affect how various memory systems contribute to cognitive function, according to some researchers. When significant amounts of stress are experienced, task performance tends to change from flexible cognitive operations to more inflexible methods or habit memory (Knauff *et al.*, 2021). This pattern has been seen after acute and long-term stress exposure in both humans and animals. Early research on acute stress showed that exposure to a powerful



stressor before learning can change learning processes (e.g., in a modified Morris water maze). Under stressful conditions, rats that had been trained to locate a hidden, cued platform exhibited a preference for a stimulus-response approach, exploring the new cue position, while control rats employed a spatial strategy, concentrating on the previous platform location. There is evidence linking the switch from spatial to stimulus-response memory systems to the amygdala and glucocorticoids (Kim *et al.*, 2019). Human psychosocial stressors were used in additional studies to establish that stress prior to learning favors basic stimulus-response learning mechanisms over more sophisticated, spatial learning strategies. This was expanded to include operant or instrumental learning techniques as well. According to Smeets *et al.*, (2023), human participants trained under stress shown insensitivity to changes in the value of food outcomes when compared to control settings. This suggests that acute stress results in habitual performance rather than goal-directed conduct. These results are corroborated by functional neuroimaging data, which demonstrates that stress inhibits the hippocampus-dependent system's ability to function, allowing the striatum to regulate behavior. Persistent stress also affects the regular transition between cognitive processes. Chronic stress causes a change in cognitive function from spatial to stimulus-response learning techniques, according to evidence from both humans and mice. The notion that chronic stress affects decision-making processes is supported by behavioral and morphological data from a noteworthy study conducted in rats (Jacqueline *et al.*, 2023). Chronic stress made rats resistant to changes in action-outcome linkages and insensitive to changes in outcome value, which affected their capacity to make decisions based on the consequences of their actions. Stress in different situations can cause opposing structural changes in the associative and sensorimotor corticostriatal circuits that support these different behavioral responses. These alterations show up as atrophy in the medial prefrontal cortex and hypertrophy in the sensorimotor striatum. The scientists state that after extended stress, the relative advantages of circuits passing via the sensorimotor striatum (Liu *et al.*, 2020). Extended periods of stress lead to bias in behavioral strategies for learned responses. Recent studies have demonstrated similar effects in people. For example, a study evaluating medical students' behavioral and cerebral reactions to instrumental tasks during test periods found that prolonged stress briefly biases decision-making approaches toward habits and changes brain activation from associative to sensorimotor networks. Atherosclerosis in the medial prefrontal cortex and caudate corresponded with these functional changes. Stress affects people differently when it comes to impaired working memory. Working memory can be affected by stress in different ways depending on a person's resilience, past stressful experiences, and genetic susceptibility



(Cahill *et al.*, 2022). These elements may contribute to an increased ability for certain people to manage stress and sustain working memory function. For example, a 2019 study by Shields *et al.*, (2019), discovered that under acute stress settings, those with higher resilience—characterized by superior stress coping methods and social support—exhibited reduced working memory impairment. This suggests that resilience can protect memory from the damaging effects of stress.

Working Memory

Stress has been shown to impair working memory, which is responsible for temporarily holding and manipulating information. It is also a cognitive system responsible for temporarily holding information necessary for complex tasks such as reasoning, learning, and comprehension. It is a critical function for daily activities and higher cognitive processes. Stress, particularly acute stress, can significantly impact working memory performance. Research indicates that acute stress can lead to a decrease in working memory performance, primarily due to the stress-induced activation of the hypothalamic-pituitary-adrenal (HPA) axis and the subsequent release of cortisol. For instance, a study by Shields *et al.*, (2020). Found that individuals exposed to acute stress showed significant impairments in tasks requiring working memory, particularly in maintaining and manipulating information. The mechanisms underlying stress-induced memory impairment involve the interaction between stress hormones and neural activity in the prefrontal cortex. Cortisol can affect synaptic plasticity, the ability of synapses to strengthen or weaken over time, which is crucial for working memory. High levels of cortisol can disrupt synaptic plasticity, leading to impaired neural connectivity and function in the prefrontal cortex (Qin *et al.*, 2019). Additionally, stress-induced changes in neurotransmitter systems, such as dopamine, can also impair working memory. Dopamine plays a vital role in modulating working memory processes in the prefrontal cortex. Acute stress can alter dopamine levels, leading to suboptimal functioning of the prefrontal cortex and resulting in working memory deficits (Arnsten, 2019).

Acute Stress and Working Memory

Acute stress, characterized by a rapid onset and short duration, can have immediate and detrimental effects on working memory. This cognitive function, which is crucial for temporarily holding and manipulating information, is highly sensitive to the physiological and psychological changes induced by acute stress. When a person experiences acute stress, the body's stress response activates the hypothalamic-pituitary-adrenal (HPA) axis, leading to the release of cortisol and other stress

hormones. These hormones can impair working memory by disrupting the prefrontal cortex, a brain region essential for working memory functions. Cortisol, a glucocorticoid hormone, plays a pivotal role in the stress response. Elevated cortisol levels can affect synaptic plasticity, which is essential for working memory. Synaptic plasticity involves the strengthening or weakening of synapses, the connections between neurons, which underpins learning and memory. High cortisol levels can disrupt synaptic plasticity in the prefrontal cortex (PFC), a brain region critical for working memory. For instance, Qin et al. (2019) found that acute stress reduced working memory-related activity in the dorsolateral PFC, a key area involved in executive functions and cognitive control. Catecholamines, including adrenaline and noradrenaline, are also released during acute stress and can affect the PFC. These neurotransmitters modulate neural connectivity and signal transmission. Arnsten (2019) explains that high levels of catecholamines can shift the balance from PFC-mediated 'top-down' cognitive control to more primitive 'bottom-up' responses mediated by subcortical structures. This shift can impair the PFC's ability to maintain and manipulate information, thus compromising working memory. Acute stress-induced anxiety can increase cognitive load, the amount of mental effort required to process information. When cognitive load is high, the limited capacity of working memory is overwhelmed, making it difficult to focus and process new information. Schoofs *et al.*, (2019) reported that participants under acute stress showed higher anxiety levels, which were associated with poorer performance on working memory tasks. The anxiety likely diverted cognitive resources away from the task, impairing performance. Can also affect attention, a key component of working memory. Stressful stimuli can capture attention and cause distraction, reducing the ability to maintain focus on the task at hand. Shields *et al.*, (2019) found that acute stress impaired participants' ability to filter out irrelevant information, leading to increased distractibility and reduced working memory performance. This suggests that stress can interfere with attentional control, a crucial aspect of working memory function. Research by Schoofs *et al.*, (2019) demonstrated that acute stress impairs working memory performance. In their study, participants subjected to a stressful situation showed decreased performance on tasks requiring working memory compared to a control group. The impairment was attributed to elevated cortisol levels interfering with the prefrontal cortex's ability to maintain and manipulate information.

Chronic Stress and Working Memory

Chronic stress, which involves prolonged exposure to stressors, can have more lasting effects on working memory. Prolonged stress exposure can lead to sustained high levels of cortisol, which can



cause structural changes in the brain. Chronic stress is associated with dendritic atrophy in the prefrontal cortex, reducing the complexity and connectivity of neurons, which is critical for maintaining working memory functions (Holmes & Wellman, 2019).

A study by Liston *et al.*, (2019) showed that individuals experiencing chronic stress had reduced prefrontal cortex volume and impaired working memory performance. These structural changes were linked to long-term exposure to elevated cortisol levels, suggesting that chronic stress can lead to lasting impairments in working memory. The effects of chronic stress on working memory are mediated through structural and functional changes in the brain, particularly in areas like the prefrontal cortex (PFC) and the hippocampus. The PFC, which is crucial for working memory, executive functions, and decision-making, is highly susceptible to the effects of chronic stress. Chronic stress can cause dendritic atrophy in the PFC, leading to a reduction in the complexity and connectivity of neurons. This structural deterioration impairs the PFC's ability to support working memory functions. Holmes and Wellman (2019) noted that chronic stress induces changes in dendritic architecture, reducing synaptic density in the PFC, which compromises cognitive processes including working memory. The hippocampus, another critical area for memory processes, is also affected by chronic stress. Chronic exposure to stress hormones, particularly cortisol, can lead to hippocampal atrophy. This reduction in hippocampal volume can impair the encoding and retrieval processes essential for working memory. Kim and Diamond (2019) reported that chronic stress results in significant hippocampal shrinkage, which correlates with deficits in working memory performance. Chronic stress leads to significant structural changes in the brain, which directly impact working memory, it does not only cause structural changes but also leads to functional impairments and alterations in neurotransmitter systems that are vital for working memory. Prolonged exposure to high levels of cortisol disrupts synaptic plasticity, the ability of synapses to strengthen or weaken over time, which is essential for learning and memory. Elevated cortisol levels can impair long-term potentiation (LTP) in the PFC and hippocampus, both of which are critical for working memory. Research by Liston *et al.*, (2019) demonstrated that chronic stress impairs LTP, leading to deficits in synaptic plasticity and, consequently, working memory. Dopamine is a key neurotransmitter involved in working memory processes in the PFC. Chronic stress can alter dopamine signalling, leading to suboptimal functioning of the PFC. Arnsten (2019) explained that chronic stress dysregulates dopamine levels in the PFC, impairing cognitive functions such as working memory and executive control. This dysregulation reduces the efficiency



of neural circuits necessary for maintaining and manipulating information. Longitudinal and experimental studies shows that where chronic stress is induced in controlled settings also support these findings. For example, Gärtner *et al.*, (2019) exposed animals to chronic stress paradigms and observed significant impairments in working memory tasks, such as maze navigation and object recognition tasks. These experimental results underscore the direct impact of chronic stress on working memory and overall cognitive health. While the Longitudinal studies tracking individuals over time have shown that those exposed to high levels of chronic stress perform worse on working memory tasks. For instance, Vedhara *et al.*, (2019) conducted a study where participants experiencing chronic occupational stress exhibited significant impairments in working memory tasks compared to those with lower stress levels. The findings highlighted the cumulative detrimental effect of chronic stress on cognitive performance. A study by Slavich and Irwin (2020) found that inflammation mediates the relationship between chronic stress and cognitive deficits, including impairments in working memory.

Declarative Memory

Declarative memory, which includes both episodic and semantic memory, is particularly susceptible to the effects of stress. Acute stress has been found to disrupt the encoding of new declarative memories. A study by Vogel and Schwabe (2020) demonstrated that participants under stress had poorer recall of a list of words compared to non-stressed participants, suggesting that stress hampers the ability to form new declarative memories. Additionally, stress can impair the retrieval of episodic memories, which are personal experiences tied to specific times and places. The mechanisms through which stress affects declarative memory are complex and involve multiple neural pathways. The hippocampus and prefrontal cortex play crucial roles in memory processing, and both regions are sensitive to the effects of stress hormones. Cortisol can alter synaptic plasticity, the process by which connections between neurons are strengthened or weakened, which is essential for learning and memory (Marin *et al.*, 2019). High cortisol levels can disrupt synaptic plasticity in the hippocampus, leading to impaired memory formation and retrieval. Furthermore, stress can influence the amygdala, a brain region involved in emotional processing, which can interact with the hippocampus and prefrontal cortex to modulate memory processes. Under stress, the amygdala's increased activity can enhance the consolidation of emotional aspects of memories while potentially impairing the detailed and contextual aspects that are crucial for declarative memory (Roosendaal *et al.*, 2019).



Impact of Acute and Chronic Stress on Declarative Memory

Acute stress can profoundly affect the encoding and retrieval of declarative memories. During stressful situations, the body's immediate response involves the release of stress hormones such as cortisol and adrenaline. These hormones can influence brain function and memory processes. Research by Wolf (2019) indicates that acute stress, especially if it occurs close to the time of learning, can impair the encoding of new declarative memories. This impairment is thought to be due to the rapid increase in cortisol levels, which can affect the hippocampus' ability to process and store new information. Moreover, acute stress has been found to impair the retrieval of previously learned information. An experiment by Gagnon and Wagner (2019) showed that participants subjected to acute stress had reduced recall accuracy for a list of previously studied words compared to a non-stressed control group. This suggests that stress hormones interfere with the neural mechanisms involved in memory retrieval. Acute stress has been shown to impair the encoding of new declarative memories. When an individual experiences acute stress, the body's immediate response involves the activation of the hypothalamic-pituitary-adrenal (HPA) axis, leading to a surge in cortisol levels. Elevated cortisol can interfere with the hippocampus's ability to encode new information effectively. For instance, Shields *et al.*, (2019) conducted a study where participants exposed to a stressor prior to a learning task showed reduced ability to encode and recall new information compared to those who were not stressed. This suggests that the high cortisol levels associated with acute stress can impair the initial encoding process, making it harder to form new declarative memories. The retrieval of declarative memories is also adversely affected by acute stress. Acute stress can disrupt the retrieval process by altering the function of the prefrontal cortex and hippocampus. A study by Smeets *et al.*, (2019) demonstrated that participants who were subjected to acute stress showed decreased performance in recalling previously learned information. The stress-induced cortisol release was found to impair the neural mechanisms involved in the retrieval process, leading to reduced recall accuracy. This indicates that acute stress can hinder the ability to access stored declarative memories. The impact of acute stress on declarative memory can also be context dependent. The timing of the stressor relative to the learning and retrieval phases plays a crucial role. For instance, Joëls *et al.*, (2019) found that stress experienced immediately before or after learning can impair memory encoding, whereas stress experienced during the consolidation phase (shortly after learning) can sometimes enhance memory consolidation, particularly for emotionally charged memories. This suggests that the timing of stress



exposure relative to the memory process can result in different outcomes, with stress potentially enhancing or impairing memory based on when it occurs. The underlying neural mechanisms for these effects involve the interaction between stress hormones and brain regions critical for memory. Acute stress triggers the release of glucocorticoids (like cortisol) and catecholamines (like adrenaline), which affect the hippocampus and prefrontal cortex. These hormones can alter synaptic plasticity, the process by which neurons form and strengthen connections, which is essential for memory encoding and retrieval (Henckens *et al.*, 2019). High levels of cortisol can impair synaptic plasticity in the hippocampus, leading to difficulties in forming and recalling declarative memories. Chronic stress, characterized by prolonged exposure to stressors, can have even more detrimental effects on declarative memory. The persistent elevation of cortisol levels associated with chronic stress can lead to structural changes in the brain. The hippocampus, in particular, is vulnerable to the adverse effects of chronic stress, which can lead to atrophy and a reduction in its volume (Lupien *et al.*, 2019). These structural changes are associated with long-term impairments in both the formation and retrieval of declarative memories. For example, individuals experiencing chronic stress may have difficulties forming new episodic memories, which are memories of specific events or experiences. A study by Schwabe and Tegenthoff (2019) found that participants with high levels of chronic stress performed worse on tasks requiring the formation of new episodic memories compared to those with lower stress levels. Additionally, the retrieval of existing episodic memories can be impaired under chronic stress conditions. Studies have shown that chronic stress can lead to increased inflammation, which negatively affects cognitive function. Inflammation can disrupt communication between neurons and contribute to cognitive decline.

Spatial Memory

Spatial memory, which allows us to navigate and understand the environment, can also be impaired by stress. The hippocampus, which plays a crucial role in spatial memory, is highly sensitive to stress hormones. Research by Kim *et al.*, (2020) indicates that stress can lead to deficits in spatial memory performance, making it harder for individuals to remember and navigate spaces effectively. Spatial memory, a cognitive process that enables individuals to remember the locations of objects, navigate their environment, and understand spatial relationships, is vital for daily functioning. This type of memory is predominantly associated with the hippocampus, a brain region that is highly sensitive to stress. Chronic stress can significantly impair spatial memory through various



mechanisms, including structural and functional changes in the brain, alterations in neurotransmitter systems, and increased inflammation. The hippocampus plays a crucial role in the formation and retrieval of spatial memory. Chronic stress can lead to atrophy of the hippocampus, thereby impairing its function. Prolonged exposure to stress hormones, particularly glucocorticoids like cortisol, has been shown to cause dendritic retraction and reduce neurogenesis in the hippocampus. A study by Kim *et al.* (2019) demonstrated that chronic stress resulted in a reduction of hippocampal volume and a subsequent decline in spatial memory performance in both humans and animal models. While the hippocampus is the primary brain region involved in spatial memory, the prefrontal cortex (PFC) also plays a supportive role by integrating spatial information and coordinating complex cognitive tasks. Chronic stress can impair PFC function through dendritic atrophy and reduced synaptic plasticity. Holmes and Wellman (2019) reported that chronic stress leads to structural changes in the PFC, which can indirectly affect spatial memory by disrupting the integration of spatial information with other cognitive processes. Chronic stress leads to sustained high levels of cortisol, which can disrupt synaptic plasticity, the ability of synapses to strengthen or weaken over time. Synaptic plasticity is crucial for learning and memory, including spatial memory. Elevated cortisol levels impair long-term potentiation (LTP) in the hippocampus, a process essential for memory formation. Liston *et al.*, (2019) demonstrated that chronic stress impairs LTP, leading to deficits in synaptic plasticity and spatial memory. Glutamate is a key neurotransmitter involved in synaptic plasticity and memory processes. Chronic stress can lead to dysregulation of glutamate transmission, resulting in excitotoxicity and neuronal damage. Popoli *et al.*, (2019) found that chronic stress alters glutamate signalling pathways, contributing to impaired synaptic plasticity and spatial memory deficits.

Effects of ELS on cognition (early life stress)

Cognitive performance was also affected by early life stress (ELS). ELS showed distinct impacts on processing speed across depressed and non-depressed individuals when evaluated comprehensively using the overall ELSQ score. We propose that these variations are due to different long-term stress adaptations that are linked to either susceptibility to or resistance to depression in later life. On the other hand, the impact of predicted ELS exposure on working memory and processing speed was unrelated to diagnosis. Long-term emotional and sexual abuse exposure has also been associated with reduced cognitive speed. Our results did not support earlier research (Polak *et al.*, 2012;



Brewin, 2014) linking ELS to worse performance in episodic memory or executive function. It's possible that differences in sample populations or assessment methods are to blame for the disparity between our findings and earlier study (Parks & Balon, 1995) that connected ELS with episodic and semantic memory deficits. We used Benton Visual Retention and Rey's Verbal Learning Tests in addition to the word-cueing approach and the Logical Memory test (Parks & Balon, 1995) used in past studies. There can be an obvious inverted U-shaped curve in the connection between ELS and processing speed. According to this model, exposure to stress in a broad sense is associated with faster processing speed, while more severe (and potentially long-lasting) ELS results in worse performance and a higher risk of depression. This is consistent with research on older individuals that links heightened processing speed to childhood stress (Feeney *et al.*, 2013). Milder stressors may improve processing speed and promote resilience in our non-depressed population (Wu *et al* 2013). On the other hand, those who are predisposed to depression could already have circuit dysfunction, a condition in which even little stress impairs cognitive function because of altered neurobiology. Working memory may exhibit a similar pattern, constant across diagnostic categories, with a link evident only with significant predicted stresses. According to other studies, childhood stress negatively affects working memory (Navalta *et al.*, 2006). This may be because stress-sensitive systems operate differently as a result of increasing allostatic load, which also negatively affects working memory (Evans & Schamberg, 2009).

Attention narrowing

Studies on human stress and lifestyle have shown some evidence that generic, non-specific stresses, such loud noises, might cause people to focus or restrict their attention to important aspects of a job. This was shown, for example, by assessing attention in various settings and discovering that the effect varied according to the type of stimulating stimuli. It has also been demonstrated that frightening challenges lead attention to narrow. Memory studies provide credence to this effect, especially when stress or emotional arousal are present. According to research on eyewitness memory, for instance, great emotional arousal may lead to a better recollection for peripheral details but a more accurate recall of the event's main aspects. The central details of an emotional story (a son visiting his surgeon father at work) were easier for participants to recall than the background details of a neutral story (a son visiting his mechanic father at work), as demonstrated by Reisberg and Heuer's (1995) research. The idea of "flashbulb" memory, on the other hand, which refers to the vivid recall of unexpected or significant occurrences together with their supporting elements, casts



doubt on the straightforward attention-narrowing theory. While attention narrowing can improve performance when concentrated attention is required, it can also cause mistakes when contextual clues are crucial (Easterbrook, 1959). As a result, events may be remembered clearly, but supporting facts may be overlooked, making it more difficult to apply the Yerkes-Dodson law to these phenomena in an easy way (Christianson, 1992). In an effort to ascertain whether attention narrowing is the principal mechanism underlying these effects, Christianson *et al.*, (1991) carried out an experiment in which participants focused more on the focal points of an emotionally charged scene—a woman involved in a bicycle accident—than on the focal points of a neutral scene—a woman riding a bicycle. The emotional scenario was recalled more accurately even when visual fixation periods were equal, indicating that memory for emotionally charged events may be improved by both visual attention time and another mechanism. Later in the debate, it is suggested that memory consolidation may be one of these processes. Stress and anxiety can have a direct influence on cognitive function, but they can also have an indirect impact on academic achievement by having an adverse effect on mental health. Elevated stress and anxiety levels have been linked to a rise in depressive symptoms, which can worsen cognitive abilities and academic achievement (Al-Khani *et al.*, 2019). Additionally, worry and stress can interfere with sleep, which can have a detrimental effect on academic performance and cognitive function (Al-Khani *et al.*, 2019).

Physiological Basis of Stress Effects on Attention

The processes of attentional shifting and narrowing during stressful conditions can be viewed as advantageous from an evolutionary perspective. By concentrating on and looking into the cause of a threat, these adaptations help animals make the most use of the few resources they have. Therefore, unless the danger is closely tied to the activity, performance on ongoing activities may suffer. Conventional physiological stress responses, such as the hypothalamic-pituitary-adrenal (HPA) axis response (Selye, 1976), are generally viewed as adaptive since they mobilize the organism's energy reserves in anticipation of danger. It is crucial to take into account whether these physiological reactions aid in the organization of adaptive cognitive responses, including attention shifting and narrowing. Though the findings are complicated and occasionally contradictory, a great deal of study has been done on the effects of hormones produced during the HPA response to stresses on general arousal and attention-like activities. Adrenocorticotrophic hormone (ACTH) and corticotrophin-releasing factors (CRF) are two examples of hormones that may affect attention. Fehm and Born (1987), for instance, showed that intravenous CRF infusions improved people'



focused selective attention to one of two audio stimuli. On the other hand, in sustained concentration activities, additional research suggests that ACTH decreases attentional lapses (Kovacs & de Wied, 1994). Nonetheless, it has also been demonstrated that ACTH counteracts the effects of CRF by defocusing auditory attention (Molle *et al* 1997). Humans' capacity to distinguish between important and irrelevant information is discovered to be hampered by cortisol, another hormone from the HPA axis (Kopel *et al.*, 1970; McEwen, 1982). These results demonstrate that there is a complex and nonlinear relationship between physiological processes and cognitive performance.

Decision Speed

Under stress, attention can shrink and change, causing one to make poor judgments or overly focused information. Stressful situations can increase response speed, causing decisions to be made before all relevant information has been processed. This trade-off between speed and accuracy is exemplified in a study where subjects performing a computerised multiple-choice analogies test under the threat of a painful electric shock made faster decisions with more errors compared to controls (Keinan, 1987). Animal studies have also shown this phenomenon, with prey selectivity decreasing under time constraint and compromising the ability to distinguish between profitable and less profitable food items (Lucas, 1985; Barnard & Hurst, 1987; Plowright & Shettleworth, 1991).

Perceived time or internal clock speed tends to run faster under high arousal conditions, such as with methamphetamine injection, slight elevations in body temperature, and elevated heart rate (Maricq *et al.*, 1981; Killeen & Fetterman, 1989; Wearden & Penton-Voak, 1995). Consequently, decisions may be made faster under high arousal conditions, though whether this directly influences decision-making speed requires further research. The concept of state-dependent memory, extensively studied in human psychology, suggests that memory recall of a specific event can be enhanced when contextual cues present during recall match those present during the initial experience. Environmental cues directly related to the event, or its surroundings are particularly effective in enhancing recall, as attention during the experience tends to focus on these elements rather than on peripheral details. Additionally, internal cues such as the individual's mood or emotional state at the time of learning can also significantly impact memory recall, with studies showing better retention when there is a congruence between the mood at learning and at recall (Bower, 1981).



Stressors introduced prior to a recall test may enhance memory recall of stressful events through a state-dependent mechanism akin to the one described above. The accuracy of recall is likely optimized when the stress state is highly specific to the event or when environmental cues are present during both the stressful event and the recall. Animal studies have demonstrated that stress hormones administered before a retention test can improve memory recall. For instance, Izquierdo (1984) showed that β -endorphin administered before a retention test mitigated the amnesic effects caused by β -endorphin administered post-training. This suggests that the pre-retention test administration of β -endorphin recreated an internal state induced by the earlier post-training treatment, thereby aiding memory recall.

While plausible, understanding precisely how stressors influence memory during or before retention tests remains challenging. The idea that certain stress hormones, like ACTH, may generally facilitate memory retrieval (Riccio & Concannon, 1981) raises questions about how specific memories are selected for recall. Contextual cues likely play a crucial role in memory specificity during recall. Moreover, stressors might enhance performance in tasks requiring memory retention through their effects on activity levels or attention. Conversely, the impairment of recall by stressors might explain findings of retroactive interference in memory when stressors are applied during the retention interval.

Conclusion

One widely accepted theory to explain the connection between stress and cognitive performance is the unidimensional inverted-U hypothesis. According to recent studies, modest stress can improve cognitive function, especially when low cognitive demands are present, or implicit memory tasks are involved. On the other hand, prolonged or high levels of stress improve performance in implicit memory and practiced activities, which are associated with the amygdala and striatum, but hinder the creation of explicit memories and complicated thinking, which usually involves the hippocampus and prefrontal cortex. Individual variations in gender and age also have a major impact on the cognitive effects of stress. This study investigates the relationship between stressor exposure, stress mediators, and the behavioral, physiological, and psychological reactions to stress on cognitive function. The long-term stress hormone cortisol can have detrimental effects on the immune system, cognitive abilities, and reproductive health, yet it is necessary for a healthy stress response. Stress's intensity, source, duration, the particular cognitive functions it affects (e.g., working memory, implicit memory, long-term memory, goal-directed learning, habitual learning),



and the information processing stages it goes through (e.g., learning, consolidation, retrieval) all have an impact on the cognitive effects of stress. Stress affects cognition through rapid catecholamine actions and slower glucocorticoid effects. Catecholamines involve beta-adrenergic receptors and glucose availability, while glucocorticoids modulate synaptic plasticity and cause long-term changes in dendritic structures. Prolonged stress exposure leads to neuron loss, particularly in the hippocampus. Recent evidence suggests that glucocorticoid-related cognitive impairments in declarative memory are linked to hippocampal changes, while catecholamine effects on emotionally charged memories involve the amygdala.

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INTERCONNECTEDNESS OF ENDOGENOUS TECHNOLOGY AND FOREIGN LANGUAGES IN MOUAAU FOR SUSTAINABLE DEVELOPMENT

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Abstract

This paper explores the intricate relationships among art, science, foreign languages, and endogenous technology within the context of Michael Okpara University of Agriculture, Umudike (MOUAAU). It demonstrates how these domains collectively shape cultural and technological advancements in the university environment. Art serves as an expressive medium that integrates scientific principles, foreign languages facilitate knowledge transfer, and endogenous technology represents indigenous innovation rooted in local knowledge. The paper delves into historical and contemporary examples within MOUAAU to illustrate the dynamic interactions between these domains and their impact on societal progress. The research methodology involves comparative analysis of different cultural contexts within the university, highlighting how these fields contribute to societal progress. Based on these findings, recommendations were made. In conclusion, Foreign Language educators are encouraged to identify the most significant factors of readiness, devise techniques that will stir interest and creativity for foreign language learners on scientific advancements at MOUAAU which form the backbone of technological progress, influencing both modern and indigenous systems.

Keywords: Art, Science, Foreign Language, Endogenous Technology, Indigenous Knowledge

Introduction

The evolution of human civilization has been significantly influenced by the synergy of art, science, language, and technology. In earlier times, in the absence of technology, “nature” was the laboratory of scientists like Plato, Aristotle, Michelangelo, and da Vinci. The study and observation of the world around them, often referred to as “nature”, or “the natural world,” was their source of inspiration, truth, and wisdom. These information were passed through using this laboratory. Plato and Aristotle laid the foundations for much of modern physics and mathematics, as well as more “artistic fields,” such as aesthetics, ethics, and political science. Leonardo da Vinci was a painter and sculptor, but was also an engineer, inventor, and anatomist. Michelangelo was also a painter and sculptor, as well as a poet, but also an engineer, anatomist, and architect (Bruner, 1991).

According to Ocholla (2011), “indigenous knowledge systems are an integral part of communicative arts and endogenous technology,” highlighting the importance of incorporating local knowledge and practices into development initiatives. Ocholla's work emphasizes the need to



recognize and value indigenous knowledge, rather than relying solely on Western approaches. This perspective is supported by research in the field of communicative arts, which recognizes the significance of cultural context in shaping communication practices (Tufte, 2001). By exploring the intersection of indigenous knowledge and communicative arts, researchers can gain a deeper understanding of the complex relationships between culture, technology, and development. This understanding can inform the development of more effective and sustainable approaches to communication and technology development.

Art provides a means of creative expression and cultural preservation, science offers systematic methodologies for discovery, foreign languages act as bridges for cross-cultural communication, and endogenous technology reflects the ingenuity of scholars and students using indigenous knowledge. Adewuyi(2019). Exposure to diverse languages and cultures is a critical component of a quality education, and the benefits of language study are well documented in many essential areas: The study of language brings students into contact with people and cultures that are very different from their own, and in a way that encourages respect for diversity as seen by Lier, (2004). This exposure lowers the barriers that are often at the root of fear and distrust of others. Language education involves the structured teaching and learning of a language, encompassing its grammar, vocabulary, pronunciation and cultural context. Kazakov (2021).

Thus, the knowledge gained from language study contributes to empathy and tolerance towards diverse peoples and reduces prejudice both at home and abroad. Thus, the study foreign language not only broadens students' perspectives of the world, but also imparts a more profound understanding of their own cultures. Exposure to cultures with long histories builds a greater sense of the past within one's own culture as well. It is well known that foreign language study increases students' skills in the use of English. Often it is in the foreign language classroom that students gain the greatest understanding of grammar and expand on their vocabulary. Kramsch, (2009). Learning the linguistic roots of language further deepens these abilities. The study of foreign languages enhances listening skills and memory, increases analytical abilities, and builds aptitude in problem solving and working with abstract concepts. It has been shown to enhance the study of other subjects. Abilities in math and English increase, and creativity grows. The study of foreign language is a distinct advantage in the professional world. Job candidates who are proficient in more than one language are extremely valuable and have a competitive edge in the U.S. economy, where a large proportion of jobs involve work with immigrants and/or are the result of



trade with foreign countries. Students who have studied foreign language have more job opportunities available to them both at home and abroad, in an increasingly global society.

One of the most important aims of education is to develop, share and communicate more knowledge, skill, and ability. This is made available through communicative arts. Students of the 21st century are very different from the students of the past. This requires educators to think continuously about how to change their teaching to empower and engage modern students, which makes for educational innovation and sustainable development. Research has shown that what students learn in the arts may help them to master other subjects, such as reading, math or social studies (Kern, 2003). Students who participate in arts learning experiences often improve their achievement in other realms of learning and life. For example, an analysis of multiple studies confirms the finding that students who take music classes in high school are more likely to score higher on standardized mathematics tests (Koppa, 2006). One explanation is that musical training in rhythm emphasizes proportion, patterns, and ratios expressed as mathematical relations. The arts nurture a motivation to learn by emphasizing active engagement, disciplined and sustained attention, by persistence, and risk taking, among other competencies.

The arts which is embedded in humanities are great learning tools for students to increase their motivation according to their interests and abilities. As cited by Awosika (2021) science should not be sought without humanities. In humanities, diverse opportunities for communication are expressed effectively. This study aims at bridging the gap and identifying the interconnectedness of foreign language and endogenous technology for sustainable development.

The Role of Art in Scientific and Technological Advancements at MOUAV

Art and science have historically been intertwined, with artistic creativity inspiring scientific inquiry and vice versa. Students in Michael Okpara University of agriculture learn the age-long contributions of French citizens to the world in the development of agriculture, science and technology particularly the indigenous discoveries by French men and women

Below are some French citizens who made remarkable impact in endogenous technology and agriculture which is still resonating from one generation to another, without the collaborative role of Foreign language educators (translators/interpreters), these inventions and discovery will remain sealed and personalized to these inventors, hence language barrier will pose a limiting factor to spreading solutions to humanity globally. Some of these inventors and their inventions include Antoine Parmentier who discovered the consumption of potatoes, Nicolas Jacques Conte who



discovered the modern Pencil and Braille Louis who raised dots for the Blind (Okeke *et al.*) 2018.e.t.c.

Scientific advancements at Michael Okpara University of Agriculture Umudike (MOUAAU) form the backbone of technological progress, influencing both modern and indigenous systems as well drives innovation and cultural understanding. Developments in agricultural sciences, biotechnology, and environmental studies have revolutionized local farming practices and sustainability efforts (MOUAAU Research Bulletin, 2023). Moreover, research conducted at the University plays a crucial role in preserving and enhancing endogenous technology, as stated by Eze (2020) thereby ensuring that traditional methods are improved through systematic innovation.

Language is essential for the dissemination of scientific knowledge and artistic expression. The adoption of foreign languages, especially English and French facilitates academic exchanges, international collaborations, and access to global research (Aluko *et al.*, 2021). Students as well as willing staff engage in multilingual education to enhance cross-cultural communication, expanding opportunities for research and professional growth as cited by Nwosu *et al.* (2022).

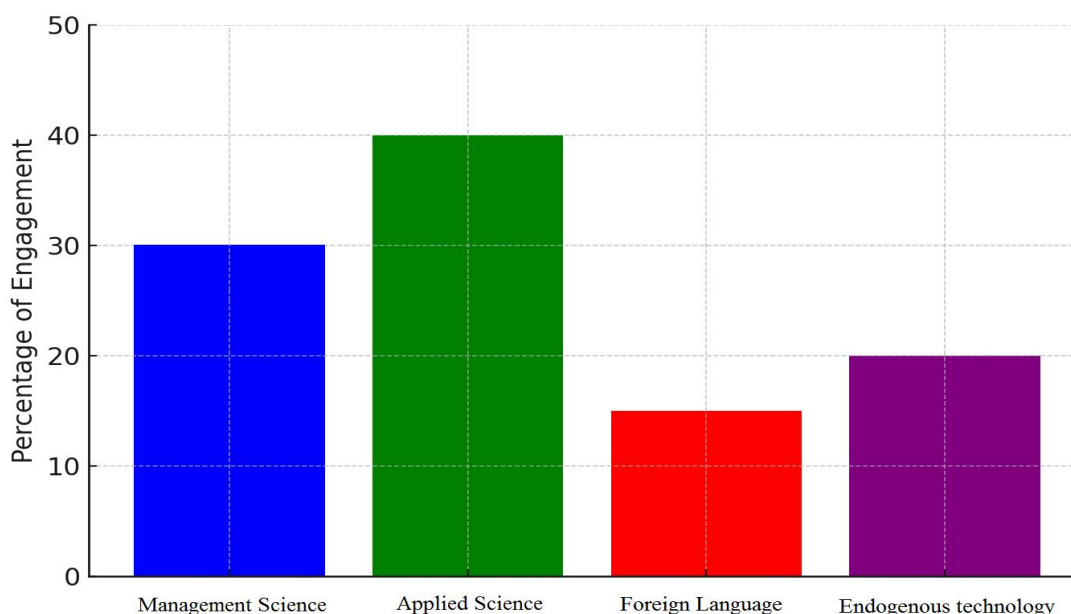
Endogenous technology refers to locally developed innovations that address agricultural, environmental, and societal challenges. Examples include indigenous soil management techniques, organic farming methods, and the adaptation of traditional food processing techniques using modern scientific principles (Ukaegbu, 2023). These technologies often integrate artistic and scientific elements, such as intricate dyeing techniques in textile production and architectural designs adapted to local climates.

Methodology

This study employs a qualitative research approach, incorporating literature review, case study analysis, and historical perspectives to examine the interplay of art, science, foreign language, and endogenous technology at MOUAAU. Data sources include academic journals, institutional reports, and credible online databases. The research methodology involves comparative analysis of different cultural contexts within the university, highlighting how these fields contribute to societal progress. Semi-structured interviews with lecturers and students were also conducted to gain insights into the integration of these fields within the academic and research environment at MOUAAU.

Results

Fig. 1.shows the percentage engagement of Art, Science, Language, and Endogenous Technology at MOUAAU.



Field study

Fig. 1: Percentage engagement of foreign language and endogenous technology

From the figure, the percentage of engagement of foreign language and endogenous technology are low having 15% and 20% percent respectively while other fields of management sciences and applied science are 30% and 40%. Integrating foreign languages and endogenous technology, provides MOUAAU students with a holistic education, preparing them to address local and global challenges and promote sustainable development.

The table below shows respondent response of the Challenges affecting new students in learning French in Michael Okpara University of Agriculture Umudike (MOUAAU)

Table 1: Challenges affecting new students in learning French

S/N	ITEMS	SA	A	D	SD	\bar{X}	STD	Remark
1	Lack of Practice opportunities	65	35	7	-	3.01	0.51	Accept
2	Fear of Speech communication	58	25	15	9	3.05	0.53	Accept
3	Loss of motivation	85	20	2	-	3.07	0.56	Accept
4	Non seriousness of student towards French language	83	18	5	1	2.56	0.42	Accept
GRAND TOTAL						2.86		Accept



Table 1 reveals that new students at Michael Okpara University of Agriculture, Umudike (MOUUAU) face significant challenges in learning French, as indicated by the grand mean of 2.86, which falls within the "Accept" range. The most prominent issues include loss of motivation ($\bar{X} = 3.07$), fear of speech communication ($\bar{X} = 3.05$), and lack of practice opportunities ($\bar{X} = 3.01$), all with relatively low standard deviations, suggesting consistent responses. Even the non-serious attitude of students towards learning French ($\bar{X} = 2.56$) was acknowledged as a valid challenge, pointing to a general consensus that these factors are key barriers to effective French language acquisition among the students.

Table 2 below shows respondents' response on the rate of student enrollment in Science, Foreign Language, and Endogenous Technology at Michael Okpara University of Agriculture Umudike (MOUUAU).

Table 2: Student Enrollment in Art, Science, Foreign Language, and Endogenous Technology at MOUUAU

Discipline	Number of Students	Percentage (%)
Art	1,200	20%
Science	2,500	42%
Foreign Language	800	14%
Endogenous Technology	1,200	24%
Total	5,700	100%

The table shows that science courses have the highest student enrollment at MOUUAU with 42%, followed by endogenous technology (24%) and art (20%), while foreign language has the lowest enrollment at 14%, which is below the 2.4 criterion mean, indicating low student interest in foreign language studies.

Table 3: Research Output in Different Fields at MOUUAU (Last 5 Years)

Field	Number of Published Papers	Research Grants Received (₦ Million)
Art	50	25
Science	120	80
Foreign Language	30	10
Endogenous	70	40



Technology		
Total	270	155

The table shows that science recorded the highest research output at MOUAAU in the last five years with 120 published papers and ₦80 million in grants, while foreign language had the lowest with 30 papers and ₦10 million, indicating minimal research activity and funding in the foreign language field.

Discussion of Findings

The findings of the study revealed that new students at MOUAAU face key challenges in learning French such as loss of motivation, fear of speech communication, lack of practice opportunities, and a lack of seriousness, all with mean scores above the 2.4 benchmark. This result aligns with the study by Okonkwo (2018), who found that language learners in Nigerian universities often struggle due to insufficient exposure and low confidence in oral communication. Similarly, Nwachukwu (2020) reported that students learning French in South-East Nigeria lacked motivation due to limited real-life use of the language and inadequate classroom interaction, supporting the findings from MOUAAU.

The result from Table 2 and Table 3, both the enrollment and research output in foreign languages were the lowest compared to other disciplines, indicating a general disinterest and low academic investment in the field. This agrees with the work of Adeyemi (2019), who observed that science and technology-related courses dominate student preferences and research funding in Nigerian universities due to better career prospects. In line with this, Ojo (2021) noted that foreign languages are often underfunded and overlooked in research policy planning, resulting in fewer publications and lower student intake. These patterns are consistent with the present findings at MOUAAU, suggesting a national trend of undervaluing foreign language education in favour of science and technology.

Challenges

Despite their interconnectedness, barriers exist in integrating art, science, foreign languages, and endogenous technology at MOUAAU. These challenges include:

- Limited funding for interdisciplinary research
- Language barriers affecting international collaborations
- Under appreciation of indigenous knowledge in favor of Western technological models



Recommendations

By integrating arts into science, students understand the inter-relatedness of everything they learn. This method of teaching and learning also promotes creativity and collaboration. And all of this leads to scientific literacy.

Fundamentally, both art and science are about encounters with the real world — the one we live in and experience as colours, textures, shapes and sounds. Every artistic creation and every scientific study is a record of experimentation.

Opportunities for policy reforms that encourage the incorporation of indigenous knowledge into scientific research and the promotion of multilingual education should be put in place in order to enhance cross-cultural communication.

Conclusion

The interplay between art, science, foreign languages, and endogenous technology is vital for cultural and technological advancement at MOUAU. By recognizing their interconnected roles, the university can leverage indigenous knowledge and modern innovations to create sustainable solutions. Encouraging interdisciplinary approaches in education, research, and policy-making will ensure that these fields continue to evolve harmoniously, fostering both cultural preservation and technological progress within MOUAU and beyond.

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SUB-THEME 2:

Endogenous Strategies and Technologies for Sustainable Waste Management in the Petroleum and other Sectors of Nigeria



PERFORMANCE EVALUATION AND TECHNOECONOMIC ASSESSMENT OF AN ORGANIC RANKINE CYCLE (ORC) SYSTEM USING SENSITIVITY ANALYSIS

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Abstract

The Organic Rankine cycle is a thermodynamic cycle that converts heat energy into work and refrigerant is used as the working fluid. However, these systems operate at comparatively low pressures on other occasions due to the network architecture and poor choice of operating parameters. These challenges can be averted through extensive modeling of these modified ORC structures with a wide range of operating evaporator pressures to augment the system efficiency and justify the start-up cost. Models were provided for energy and exergy using three different refrigerants for the four cycles, and the basic operating parameters on cost and performance were simulated using an Engineering Equation Solver (EES). The results show that the cost of the product for the turbine with refrigerants R11, R113, and R141b gave 5.149, 4.204 and 5.722 \$/hr, respectively, at 252 kW of evaporator heat input. Using corresponding turbine output in the cycle for the considered refrigerants, the cost of electricity, were it to be sold to the grid, is valued at 0.08397 \$/kWh (for R11), 0.09052 \$/kWh (for R141b), 0.08625 \$/kWh (for R113). The overall exergy efficiency and net turbine output for the GC-HX-TB configuration are best even regarding cost rate of operation.

Keywords: *Techno-economic, Exergy, Organic Rankine cycle, Refrigerant,*

Introduction

Organic Rankins cycle (ORC) is a promising low grade waste heat recovery technology (Fankam *et al.*, 2008). It is generally used when the net power output is below 2 MW (Vélez *et al.*, 2012). There are many research studies on ORC cycle efficiency improvement, such as organic working fluid selection, reduction of ORC condensing temperature, and ORC turbine design. Pei *et al.* 2010 analyzed two innovative solar ORC systems with two-stage collectors. They pointed out that the ORC efficiency could be increased by improving the heat collection efficiency provided by the two-stage solar collectors. The ORC technology is based on the Rankine cycle with high-molecular-mass organic fluid, which evaporates at significantly lower temperature and pressure than water in the classic Rankine cycle (Julijeet *et al.*, 2013). The regeneration of the Organic Rankine Cycle to



utilize the solar energy over a low temperature range using flat plate solar collectors (Wang *et al.*, 2009). The performance of solar based Organic Rankine Cycle was examined through the various working conditions such as temperature and inlet pressure of the turbine (Gao *et al.*, 2014). The performance of some working fluids under different heat source temperatures indicated that the boiling point of the working fluids has a strong influence on the system's thermal efficiency (Mago *et al.*, 2007).

Over time, its implementation has been in the basic ORC cycle which traditionally includes a pump, an evaporator (which replaces the boiler), a turbine and a condenser. The exergy flow losses of the ORC system were 159.8 kW (evaporator), 94 kW (condenser), 91 kW (expander) and 1.7 kW (pump) at an evaporation pressure of 922 kPa under an 80% M/E load with Cyclohexane but evaporator was the highest, followed by the condenser, expander and pump (Long *et al.*, 2023).

With this simple arrangement, theoretical and experimental studies have been conducted with a variety of refrigerants, different heat sources, different condensing methods, cost analysis, optimization and an avalanche of condensing and evaporating pressures (Velez *et al.*, 2012; Quoilin *et al.*, 2011; Manolakos *et al.*, 2009; Canada *et al.*, 2004; Chen *et al.*, 2010). It was observed that R602 showed excellent performance in comparison with other working fluids, such as R601 and R601a (Mahmoudan *et al.*, 2020).

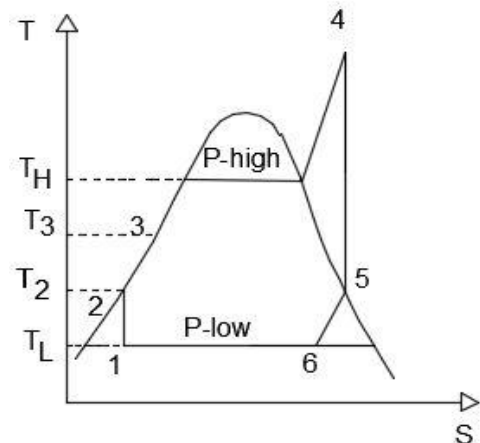
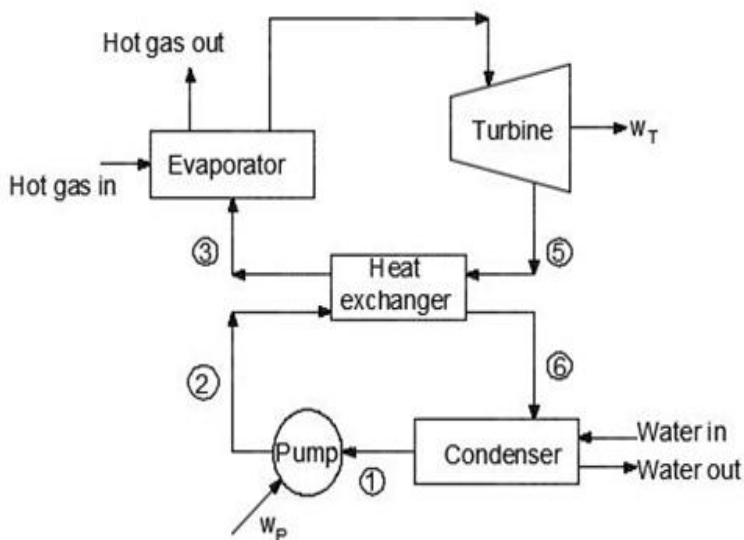
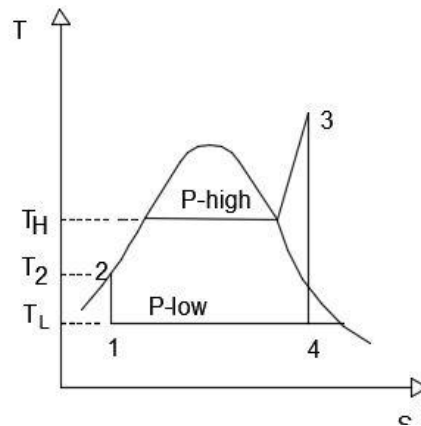
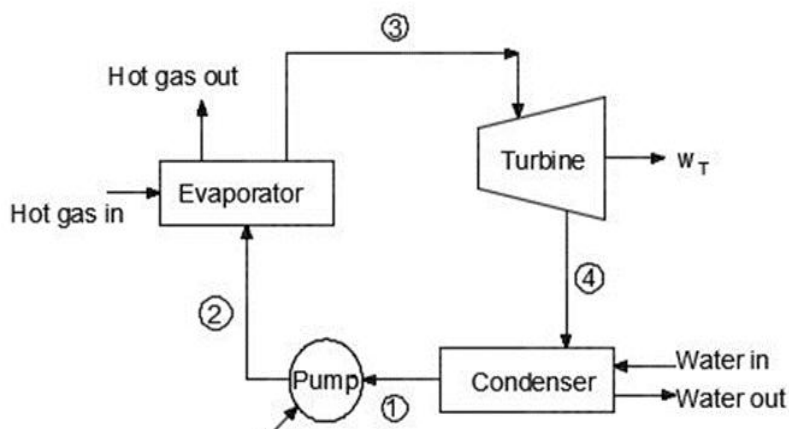
In terms of efficiency, it is desirable to operate the cycle at lower condenser pressure and lower turbine inlet pressures and components operating at low pressure will also diminish the incurred costs of making up the cycle (Jafary *et al.*, 2020). Of note is the presentation of a framework for the energy and exergy evaluation of the basic and three modified ORCs. The results showed substantive improvement in overall energy and exergy efficiencies and specific turbine work (Sahar and Fereshteh, 2015). Accordingly, the exergy analysis method for modeling modified ORCs is employed here since the modern approach to thermal process analysis employs the exergy concept, which provides a more realistic view of all thermodynamic processes. A comprehensive exergy analysis involving the degree of exergy destruction identifies the location, the magnitude and the source of thermodynamic inefficiencies in thermal systems (Saidur and Jamaluddin, 2007). This knowledge is helpful in directing the attention of process design researchers and practicing engineers to those components of the system analyzed that offer the maximum opportunities for improvement (Dincer, 2007).

Exergy analysis usually predicts the thermodynamic performance and the inefficiency of an energy system (Abamet *et al.*, 2014). While optimisation of the basic ORCs abounds in literature, there is none in the area of evaluation of the optimal operation of the modified ORCs. Consequently, the objective of this research work is the thermo-economic evaluation and exergo-sustainability analysis of modified ORCs using energetic and exergetic approaches (Uduma *et al.*, 2024).

Methodology

Modification of Organic Rankine Cycle Structures

The Organic Rankine Cycle, is a thermodynamic cycle that transforms heat energy into work and different refrigerants are used as a working fluid in this cycle. The modified ORC cycles from structure one to the heat exchanger including refrigerant bleeding with three different refrigerants (R141b, R11 and R113) and schematics structures are presented in Fig 1 as part of the materials for consideration in this research.



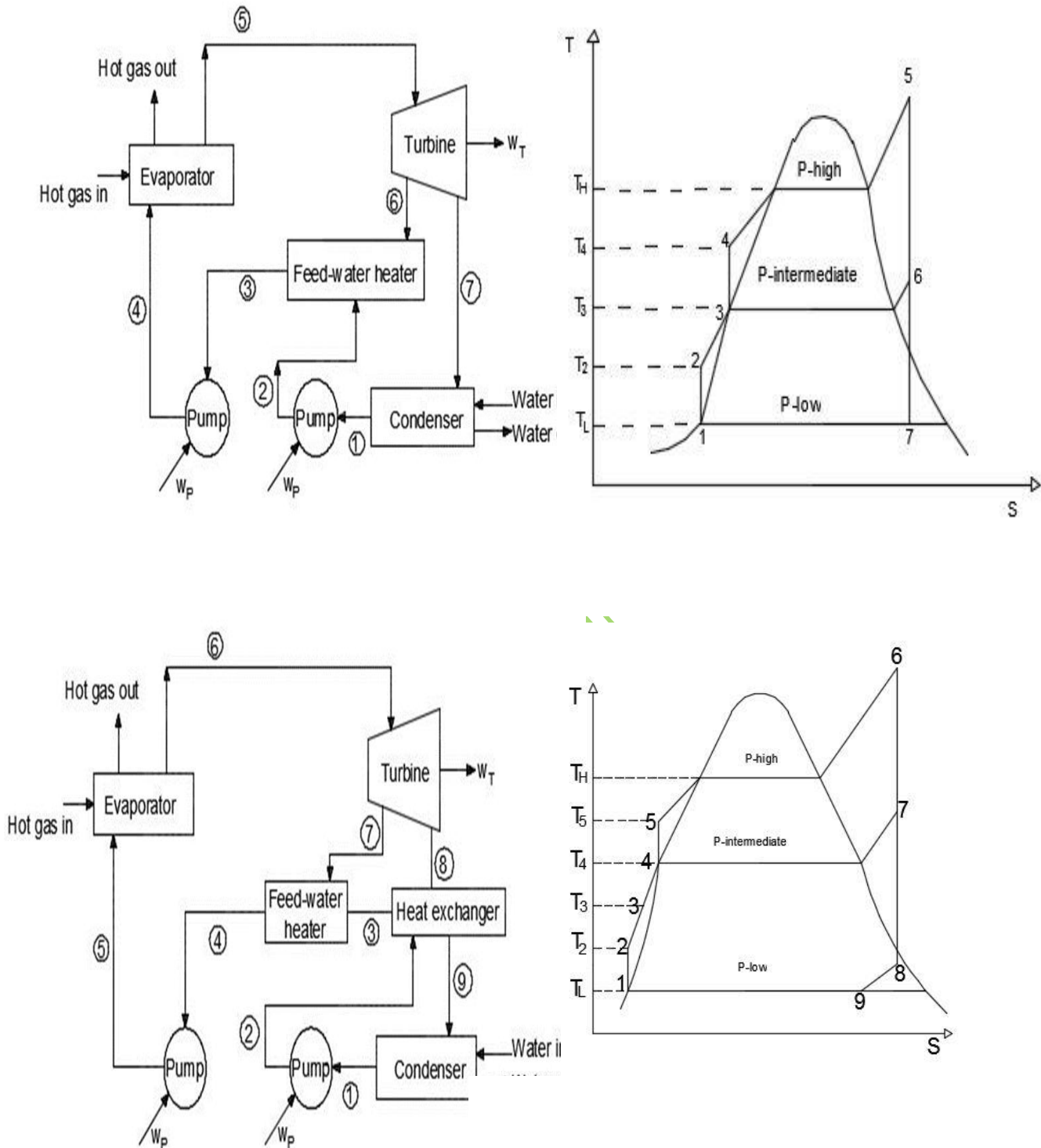


Figure 1: Schematic diagrams: (a) Basic ORC and T-S, (b) ORC with a heat exchanger and T-S, (c) ORC with feed heater and turbine bleeding and T-S, and (d) ORC with feed heater and turbine bleeding incorporated with a heat exchanger and T-S.

Exergoeconomic Analysis of the Orc System. Exergoeconomic analysis and optimization assists in the assessment of techno-economic performance on an exergy basis, and determines the cost per unit exergy of the products of a system (Bejan and Tsatsaronis, 1995). Cost rates are determined with exergy costing for each exergy transfer in the form of either matter or power or heat transfer, and these cost rates are related to the expression (Bejan and Tsatsaronis, 1995):

$$\sum_{j=1}^n [c_j \dot{E}_j]_{in} + \dot{Z} = \sum_{j=1}^m [c_j \dot{E}_j]_{out} \quad 1$$

Where c is the cost per unit exergy of each stream and $\dot{C} = c\dot{E}$. Equation 1 shows that the cost rates associated with all input exergy streams to a component as well as the cost rates associated with its capital investment and operation/maintenance must be accounted for in the cost rate of the existing product exergy streams. Details of the calculation procedure using the F-rule and P-rule are described elsewhere (Bejan and Tsatsaronis, 1995)

Cycle 1 Cost Balance Equations

Cost balances for the components of the basic ORC system are presented for the evaporator, the turbine, the condenser and the pump as follows:

$$c_{g,in} + c_2 + Z_{evap} = c_{g,out} + c_3 \quad 2$$

$$c_{w,pump} + c_1 + Z_{pump} = c_2 \quad 3$$

Four auxiliary equations are developed to effect a solution as follows:

$$ex_{g,out}c_{g,in} - ex_{g,in}c_{g,out} = 0 \quad 4$$

$$ex_{w,pump}c_{w,T} - ex_{w,T}c_{w,pump} = 0 \quad 5$$

Cycle (2) Cost Balance Equations

Cost balances for the components of the basic ORC system incorporating a heat exchanger are presented for the evaporator, the turbine, the heat exchanger, the condenser and the pump as follows:

$$c_{g,in} + c_3 + Z_{evap} = c_{g,out} + c_4 \quad 6$$

$$c_2 + c_5 + Z_{HE} = c_3 + c_6 \quad 7$$

Five auxiliary equations are developed as follows:

$$ex_{g,out}c_{g,in} - ex_{g,in}c_{g,out} = 0 \quad 8$$

$$ex_6c_5 - ex_5c_6 = 0$$

9

Cycle (3) Cost Balance Equations

Cost balances for the components of the basic ORC system incorporating turbine bleeding are presented for pump 1, the feed heater, pump 2, the evaporator, the turbine and the condenser as follows:

$$x * c_{w,PT} + c_1 + Z_{pump1} = c_2 \quad 10$$

$$c_{w,in} + c_7 + Z_{cond} = c_{w,out} + c_1 \quad 11$$

Equations 5 through to 10 form six expressions with 11 variables. Consequently, five auxiliary equations are formulated using the F- and P-rule to effect a solution as follows:

$$ex_{g,out}c_{g,in} - ex_{g,in}c_{g,out} = 0 \quad 12$$

$$ex_{W,PT}c_{W,T} - ex_{W,T}c_{W,PT} = 0 \quad 13$$

Cycle (4) Cost Balance Equations

Cost balances for the components of the basic ORC system incorporating turbine bleeding, for pump 1, pump 2, feed heater, heat exchanger, condenser, evaporator, and turbine are as follows:

$$x * c_{w,PT} + c_1 + Z_{pump1} = c_2 \quad 14$$

$$c_6 + Z_{Turb} = c_7 + c_8 + c_{WT} + c_{WPT} \quad 15$$

Equations 17 through 23 form seven expressions with 13 variables. Consequently, six auxiliary equations are formulated using the F- and P-rule to effect a solution as follows:

$$ex_9c_8 - ex_8c_9 = 0 \quad 16$$

$$ex_{g,out}c_{g,in} - ex_{g,in}c_{g,out} = 0 \quad 17$$

Cost Rate of Components

The cost rates for the ORC components which appeared in the cost balance equations are modeled with respect to the operating parameters of the system in monetary units. The cost rate of each plant component is modeled as obtained in (Balliet *al.*, 2008; Sayyadi and Sabzaligol, 2009).

$$Z_k \left(\frac{\$}{hour} \right) = \frac{\phi_k \cdot c_K}{N} \quad 19$$

Where ϕ_k is the maintenance factor for each plant operation whose expected life is n years. N is the annual levelised cost. In line with values for capital (PWF), C_K is expressed as (Gorji-bandpyet *al.*, 2010).

$$Z_k \left(\frac{\$}{\text{hour}} \right) = [PEC - (SV) * PWF(i, n)] CFR(i, n) \quad 20$$

$$\text{Where } CRF = \frac{i(1+i)^n}{[(1+i)^n - 1]} \quad 21$$

$$\text{And } PWF = (1 + i)^{-n} \quad 22$$

Exergo-Economic Parameters

A number of exergoeconomic parameters are needed to quantify the cost system of the ORC plant and includes the average unit costs of fuel c_F and product c_P , cost rate of the exergy destruction rate \dot{C}_D , relative cost difference r and exergoeconomic factor f (Bejan and Tsatsaronis, 1995).

The relative cost difference r_k is defined for the k^{th} component as:

$$r_k = \frac{c_{p,k} - c_{f,k}}{c_{f,k}} \quad 23$$

The exergoeconomic factor f_k is expressed as:

$$f_k = \frac{\dot{Z}_{p,k}}{\dot{Z}_k + c_{f,k}[\dot{E}_{D,k}]} \quad 24$$

The objective function is the total product cost, expressed as:

$$C_T = \sum_{k=1}^N \dot{Z}_k + c_{f,k} \dot{E}_{D,k} \quad 25$$

ORC Component Purchase and Equipment Cost

It is necessary to account for the purchase and equipment cost of each ORC components as a function of the thermoeconomic operating parameters to effect the computation of the cost rates associated with plant usage for electricity generation. The parameters of the fourth ORC configuration are used to represent the cost equations since the same components appear in other configurations. Consequently, expression for the PEC is stated below:

ORC turbine:

The cost of the ORC turbine is correlated as (Rosen *et al.*, 2003):

$$PEC_{ORCT} = 3880.5(W)^{0.7} \left[1 + \left(\frac{0.05}{1-n_s} \right)^3 \right] \left[1 - \exp \left(\frac{T_{in} - 866K}{10.42K} \right) \right] \quad 26$$

ORC condenser:

The cost of an ORC condenser is expressed as follows (Klein *et al.*, 2004)

$$PEC_{cond.} = 280.74 \frac{Q_{cond.}}{22000 \left\{ \frac{(T_{9-TW,out}) - (T_1 - T_{W,in})}{\ln \left(\frac{T_{9-TW,out}}{T_1 - T_{W,in}} \right)} \right\}} + 746m_9 \quad 27$$

ORC pumps

PEC for the ORC pumps is expressed as (Klein et al. 2004)

$$PEC_{pump} = 705.48(w_p)^{0.71} \left[1 + \left(\frac{0.2}{1-n_p} \right) \right] \quad 28$$

Where w_p represent the work done by the pump in kW.

ORC heat exchanger

The cost of the heat exchanger is expressed as (Klein *et al.*, 2004):

$$PEC_{HE} = 130 \left(\frac{A_{HE}}{0.093} \right)^{0.83} \quad 29$$

Where A_{HE} for the heat exchanger is expressed as:

$$A_{HE} = U_{HE} \left\{ \frac{(T_8 - T_3) - (T_9 - T_2)}{\ln \left(\frac{T_8 - T_3}{T_9 - T_2} \right)} \right\} \quad 30$$

Evaporator

The expression for the equipment cost for the ORC evaporator is expressed as:

$$PEC_{EVA} = 130 \left(\frac{A_{EVA}}{0.093} \right)^{0.83} \quad 31$$

Where A_{EVA} for the evaporator is expressed as:

$$A_{EVA} = U_{EVA} \left\{ \frac{(T_{g,in} - T_6) - (T_{g,out} - T_5)}{\ln \left(\frac{T_{g,in} - T_6}{T_{g,out} - T_5} \right)} \right\} \quad 32$$

All values for the heat transfer coefficient, where applicable are taken as 2.1 kW/m²K.

Exergo-Environmental Sustainability Indicators

The exergo-environmental sustainability indicators are expressed as follows:

Waste exergy ratio: This is obtained as the overall exergy waste for the system based on the total exergy input. It is mathematically expressed as:

$$\dot{e}_{WR} = \frac{\sum_i^N \dot{e}_W}{\dot{e}_{FUEL}} \quad 33$$

Environmental effect factor: This is obtained as the ratio of the waste exergy ratio upon the exergy efficiency. It is mathematically expressed as:

$$EEF = \frac{\dot{e}_{WR}}{\psi} \quad 34$$

Exergy efficiency: the exergy efficiency is the ratio of the net power generated to the total exergy input. It is mathematically expressed as:

$$\psi = \frac{\dot{e}_{\text{exergy in product}}}{\dot{e}_{\text{FUEL}}} \quad 35$$

Exergetic sustainability index: The reciprocal of the environmental effect factor is termed the exergetic sustainability index and provides a platform for comparing environmental degradation due to power production from each system.

$$ESI = \frac{1}{EEF} \quad 36$$

Results and Discussions

A thermoeconomic evaluation of the system is performed using exergoeconomic models. The purchase and equipment cost of the components are monetised as functions of the operating variables in US dollars (1991 equivalent) (Frangopoulos, 1991; Roosenet *al.*, 2003).

Table 1: Summary of exergoeconomic cost indices

Component	PEC [USD]	Cost of Fuel [\$ /hr.]	Cost of Product [\$ /hr.]	Cost of Destruction [\$ /hr.]	Equipment Cost Rates (Z) [\$ /hr.]
R11					
Condenser	232.4	0.3944	0.2799	0.2744	0.005472
Evaporator	154104	0	3.628	0	3.628
Feedheater	58.1	1.558	1.56	0.502	0.001368
Heat excha.	933.5	0.2677	0.12	0.07119	0.02198
Pump 1	1441	0.09275	0.1267	0.09229	0.03393
Pump2	2033	0.1067	0.1545	0.07524	0.04787
Turbine	71780	4.053	5.149	0.8106	1.69
R113					
Condenser	247.1	0.04854	0.8325	0.6692	0.005817
Evaporator	154708	0	0	0	3.642



Feedheater	61.77	0.06191	1.836	0.6432	0.001454
Heat excha.	7342	0.04419	0.7579	0.1358	0.1729
Pump 1	929.1	0.118	0.05271	0.05263	0.02187
Pump2	1954	0.08137	0.1036	0.07391	0.046
Turbine	67001	0.06052	4.204	0.8408	1.577
R141b Condenser	295.5	0.2094	0.115	0.1081	1.726
Evaporator	169130	0	3.982	0	0.06628
Feedheater	73.87	2.104	2.105	0.5516	0.03162
Heat excha.	933.5	0.07577	0.1013	0.02968	0.02198
Pump 1	1343	0.102	0.1336	0.1016	0.001739
Pump2	2815	0.1818	0.2481	0.129	3.982
Turbine	73323	4.489	5.722	0.8977	0.006957

The cost of product, fuel, destruction, cost rates as well as purchase and equipment cost for each component is presented in Table 1. Details on electricity tariffs can be easily accounted for, using values of the cost of the product in Table 1 and the cost streams associated with the components. Cost rates for the pump mechanical power requirements and turbine are useful. The cost of the product for the turbine with refrigerants R11, R113, and R141b gave 5.149, 4.204 and 5.722 \$/hr respectively at 252 kW of evaporator heat input. Using corresponding turbine output in the cycle for the considered refrigerants, the cost of electricity, were it to be sold to the grid, is valued at 0.08397 \$/kWh (for R11), 0.09052 \$/kWh (for R141b), 0.08625 \$/kWh (for R113).

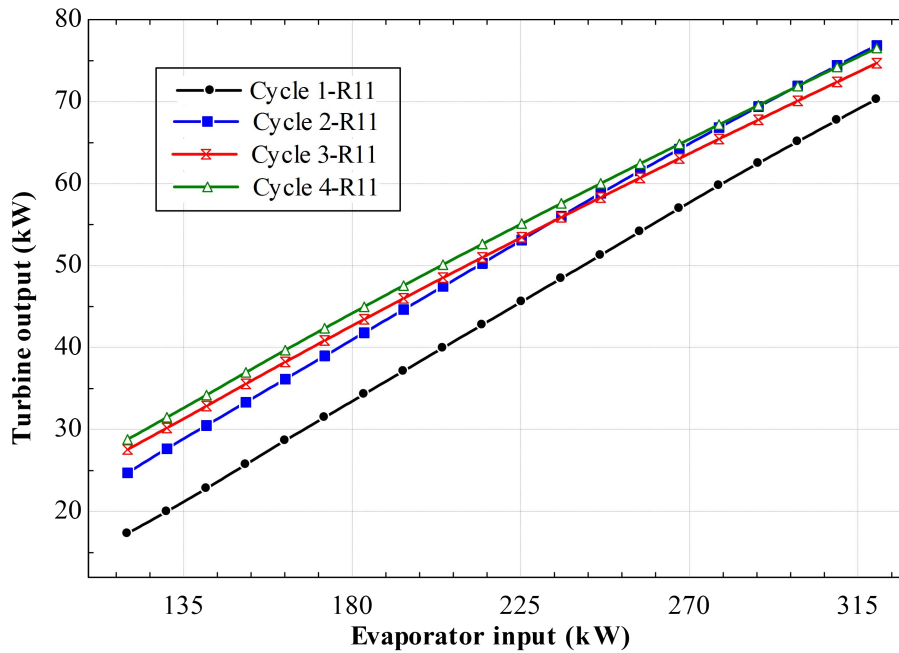


Figure 1: Variation of net turbine output and evaporator heat input.

Table 2: Net turbine output for varying evaporator heat input

Heat (kW)	Turbine output (kW)							
	R11 Cycle 1	R11 Cycle 2	R11 Cycle 3	R11 Cycle 4	R141b Cycle 1	R141b Cycle 2	R141b Cycle 3	R141b Cycle 4
120.00	17.33	24.70	27.56	28.79	13.35	21.56	27.86	29.27
130.53	20.01	27.67	30.19	31.48	15.46	24.11	30.59	32.08
141.05	22.81	30.50	32.85	34.2	17.71	26.77	33.34	34.90
151.58	25.73	33.32	35.56	36.96	20.07	29.54	36.1	37.73
162.11	28.66	36.15	38.23	39.68	22.55	32.41	38.88	40.58
172.63	31.48	38.97	40.85	42.35	25.15	35.39	41.66	43.42
183.16	34.31	41.8	43.44	44.97	27.85	38.46	44.41	46.23
193.68	37.13	44.62	45.99	47.56	30.66	41.62	47.10	48.97
204.21	39.96	47.45	48.51	50.11	33.57	44.66	49.73	51.65
214.74	42.78	50.27	50.99	52.63	36.59	47.66	52.32	54.28
225.26	45.61	53.12	53.45	55.11	39.69	50.67	54.86	56.86
235.79	48.43	56.01	55.89	57.58	42.85	53.67	57.35	59.39
246.32	51.26	58.81	58.30	60.01	45.85	56.67	59.81	61.88
256.84	54.14	61.54	60.70	62.43	48.85	59.67	62.23	64.34
267.37	56.99	64.21	63.07	64.82	51.85	62.67	64.61	66.75
277.89	59.77	66.82	65.43	67.19	54.85	65.67	66.96	69.13
288.42	62.48	69.39	67.76	69.55	57.85	68.66	69.28	71.47
298.95	65.13	71.91	70.09	71.89	60.85	71.54	71.57	73.79
309.47	67.73	74.40	72.39	74.21	63.85	74.33	73.83	76.07
320.00	70.28	76.85	74.69	76.52	66.85	77.04	76.07	78.32

Variation in net turbine output for evaporator heat input is evaluated and presented in Table 2 while similar values for the remaining refrigerants are shown in Fig 1. The result shows that additional equipment added to alter the generic cycle is worthwhile with energy output reflecting changes in line the architecture of cycles 1, 2, 3, and 4. Similar increased output is also noticed with refrigerants R11 and R141 b as shown in Fig 1

Table 3: Exergetic sustainability values for the four cycles

		Cycle 1		
		R11	R113	R141b
Cycle 2	SI	0.7579	0.7164	0.6274
		R11	R113	R141b
Cycle 3	SI	0.9698	0.8779	0.8991
		R11	R113	R141b
Cycle 4	SI	0.949	0.7934	0.9861
		R11	R113	R141b
	SI	1.045	1	1.099

The SI indicators are scaled for the cycles with mono refrigerant, and for the refrigerants with mono cycle. The result as shown in Table 3 presents the fourth cycle configuration with higher network output per total exergy destruction resulting in more than unity exergetic sustainability index for the three refrigerants. The third cycle which incorporates turbine bleeding for preheating the refrigerant before heat addition in the evaporator, although reasonable in overall exergy efficiency, has more total exergy destruction relative to the network output. The SI is at about 0.9, and the refrigerants are within this range. The differences in SI values for the fourth cycle are comparatively small so that any of these refrigerants may be used when concern on exergy destruction is of importance.

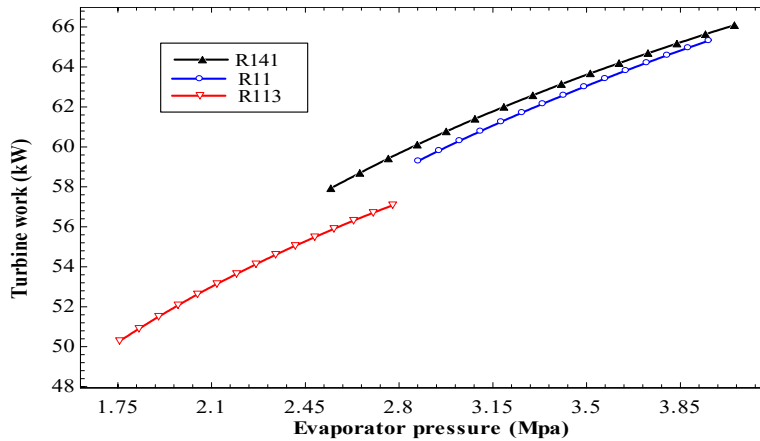


Figure 2: Effect of evaporator pressure on turbine

Consequently, sensitivity analysis of optimum operating pressure for the refrigerants in the fourth architecture is shown in Fig. 2. For the three refrigerants, an increase in operating evaporator pressure results in increasing net output and efficiency with corresponding turbine inlet temperature (TIT). In the expression for the whole system cost rates (refer to Eqns. 49), the pressure, which is integral in the performance of the system is not an operating parameter in these expressions. The cost rates of the condenser, feed heater, evaporator, heat exchanger, and the pumps are added up to the cost rates due to the turbine.

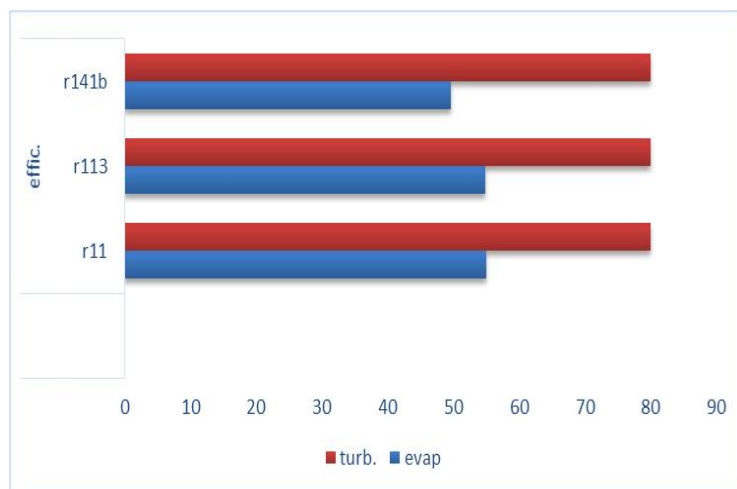


Figure 3: Component exergy efficiencies for different refrigerants (Basic ORC).

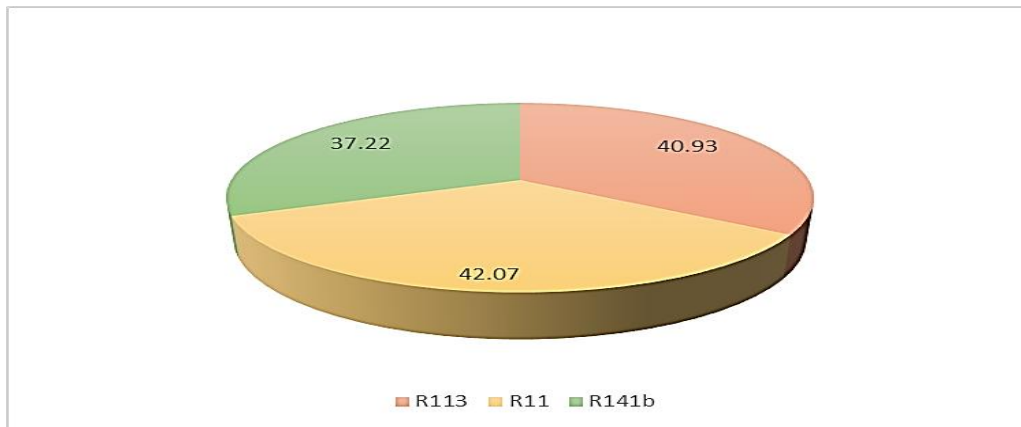


Figure 4: ORC exergy efficiencies for considered refrigerants (basic ORC)

- The results from exergy efficiencies of the system interaction are presented in Fig. 3. The components considered for exergy efficiencies are the turbine and evaporator for the simple ORC system. The corresponding efficiencies for R113, R11, and R141b, are 54.87 %, 55.09 %, and 49.56 % respectively. Exergetic efficiencies for the evaporator in line with the considered refrigerants is about 80 % and remains partly constant due to the same heat input to the evaporator. Exergy efficiency values for the whole system are similarly computed and presented in Fig. 4. For R113, R11, and R141b, corresponding exergy efficiency values are 40.9 %, 42.07, and 37.22 % respectively.

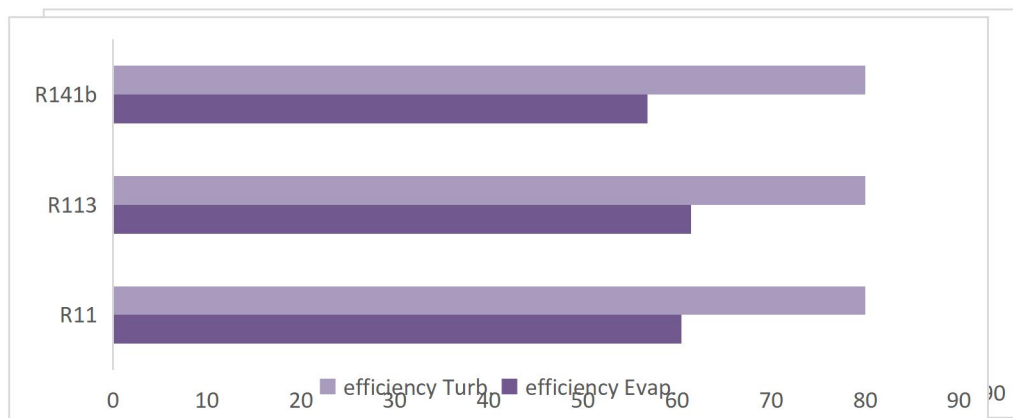


Figure 5: Component exergy efficiencies for different refrigerants (ORC with heat exchanger)

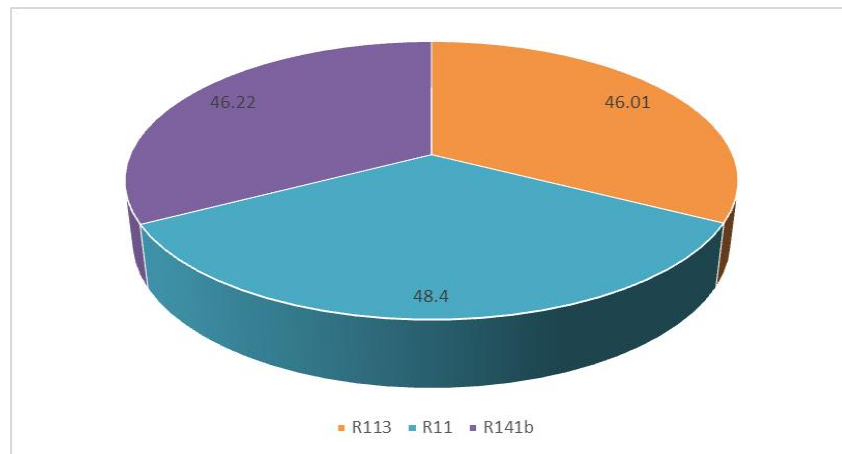


Figure 6: ORC exergy efficiencies for considered refrigerants (ORC with heat exchanger)

For the ORC system incorporating a heat exchanger, component exergy efficiencies for the refrigerants are shown in Fig. 5. Exergy efficiencies for the cycle incorporated with a heat exchanger are significantly higher than the basic ORC even with the same heat input. This trend is shown in Fig. 6. The marginal efficiency increase results from the heat exchanger which increases the refrigerant enthalpy en route the evaporator. The result also shows that for identical operating conditions, R11 performs better in terms of overall system exergy efficiency. R141b. R113 has a minimal operational heat input range, but possesses reasonably acceptable exergy efficiency values, and may be considered in real applications when issues related to exergetic sustainability are pertinent

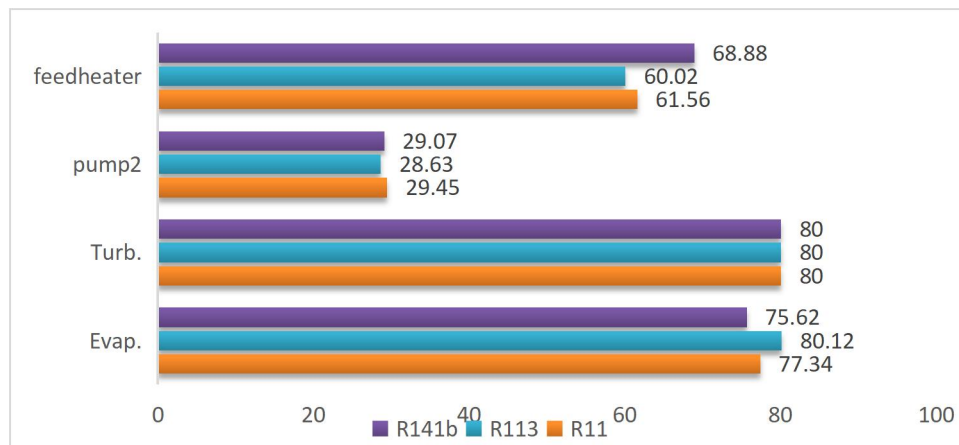


Figure 7: Component exergy efficiencies for different refrigerants (ORC with turbine bleeding)

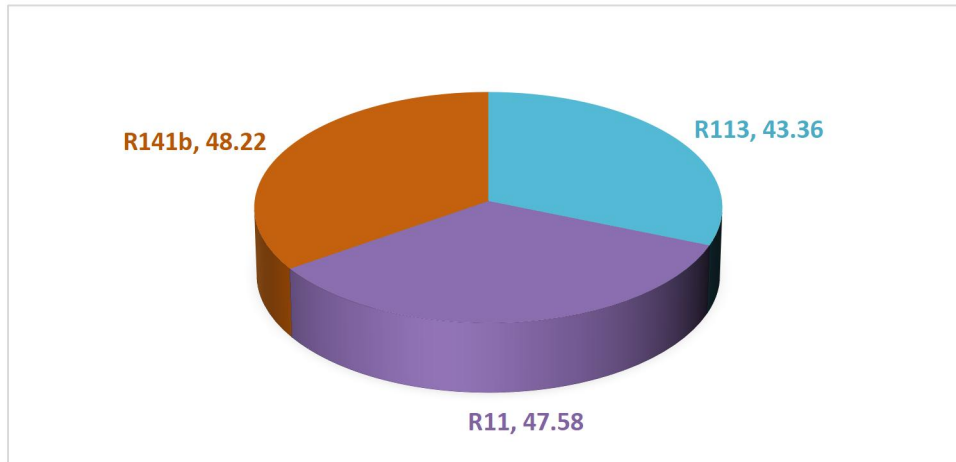


Figure 8: ORC exergy efficiencies for considered refrigerants

(ORC with turbine bleeding)

For the third cycle which incorporates turbine bleeding into a feed heater, corresponding cycle efficiencies for the refrigerants are comparatively higher than values obtained from the basic cycle and the one with a heat exchanger. In Fig. 8, this efficiency trend is shown where values are 48.22, 43.36, and 47.58 % for R141b, R113, and R11 respectively

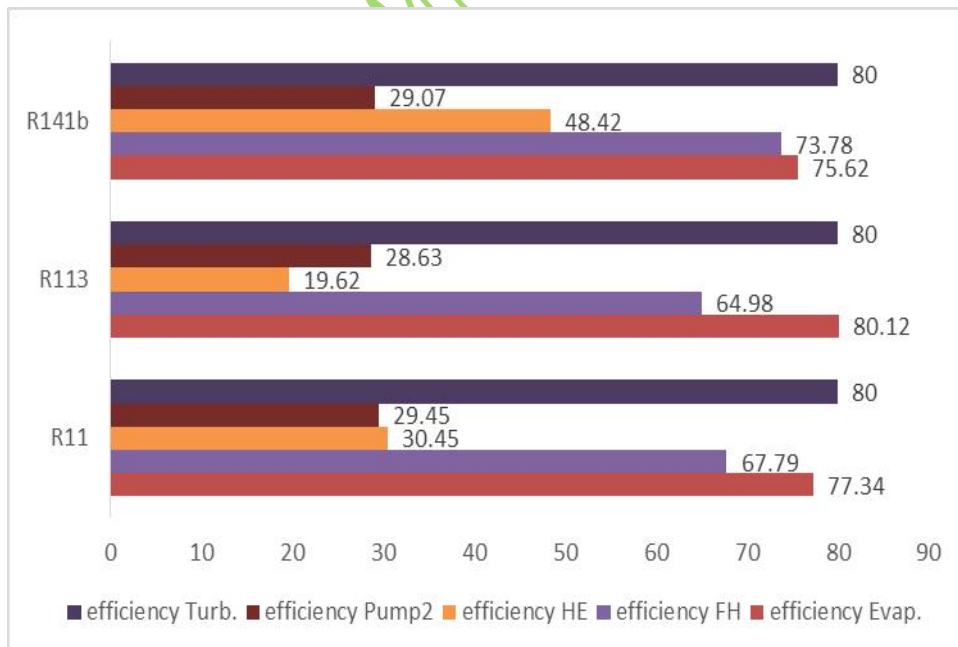
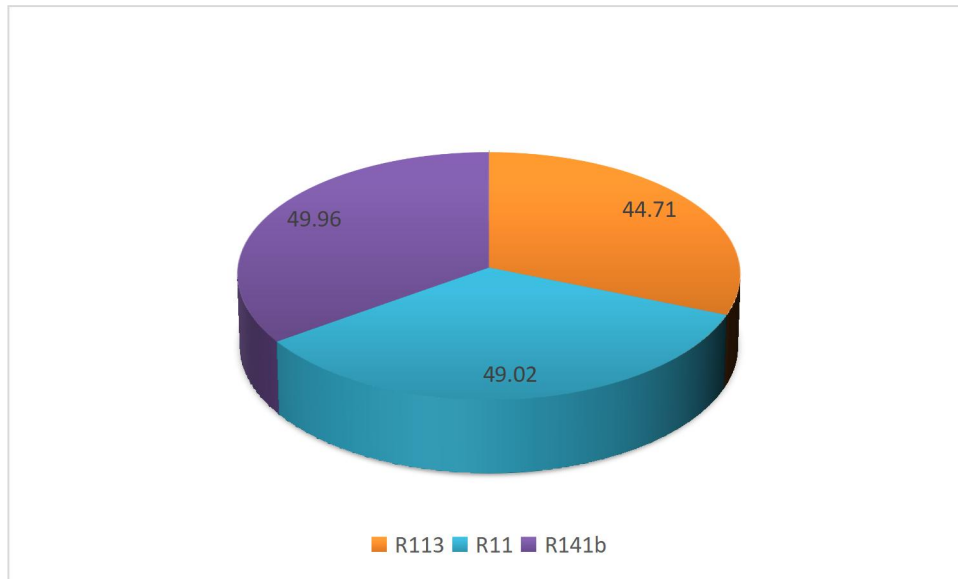


Figure 9: Component exergy efficiencies for different refrigerants

(ORC with turbine bleeding/heat exchanger)



**Figure 10: ORC exergy efficiencies for considered refrigerants
(ORC with turbine bleeding/heat exchanger)**

For the fourth refrigerant which includes both turbine bleeding and heat exchanger, the cycle efficiencies for the refrigerants are shown in Fig. 10. Cycle efficiencies for R113, R141b and R11 are 44.71, 49.96, and 49.02 % for the fourth cycle respectively, and remain higher than the previous cycles.

Conclusion

In this study, theoretical studies on the exergy efficiency and components performances were studied for three different refrigerants. The conclusions of the study are as follows: The purchase and equipment cost of the components are monetised as functions of the operating variables in US dollars (1991 equivalent) (Frangopoulos, 1991; Roosen *et al.*, 2003).

The cost of the product for the turbine with refrigerants R11, R113, and R141b gave 5.149, 4.204 and 5.722 \$/hr respectively at 252 kW of evaporator heat input.

The third cycle which incorporates turbine bleeding for preheating the refrigerant before heat addition in the evaporator, although reasonable in overall exergy efficiency, has more total exergy destruction relative to the network output.

Using corresponding turbine output in the cycle for the considered refrigerants, the cost of electricity, were it to be sold to the grid, is valued at 0.08397 \$/kWh (for R11), 0.09052 \$/kWh (for R141b), 0.08625 \$/kWh (for R113).



From the configuration of the four cycles, an optimum operating pressure is necessary for improved turbine output and efficiency.

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THE EFFECT OF AGRICULTURAL WASTE-DERIVED ACTIVATED CHARCOAL ON THE PERFORMANCE OF BROILER AND LAYER CHICKENS

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Abstract

Nigeria is endowed with abundant quantities of agricultural residues that can be harnessed to produce value added products like activated charcoal (AC) for inclusion in poultry feeds to reduce feed cost which makes up about 75% of the total cost of production. This study was carried out with 120 day old broilers and 16 weeks old Isa Brown layer pullets. Each was divided into four groups (G1-G4) with G1 as the control and G2, G3 and G4 fed AC at inclusion rates of 0.5, 1.0 and 1.5kg/100 kg of feed, respectively. The broiler chickens were maintained ad-libitum on compounded starter and finisher diets for 4 and 2 weeks, respectively while the pullets were given grower mash until 22 weeks of age when 10% hen day egg production before being placed on layer feed. Data on feed intake, live weight, dressed weight and egg production and egg weight for layers were taken following standard procedures. Data obtained were subjected to one-way analysis of variance. AC inclusion significantly ($P < 0.05$) reduced feed intake and increased ($P < 0.05$) live weight, feed conversion and dressed weight in broilers. In layers, there was significant increase ($P < 0.05$) in hen-day egg production. In conclusion, the inclusion of agricultural waste-derived AC in feed improved performance of broiler and layer chickens and is therefore recommended as a feed additive.

Introduction

The expansion of agricultural production has naturally resulted in increased quantities of livestock wastes, agricultural crop residues and agro-industrial by-products (Akorede *et al.*, 2017). The need for more animal protein to sustain the increasing teeming population has led to an obvious increase in livestock production through the establishment of large-scale farm (Iregbu *et al.*, 2014). This invariably had given rise to monumental increase in animal wastes such as pig dung resulting to waste management challenges. Pig waste is a biomass that changes rapidly from the time of excretion thereby creating a serious pollution problem. The odour emitted from intensive pig production system is a very serious nuisance to people living in the vicinity of pig farms and has led to health problems and closure of pig farms due to litigations (Okoli *et al.*, 2019). The challenges of



handling pig dung are recognized as a major issue in sustaining the growth of pig industry in Nigeria (Okoli *et al.*, 2019). Twenty-two co-operative farmers' societies at Oke-Aro in Ogun State, Nigeria which host the largest pig farm in West Africa was granted 25 million naira in 2007 by the World Bank through FADAMA programme in order to buy a machine that can convert their pig dung into dry organic manure which are sold to crop farmers.

This notwithstanding, there is a desperate and urgent need to extend this technology further to ensure the removal of all animal, human, palm oil wastes and industrial wastes from the environment (Iregbu *et al.*, 2014, Mohamed and Yusup, 2021) and transform them to value-added products. One of such technologies would be the conversion of animal dung and palm oil wastes to value added products like activated charcoal through thermal pyrolysis using physical method of activation for use in varying adsorptive applications in homes, agriculture, pharmaceutical companies and in environmental remediation (Mohamed and Yusup, 2021). Agricultural wastes and by-products are being advocated for the production of adsorbents such as activated carbon (AC) due to their carbon content and the possibility of mitigating environmental pollution through such process (Schmidt *et al.*, 2019).

Therefore, research on agricultural wastes is desirable because of their contribution to environmental degradation and the need to convert them to renewable energy (Okey, 2023) and most importantly activated charcoal (AC) which can be added to animal feeds. Activated charcoal or activated carbon or biochar as it is synonymously described when produced from agricultural wastes have been found to be relatively less expensive when compared to other activated carbon precursors of industrial and petroleum origin such as wood, coal and lignite (Mohammed *et al.*, 2018). Activated charcoal is a solid, porous, tasteless and black carbonaceous material prepared from a variety of carbon containing materials, including agricultural residues (AAFCO, 2012). Emerging reports revealed that activated charcoal adsorbs more toxins than any natural substance known to mankind (Mohammad *et al.*, 2022). It is this high adsorption property that makes activated carbon useable in water purification and in the removal of undesirable odours and impurities from food (Schmidt *et al.*, 2019; Mohammad *et al.*, 2022). Activated charcoal is a very effective adsorbent for reducing the levels of mycotoxins in feed when compared with other mineral adsorbents such as aluminosilicates and bentonite (Bhatti *et al.*, 2018).

More so, the wide differences between agricultural wastes in their carbon content is an indication that their physical and chemical properties could vary necessitating the evaluation of the



physicochemical properties of activated charcoals produced from different feedstocks (Mohamed and Yusup, 2021). Rattanawut *et al.* (2021) observed that when feeding bamboo charcoal powder to broiler and layer chickens, it increased performance and provided greater surface area for absorption of nutrients in the intestines of the supplemented groups which was attributed to the increased population of beneficial bacteria. The main objective of the study was to produce AC from a blend of agricultural wastes, evaluate its physico-chemical properties and determine the effect of its dietary supplementation on the performance of broiler and layer chickens.

Materials and Methods

Location of the study

The study was carried out at the Teaching and Research Farm of Michael Okpara University of Agriculture Umudike, Abia State. Umudike is located within the South East agro-ecological zone of Nigeria with geographical coordinates of 5.4801° N and 7.5437° E.

Collection and preparation of precursor feedstock

Palm kernel shell and palm fruit fibre were collected from a palm oil mill located at Amaba while freshly voided pig dung was collected into a plastic container using a parker from a pig farm at Ndolu all within Umudike. Each material was sun-dried to a constant weight and crushed manually to reduce the particle size before being blended at a ratio of 4:3:3 weight for weight for pig dung, palm kernel shell and palm fruit fibre, respectively following the recommendation by Ohanaka *et al.* (2022).

Activated carbon preparation

The physical method of preparation of AC which involved thermal decomposition or carbonization of the precursors followed by steam activation was employed in the study (Gunamartha and Widana, 2018; Ohanaka *et al.*, 2022). The activated charcoal sample produced was characterized by determining its physicochemical properties using standard laboratory procedures and subsequently supplemented in broiler and layer feeds to determine the effect in the improvement of production performance of broiler and layer chickens.

Experimental animals, design, management and duration

This study was carried out with 120 day old broilers and 16 weeks old Isa Brown layer pullets. Each was divided into four groups (G1-G4) with G1 as the control and G2, G3 and G4 fed activated charcoal at inclusion rates of 0.5, 1.0 and 1.5kg/100 kg of feed, respectively. All the birds were

raised on deep litter and treatments were replicated thrice with each having ten birds in a completely randomized design. The broiler chickens were maintained ad-libitum on compounded starter and finisher diets for 4 and 2 weeks, respectively. The pullets were placed on grower mash until 22 weeks of age when 10% hen day egg production was reached before changing to layer feed. Data on feed intake, live weight, and FCR for both broilers and layers and egg production, egg weight for layers were taken following standard procedures. Data obtained were subjected to one-way analysis of variance.

Results

Table 4.1 shows moisture content, pH, bulk density, water-holding capacity, specific gravity, oil adsorption capacity, and surface area were 5.40%, 7.70, 0.72 g/cm³, 77.50%, 0.73, 118.50%, and 587cm²/g, respectively. Table 4.2 shows that the AC produced contained 79.43% carbon, 6185.11mg/kg calcium, 18603.29mg/kg phosphorus, 1722.47mg/kg sodium, 10275.48mg/kg potassium, 3980.14mg/kg magnesium, 721.00mg/kg manganese, 996.35mg/kg iron, 95.47mg/kg zinc, 33.69mg/kg copper, 13.38mg/kg arsenic, and 3008.04mg/kg nitrogen.

Table 4.1: Physical properties of activated charcoal produced from a blend of agricultural waste materials

Parameter	Observed value	Published value	Precursor	Reference
Act. charcoal yield (%)	72.70	74.19	PKS	Kong <i>et al.</i> (2013)
Moisture (%)	5.40	3.50 3.50	Poultry litter, Cow bone	Lima and Marshal, 2004 Nwankwo, 2018
pH	7.70	6.64	PKS	Evbuoman <i>et al.</i> (2013)
Bulk density (g/cm ³)	0.72	0.871	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Water-holding capacity (%)	77.50	47.40	PKS	Kong <i>et al.</i> (2013)
Specific gravity	0.73	0.725	0.64	Okoroigwe <i>et al.</i> (2013)
Oil adsorption capacity (%)	118.50	125	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Surface area (cm ² /g)	587.00	248-253	Poultry litter	Lima and Marshal, 2004

Table 4.2: Chemical properties of activated charcoal produced from a blend of agricultural waste materials

Parameter	Observed value	Published value	Precursor	Reference
Carbon content (%)	79.43	88.40 18.88	PKS Cow dung	Okoroigwe <i>et al.</i> (2013) Gunamartha & Widana 2018,



Calcium (mg/kg)	6185.11	5550.28	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Phosphorus (mg/kg)	18603.29	2100	Corn stalk	Chan and Xu, 2009
Sodium (mg/kg)	1722.47	1405.18	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Potassium (mg/kg)	10275.48	9400	Corn cobs	Chan and Xu, 2009
Magnesium mg/kg)	3980.14	4410.10	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Manganese (mg/kg)	721.00	671.33	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Iron (mg/kg)	996.35	1304.65	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Zinc (mg/kg)	95.47	103.48	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Copper (mg/kg)	33.69	39.46	Bamboo/PKS/Pig dung	Ohanaka <i>et al.</i> (2022)
Arsenic (mg/kg)	13.38	< 30	Agrowaste	EBC, 2012

Table 4.3 showed the growth parameters of broiler chicks fed AC supplemented rations from day old to 42 days of age. The feed intake of G1 was significantly ($p < 0.05$) higher than that of G2 and G4 at 7 days of age. At 28 days of age, the live weight of G3 was significantly ($p < 0.05$) greater than G1 while its weight gain was significantly ($p < 0.05$) higher than G1 and G4. More so, the feed intake and FCR of G1 was significantly ($p < 0.05$) higher than G3 and G4. At 42 days of age, the live weight of G3 was significantly ($p < 0.05$) higher than G1 with the feed intake of G1 higher ($p < 0.05$) than G2 and G3.

Table 4.3: Growth parameters of broiler chickens fed varying dietary levels of activated charcoal

		Experimental groups				p-value
Age (days)	Parameters	G1	G2	G3	G4	
Day old	Initial weight (g)	37.80±2.14	38.07±2.41	37.73±2.13	37.43±2.46	0.644
7	Live weight (g)	158.4±1.94	156.7±2.31	160.00±3.05	157.4±5.24	0.671
	Weight gain (g)	120.57±1.30	118.63±1.76	122.27±3.25	119.97±5.52	0.636
	Feed intake (g)	212.32±2.37 ^b	201.74±2.74 ^a	204.33±1.24 ^{ab}	198.31±1.72 ^a	0.044
	FCR	1.76. ±0.01	1.70±0.07	1.67±0.03	1.65±0.05	0.168
28	Live weight (g)	975.76±19.00 ^b	1042.96±20.73 ^{ab}	1084.86±24.14 ^a	999.33±2.71 ^{ab}	0.000
	Weight gain (g)	817.37±20.96 ^c	886.26±18.63 ^{ab}	924.87±23.10 ^a	843.27±3.27 ^{bc}	0.000
	Feed intake (g)	670.25±8.12 ^c	648.90±7.97 ^{bc}	624.96±10.34 ^{ab}	601.51±9.58 ^a	0.000
	FCR	0.82±0.05 ^a	0.73±0.03 ^b	0.68±0.03 ^c	0.71±0.02 ^{bc}	0.000



42	Live weight (g)	1947.67±55.08 ^a	2027.67±26.41 ^{ab}	2114.33±80.21 ^b	1988.33±17.04 ^a	0.027
	Weight gain (g)	959.83±54.62	976.67±17.89	1000.33±44.58	964.37±48.34	0.682
	Feed intake (g)	1095.43±8.00 ^b	1056.44±6.72 ^a	1056.72±5.67 ^a	1071.35±8.00 ^{ab}	0.010
	FCR	1.14±0.07	1.08±0.07	1.05±0.08	1.11±0.11	0.285

Results are mean ± SD; a, b, c: means on the same row with different superscripts are significantly different ($P \leq 0.05$).

The results on live weight, egg weight, hen day egg production and FCR of the experimental hens are presented in Table 4.4. The results showed that feeding of AC in the diet of laying hens significantly improved hen day egg production in G2 at 24 and 28 weeks of age. The supplementation of this activated charcoal in feed improved performance and carcass yield in broiler chickens and improved egg production in layer chickens.

Table 4.4: Live weight, egg weight (g), feed conversion ratio and hen day egg production (%) of layer chickens fed varying dietary levels of activated charcoal

Age (wk)	Experimental groups				p-value
	G1	G2	G3	G4	
Live weight					
20	1386.67±33.50	1479.67±115.52	1476.33±70.87	1385.33±40.22	0.263
28	1639.00±108.06	1648.33±60.62	1654.67±151.16	1654.33±127.11	0.998
Egg weight					
20	36.69±16.56	37.91±17.17	43.71±3.15	42.00±7.30	0.693
24	49.45±1.51	50.65±1.09	50.45±1.69	50.54±1.37	0.394
28	53.29±2.03	52.79±2.12	52.17±1.33	51.47±1.64	0.290
33	55.98±2.21	57.67±2.17	55.30±1.87	56.98±1.00	0.650
Hen day egg production					
20	9.16±4.92	10.07±4.47	8.57±4.76	6.42±2.43	0.475
24	42.86±4.88 ^b	52.86±2.67 ^a	47.86±6.36 ^{ab}	43.57±3.78 ^b	0.002
28	70.71±4.50 ^b	82.86±2.67 ^a	74.29±3.45 ^b	71.43±2.44 ^b	0.000
33	73.33±2.88	86.66±2.88	76.66±2.88	80.57±8.66	0.055
FCR					
20	2.60±0.27	2.51±0.28	2.17±0.20	2.26±0.52	0.706
24	2.53±0.07	2.47±0.05	2.48±0.08	2.47±0.06	0.366
28	2.34±0.24	2.37±0.19	2.39±0.61	2.43±0.07	0.315
33	2.25±0.10	2.18±0.09	2.25±0.08	2.19±0.05	0.659

Results are mean ± SD; a, b: means on the same row with different superscripts are significantly different ($P \leq 0.05$).

Discussion

In Table 4.1, the value of 72.70% activated charcoal yield obtained in the present study is less than the 74.19% yield from palm kernel shell feedstock alone reported by Kong *et al.* (2013) and higher than 21.60% and 14.24% for cow and pig dung-derived activated charcoal reported by Gunamantha and Widana (2018). The inclusion of pig dung and palm fruit fibre in the present study may have been responsible for the lower activated charcoal yield obtained. A blend of pig dung, palm fruit fibre and palm kernel shell are less dense than palm kernel shell when used alone and may have lesser activated carbon yield considering their lower lignocellulosic content of the blended biomass materials (Dhyani and Bhaskar, 2017).

The AC produced in this study exhibited a slightly alkaline pH value of 7.67 which is within the preferred range of 6.0-10.0 as reported for most agricultural residue-derived AC (Boadu *et al.*, 2018). It has also been reported that acidic and slightly alkaline AC exhibits greater adsorption capacity and are more effective adsorbents than those with very high pH values (Madu and Ladije, 2013). The pH result obtained in this study was higher than the 6.1, 6.64, 6.60 and 6.60 reported by Okoroigwe *et al.* (2013), Evbuoman *et al.* (2013), Gunamantha and Widana (2018) and Nwankwo (2018) using agricultural residues as precursors for pyrolysis. The bulk density (BD) was higher than the 0.64g/cm³ and 0.56g/cm³ reported by Evbuoman *et al.* (2013) for palm kernel shell and oil palm fibre derived-AC. The value of the BD is however within the preferred range of 0.06-1.03g/cm³ recommended by Bryne and Nagle (1997) for AC with high adsorption capacity and micro-porosity required for water treatment processes and environmental remediation, respectively. The water-holding capacity (77.50%) of the AC produced in this experiment was higher than the value (47.40%) obtained by Kong *et al.* (2013) for PKS-derived AC. Mollinedo *et al.* (2015), demonstrated the use of AC to improve the water-holding capacity of different soil samples and discovered that treatment of soil increased the water retention in soil for up to 25%.

The results in Table 4.2 showed that the value of the carbon content was 79.43%. This value is higher than the 65.4 % reported by Kong *et al.* (2013), but lower than 88.40% reported by Okoroigwe *et al.* (2013) for AC from palm fruit fibre as precursor material. However, the carbon content of 79.43% obtained in the present study is within the preferred range of 62.20- 92.40% recommended by Domingues *et al.* (2017) for AC with high degree of micro-porosity and adsorption capacity. Again, this value can be adjudged to be high when compared to the International Biochar Initiative (IBI) standard which requires 10% minimum organic carbon in AC



(EBC, 2012; IBI, 2017). The mineral concentrations were much higher than the values reported by Okoroigwe *et al.* (2013) and Gunamartha and Widana (2018), for palm kernel shell and cow dung-derived AC, respectively. These variations could be attributed to the nature of the starting material (precursor) which influences the mineral composition and concentration of the resulting AC (Tadda *et al.*, 2016). The high concentration of potassium in the activated charcoal produced in this experiment could be attributed to the inclusion of palm fruit fiber as one of the precursors. Activated charcoal rich in potassium could serve as fertilizer for growing crops (Udoetok, 2012). Therefore, AC produced in the present study could be used to improve crop production. Results on elemental analysis of heavy metal contents, including arsenic and the micro minerals (copper and zinc) were within the EBC (2012) allowable threshold of these elements in AC.

The observed significantly lower feed intake of broiler chickens in the supplemented groups across the age periods (Table 4.3) is in agreement with the report of Kutlu *et al.* (2001) who observed that charcoal supplementation in diets reduced feed intake. The reduction in feed intake in the supplemented groups could result from the prebiotic effect of AC which enhances the efficient use of the nutrients in a diet (Damron, 2009). The significantly higher live weight and weight gain in G2 and G3 at 28 days and higher live weight in G3 at 42 days as well and the better FCR in the supplemented groups across the age periods were in agreement with the findings of Jiya *et al.* (2013) and Dim *et al.* (2018) whose results showed improved growth performance on inclusion of AC in broiler diets.

In Table 4.4, The positive effects of AC on hen-day egg production in G2 could be ascribed to its beneficial effects on gut health through improvement of digestion and absorption of nutrients (Rattanawut *et al.*, 2021). This result on hen-day egg production was in conformity with the work of Rattanawut *et al.* (2021), who reported that bamboo AC at 5% inclusion improved laying performance in hens. The inclusion of AC in this study may have improved performance of the layers through several mechanisms including decreasing gut pH which inhibited the growth of pathogens and enhanced the growth of beneficial intestinal micro-organisms.

Conclusion

The contribution of this work to science lies in the transformation of agricultural wastes to an environmental friendly and value added product that can be used as feed additives to improve performance of layer and broiler chickens. The use of activated charcoal as feed additive has the potential to improve feed efficiency and livestock productivity. In conclusion, the inclusion of



agricultural waste-derived AC in feed improved the feed the feed conversion efficiency and performance of broiler and layer chickens and is therefore recommended as a feed additive.

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SUB-THEME 3: Innovative, Machine based and Endogenous Strategies and Technologies for Environmental Pollution detection, assessment and remediation



INVESTIGATION ON RADIATION WITHIN BUILDING MATERIALS SHOPS IN IKOT EKPENEN LOCAL GOVERNMENT AREA AKWA IBOM STATE, NIGERIA

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Abstract

This research was set up to evaluate the effective dose in building material shops, in Ikot Ekpene, Akwa Ibom State. To determine if the evaluated dose levels could lead to any radiological health effect in the workers, and also determine if the industries require regulatory control. The gamma ray exposure at eighteen (18) shops measured using an exposure meter were converted to effective dose and compared with the public and occupational values. The result of the computed mean equivalent dose rate for the building material shops was range between 0.09-0.12 μ sv/hr and 0.158-0.210mSv/yr respectively, the average value of the background gamma ray exposure was 0.10 μ sv/hr with corresponding whole body effective dose of 0.178mSv/yr. The evaluated effective dose value in the building materials shops were below public and occupational exposure limits and may not result in any radiological health hazard. Therefore they may not require regulatory control.

Keywords: Dose Rate, Effective Dose, Radionuclides, Gamma activity

Introduction

Radiation is the emission or transmission of energy in the form of waves or particles through space or a material medium.(Farlex,F.2014).Ionization radiation and natural occurring radioactive materials (NORM) are found naturally everywhere including, rocks, soil, vegetation air and water, and their levels depend on the distribution of natural radionuclides within the environment. Building materials may be either part of the environment or comes from natural occurring materials .Timber, Cement Bricks and other clay based building materials like tiles are extensively used for building construction. Human activities involving mining, the used industrial waste materials like ash from the manufacturing of cement and bricks, and processing of radionuclides or items which contain radionuclides, can enhance the levels of environmental radiation .Industrial and medical uses of radiation are beneficial to man. The use of radiation and radionuclide can be hazardous to man and the environment if such use is not regulated, and exposure to radiation kept within acceptable limit. (Inyang *et al*, 2009).

Building materials is great way to reduce the environmental footprint of a building, building materials are not particularly radioactive, and most do not emit substantial amount of radon, radiation in building materials can lead to an industrial hygienist. (Linda Kincaid, MPH, CIH 2009).The planet earth is continuously radioactive and this is evident in that a lot of radionuclides



exist naturally. Living things such as plants, animals, and human beings are constantly exposed to this ionizing radiation, both from natural and artificial sources. (UNSCEAR, 2000.).

Radiation dose that are received at higher levels give greater chances of developing cancer by the exposed individual (EPA, 2005). The effect of low level radiation dose may not readily manifest, but there is still a long term effect (Avwiri *et al.*, 2015).

It was established that about 80% of radiation dose to man comes from natural sources of which radon contributes about 55%. Radon is a decay product of uranium found nearly in all the soils, rocks and minerals. When it is inhaled, it penetrates the lungs, and the fact radon is an alpha emitter enables it to initiate damage which often results in cancer of the lungs upon interaction with cells of the lungs (US EPA, 2005; Patel, 1988; Folland *et al.*, 1995). Cosmic rays constitute a fraction of the annual radiation exposure of human beings on the earth, averaging 0.39 mSv out of a total of 3 mSv per year (13% of total background) for the Earth population. Ionizing radiation in certain conditions can damage living organisms, causing cancer or genetic damage. (Kwan, Hoong.N.2003). Non-Ionizing radiation in certain conditions also can cause damage to living organisms, such as burns (IARC, 2011). The effect of non-ionizing forms of radiation on living tissue. (Moulder, John .E.(2007). Ionizing radiation has the ability to affect the chemical state of a material and so causes changes which are biologically important. (Jwanbot, *et al.*, 2013)

This environmental ambient radiation varies in intensity and quality from place to place and from time to time (Ndiriza *et al.*, 2008). Due to the risk associated with exposure to ionizing radiation, this work is aimed at measuring and thereby monitoring the level of this radiation in building materials shops.

Materials and Method

The study area covered part of Ikot Ekpene Local Government Area Located between longitude 7° , 42° , 59° , 99° E latitude 5° , 10° to 60° .00 N in Akwa Ibom State.

The material used for this research were, exposure meter and a measuring tape. The exposure meter was used for measuring the gamma-ray and the exposure levels within the selected shops, while the measuring tape was used for a specified distance away from the selected shops to determine the background radiation.

Eighteen (18) building materials shops within Ikot Ekpene including shops with cements, tiles and woods, situated along market road.

The exposure meter used in this study was Radex(RD1212), a portable digital handheld radiation meter with a measuring unit of micro Sievert per hour ($\mu\text{Sv/h}$). The measurements were carried out

by positioning the radiation meter at targeted sample (cements in bags , woods and tiles in cartons). During the measurement process the exposure meter was positioned at a distance of 100cm away from targeted sample and 100cm from ground level ensuring that the meter points directly towards a stacked of targeted sample .At different points with the selected shops ,measurement were taken and the mean value were considered .At a distance of 1000cm away from the selected building materials shops, measurement of gamma radiation exposure was taken to establish the average background radiation (Inyang *et al.*, 2009).

The background measurements were taken at different locations 1000cm away from the surveying shops and the mean value was considered and the background radiation was then deducted from the mean value to obtain the actual mean radiation levels emitted by each sample type.

The data generated from the radiation measurement in micro Sievert per hour ($\mu\text{sv/h}$) were converted into effective dose measured in millisievert per year (msv/yr) by multiplying the value from radiation measurement in $\mu\text{sv/h}$ by 8.76 msv/yr/ $\mu\text{sv/h}$. The effective dose presented in milli Sievert per year (msv/y) were used in determining the radiological impact in selected shops through the use of the whole body effective dose measured in Sievert (sv) (Inyang *et al.*, 2009).

Results

Gamma ray exposure values measured in $\mu\text{sv/hr}$ with the corresponding maximum standard deviation (SD) and the associated effective dose in msv/yr estimated from the measured gamma ray exposure values are given in Table 1. The exposure values reported in the Table 1 are average values of at least 10 measurements taken under similar conditions and environment.

Exposure measurements taken at each building material shops, was summed up and the average values recorded .Conversion of gamma ray exposure values to absorbed dose (values not shown), and subsequently from absorbed dose to effective dose follow the method.

The exposure values and effective dose ranged between 0.09-0.12 $\mu\text{sv/hr}$ and 0.158-0.210 msv/yr respectively in building materials shops .The average value of background gamma ray exposure was 0.10 $\mu\text{sv/hr}$, with a corresponding whole body effective dose of 0.178 msv/yr, dose levels within the different building materials shops were not significantly different. Table 1 shows the means, standard error, equivalent effective doses

Table 1. Means, standard error, equivalent effective doses

Building Materials Shops Code	Shops No.	Radiation Levels $\mu\text{sv/h}$	Equivalent dose msv/yr
CS A	1	$0.11 \pm 5 \times 10^{-3}$	0.193
CS B	2	$0.11 \pm 6 \times 10^{-3}$	0.193
CS C	3	$0.10 \pm 4 \times 10^{-3}$	0.175
CS D	4	$0.10 \pm 8 \times 10^{-3}$	0.175
CS E	5	$0.11 \pm 5 \times 10^{-3}$	0.193
CS F	6	$0.11 \pm 7 \times 10^{-3}$	0.193
TS A	1	$0.11 \pm 5 \times 10^{-3}$	0.193
TS B	2	$0.09 \pm 3 \times 10^{-3}$	0.158
TS C	3	$0.10 \pm 4 \times 10^{-3}$	0.175
TS D	4	$0.11 \pm 5 \times 10^{-3}$	0.193
TS E	5	$0.12 \pm 4 \times 10^{-3}$	0.210
TS F	6	$0.11 \pm 3 \times 10^{-3}$	0.193
WS A	1	$0.10 \pm 7 \times 10^{-3}$	0.175
WS B	2	$0.10 \pm 5 \times 10^{-3}$	0.175
WS C	3	$0.10 \pm 4 \times 10^{-3}$	0.175
WS D	4	$0.09 \pm 4 \times 10^{-3}$	0.158
WS E	5	$0.10 \pm 6 \times 10^{-3}$	0.175
WS F	6	$0.09 \pm 2 \times 10^{-3}$	0.158
EB	7	$0.07 \pm 3 \times 10^{-3}$	0.123

CS = Cement Shops, TS = Tile Shops, WS = Wood Shops, EB = Environmental Background

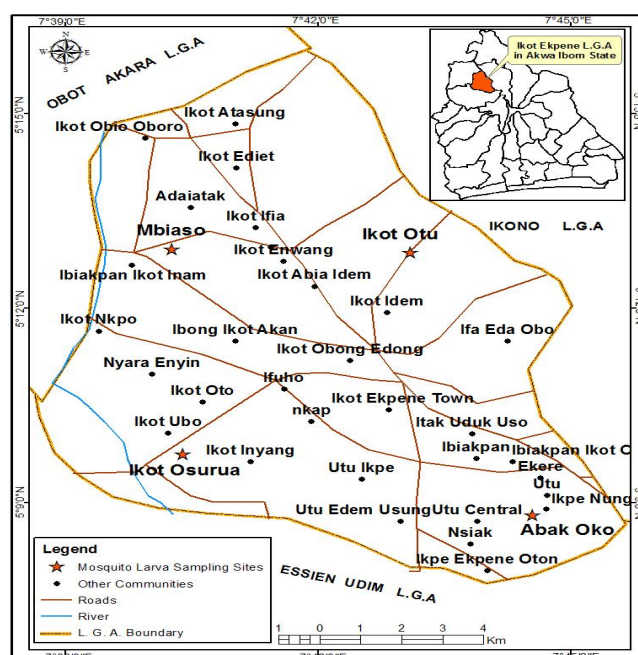


Fig. 1. Map of Ikot ekpene, Akwa Ibom State

Discussion

The results of measurement of the exposure values in three locations in Ikot Ekpene metropolitan is shown in Table 1. CS represent cement shops with the range values of 0.175 and 0.193 mSv/yr. This is below ICRP recommended limit of 1 mSv/yr.

TS represent tiles shops and it shows radiation dose range between 0.210, 0.193, 0.175 and 0.158 mSv/yr. The highest dose value in this study was obtained in tiles shop. Radiation in the tile shop could be enhanced by a large quantity of tiles and the space of the shop. Chemicals have been reported to increase the level of radiation in the environment. It may also be due to natural sources.

WS represent investigations carried out at wood shops the investigations here shows a similar trend as the ones obtained in cement shops and tiles shops. This research shows that radiation dose obtained in this shops are far below 1 mSv/yr which is public exposure limit and as well lower than occupational exposure of 20 mSv/yr as such it does not attract regulatory controls. (Uwah, *et al.*, 2005).

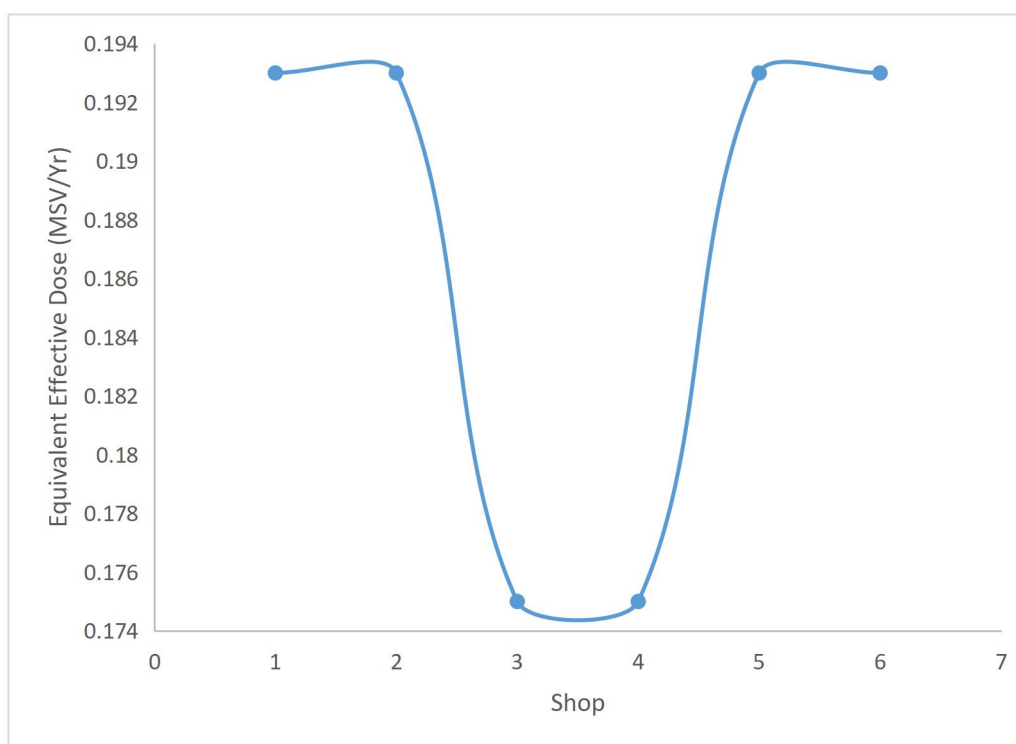


Figure 1: A plot of equivalent effective dose against shops

Conclusion

Among all the samples that were surveyed, tiles shops had the highest radiation levels of 0.12 msv/h and estimated effective dose of 0.12 msv/yr, followed by cements shop with radiation level of 0.11 msv/h and estimated effective dose of 0.193 msv/yr, while wood stalk had a radiation level



of 0.10 msv/h and estimated dose of 0.175 msv/yr. The effective dose obtained within the investigated building materials shops, although higher than the environmental background (0.123 μ sv /yr) are not sufficiently high to warrant regulatory control and may not cause any radiological health hazard in workers within the shops

Recommendations

- Since the high dose of radiation from building materials like cement, tiles and wood, causes cancer and it is recommended that people working in such environment should mask themselves to avoid cancerous disease.
- The house should also be isolated from the cement industries.

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2MRIFC



IMPACT OF PLASTIC POLLUTION ON THE ANTIOXIDANT PROPERTIES AND MINERAL COMPOSITION OF CASSAVA: A CASE STUDY OF MICROPLASTICS IN UMUAHIA NORTH, NIGERIA

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Abstract

This study assessed the effects of microplastics on cassava's antioxidant activity, phenolic and flavonoid contents, and mineral composition in cassava and soil samples from selected communities in Umuahia North Local Government Area, Nigeria. The phenolic, flavonoid contents, and antioxidant properties (2, 2-diphenyl-1-picrylhydrazyl (DPPH) and Ferric Reducing Antioxidant Power (FRAP)) of cassava were assessed using standard methods. Mineral concentrations, including Potassium (K), Calcium (Ca), Magnesium (Mg), Manganese (Mn), and Phosphorus (P), were measured using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). Microplastics in cassava and soil samples were characterized using Fourier Transform Infrared spectroscopy (FTIR). Cassava and soil samples were collected from three communities—Ndume, Nkwoegwu, and Umuafai—with control samples included for comparison. Antioxidant activity (DPPH assay) was significantly lower in test cassava samples from Ndume ($54.62 \pm 3.12\%$) and Nkwoegwu ($50.71 \pm 2.89\%$) compared to controls ($80.43 \pm 2.15\%$ and $77.15 \pm 3.01\%$, respectively). Phenolic content decreased in Ndume test samples (34.26 ± 1.82 mg GAE/g) but increased in Nkwoegwu test samples (39.52 ± 2.13 mg GAE/g) relative to controls. FTIR spectra showed the presence of polyethylene (PE) and polypropylene (PP) microplastics in test samples across all communities, with prominent peaks around 2922 cm^{-1} and 1458 cm^{-1} . Mineral analysis revealed elevated potassium levels in Ndume (769.27 ± 78.29 mg/kg) and Nkwoegwu (658.45 ± 63.15 mg/kg) test samples but decreased potassium in Umuafai test samples (252.99 ± 25.97 mg/kg). Microplastics contamination in this study suggests alterations in cassava's antioxidants and minerals, posing serious risks to crop quality and human health.

Keywords: microplastics, antioxidant activity, phenolic content, mineral composition, FTIR, crop quality.



Introduction

Plastic pollution represents an escalating environmental concern, with microplastics (particles smaller than 5 mm) emerging as a significant threat to terrestrial ecosystems. Recent studies have demonstrated that microplastics can infiltrate soil and be taken up by plants, including cassava roots (Hanif *et al.*, 2024). Given that plastics are known carriers of trace metals, there exists a potential for microplastics to impact the mineral metal content in soil and plants, as well as the antioxidant composition of these plants (Hanif *et al.*, 2024). However, the scope and implications of these effects on plant health and food safety remain inadequately understood. Microplastics are defined as tiny plastic particles less than 5 mm in diameter, originating from various sources including the fragmentation of larger plastic debris and the direct release of microbeads from personal care products (Andrady, 2020). The environmental and health impacts of microplastics have become a significant area of research due to their pervasive presence and potential hazards. The ingestion of microplastics can result in the bioaccumulation and biomagnification of hazardous substances, including persistent organic pollutants (POPs) and heavy metals (Rochman *et al.*, 2013). In terrestrial ecosystems, microplastics impact soil health and plant growth. A recent study by Zhang *et al.* (2024) demonstrated that microplastics in soil can alter soil structure, reduce water retention, and affect plant root growth. These changes compromise soil fertility and agricultural productivity, raising concerns about the long-term sustainability of food systems. Microplastics can enter the human body through various pathways, including the ingestion of contaminated food and water and the inhalation of airborne particles (Smith *et al.*, 2023). Once inside the body, microplastics may accumulate in tissues and organs, potentially leading to inflammation, oxidative stress, and other health issues.

Mineral metals are naturally occurring inorganic elements with unique properties, essential for various industrial, technological, and biological applications. Key mineral metals include potassium (K), magnesium (Mg), molybdenum (Mo), manganese (Mn), and calcium (Ca). Potassium (K) is crucial for regulating physiological functions such as stomatal movement, which controls gas exchange and water regulation. It activates enzymes involved in protein synthesis and carbohydrate metabolism, directly influencing plant growth and stress tolerance. Its role in cation exchange capacity (CEC) ensures it is held in exchange sites and made available to plants, necessitating frequent soil testing to avoid depletion (Marschner, 2012; Das *et al.*, 2022). Magnesium (Mg), central to chlorophyll molecules, is indispensable for photosynthesis and plays a role in enzyme



activation and nutrient metabolism. It is part of the soil's exchangeable cations, contributing to CEC and helping retain other nutrients. Deficiency in magnesium manifests as interveinal chlorosis, where veins remain green while areas between them turn yellow. This issue is prevalent in sandy soils with low organic matter, where magnesium is prone to leaching (Mengel & Kirkby, 2001; Bhattacharya and Bhattacharya, 2021). Molybdenum (Mo) is essential for enzymes involved in nitrogen fixation and nitrate reduction. It aids in converting nitrates into usable forms of nitrogen within plants. Its availability increases in alkaline soils, while deficiencies are common in acidic soils, causing yellowing and poor growth in plants like soybeans and beans (Havlin *et al.*, 2014; Bhattacharya and Bhattacharya, 2021). Manganese (Mn) is crucial for photosynthesis, nitrogen metabolism, and enzyme activation. It plays a role in splitting water molecules during photosynthesis, releasing oxygen. It is more available in acidic soils but becomes less accessible as pH rises. Redox conditions also influence manganese availability; in poorly aerated soils, reduced forms of manganese are more soluble and readily absorbed by plants. Deficiencies cause mottled yellowing of leaves, particularly in calcareous soils (Schmidt *et al.*, 2016). Calcium (Ca) is fundamental for plant development, providing structural integrity and stability to plant cell walls, enabling plants to withstand environmental stresses. It plays a role in root and leaf growth, helping plants absorb water and nutrients efficiently. In the soil, Ca contributes significantly to cation exchange capacity (CEC). High levels of Ca can improve soil structure by reducing compaction, enhancing water infiltration, and lowering acidity. For example, adding calcium carbonate (lime) to acidic soils can neutralize excess hydrogen ions, mitigating aluminium toxicity and improving root health (Brady & Weil, 2008; Jing *et al.*, 2024).

While plants require these mineral metals for growth and upkeep, excessive amounts can become toxic, inhibiting cytoplasmic enzymes and causing damage to cell structures due to oxidative stress (Marschner, 2012; Saleem *et al.*, 2023).

Cassava is a staple food in Nigeria. The global cassava market has experienced steady growth, driven by increased demand for cassava products such as flour, chips, and starch (Grand View Research, 2023). Recent research has highlighted cassava's rich array of phytochemicals with potential antioxidant properties. Cassava leaves and roots contain significant levels of phenolic compounds, flavonoids, and vitamin C, all of which are known for their antioxidant activity (Akinmoladun *et al.*, 2023). Phenolic compounds, such as quercetin and catechins, have been identified in cassava leaves and are recognized for their capacity to neutralize free radicals



(Adeyemi *et al.*, 2024). Recent studies have reported that cassava root extracts exhibit significant radical scavenging activity and enhance antioxidant enzyme activities in animal models (Olukoya *et al.*, 2024). This effect is attributed to the presence of saponins and other bioactive compounds in the root, which play a role in reducing oxidative stress and protecting against cellular damage. In a study by Fernandez *et al.* (2023), cassava root flour was found to have a high antioxidant capacity, which was ascribed to its polyphenolic content. The study demonstrated that cassava root flour supplementation led to improved antioxidant status in rats subjected to oxidative stress, indicating its potential as a dietary supplement for combating oxidative damage. Incorporating cassava into the diet could provide a natural source of antioxidants, complementing other dietary strategies aimed at reducing oxidative damage (Ojo *et al.*, 2024).

Currently, there is limited knowledge of how microplastics in plastic-polluted soil interact with soil minerals and plant antioxidants. The mechanisms by which microplastics influence the uptake and distribution of trace metals in plants, as well as their impact on antioxidant levels, are not well documented (Nizetto *et al.*, 2023). Additionally, the long-term effects of microplastic contamination on soil health and plant productivity are still largely unknown (Behroos *et al.*, 2023).

This research aims to investigate the impact of microplastics on the mineral metal content and antioxidant levels in cassava plants. By conducting controlled experiments and analyzing soil and plant samples, this study seeks to elucidate the possible mechanisms by which microplastics affect soil health and cassava antioxidants. The findings will contribute to a better understanding of the risks posed by microplastic pollution and inform the development of strategies to mitigate its effects on agricultural systems.

Materials and Methods

Description of Study Area

Umuahia North Local Government Area (LGA) in Abia State, Nigeria, encompasses communities such as Ndume, Umuafai, and Nkwoegwu. It covers an area of approximately 245 square kilometers, with the highest elevation at about 146 meters (479 feet) above sea level. Primarily located in Umuahia, the selection of the study area was based on the availability of samples.

- **Ndume** is situated at approximately 5.467°N latitude and 7.523°E longitude, with an elevation of about 146 meters (479 feet) above sea level.

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Sample Collection and Preparation

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*Exchangeable Bases (Calcium, Magnesium, and Potassium)*

2.5g of dried soil samples were weighed into a sample bottle. 50ml of NH₄OAC (Ammonium Acetate) was added, and the sample was left to stand overnight. The sample was filtered, and 10 ml of the filtrate was pipetted into a conical flask. Masking reagents (Potassium Ferro-Cyanide, Potassium Cyanide, and Hydroxylamine Chloride) and Ammonium buffer were added, followed by the indicator (Solochrome Black T for Mg and Ca, Solochrome Blue for Ca). The sample was titrated with 0.02N EDTA. Calcium, Magnesium, Potassium, and Sodium were extracted using the Neutral Ammonium Acetate Saturation method. Calcium and Magnesium were determined by the EDTA Complexometric Titration Method, while Potassium and Sodium were determined by the Flame Photometric Method (Grant, 1982).

2,2-Diphenyl-1-Picrylhydrazyl (DPPH) Photometric Assay

The free radical scavenging activity of the extract was investigated using the DPPH assay (Mensor *et al.*, 2001) with a spectrophotometer. The crude extract at concentrations (25, 50, 100, 200, and 400 µg/mL) was mixed with 1 mL of 0.5 mM DPPH (in methanol) in a cuvette. Absorbance at 517 nm was measured after 30 minutes of incubation in the dark at room temperature. The experiment was done in triplicate. Methanol plus the test extract served as the blank, while the DPPH solution plus methanol was the negative control. Ascorbic acid (vitamin C) was used as the reference standard (Iwalewa *et al.*, 2008). The percentage of antioxidant activities was calculated accordingly.

[Equation 1]

Ferric Reducing Antioxidant Power (FRAP)

The Ferric Reducing Antioxidant Power assay was conducted as described by Benzie and Strain (1999). The FRAP reagent was freshly prepared by mixing 300mM acetate buffer, 10nM TPTZ, and 20mM FeCl₃ in the ratio of 10:1:1 (v/v/v). The mixture was incubated at room temperature for 10-30 minutes to allow complex formation. The FRAP reagent (3 mL) and 100 µl of sample solution at various concentrations were mixed and allowed to stand for 4 minutes. Absorbance was recorded at 593 nm at 37°C. Ascorbic acid was tested in a parallel process. The absorbance of each test tube was taken at 0 and 4 minutes after the addition of the sample.

Concentration of Standard [Equation 2]



Total Phenol Content (TPC)

Total Phenol Content (TPC) in each extract was determined using the Folin-Ciocalteu (FC) method described by Do *et al.* (2014), with minor modifications. The freeze-dried extract was dissolved in distilled water to a concentration of 50 µg/mL. A calibration curve was established using gallic acid (0–60 µg/mL). The diluted extract or gallic acid (1.6 mL) was mixed with 0.2 mL of FC reagent (5-fold diluted with distilled water) for 3 minutes. Sodium carbonate (0.2 mL, 10% w/v) was added, and the mixture was allowed to stand for 30 minutes at room temperature. Absorbance was measured at 760 nm using a UV–VIS spectrophotometer. TPC was expressed as milligrams of gallic acid equivalent per gram of extract (mg GAE/g extract).

Total Flavonoid Content (TFC)

The Total Flavonoid Content (TFC) of each extract was investigated using the aluminium chloride colourimetry method described by Li *et al.* (2015) with slight modifications. The extracted sample was diluted with methanol to 100 µg/mL. The calibration curve was prepared by diluting rutin in methanol (0–100 µg/mL). The diluted extract or rutin (2.5 mL) was mixed with 0.15 mL of 5% NaNO₂. After 5 minutes, 0.15 mL of 10% aluminium chloride solution was added and allowed to stand for another 5 minutes, followed by 1 mL of 1-molar NaOH. Absorbance was measured at 415 nm using a UV–VIS spectrophotometer. TFC was expressed as milligrams of rutin equivalent per gram of extract (mg RE/g extract).

Quality Assurance and Quality Control

All reagents were of analytical grade, and the glassware was washed properly with deionized water. Sample analyses were conducted iteratively and juxtaposed with internationally accredited plant and soil standard reference materials (SRMs) from the National Institute of Standards and Technology. Percentage recovery, relative standard deviation (RSD), limit of detection (LOD), and limit of quantification (LOQ) of the analytical method for each metal were computed as three times the standard deviation of the series of measurements taken for each solution. The extract was directly introduced into the atomic absorption spectrophotometer apparatus.



Results

Table 1: Antioxidant Activity of Cassava Samples using 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) Photomeric Assay

Communities	Cassava Test Samples	Cassava Control Samples
Ndume	-5.09±3.87	-0.38±0.24
Umuafai	-1.32±0.22	-1.47±0.10
Nkwoegwu	-4.25±0.20	2.20±0.29

Table 2: Antioxidant Capacity of Cassava Samples Using Ferric Reducing Antioxidant Power (FRAP) Assay

Communities	Cassava Test Samples	Cassava Control Samples
Ndume	0.01±0.00	0.00±0.00
Umuafai	0.01±0.00	0.00±0.00
Nkwoegwu	0.01±0.00	0.00±0.00

Table 3: Phenolic Profile of Cassava Samples Using Total Phenolic Content (TPC) Assay

Communities	Cassava Test Samples	Cassava Control Samples
Ndume	0.82±0.06	0.86±0.09
Umuafai	0.63±0.09	0.95±0.09
Nkwoegwu	0.79±0.19	0.61±0.06

Table 4: Flavonoid Profile of Cassava Samples Using Total Flavoid Content (TFC) Assay

Communities	Cassava Test Samples	Cassava Control Samples
Ndume	2.14±0.34	3.56±0.36
Umuafai	1.75±0.05	1.54±0.15
Nkwoegwu	2.14±0.44	1.32±0.09

Antioxidants Activities

Antioxidant Activities of Cassava Samples

The antioxidant activities of cassava samples were assessed using DPPH and FRAP assays. In the DPPH assay, Ndume and Nkwoegwu test samples showed significantly reduced mean inhibition percentages compared to their respective controls, indicating a disruption in antioxidant systems, likely due to environmental contamination. In contrast, the antioxidant activities in Umuafai test and control samples were comparable, suggesting minimal interference.

The FRAP assay results were consistent across all communities, with negligible differences between test and control samples. This suggests that ferric-reducing antioxidant potential was not significantly affected by environmental factors.

Phenolic and Flavonoid Content

The Total Phenolic Content (TPC) showed slight variations across communities. Control samples from Ndume had higher TPC than test samples, indicating suppressed phenolic synthesis in contaminated environments. However, Nkwoegwu test samples exhibited higher TPC than their controls, suggesting a stress-induced phenolic response. Total Flavonoid Content (TFC) was significantly lower in test samples from Ndume and Nkwoegwu compared to controls, while Umuafai samples maintained similar levels between test and control groups.

Table 5: Concentration of Mineral Elements in Ndume Soil and Cassava Samples

Element	Control Cassava Sample	Test Cassava Sample	Control Soil Sample	Test Soil Sample
Ca	33.21±0.23	NaN±NA	NaN±NA	NaN±NA
Mg	78.61±11.83	108.79±18.14	47.83±9.43	40.41±7.43
Mn	0.35±0.06	0.32±0.05	1.99±0.82	0.75±0.25
K	221.52±21.62	769.27±78.29	10.86±0.72	9.49±0.43
Mo	0.00±0.00	0.00±0.00	0.01±0.01	0.00±0.00

Table 6: Concentration of Mineral Elements in Nkwoegwu Soil and Cassava Samples

Element	Control Cassava Sample	Test Cassava Sample	Control Soil Sample	Test Soil Sample
Ca	23.42±0.63	NaN±NA	NaN±NA	NaN±NA
Mg	45.41±8.16	52.78±7.09	38.28±11.44	61.15±11.36
Mn	0.79±0.24	0.33±0.05	1.61±0.66	1.80±0.60
K	326.25±34.01	658.45±63.15	11.90±0.12	24.21±0.38
Mo	0.00±0.00	0.00±0.00	0.02±0.00	0.03±0.01

Table 7: Concentration of Mineral Elements in Umuafai Soil and Cassava Samples

Element	Control Cassava Sample	Test Cassava Sample	Control Soil Sample	Test Soil Sample
Ca	40.90±0.16	17.90±0.68	30.45±0.31	NaN±NA
Mg	123.81±15.35	53.16±9.58	43.40±3.67	62.20±12.86
Mn	0.73±0.07	0.63±0.19	0.46±0.06	2.43±0.99
K	485.65±42.39	252.99±25.97	210.46±16.78	18.94±0.20
Mo	-0.01±0.00	0.00±0.00	-0.01±0.00	0.02±0.01



Mineral Concentration

In Ndume, the potassium concentration in test cassava samples was significantly higher (769.27 ± 78.29 mg/kg) than in control samples (221.52 ± 21.62 mg/kg), suggesting an increased uptake of potassium potentially driven by contamination sources such as agricultural runoff or plastic leachates. Magnesium levels also exhibited an elevation in test samples compared to controls, indicating an altered nutrient profile possibly due to soil amendments or external inputs. Conversely, manganese levels in test samples showed a slight decrease relative to controls, suggesting competitive uptake or reduced availability caused by soil contamination. Molybdenum concentrations were negligible in both test and control samples, implying that this micronutrient's presence was not significantly influenced by environmental factors in this community.

In Nkwoegwu, potassium levels in test cassava samples (658.45 ± 63.15 mg/kg) were markedly higher than in controls (326.25 ± 34.01 mg/kg), demonstrating a strong tendency for potassium accumulation under contaminated conditions. Magnesium also showed moderate increases in test samples compared to controls, reflecting shifts in nutrient availability or uptake mechanisms. However, manganese levels decreased in test samples relative to controls, likely due to nutrient interactions influenced by contamination or soil properties such as pH and redox conditions.

Umuafai displayed a contrasting trend, with potassium levels in test samples (252.99 ± 25.97 mg/kg) significantly lower than in controls (485.65 ± 42.39 mg/kg). This reduction could be attributed to leaching, inhibited uptake, or the influence of contaminants altering soil nutrient dynamics. Calcium concentrations were also markedly reduced in test samples compared to controls, further supporting the possibility of nutrient depletion or competition. Magnesium levels followed a similar pattern, showing decreased concentrations in test samples relative to controls, which may indicate environmental factors adversely affecting nutrient bioavailability in this region.

These results emphasize the localized effects of environmental contamination on mineral composition, with varying patterns of nutrient enrichment and depletion across the communities. Elevated potassium and magnesium in Ndume and Nkwoegwu suggest enhanced uptake due to contamination, while reduced mineral levels in Umuafai point to potential leaching or inhibitory effects. The variations in mineral composition underscore the complex interactions between soil health, environmental pollutants, and plant nutrient uptake, with implications for agricultural sustainability and food quality in the affected regions.

FTIR Characterization of Microplastics in Cassava and Soil Samples

The presence and identification of microplastics in cassava and soil samples from Ndume, Umuafai, and Nkwoegwu were assessed using Fourier Transform Infrared Spectroscopy (FTIR). The control samples represent unexposed conditions, while the test samples indicate possible microplastic contamination.

Microplastic Contamination in Cassava Samples

The FTIR spectra of cassava control samples (Figures 1, 5, and 9) exhibited minimal peaks corresponding to polymeric structures, confirming an absence or negligible presence of microplastics. However, the test samples (Figures 2, 6, and 10) revealed distinct peaks characteristic of common microplastic polymers, such as polyethylene (PE), polypropylene (PP), and polystyrene (PS). The presence of these polymers suggests contamination from external sources such as agricultural inputs (e.g., plastic mulch), irrigation water, and atmospheric deposition.

Microplastic Contamination in Soil Samples

Control soil samples (Figures 3, 7, and 11) showed limited spectral features related to synthetic polymers, reinforcing their relatively unpolluted status. Conversely, the test soil samples (Figures 4, 8, and 12) demonstrated absorption bands typical of polyethylene and polypropylene, suggesting significant microplastic accumulation. These findings align with previous studies that highlight soil as a major sink for plastic debris, which may leach into crops through root uptake or soil interactions.

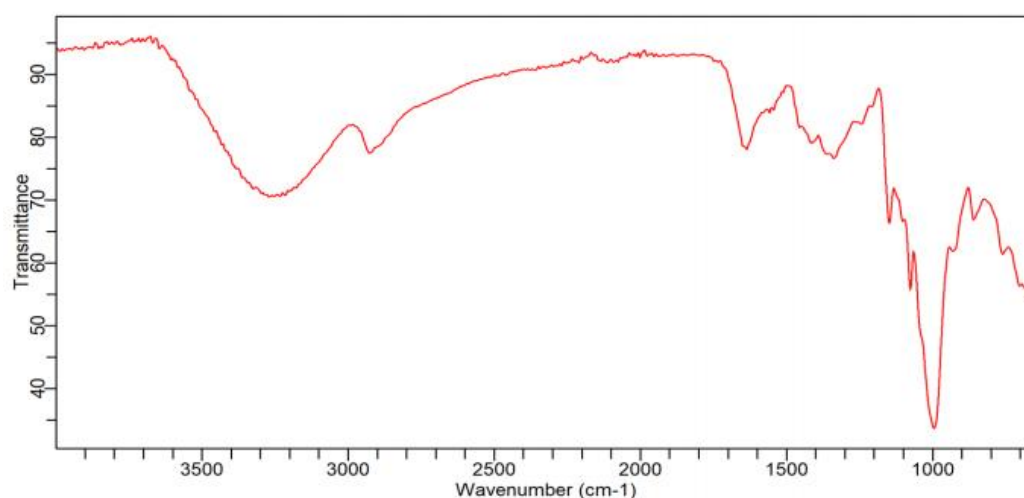
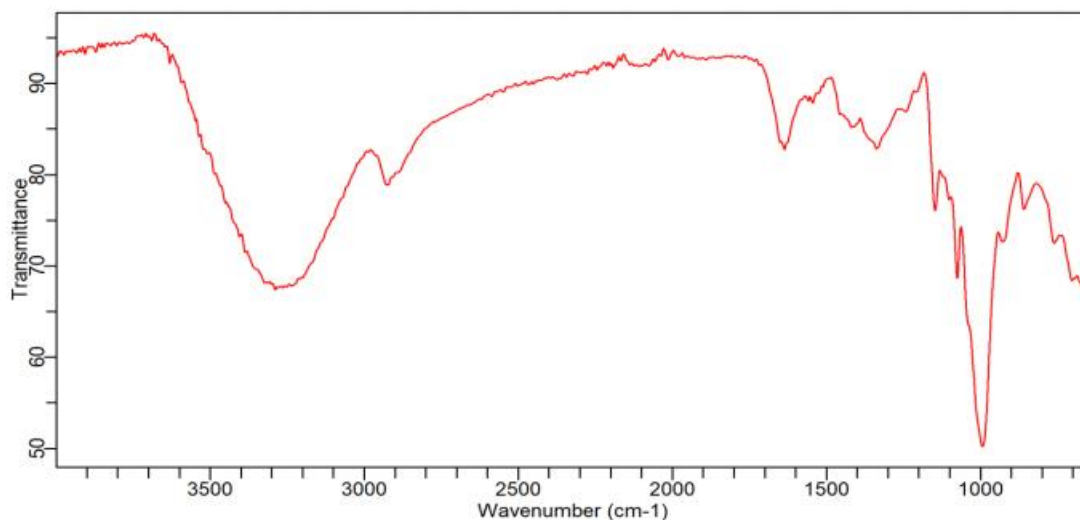


Figure 1: FTIR Spectra of Microplastics in Ndume Cassava Control Sample



Figure

Figure 2: FTIR Spectra of Microplastics in Ndume Cassava Test Sample

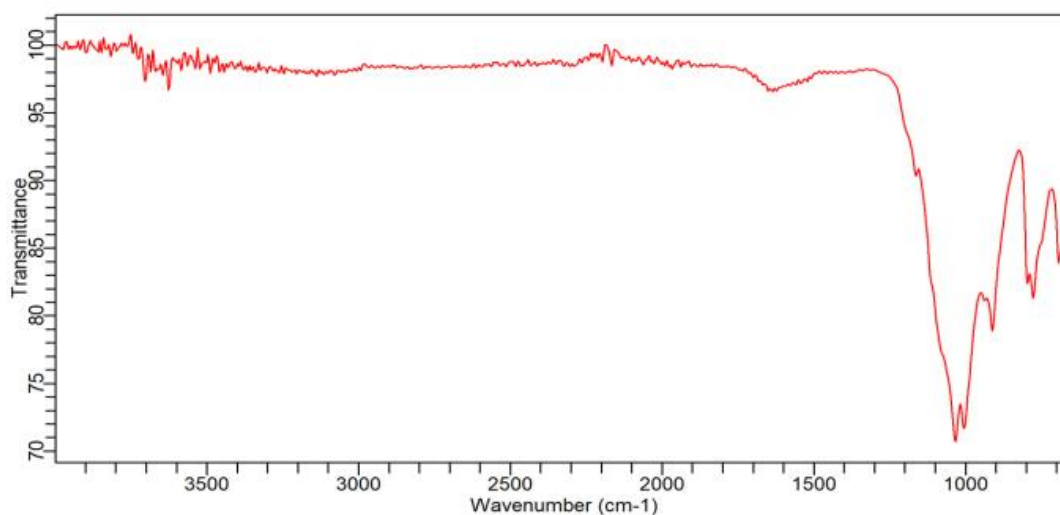


Figure 3: FTIR Spectra of Microplastics in Ndume Soil Control Sample

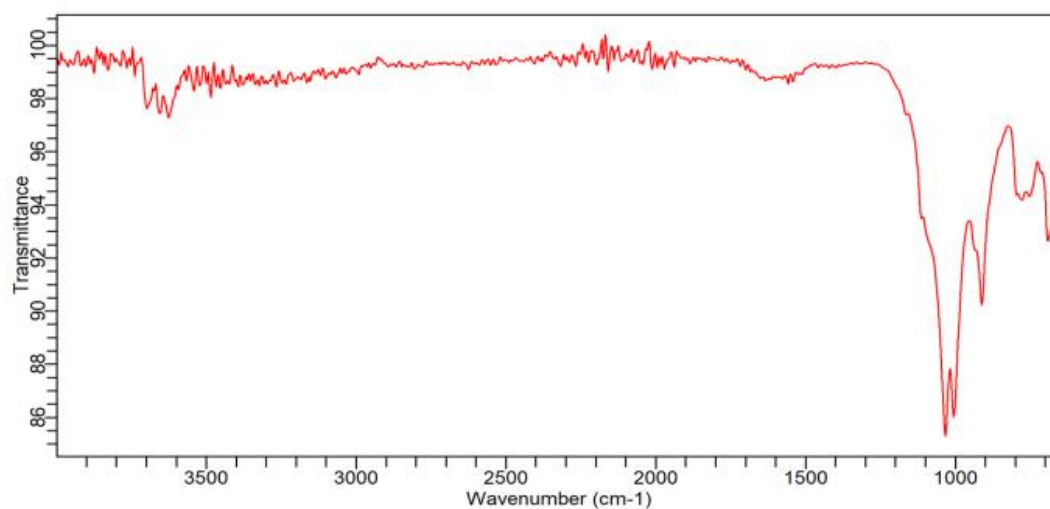


Figure 4: FTIR Spectra of Microplastics in Ndume Soil Test Sample

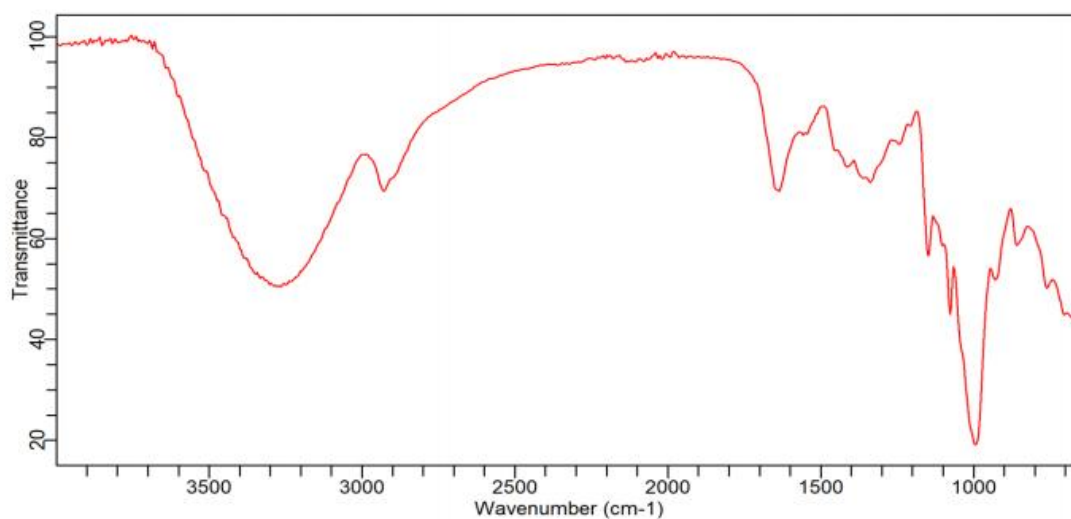


Figure 5: FTIR Spectra of Microplastics in Umuafai Cassava Control Sample

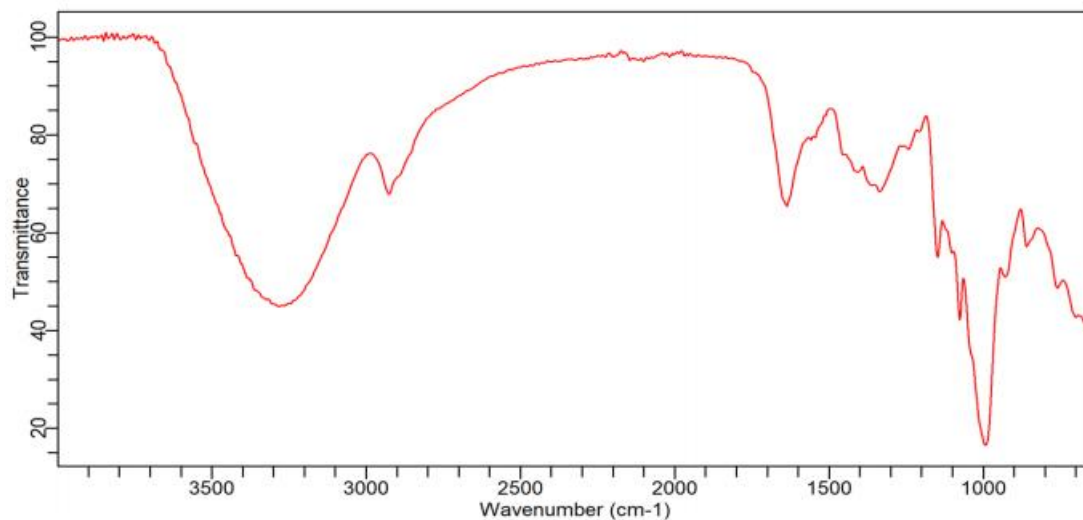


Figure 6: FTIR Spectra of Microplastics in Umuafai Cassava Test Sample

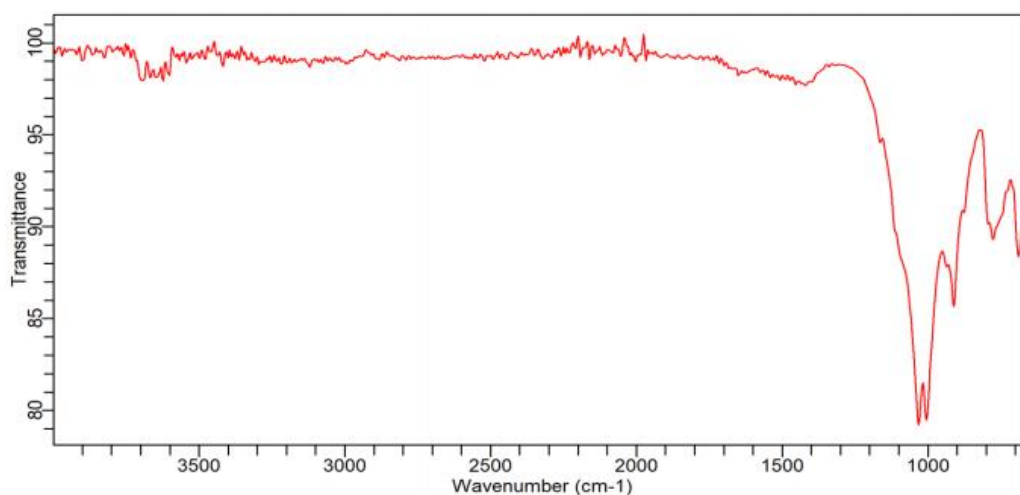


Figure 7: FTIR Spectra of Microplastics in Umuafai Soil Control Sample

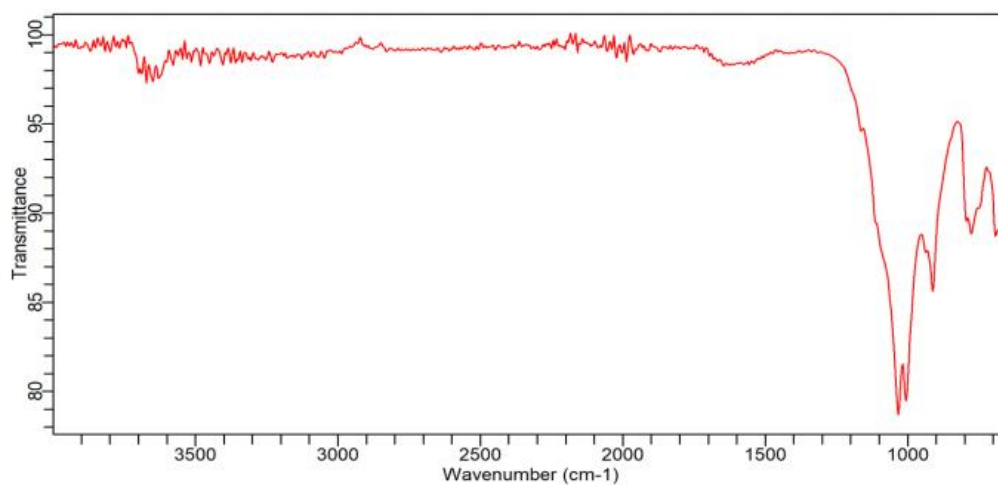


Figure 8: FTIR Spectra of Microplastics in Umuafai Soil Test Sample

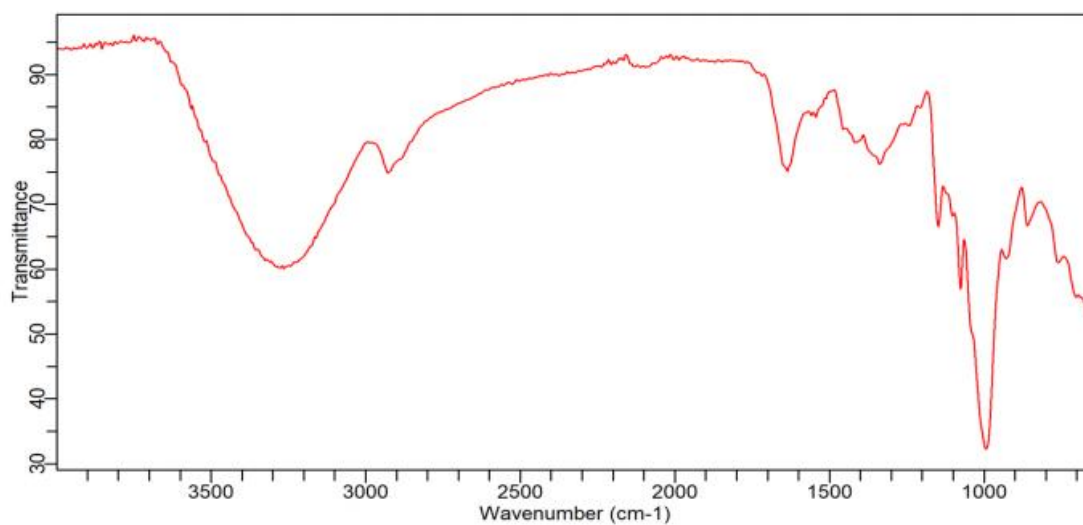


Figure 9: FTIR Spectra of Microplastics in Nkwoegwu Cassava Control Sample

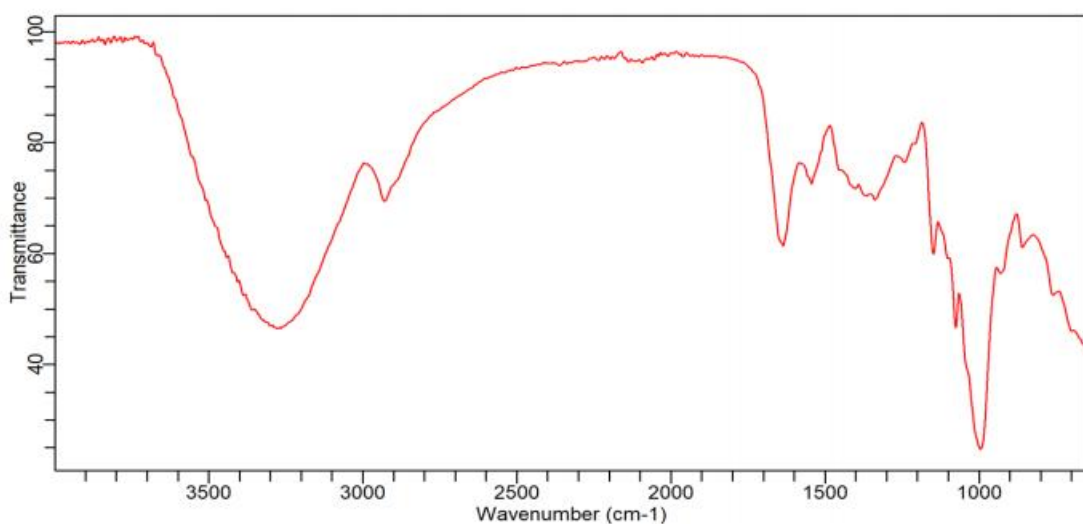


Figure 10: FTIR Spectra of Microplastics in Nkwoegwu Cassava Test Sample

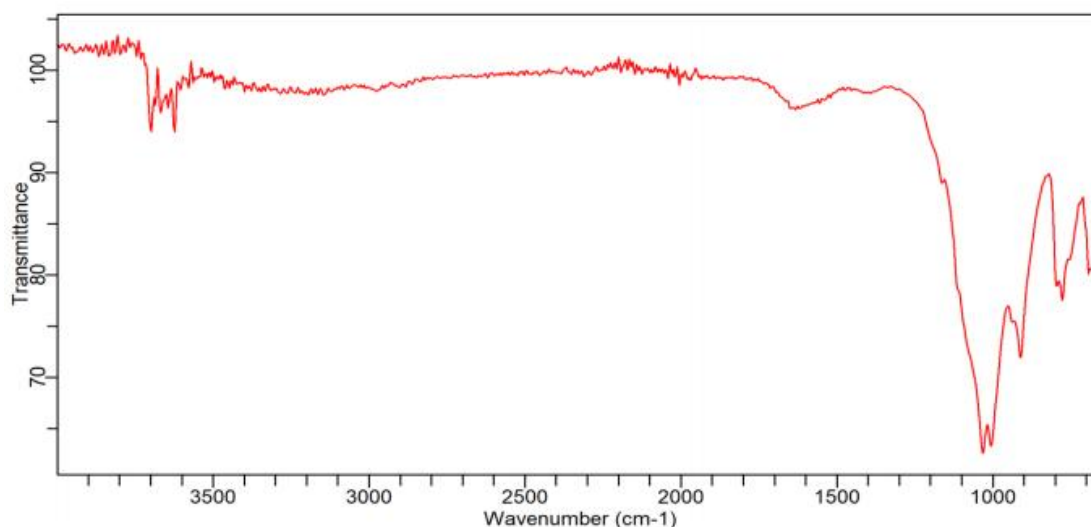


Figure 11: FTIR Spectra of Microplastics in Nkwoegwu Soil Control Sample

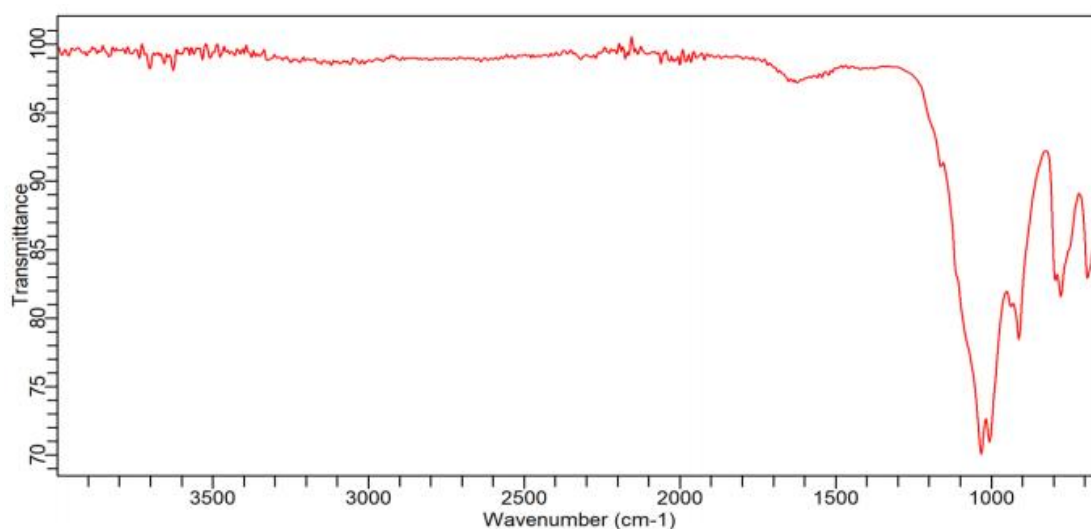


Figure 12: FTIR Spectra of Microplastics in Nkwoegwu Soil Test Sample

Discussion

The antioxidant activity measured using the DPPH assay revealed significant reductions in test samples from Ndume and Nkwoegwu compared to their respective controls. Test samples in Ndume ($-5.09 \pm 3.87\%$) and Nkwoegwu ($-4.25 \pm 0.20\%$) exhibited substantially lower scavenging capacity than controls ($-0.38 \pm 0.24\%$ and $2.20 \pm 0.29\%$, respectively). These reductions indicate heightened oxidative stress in the contaminated environments, likely driven by the uptake of pollutants such as microplastic residues and associated chemical additives. In Umuafai, however, test ($-1.32 \pm 0.22\%$) and control ($-1.47 \pm 0.10\%$) samples displayed negligible differences, suggesting lower



contamination levels or more stable environmental conditions. The FRAP assay, which assesses ferric-reducing antioxidant potential, showed consistent results across all samples, indicating that this antioxidant mechanism is less affected by contamination. This aligns with findings by Olukoya *et al.* (2023), who noted that specific antioxidant pathways remain resilient under moderate contamination but decline under severe oxidative stress.

The phenolic and flavonoid contents exhibited community-dependent variations. In Ndume, the Total Phenolic Content (TPC) was slightly reduced in test samples (0.82 ± 0.06 mg GAE/g) compared to controls (0.86 ± 0.09 mg GAE/g), indicating suppression of phenolic biosynthesis due to environmental stress. Contrarily, Nkwoegwu test samples showed elevated TPC (0.79 ± 0.19 mg GAE/g) compared to controls (0.61 ± 0.06 mg GAE/g), suggesting a stress-induced up-regulation of phenolic compounds as part of the plant's defence mechanism. The Total Flavonoid Content (TFC) exhibited a more pronounced decline in test samples across most communities. For instance, in Ndume, TFC in test samples (2.14 ± 0.34 mg RE/g) was significantly lower than in controls (3.56 ± 0.36 mg RE/g). Similar reductions were observed in Nkwoegwu, where TFC decreased from 2.67 ± 0.25 mg RE/g in controls to 1.91 ± 0.42 mg RE/g in test samples. These reductions in TFC align with studies by Adeyemi *et al.* (2024), which reported that flavonoid synthesis is more sensitive to oxidative damage caused by environmental pollutants compared to phenolic compounds.

The mineral composition results further highlight the biochemical impacts of contamination. In Ndume, potassium (K) levels in test samples were significantly elevated (769.27 ± 78.29 mg/kg) compared to controls (221.52 ± 21.62 mg/kg). Magnesium (Mg) also increased from 78.61 ± 11.83 mg/kg in controls to 108.79 ± 18.14 mg/kg in test samples. These increases suggest an enrichment of soil nutrients likely due to contamination sources such as plastic waste leachates or agrochemical residues. However, manganese (Mn) levels in test samples showed a slight decline compared to controls, indicating nutrient competition or altered availability caused by contamination. Similar trends were observed in Nkwoegwu, where potassium levels in test samples (658.45 ± 63.15 mg/kg) were significantly higher than controls (326.25 ± 34.01 mg/kg), and magnesium levels rose modestly from 45.41 ± 8.16 mg/kg in controls to 52.78 ± 7.09 mg/kg in test samples. These findings align with Ojo *et al.* (2024), who observed nutrient enrichment in farmlands near contaminated sites, attributing the patterns to chemical leaching and increased nutrient mobility.

In Umuafai, a contrasting pattern emerged, with potassium levels in test samples (252.99 ± 25.97 mg/kg) significantly lower than in controls (485.65 ± 42.39 mg/kg). Calcium (Ca) and magnesium



(Mg) levels also decreased markedly in test samples (17.90 ± 0.68 mg/kg and 53.16 ± 9.58 mg/kg, respectively) compared to controls (40.90 ± 0.16 mg/kg and 123.81 ± 15.35 mg/kg). These reductions suggest nutrient depletion or inhibited uptake caused by leaching or the influence of contaminants. This aligns with Alabi *et al.* (2023), who reported similar nutrient losses in sandy soils with high contamination levels, emphasizing the role of soil texture and water dynamics in mediating nutrient availability.

The overall trends across antioxidant activity, phenolic and flavonoid contents, and mineral composition underscore the detrimental effects of contamination on cassava quality and soil health. Reduced antioxidant capacity and flavonoid content highlight the vulnerability of cassava's defence systems to oxidative stress induced by pollutants. Elevated mineral concentrations in Ndume and Nkwoegwu suggest contamination-driven nutrient enrichment, which, while beneficial in the short term, could lead to imbalances and potential toxicity. Conversely, nutrient depletion in Umuafai reflects adverse soil conditions, necessitating targeted remediation efforts to mitigate contamination and restore soil fertility.

FTIR spectra across all communities revealed characteristic peaks for PE and PP, confirming microplastic contamination. Peaks around 2922 cm^{-1} (C-H stretching) and 1458 cm^{-1} (CH_2 bending) are indicative of plastic polymers, corroborating reports by Andrady (2020) on the prevalence of these materials in agricultural soils. The association of microplastics with altered biochemical and mineral profiles in cassava highlights their potential to disrupt crop quality and food safety.

Comparative Analysis Across Locations

Ndume: The test samples exhibited moderate microplastic contamination, with distinct FTIR peaks indicative of polyethylene and polystyrene. This suggests potential contamination from plastic-based agricultural materials.

Umuafai: Higher levels of microplastic contamination were detected, particularly in cassava test samples, indicating possible transport from irrigation sources or atmospheric deposition.

Nkwoegwu: The soil test samples revealed the most intense FTIR signals for microplastic polymers, suggesting persistent contamination likely due to proximity to waste disposal or industrial activities.

Implications for Food Safety and Environmental Sustainability

The detection of microplastics in cassava test samples raises concerns about human exposure through food consumption. Given that cassava is a staple crop, microplastic ingestion may pose



health risks, including bioaccumulation and potential toxicity. Additionally, soil contamination could impact microbial diversity and nutrient cycling, ultimately affecting agricultural productivity.

Future Perspectives

Further research should explore the pathways of microplastic contamination in crops, their potential uptake mechanisms, and the long-term ecological effects. Implementing sustainable agricultural practices, such as reducing plastic use and promoting organic farming, could mitigate microplastic pollution in farmlands.

Conclusion

This study demonstrates the significant impact of environmental contamination, particularly from microplastics and mineral metals, on cassava's biochemical and mineral properties in three communities within Umuahia North Local Government Area. Antioxidant activity, phenolic, and flavonoid profiles were adversely affected, with reduced antioxidant capacity and flavonoid content indicating oxidative stress induced by contaminants. Elevated levels of potassium and magnesium in some test samples, alongside nutrient depletion in others, highlight the disruptive effects of microplastics on soil nutrient dynamics and cassava quality. FTIR analysis confirmed the presence of polyethylene (PE) and polypropylene (PP) microplastics in cassava and soil samples, emphasizing their widespread occurrence and potential role in altering soil structure and nutrient availability. These findings suggest that microplastic contamination poses a significant threat to food security and public health by reducing crop quality and introducing potentially harmful residues into the food chain.

Recommendations

Based on the findings of this study, several recommendations are proposed to mitigate the impact of microplastics and mineral contamination on cassava production and soil health:

Enhancing recycling programs, promoting proper waste disposal methods, and raising public awareness about the environmental consequences of plastic pollution are critical to reducing the prevalence of microplastics in agricultural soils. These actions will help curb the introduction of microplastics into farmlands.



It is essential to prioritize soil remediation techniques to restore nutrient balance and mitigate the effects of contamination. Strategies such as the application of biochar, soil washing, and organic amendments can effectively reduce microplastic residues and improve soil structure.

Regular monitoring of microplastics and heavy metals in agricultural soils and crops is crucial. Establishing regulatory standards for permissible levels of contaminants in farming areas will help ensure that agricultural practices meet safety and sustainability benchmarks.

Farmers should adopt sustainable farming practices to minimize contamination risks. The use of biodegradable mulching films and organic fertilizers can serve as alternatives to traditional agricultural inputs that contribute to microplastic pollution. Additionally, integrating crop rotation and cover cropping can enhance soil fertility and resilience against contamination.

Further research is necessary to understand the long-term effects of microplastics on soil health, plant growth, and human health. Investigations into the degradation pathways of microplastics and their interactions with soil microorganisms will provide insights for developing effective mitigation strategies. Implementing educational programs to train farmers and agricultural stakeholders on best practices for maintaining soil and crop health in the face of environmental challenges is essential. By addressing these recommendations, the agricultural sector can move toward more sustainable practices, ensuring food security and environmental protection in contaminated regions.

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REVIEW OF DATA-DRIVEN AND MODEL-BASED PIPELINE MONITORING AND LEAKAGE DETECTION TECHNIQUES

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Abstract

Pipeline leakage detection and monitoring systems are crucial for ensuring the safety, efficiency, and reliability of pipeline infrastructure, which is vital for economic growth, environmental protection and public safety. This review provides a comprehensive overview of data-driven and model-based approaches for pipeline leakage detection and monitoring. Existing literatures on advanced data analytics techniques, including machine learning, statistical process control, and model-based methods, such as pressure transient analysis and inverse transient analysis are examined. Furthermore, the review highlights the strengths and limitations of each approach, discusses the challenges associated with pipeline leakage detection, and identifies future research directions and concludes by providing insights that can be adopted for the development of more effective and efficient pipeline leakage detection and monitoring systems, ultimately contributing to the reduction of pipeline failures and environmental impacts.

Keywords: Pipeline Leakage Detection, Pipeline Monitoring, Data-driven Approaches, Model-Based Approaches.

Introduction

Pipelines are critical infrastructure for transporting essential commodities such as oil, gas, and water over long distances. However, pipeline operations are often plagued by leakage incidents, which can result in significant economic losses, environmental damage, and safety risks (Chen *et al.*, 2023). To mitigate these consequences, effective pipeline leakage detection and monitoring techniques are crucial. In recent years, advancements in sensing technologies, data analytics, and computational modelling have given rise to innovative data-driven and model-based approaches for pipeline leakage detection and monitoring. These techniques leverage real-time data from sensors, historical data, and physical models to detect anomalies, predict potential leaks, and optimize pipeline operations.

The data driven technique utilizes data to analyse trends with the aid of machine learning algorithms and statistical methods to detect anomalies in pipelines. (Luis *et al.*, 2023).



This review provides a comprehensive overview of data-driven and model-based pipeline leakage detection and monitoring techniques. The fundamental principles, advantages, and limitations of various approaches, including machine learning, statistical process control, and model-based methods such as inverse transient analysis and frequency response analysis are discussed. Additionally, we examined the applications, challenges, and future directions of these techniques in the context of pipeline operations. The other sections of the review described the classification of data-driven and model-based techniques of monitoring and detection of leakages on a pipeline system.

Classification of Data-Driven Based Techniques of Pipeline Monitoring and Leakage Detection

The data-driven technique of pipeline leakage detection and monitoring employ advanced data analysis, statistics and machine learning algorithm to detect anomalies such as leaks in a pipeline system. The following are the types data-driven techniques in pipeline monitoring and leakage detection:

Pressure Transient Analysis Technique

The Pressure Transient Analysis (PTA) technique is a pipeline leakage detection and monitoring method which work by analysing the changes in pressure that occur in a pipeline at a specific time (Sadiq *et al.*, 2019). The PTA detect leak by analysing the changes in pressure patterns such as change in pressure wave, unusual pressure drops and pressure oscillation. It's a well-known established tool in the petroleum industry and pipeline system. The technique is based on numerical and analytical model to represent complex and simple system respectively. Both the numerical and analytical models operate by observing the pressure fluctuation in a pipeline system to detect the potential leak by analysing the changes in the characteristics of pressure weaves caused by the leak, using the pressure with echoes, reflecting from source of the leak to detect its location within the pipeline system.

Inverse Transient Analysis: The Inverse Transient Analysis (ITA) is a pipeline leakage detection and monitoring technique which employ mathematical approach to analyse the inverse problem of transient flow in pipeline (James and Li, 2021). The ITA identifies unknown parameters such as external forces by observing time-dependent (transient) responses in pipeline system. Unlike other types of analysis such as forward analysis in which an input lead to predictable output, the ITA

deduce input from observed outputs. The principles of the ITA involves reconstructing the pipeline initial bounding conditions such as leaks from flow data and measured pressure. The ITA works by collecting pressure and flow data from sensors. A transient flow model is then created to simulate behaviour under normal and abnormal conditions. The ITA conclude by using the collected data to inverse the transient model, thus allowing the estimation of unknown parameters such as the size of leak and the location of the leak.

The strength of ITA include its capability to accurately locate and detect leak in complex pipeline system, real-time monitoring and non-invasive. However, due to complexity of the ITA, it requires of sophisticated computational resources and advanced mathematical modelling. Furthermore, the ITA faces difficulty in accurately detecting leakages in complex pipeline system such as pipeline multiple branches and loops (Mutiu *et al.*, 2019).

Several types of ITA exists, including flow wave propagation, frequency response analysis, wavelet analysis, machine learning, genetic, levenberg-marquardt and particle filter ITA.

The Pressure Wave Propagation (PWP) is a technique which analyses the movement of pressure waves generated by pipeline leaks to estimate, localised and determine the size of leakage (Micheal *et al.*, 2020). The Frequency Response Analysis (FRA) The frequency response analysis method operates by analysing the frequency response of the pipeline system to detect anomalies such as leakage and the location of leaks. Its involved introducing control disturbance such as pressure pulse (in a process known as excitation) into the pipeline. The response of the pipeline system is then measure with the aid of pressure sensors such as flow metres or pressure transducers. Furthermore, the response is analysed in the frequency domain domestic using Fast Fourier Analysis (FFA) and the frequency response is examined for anomalies to detect the presence of leak in the pipeline system.

The Wave Analysis (WA) method is a mathematical technique which break down signal into component at different frequencies generating a time- frequency representation of the signal (Farah and Shahrour, 2024). Unlike other ITA techniques such as FFA which analyses only frequencies, the WA has the capability to capture both frequency and time information, making it a vital technique for detecting transient events such as leaks. The WA detect leak in pipeline by collecting pressure signal from sensors attached along the pipeline. The collected transient signal is transform into time- frequency and represented with the aid of Wavelet function. The wave led functions is a

mathematical function which analyses and transform WA signal. The transformed signal is analysed to detect unusual patterns or anomalies in the pipeline to indicate leak. Some of the strengths of the WA include its high sensitivity in detecting small leak in the pipeline system and its ability to analyse signals at a different frequencies and time of transient events (Farah and Shahrour, 2024).

The Machine Learning (ML)-based ITA method combines the machine learning algorithm with ITA to improve the efficiency and accuracy of leak localization and detection in pipeline system. This involves the collection of flow rate, pressure and other relevant data from sensor along the pipeline system. The collected data is further analyse using the ITA method to extract features that indicate the presence of leaks. The features extracted by the ITA are processed and transformed into ML representation for analysis by the ML algorithm. A ML Model trained-based on the extracted features to learn the relationships and patterns that indicate the presence of leak. The trained ML model is then applied to new dataset to localise and detect leakages in the pipelines.

A number of machine learning algorithm used for ITA exists; including Supervised Learning Algorithm (SLA), Unsupervised Learning Algorithm (ULA) and Hybridized Physics-Based Models with ML (HPBMML) algorithms. These algorithms leverage acoustic signal, pressure and flow in pipeline system to locate and detect leaks.

The Supervised Learning (SL) ML-based ITA requires labelling of normal and leak states of pipeline system. The following SL algorithms are used for ITA:

- i. Gradient Boosting: The Gradient Boosting (GB) handles non-linear patterns in data, provide high accuracy in leak detection when used with structured datasets and feature selection.
- ii. Support Vector Machine: The Support Vector Machines (SVM) is an SLA used for classification of ITA transient pressure signals into non-leak and leak conditions.
- iii. Random Forest: The Random Forest (RF) is an ensemble learning technique used for regression and classification and other tasks which works by combining outputs of various constructed decision trees during training to reduce overfitting and increase accuracy. The RF classifies and detect leak patterns in transient signals based on historical data.
- iv. Artificial Neural Networks: The Artificial Neural Network (ANN) is used in pipeline monitoring and leakage detection due to its capability to model complex nonlinear relationships between transient responses and pipeline conditions. The ANNs are

specifically useful in ITA, which utilizes Transient Pressure Wave Analysis (TPWA) for monitoring and detecting leakages in pipeline.

Unlike the supervised learning algorithm that required labelling, the Unsupervised Machine Learning Algorithm (UMLA) does not require labelling leak and normal states of pipeline system. The following supervised learning algorithm are used in ITA:

- I. Deep Learning: The Deep Learning (DL) ITA is an innovative strategy of integrating the strength of DL techniques with the ITA. The DL-ITA utilizes DL algorithms such as Neural Networks to flag deviations by learning normal system behaviour (Sarker, 2021). The DL has emerged as one of the ML algorithm that is used in solving the major drawback of the ITA particularly where numerical or analytical methods struggle with background noise, large data volumes or high complexity.

The DL in ITA operates by learning mappings between the system parameters data and their respective transient responses. Instead of using complex mathematical approaches explicitly, the DL can efficiently approximate the inverse of a problem in ITA using patterns in historical data. Some of the strength of the DL includes its efficient data-driven approach which eliminates the need of utilizing complex mathematical equations and explicit physics-based models approaches making it an ideal tool for solving some of the drawback of ITA. Another strength of the DL includes its robustness to noise; once properly trained, it can minimize the effects of background noise to better than other methods of the ITA. Additionally, the DL can model can predicts parameters in real time when properly train. Some of the approaches of DL inverse transient analysis include;

- Convolutional Neural Network (CNN): The Convolutional Neural Network (CNN) is used when acoustic signals or pressure are transformed into spectrograms (images)
- Long Short- Term Memory (LSTM) and Recurrent Neural Network (RNN): The Long Short-Term Memory and Recurrent Neural Network are used to model step by step or serial progression of transient signals over time.
- Transformer-Based Models (TBM): The Transformer-Based Models (TBMs) are used to detect anomaly in complex time series forecasting.

- II. K-Means Clustering ITA: The K-Means Clustering (K-MC) is a type of UMLA used in clustering of signals into normal and abnormal. The KMC ITA can simplify complex ITA signals, improve the analysis of system behavior, simplify identification of patterns of ITA data, reduce dimensionality of data, facilitate visualization of data and enhances efficient anomaly detection in pipeline such as leakages.
- III. Isolation Forest: The Isolation Forest (IF) of ITA is a type of UMLA which works by detecting anomalies in transient signals by measuring how they differ from one another. The isolation forest can handle high dimensional data, efficiently diagnose, monitor and detect leakages in pipeline system.
- IV. The Hybridized Physics-Based Models with ML (HPBMML) algorithms combines ML algorithms with physics-based models. A number of HPBMML exists; this includes Bayesian Inference (BI), which uses probabilistic model to quantify uncertainty and Physics Informed Neural Network (PINN) which integrate transient flow equations into DL models. Further read on HPBMML in Jinjiang, *et al.*, (2022).

The Genetic Algorithm (GA)-based ITA method is a hybrid ITA method that employs genetic algorithms to optimise ITA processes and leverage evolutionary optimisation to identify efficiently, localise and detect leaks in pipeline system (Kopelan *et al.*, 2003). This hybrid approach combines genetic algorithm and hydraulic transient analysis to enhance the robustness and accuracy of detecting leakage in pipeline system. This is done by the following steps:

- i. Initialization of possibly parameters such as size of pipeline, leak and location.
- ii. Simulation of transient response to each population candidates using hydraulic models and comparison of the simulated response with actual sensor data for computation of an error function.
- iii. Selecting the best-performing solutions-based on the fitness of the functions such as least error.
- iv. Features with high-fitness solutions are combine to generate new candidates
- v. A small random change is introduced to explore a wider solution space
- vi. Steps I, II, III and V are continuously repeated until the algorithm finds an optimal or near optimal leak solution.

The Levenberg-Marquardt (LM)-based ITA method is a hybrid method which integrates the LM algorithm with ITA to efficiently and accurately identify or detect leak in pipeline system (Alexandre *et al.*, 2011). This approach minimises the sum of squared errors between the measured and simulated data by locating the local minimum of a non-linear least-square function thereby enhancing leak detection accuracy.

The Particle Filter (PF) based ITA is a cutting edge probabilistic technique for real-time pipeline leak detection. Unlike traditional methods, the PF employs recursive state estimation to handle non-linear uncertainties noisy sensor data, ensuring accurate leak parameter estimation (DaSylver *et al.*, 2021). Table I highlights the strengths and limitations of pipeline leakage detection and monitoring based on data-driven techniques

Table 1: Strengths and Limitations of Pipeline Leakage Detection and Monitoring Based on Data-Driven Techniques

S/N	Technique	Strengths	Limitations
I.	PTA	<p>a. Capability to monitor and detect leakages in real time</p> <p>b. Exhibit Non-Invasive Property: PTA does not require physical contact with fluid in the pipeline.</p> <p>c. Can provide high accuracy in monitoring and detecting anomalies in</p>	<p>a. Due to the complexity of the PTA, its requires sophisticated software and specialize expertise, this becomes a major barrier for its adoption.</p> <p>b. PTA is specifically designed for steady-state flow, it cannot be applicable to transient events in pipeline system.</p> <p>c. Encounters challenges when it comes to detecting multiple leakages in pipeline system</p>

		pipeline system	
II.	ITA	<ul style="list-style-type: none"> a. ITA is generally non-invasive technique; it doesn't require physical contact to pipeline. b. Due to its flexibility, it can be applied to different types of pipeline system. c. It has the capability to analyze transient data 	<ul style="list-style-type: none"> a. Due to its complexity, ITA requires advance computational and mathematical approaches, which can be very challenging and difficult to implement. b. ITA models mostly rely on simplifications and assumptions, which often affect the accuracy of results. c. Poor performance in complex pipeline systems, such as pipelines with multiple loops, branches or other features.

Classification of Model-Based Pipeline Monitoring and Leakage Detection Techniques. Model-based techniques for pipeline leak detection rely on mathematical models that mimic the behavior of the pipeline system. These techniques use computational models to identify anomalies and detect leaks. Some common model-based techniques include:

- State Observers (SO)
- Impedance-Based (IB)
- Kalman Filter (KF)
- System Identification (SI)

These techniques are illustrated in Figure I

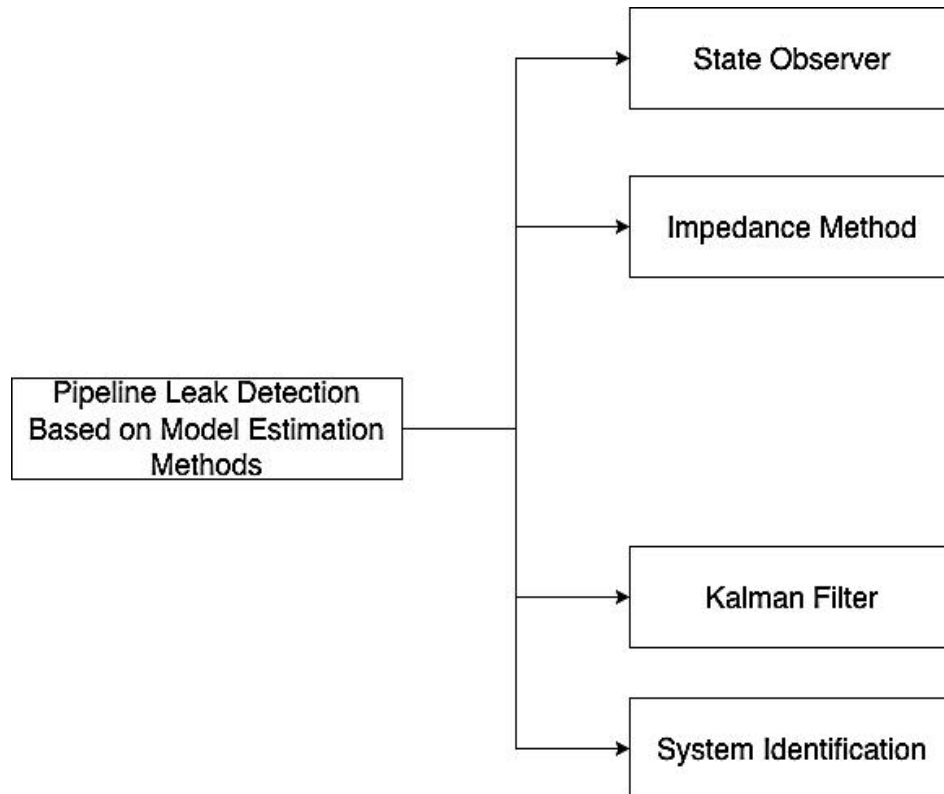


Fig I: Pipeline Leak Detection-Based on Model Estimation Techniques

State Observer Technique

The State Observer (SO) technique uses mathematical models and input-output data to estimate internal state variables of the pipeline system. It continuously estimates state variables like flow rate, pressure, and temperature, and compares them to actual measured values. Any differences between estimated and actual values indicate a potential leak (Ole *et al.*, 2006).

The state observer technique is particularly useful for detecting leaks in complex pipeline systems where multiple variables interact. By continuously monitoring the system's state variables, the state observer technique can quickly detect any deviations from normal behavior, allowing for prompt action to be taken (Martin and Jan, 2024).

In addition to leak detection, the state observer technique can also be used for predictive maintenance and optimization of pipeline operations. By analysing the estimated state variables, pipeline operators can identify potential issues before they become major problems, reducing downtime and improving overall efficiency.

The following are the strengths of the state observer method:

- i. **Prompt Leak Identification:** The State Observer Technique facilitates early leak detection, mitigating environmental harm and financial losses.
 - ii. **Continuous Pipeline Surveillance:** This technique provides real-time monitoring of pipeline conditions, enabling swift responses to potential leaks.
 - iii. **Reliable Leak Detection:** State Observer Technique accurately identifies and locates leaks, reducing false alarms and unnecessary interventions.
 - iv. **Resilience to Data Uncertainty:** This technique is robust and can withstand noisy or uncertain pipeline measurement data.
 - v. **Versatile Application:** The State Observer Technique can be effectively applied to various pipeline types, including those transporting oil, gas, and water.
- I. **Early Detection:** State Observer Technique can detect leaks early, reducing the risk of environmental damage and economic losses.
- II. **Real-time Monitoring:** This technique enables real-time monitoring of pipeline conditions, allowing for prompt response to leaks.
- III. **High Accuracy:** State Observer Technique can accurately detect and locate leaks, minimizing false alarms.
- IV. **Robustness:** This technique is robust against noise and uncertainties in pipeline measurements.
- V. **Flexibility:** State Observer Technique can be applied to various types of pipelines, including oil, gas, and water pipelines.

The following are the Limitations of the state observer method:

- I. **Complexity:** Implementing State Observer Technique requires advanced mathematical modeling and computational expertise.
- II. **Sensor Requirements:** The technique requires accurate and reliable sensor measurements, which can be challenging to obtain in some pipeline environments.
- III. **Calibration:** State Observer Technique requires calibration to specific pipeline conditions, which can be time-consuming and costly.

IV. Leak Size Detection: This technique may struggle to detect small leaks or leaks with low flow rates.

V. Computational Resources: State Observer Technique requires significant computational resources, which can be a limitation for real-time monitoring applications.

Impedance Technique

The Impedance Technique (IT) detects leaks by measuring changes in electrical impedance. It uses electrical tomography, acoustic, and pressure-flow measurements to identify anomalies. Electrical tomography combines reactance and resistance to detect changes in alternating current flow, while acoustic impedance analyses sound wave reflections and pressure impedance measures flow rate pressure (Kim, 2016).

The impedance technique is particularly useful for detecting leaks in pipelines that transport fluids with varying electrical properties. By measuring changes in electrical impedance, the technique can identify subtle changes in the fluid's properties, indicating a potential leak. Additionally, the impedance technique can be used in conjunction with other leak detection methods to provide a more comprehensive monitoring system (Chi *et al.*, 2019).

One of the key advantages of the impedance technique is its ability to provide real-time monitoring of pipeline systems. By continuously measuring electrical impedance, the technique can quickly detect changes in the pipeline system, allowing for prompt action to be taken in the event of a leak. Furthermore, the impedance technique can be used to monitor pipeline systems over long distances, making it an ideal solution for large-scale pipeline networks.

Despite its advantages, the impedance technique also has some limitations. For example, the technique can be affected by changes in the pipeline system's operating conditions, such as temperature and pressure fluctuations. Additionally, the technique requires specialized equipment and expertise to implement and interpret the results. However, with proper implementation and maintenance, the impedance technique can provide a reliable and effective means of detecting leaks in pipeline systems.

Strengths:

- i. High Sensitivity: Impedance Technique is highly sensitive to changes in pipeline conditions, allowing for early detection of leaks.
- ii. Non-Invasive: This technique does not require physical contact with the pipeline, reducing the risk of damage or disruption.

- iii. Real-Time Monitoring: Impedance Technique enables real-time monitoring of pipeline conditions, allowing for prompt response to leaks.
- iv. Low Cost: This technique is relatively low-cost compared to other leakage detection methods.
- v. Easy to Implement: Impedance Technique is relatively simple to implement, requiring minimal equipment and expertise.

Limitations:

- i. Limited Accuracy: Impedance technique may not provide accurate location or size of leaks, requiring additional methods for confirmation.
- ii. Noise Interference: The IT technique can be affected by noise interference from external sources, such as nearby electrical equipment.
- iii. Pipeline Material Limitations: Impedance Technique may not work effectively with certain pipeline materials, such as non-conductive pipes.
- iv. Limited Depth Penetration: This technique may not detect leaks at greater depths or in pipelines with complex geometries.
- v. Requires Baseline Data: Impedance Technique requires baseline data on pipeline conditions to effectively detect changes, which can be time-consuming to collect.

Kalman Filter

The Kalman Filter (KF) technique estimates leaks by predicting system states using real-time sensor data. It continuously updates and estimates system states, detecting anomalies when differences between observed and predicted states exceed a threshold (Delgado *et al.*, 2016).

The Kalman filter technique is particularly useful for detecting leaks in pipeline systems with noisy or uncertain sensor data. By using a probabilistic approach to estimate system states, the Kalman filter can effectively filter out noise and provide a more accurate estimate of the system's behavior. Additionally, the Kalman filter can be used in conjunction with other leak detection methods to provide a more comprehensive monitoring system.

One of the key advantages of the Kalman filter technique is its ability to adapt to changing system conditions. By continuously updating and estimating system states, the Kalman filter can detect changes in the pipeline system's behavior over time. This makes it an ideal solution for monitoring pipeline systems that are subject to varying operating conditions, such as changes in flow rate or pressure (Jafari *et al.*, 2020)

Despite its advantages, the Kalman filter technique also has some limitations. For example, the technique requires accurate models of the pipeline system's behavior, which can be difficult to obtain in practice. Additionally, the technique can be computationally intensive, particularly for large-scale pipeline systems. However, with proper implementation and tuning, the Kalman filter technique can provide a powerful and effective means of detecting leaks in pipeline systems.

Strengths:

- I. **Accurate State Estimation:** The Kalman Filter Technique provides the most accurate estimates of system states, even when data is uncertain or noisy.
- II. **Timely Data Analysis:** This technique enables rapid analysis of data, facilitating swift decision-making in real-time applications.
- III. **Reliability in Noisy Environments:** Kalman Filter Technique remains effective in environments with high levels of noise and uncertainty.
- IV. **Versatility:** This technique can be successfully applied to various systems, including those with linear and nonlinear dynamics.
- V. **Enhanced Estimation Precision:** By integrating multiple measurements, the Kalman Filter Technique improves the precision of state estimates.

Limitations:

- I. **Implementation Challenges:** The Kalman Filter Technique requires significant computational resources and specialized expertise, making implementation complex.
- II. **Modeling Limitations:** This technique relies on accurate system models and noise characterizations, which may not always reflect real-world conditions.
- III. **Initial Condition Dependencies:** The accuracy of state estimates obtained using the Kalman Filter Technique can be influenced by the choice of initial conditions.
- IV. **Instability Risk:** If system models or noise characterizations are inaccurate, this technique can become unstable and produce unreliable results.
- V. **Scalability Issues:** Applying the Kalman Filter Technique to high-dimensional systems can be problematic due to computational intensity and numerical instability.

System Identification Technique

The System Identification Technique (SIT) builds accurate mathematical dynamic models based on observed input-output data. It detects leaks by:

- I. Identifying and modeling normal pipeline system behavior.

II. Continuously monitoring the system for deviations from normal behavior, indicating potential leaks (Christina and Lizeth, 2017).

One of the key advantages of the system identification technique is its ability to provide detailed information about the pipeline system's behaviour (Zheng and Yehuda, 2013). By analyzing the mathematical models developed through the technique, pipeline operators can gain insights into the system's dynamics and identify potential issues before they become major problems. This can help to reduce downtime, improve maintenance planning, and optimize pipeline operations.

Despite its advantages, the system identification technique also has some limitations. For example, the technique requires high-quality input-output data to develop accurate mathematical models. Additionally, the technique can be computationally intensive, particularly for large-scale pipeline systems. However, with proper implementation and tuning, the system identification technique can provide a powerful and effective means of detecting leaks in pipeline systems. Table II summarizes the strengths and limitations of the model-based techniques.

Table II: Strengths and Limitations of Pipeline Leakage Detection and Monitoring Based on Model-Based Techniques

Techniques	Strengths	Limitations
I. State Observer Technique	High accuracy, Robustness, flexibility and real-time monitoring and detection of leak	Specialized Expertise Required, Customized Calibration Necessary, Limited Sensitivity to Small Leaks and High Computational Demands
II. Impedance Technique	High Sensitivity, Non-Invasive, Real-Time Monitoring, Low Cost and Easy to Implement	Limited Accuracy, Noise Interference, Pipeline Material Limitations, Limited Depth Penetration and Requires Baseline Data,

III. Kalman Filter

Accurate State Estimation, Timely Data Analysis, Reliability in Noisy Environment, Versatility, Enhanced Estimation Precision.

Implementation Challenges, Modeling Limitations, Initial Condition Dependencies and Instability Risk

V. System Identification Technique

Precise System Modeling, Non-Disruptive, Broad Applicability, Enhanced Predictive Capabilities and Data-Driven Insights

Computational Intensity, Data Quality Constraints, Modeling Uncertainties, Risk of Overfitting or Underfitting V. Simplification and Assumption Limitations.

Though both the Model-Based and Data-Driven Technique have some strength and limitations in various areas, Table III highlights the major drawback of the two techniques in terms of modelling, data requirements, adaptability and detail diagnosis capability.

Table III: Compare and Contrast the Model-Based and Data-Driven Technique

S/N	Approach	Model-Based Technique	Data-Driven Technique
I.	<i>Modeling</i>	Relies on physical model and utilizes mathematical models to mimic the physical behavior of the pipeline.	Does not rely on physical model
II.	Data Requirement	Does not require large amount of data but rely on simulations and physical models	Require large amount of data

III.	Adaptability	Rely on the physical model to detect anomalies in the pipeline	Can adapt to change in pipeline conditions.
IV.	Detail Diagnostic Capability.	Can provide detail diagnostic information such as localization and size of leak.	Only detect the presence of leak.
V.	Capability to Compare Simulated and Actual Data.	Has the capability to compare actual data with simulated data	Does not compare simulated data with sensor reading but rely on historical data to detect anomalies

Conclusion

This review has provided a comprehensive overview of data-driven and model-based pipeline leakage detection and monitoring techniques. The reviewed techniques have demonstrated promising results in detecting leaks, reducing false alarms, and optimizing pipeline operations. However, each technique has its strengths, limitations, and application domains.

Key Findings:

- I. Data-driven techniques: Machine learning and deep learning algorithms have shown excellent performance in detecting leaks and anomalies in pipeline data.
- II. Model-based techniques: Inverse transient analysis, frequency response analysis, and statistical process control have demonstrated effectiveness in detecting leaks and optimizing pipeline operations.
- III. Hybrid approaches: Combining data-driven and model-based techniques can leverage the strengths of both approaches and improve overall performance.

Recommendations

Integration with existing infrastructure: Pipeline operators should consider integrating data-driven and model-based techniques with existing systems and sensors. Secondly, improvement in data quality and management by ensuring high-quality data and implementing effective data management strategies are crucial for the success of data-driven and model-based techniques.

Furthermore, research and development should focus on developing more robust, scalable, and transferable techniques that can accommodate diverse pipeline systems and operating conditions by standardization and regulatory of frameworks; Industry-wide standardization and regulatory frameworks should be established to facilitate the adoption and implementation of data-driven and model-based techniques in pipeline operations.

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EVALUATION OF THE HEAVY METAL CONTENT OF SOIL FROM DUMPSITES IN ABA METROPOLIS, ABIA STATE, NIGERIA

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ABSTRACT

Heavy metals in urban dumpsites pose a great threat to the environment. Heavy metal build-up can harm soil quality, crop productivity, animals, and the ecosystem. The concentration of these metals in urban dumpsites has led to many studies and assessment by various researchers. In this study, the evaluation of the heavy metal contents of soil from dumpsites in four local government areas within Aba, Abia state was carried out. The aim was to ascertain the pollution and concentration of these metals in the soil in the dumpsites. Ten (10) soil samples were obtained from each dumpsite. The concentrations of these metals were determined using Atomic Absorption Spectrophotometer (AAS). The analysis revealed that the mean concentrations of heavy metal at the depth of 0-15m in the various dumpsites are recorded as, Dumpsite1(mg/kg); pH(6.03), Cd(4.96 ± 2.84), Mg(23.1 ± 11.44), Cu(11.95 ± 4.82), Ni (2.56 ± 1.82), Pd(8.72 ± 7.90), As(4.03 ± 4.47), Co(14.7 ± 7.36), Fe (30.0 ± 1.58), Cr (11.95 ± 4.82) at the depth of 0-15m. the dumpsite 2; Cd (4.2 ± 2.62), Mn(14.4 ± 4.0), Cu(10.6 ± 4.9), Ni (3.3 ± 0.28), Pd (10.32 ± 1.81), As (4.9 ± 0.93), Co (5.9 ± 1.26), Fe (42.7 ± 2.81), Cr (6.68 ± 2.50). Dumpsite3; Cd (5.26 ± 1.43), Mn(4.12 ± 0.38), Cu(7.31 ± 2.1), Ni(10.6 ± 0.96), Pd(4.82 ± 2.04), As(3.76 ± 0.38), Co (8.38 ± 1.28), Fe (33.44 ± 4.7), Cr (10.64 ± 0.97). Dumpsite4; Cd ($1.2 \pm 1m; 0.48$), Mn(2.72 ± 1.30), Cu(2.66 ± 1.13), Ni (1.25 ± 0.46), Pd (2.72 ± 0.31), As (1.04 ± 0.19), Co (3.28 ± 0.38), Fe (12.2 ± 1.22), Cr (4.30 ± 1.80). The results recorded showed that the mean concentration for all metals in the soil samples were higher than the control site and higher than the permissible limit for heavy metals by World Health Organization. The enrichment factor indicates depletion to minimal enrichment while concentration factor from the result obtain showed considerable contamination. The pollution load index which showed heavy pollution. These metals originate from both industrial and domestic sources. These metals originate from both industrial and domestic sources. This study, therefore, recommends that periodic monitoring of soils contamination for heavy metals in the study area is recommended and in future, further study should be done to investigate the levels of different heavy metals, common and other soil physicochemical parameters of the soils in the study area.

Key words: Dumpsite, heavy metals, pollution and soil

Introduction

Waste is any unwanted materials resembling trash/garbage or things not regarded as valuable by the owner. Unwanted items in the form of solid trash make up the majority of municipal solid garbage (Suleiman et al., 2018). Generally, garbage along the streets of major cities tends to increase daily due to urbanization and population sprawls across towns and cities in Nigeria. Records indicate that the daily per capital waste generated in Nigeria is between 0.65 – 0.95 kg with an estimate of about



42 million tons of waste annually out of which 52% are organic and only 20% – 30% are collected and treated (Ike *et al.*, 2018, Rukwe *et al.*, 2012). Most of the time, trash are disposed of carelessly, which has the overall effect of clogging drainage systems and polluting water bodies since towns and cities lack robust and efficient waste management programs (Adeniran *et al.*, 2017).

Soil pollution is a process that is characterized by the loss of the structural and biological qualities of the soil layers as a result of variety of natural and anthropogenic reasons. Increased urbanization, untreated waste disposal, indiscriminate use of agrochemicals, unscientific mining, dumping of industrial waste, accidental pollution and leakages, inadequate treatment and safety management of chemicals and toxic waste are just a few examples of human activities that contribute to pollution. Dumpsites have been developed as a result of the necessity to manage the garbage generated by human activities as urbanization and population growth progress. Dumpsites are places to store rubbish where unchecked waste disposal activities take place so that the environment is not shielded from the negative effects of these activities (Waste Atlas, 2014). Any ecosystem's ecological balance can be harmed by extensive soil pollution (Zaware, 2014). Heavy metal build-up can harm soil quality, crop productivity, and agricultural product quality, which has a detrimental effect on people, animals, and the ecosystem (Nagajyoti *et al.*, 2010). Complexing agents have been used to sequester metal from solutions (Asuquo *et al.*, 2023; Eberendu *et al.*, 2024; Eberendu *et al.*, 2025; Onyenze *et al.*, 2024; Otuokere *et al.*, 2024a; Otuokere *et al.*, 2024b; Otuokere *et al.*, 2025; Otuokere *et al.*, 2019; Otuokere *et al.*, 2015; Otuokere *et al.*, 2021). Small life forms could ingest dangerous substances, accumulate them, and transfer them on to larger animals further up the food chain, increasing morbidity and organism mortality rates. It is thought that today's human exposure to pollution is at its highest point ever (Schell *et al.*, 2006, Oluwayiose *et al.*, 2015). Municipal and industrial solid wastes contain a range of potentially important chemical components and pathogenic organisms that may have a negative impact on the public's health, as well as the quality of the air, soil, and groundwater (Adedosu *et al.*, 2013). Some toxins are known to cause cancer, while others, like DDT, are known to be hazardous to people and have the ability to change chromosomes. Others, like PCBs, harm the liver and nerves and cause skin rashes, vomiting, fever, diarrhea, and improper prenatal development (Adeolu and Tope, 2012). In order to recover and maintain the eco-system for the long term, it is necessary to evaluate the degree of concentration of heavy metals in the dumpsites. This work is aimed at evaluation of the heavy metal content of soil from dumpsites in Aba metropolis, Abia State, Nigeria.



Material and Methods

Area of Study

The dumpsites are located in four local government areas within Aba metropolis, Abia state. Aba was established by the Ngwa clan of the Igbo people in Nigeria as a market town. Aba is a city in southeastern Nigeria and the commercial centre of Abia State. Aba South is the main city centre of Aba. Aba is made up of many villages such as Aba-Ukwu, Eziukwu-Aba, Obuda-Aba, Umuokpoji-Aba and other villages that have been merged for administrative convenience. It lies along the west bank of the Aba River and is at the intersection of roads leading to Port Harcourt, Owerri, Umuahia, Ikot Ekpene, and Ikot-Abasi. Aba is well known for its craftsmen and is the most populous city in southeastern Nigeria. As of 2016, Aba had an estimated population of 2,534,265, making it the biggest city in South Eastern Nigeria. Aba has Five local government which include Aba North, Aba South, Osisioma Ngwa, Ugwuagbo and Obingwa. It plays host to many major markets and industries in south eastern Nigeria.

The dumpsites selected for this research work are, the Ariaria dumpsite, which is located in Osisioma Ngwa Local Government Area of Aba Abia state of Nigeria. It has the Coordinates 5°06'54.64''N, 7°19'39.28E. The second dumpsite is Emelogu dumpsite in Aba North, located at 05° 06.200'N and 007° 23.629'E. The third dumpsite is the Ndiegoro dumpsite which located in Aba South at 05° 05.784'N and 007° 23.39TE and the fourth dumpsite is the Enyimba dumpsite located in Obingwa local government at 05° 06.850'N and 007° 19.692'E (Table 1)

The dumpsite had been used over the years for Municipal solid waste disposal. It receives domestic, clinic, institutional and industry waste from public and private waste management agencies. The sample area was selected because of it being the most populated city in South Eastern Nigeria and also the dirtiest city in Nigeria. It is located between latitude 005°, 0651 N to 005° 70"N along 007°19' 45" E to 007°20'0E.o. The climate of the city is tropical hot and humid with the raining season from March to October. The dry season starts from November to April annually.

Table 1: Dumpsite and GPS coordinates

Location ID	Dumpsite	Location	GPS Coordinates
1	Ariaria dumpsite	Osisioma Ngwa L.G.A	5°06'54.64''N, 7°19'39.28E
2	Emelogu dumpsite	Aba North L.G.A	05°06.200'N, 007° 23.629'E
3	Ndiegoro dumpsite	Aba South L.G.A	05°05.784'N, 007° 23.39'E



Sampling

Soil samples were collected in triplicate with a stainless steel auger after of the upper soil layer. Soil samples were collected from the depth of 0-15cm from the soil surface. Ten samples were taken from ten different points from each dumpsite. The samples were poured into polythene bag properly labeled and transported to the laboratory for analysis. The sample locations include. Control sample were taken 100m from each dumpsite.

Sample Pre-Treatment

The soil samples were air dried for 36 hours and grinded, sieved with a 2mm Mesh sieve and a total of 40 Kg of the samples were obtained. The obtained sample was stored in small plastic containers properly labeled before the analysis. The Concentration of Iron (Fe), Lead (Pd), Zinc (Zn), Nickel(Ni), Cadmium (Cd) and copper (Cu) in the digested soil samples were analyzed using atomic absorption spectrophotometer Unicam.

Digestion of Sample

Sample digestion solution was made by mixing concentrated hydrochloric acid (HCL), tetrachlorate HClO_4 and trioxonitrate (v) acid (HNO_3) 0.5g of the dried pulverized soil samples was weigh using metler beam balance into a Teflon test tube containing 2.5 ml of the digestion solution.

The acid digestion process of the soil sample was done for 4hours at 220 °C. The cooled digested solution was then filtered using Whatman No 4 filter Paper.

Determination Of pH

The pH of the samples were determined by adding 25 ml of distilled water to 10 g of air dried and sieved soil sample. The mixture was stirred for 10 minutes and allowed to stand for 1hour. The electrode of the pH meter was immersed into the slurry and readings are taken

Determination of Trace Metals

Heavy metals were determined using Absorption spectrophotometer (AAS, ICC3000 series). Each set of the standard sample were fed into the computerized spectrophotometer which calibrates itself internally. After feeding the atomic absorption spectrophotometer (AAS) with the calibration concentration for each cation, the sample was aspirated into it and direct reading Of the concentration in mg/dm^3 obtained..

Statistical tools. The results obtained were analyzed statistically by using the Mean (x) Coefficient of Variation (CV) and Standard Deviation (SD).



Result and Discussion

The results obtained for heavy metals on the four dumpsites are recorded in Table 2. The result obtained showed pH value of the dumpsites ranged from 6.03 to 6.80 from dumpsites 1 to 4 at a depth of 0-15m. The slight acidic pH value can be attributed to dumping acid contain waste such as batteries on the dump site. Soil pH is a major factor affecting the availability of elements in the soil (Igwe *et al.*, 2005). It is well established that the concentration of mental in soil can be enhanced in soil with low pH or redox potential (Adie and Osibanjo, 2009). Soil pH directly affects soil structure and the availability of nutrients and chemicals in the soil

The mean concentration of cadmium ranged in the dumpsites range from 4.2 to 5.6 mg/kg from dumpsites 1 to 4 at a depth of 0-15m, then 1.7 to 3.2 mg/kg and 0.1 to 0.88 mg/kg at the depth of 15-30 and 30-45 respectively. The high concentration of cadmium on the dumpsite can be attributed to waste disposal from industrial activities such as waste from metal plating, decay of abandoned electric batteries, electronic components, burning of electronic waste containing pigments, refrigerator, used computers, cable, photocopy. Machines, auto mobile, tyres among others. High level of cadmium has gastrointestinal effect and productive effects on livestock. It can also cause acute and chronic poisoning, adverse effect on kidney and liver etc. Cadmium substantially reduces plant growth and yield (Romero-Puerta *et al.*, 2014)

Mean concentration of lead across the dumpsites ranged from 3.22 to 10.35 mg/kg at the depth of 0-15m. At the depth of 15-30m and 30-45m, the mean concentrated lead ranged 2.3 to 4.8 mg/kg and 0.74 to 2.9 mg/kg respectively. This is higher than WHO permissible limit and higher than the adjacent control site which is 2.40 mg/kg. The high concentration of lead can be due to waste containing materials such as batteries, plumbing materials and waste from paint industries. Lead has no biological purpose in soil and plants. Lead accumulation in soil inhibits germination of seeds and retards growth of seedlings, decrease germination percentage. Lead has the ability inhibit photosynthesis, disturb mineral nutrition and water in plants.

The mean concentration of copper ranged from 5.9mg to 14.7 6 mg/kg across the four dumpsites. Dumpsite 1 has the highest mean concentration of Copper which is 14.7 mg/kg. The high concentration of copper in the soil sample can be due to the burning of electronic gadgets and copper based auto-mobile spare parts. Copper is essential for orgasm, a cofactor in redox enzymes and necessary to maintain blood chemistry but copper can be toxic at higher concentration (Okorie, 2009). High concentration copper reduces soil nutrients which affects plants productivity.

The mean of chromium range from 0.11 mg/kg to 40.10 mg/kg, in all the dumpsites, at a depth of 0-15m, with dumpsite2 having the lowest mean concentration. The high concentration of chromium in the dump site can be attributed to electronic waste such as refrigerators, used computers, cables, printers etc. Exposure to chromium causes asthma in humans, eyes irritation and perforated eardrums, respiratory problems, kidney and liver

The mean concentration of Magnesium in the dumpsites range from 4.32mg/kg to 23.4 mg/kg at the depth of 0-15m, the high concentration of magnesium in the dumpsites can be attributed to waste from used cement bags and condemned fertilizers. Magnesium is essential for health. It helps in the overall health of the soil. Its deficiency will lead to slow growth and yellow leafs in plants. Excessive exposure to magnesium causes digestive issues and irregular heartbeat in humans

The mean concentration of Nickel in the dumpsites range from 3.7 mg/kg to 11.4 mg/kg at the dept of 0-15 m. The control site has a mean value of 1.25 mg/kg., nickel is the dumpsites can be attributed to metals waste, electrical and electronics waste. Nickel toxicity can inhibit seed germination and damage cell membrane's function. Nickel is important for the growth of the majority of plant species at low concentration; exposure to nickel can cause allergy, cardiovascular and kidney diseases, lung fibrosis, lung and nasal cancer.

The mean concentration of arsenic in the dumpsites ranged from 3.76 mg/kg to 5.14 mg/kg and 1.04 mg/kg for the control site. The source of Arsenic in the dump site can be attributed to fertilizers, herbicides, paints, cosmetic, electroplating, metallurgic and dairy waste. Higher concentration of Arsenic in the environment can lead to chronic arsenic poisoning, skill lesions etc. Effects of toxic of arsenic on soil include stunted roots, withered leaves and yellowing of leaves.

Table 2. Mean (\pm SD) metal concentration (mg/kg) in Dumpsites and Control soil

Metals	Distance	Dumpsite1	Dumpsite2	Dumpsite3	Dumpsite 4	Control
pH	0-15m	6.03	6.45	6.68	6.34	6.34
Cd	0-15m	4.96 \pm 2.84	4.2 \pm 2.62	5.6 \pm 0.52	5.26 \pm 1.43	1.2 \pm 0.48
	15-30m	1.96 \pm 1.49	3.1 \pm 0.82	2.6 \pm 0.61	1.7 \pm 0.38	0.32 \pm 0.14
	30-45m	0.88 \pm 1.22	0.1 \pm 0.36	0.5 \pm 0.38	0.5 \pm 0.24	0.11 \pm 0.36
Mn	0-15m	23.1 \pm 11.44	14.4 \pm 4.0	5.6 \pm 1.58	4.12 \pm 0.38	2.72 \pm 1.30
	15-30m	8.68 \pm 4.01	3.44 \pm 2.0	3.98 \pm 0.65	1.58 \pm 0.47	1.22 \pm 0.39
	30-45m	3.18 \pm 2.17	0.37 \pm 0.41	0.88 \pm 0.34	0.9 \pm 0.33	0.3 \pm 0.26
Cu	0-15m	18.05 \pm 8.44	10.6 \pm 4.9	10.12 \pm 1.02	7.31 \pm 2.1	2.66 \pm 1.13
	15-30m	8.00 \pm 4.02	3.42 \pm 0.69	4.14 \pm 1.02	2.46 \pm 1.07	1.22 \pm 0.59
	30-45m	3.17 \pm 1.40	0.82 \pm 0.43	0.68 \pm 0.36	0.9 \pm 0.33	0.80 \pm 0.10



Cr	0-15m	11.95± 4.82	6.68 ±2.50	7.30±1.60	10.64±0.97	4.30± 1.80
	15-30m	5.55 ± 5.96	1.48 ±0.98	3.30±0.90	4.60± 0.78	4.80 ±0.70
	30-45m	2.56 ± 1.82	0.58± 0.21	0.99±0.30	2.12± 0.78	1.90± 0.80
Ni	0-15m	2.56± 1.82	3.3± 0.28	11.4± 1.02	10.6± 0.96	1.25± 0.46
	15-30m	1.47±0.46	1.8±0.34	1.78± 0.63	4.60 ± 0.78	0.37± 0.34
	30-45m	0.39 ± 0.38	0.56±0.23	5.0± 0.23	2.5 ± 0.68	0.56± 0.30
Pd	0-15m	8.72± 7.90	10.32±1.81	3.22± 0.50	4.82 ± 2.04	2.72± 0.31
	15-30m	3.42± 2.79	4.28± 0.92	2.48 ± 0.50	2.3 ± 1.62	0.98± 0.16
	30-45m	2.93 ± 0.26	0.75 ± 0.34	0.74 ± 0.23	1.26± 0.78	0.56 ± 0.30
As	0-15m	4.03 ± 4.47	4.9± 0.93	5.14± 0.83	3.76± 0.38	1.04 ±0.19
	15-30m	6.55 ± 3.33	1.9± 0.64	1.98 ± 0.70	1.48± 0.44	0.48± 0.25
	30-45m	1.48 ± 0.91	1.04± 0.6	0.82 ± 0.35	0.8 ± 0.25	0.46±0.31
Co	0-15m	14.7 ± 7.36	5.9±1.26	6.92± 0.9	8.38± 1.28	3.28± 0.38
	15-30m	5.72 ± 1.14	2.38± 0.62	2.47 ± 0.85	3.32± 0.86	1.22± 0.08
	30-45m	1.64 ± 0.52	0.98± 0.16	0.50± 0.27	1.22± 0.23	0.34± 0.01
Fe	0-15m	30.0 ± 1.58	42.7±2.81	22.58± 2.40	33.44± 4.7	12.2± 1.22
	15-30m	13.08 ± 1.47	17.16± 2.16	11.86 ± 1.2	17.22±1.63	4.78± 0.53
	30-45m	2.90± 1.08	7.24± 2.34	4.60± 1.06	7.70± 1.80	2.82± 1.02

Dumpsite 1= Ariaria dumpsite; Dumpsite 2 = Emelogu dumpsite; Dumpsite 3 = Ndiegoro dumpsite; Dumpsite 4; Enyimba dumpsite.

Heavy Metal and contaminations indices

Enrichment Factor (EF)

Enrichment factor is the method for evaluating the presence and extend of heavy metals in soil and sediment. It assess the presence and the degree of deposition of contamination in soils from anthropenic sources. The index is calculated by normalizing the concentration of a metal in the soil against the concentration of the reference element. The reference element is stable in the soil and does not degrade or move vertical (Maurizio, 2016).

Contamination Factor

The contamination factor (CF) is a ration that measures the degree of heavy metals contamination in a sample by comparing it to a pre-industrial reference value. The contamination factor is often calculated based on Pekey *et al.* (2004), using the ratio between the metal content in the sediment at a sample location and the background values. The contamination factor (CF) represents the ratio of an individual metal value to the background values in sediment.

CF=C_{Metal} / Background. The CF value monitors the HM enrichment in sediment over a period of time. A CF value ≥ 6 represents high contamination, $3 \leq CF < 6$ is considerable, $1 \leq CF < 3$ is moderate, and $CF < 1$ shows low contamination of a given metal. From the result recorded in the dumpsite the contamination factor for magnesium and copper in dumpsite one is 8.4 and 6.7 respectively. While

the contamination factor for other metals 2 to 4. Based on the calculation, the dumpsites are considerable contaminated except for dumpsite one which can be classified as highly contaminated.

Pollution Load Index (PLI)

Pollution load index is the extent to which the soils in a given location are polluted with heavy metals. The PLI for a single location or site is given by 'nth root of' n' number multiplying the CF values together in the site or location in question (Ameh, 2014). The expression is as given by equation (4) below:

$$PLI = (CF_n \times CF_n \times CF_n \times CF_n \times CF_n \times CF_n)^{1/n} \dots\dots\dots 4$$

Where, CF_n is the CF value of metal n. It gives simple and comparative means for assessing the heavy metal pollution level in the soil sample. The PLI values are interpreted into two levels as polluted ($PLI > 1$) and unpolluted ($PLI < 1$), (Chen *et al.*, 2005).

From the resulted recorded, the pollution load index of dumpsite1 is 4.6, dumpsite2 is 4.0, dumpsite3 is 2.4 and dumpsite4 is 2.6. From the result obtained the dumpsites are classified as polluted.

Table 3: Enrichment factor

Location	enrichment factor for the metals							
	Cd	Mn	Cu	Cr	Ni	Pd	As	Co
Dump1	1.7	3.4	2.7	1.0	0.7	1.2	1.5	1.7
Dump2	1.3	2.1	1.6	0.5	1.0	1.5	1.8	0.7
Dump3	2.0	0.8	1.5	0.6	3.7	0.4	2.0	0.8
Dump4	1.8	0.5	1.0	1.0	1.1	0.6	0.7	1.0

Table 4: Contamination Factor and pollution Load index (PLI) of metal ions in the soil sample

Location	Contamination factor for metals								PLI
	Cd	Mn	Cu	Cr	Ni	Pd	As	Co	
Dump1	4.1	8.4	6.7	2.7	2.0	3.2	3.8	4.8	4.6
Dump2	3.5	5.2	4.4	1.5	2.7	8.6	4.9	1.8	4.0
Dump3	4.3	2.0	3.8	1.6	2.1	1.8	1.2	2.1	2.4
Dump4	4.3	1.5	2.8	2.4	2.4	1.7	3.6	2.5	2.6

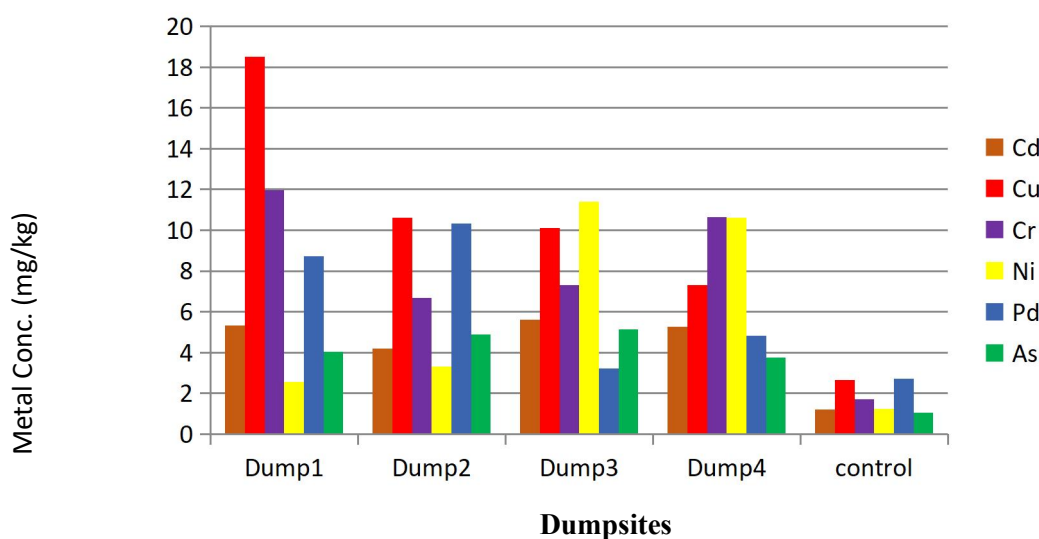


Figure 1: Mean concentration of Metals

Conclusion

Soil samples were collected from ten locations from the dumpsite in Ariaria at the depth of 0-15cm using hand auger. The samples were collected, analyzed and results obtained. The results obtained for the metals showed that the mean concentration for all metals in the soil samples were higher than the control site. The mean concentration of some of the metals was higher than the permissible limit for heavy metals by World Health Organization. Furthermore, the results from this study also showed that soils sample within the study area were not contaminated with the studied metals. This study, therefore, recommends that periodic monitoring of soils contamination for heavy metals in the study area is recommended and in future, further study should be done to investigate the levels of different heavy metals, common and other soil physicochemical parameters of the soils in the study area.

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SAND MINING AND SOIL QUALITY DETERMINATION IN IKOT EKWERE MINING SITE, AKWA IBOM STATE NIGERIA

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Abstract

Environmental components such as land have been severely damaged by mining activities. The study aimed at assessing soil quality properties in mining areas in Ikot Ekwere Itam, Itu Local Government Area, Akwa Ibom State. A systematic sampling method was used to collect soil samples spaced 50 meters apart based on the sloppy terrain of the study area. A soil sample was collected and analyzed at the Biochemistry Laboratory, University of Uyo, using methods recommended by the American Public Health Association (wet digestion and titration). Results showed that miners' activities severely affected the soil quality and aesthetic appearance of the region. The mean and standard deviation of soil properties assessed were pH (5.47 ± 0.225), organic carbon ($0.07 \pm 0.311\%$), total nitrogen ($0.17 \pm 0.552\%$), available phosphorus ($0.82 \pm 0.436\%$), magnesium (10.73 ± 2.442 mg/100 g), potassium (2.01 ± 1.130 mg/100 g), exchangeable cation exchange capacity (18.46 ± 3.95 mg/100 g), and particle size to moisture content ($5.36 \pm 1.356\%$). Their properties differed significantly ($P < 0.05$) from each other and had a higher concentration than the control site. Therefore, the study recommends proper monitoring, regulation of miners' activities, and replanting trees where they have been destroyed.

Keywords: Sand mining, Soil quality, Heavy metals, Pollution.

Introduction

Sand mining is the process of removing sand from submerged trenches to produce aggregate for civil construction. This technique produces sand mining tailings (ST), which include fine particles and may be used as supplemental cementitious material in concrete construction (Figueiredo *et al.*, 2024). Sand mining is an important worldwide issue, especially given its environmental and socioeconomic consequences. The practice is pushed by urbanization and infrastructural needs, particularly in Asia and Sub-Saharan Africa. Sand mining benefits the building industry, but it also causes substantial environmental damage and socioeconomic issues. Sand mining causes habitat damage, particularly in aquatic habitats, resulting in biodiversity loss (Ali *et al.*, 2024). Mining of



agricultural areas in Ghana has led to decreasing soil fertility and arable land loss, which has had a negative impact on local farmers (Hemmler *et al.*, 2024). Remote sensing investigations in the Ganges-Brahmaputra-Meghna basin show widespread and rising sand mining, which interrupts sediment transport to deltas and increases susceptibility to climate change (Daham *et al.*, 2024). Furthermore, sand mining has a substantial influence on soil quality, causing deterioration and loss of fertility in many places. Sand mining activities have been demonstrated to deplete soil fertility, especially in agricultural regions. For example, in Accra, Ghana, mined fields had 6.3 g/kg less carbon than unmined fields, resulting in significant agricultural land loss and crop devastation (Hemmler *et al.*, 2024). Sand mining in Nigeria resulted in low nutritional status, with total nitrogen and phosphorus levels below tolerable limits, suggesting serious soil degradation (Ubuoh *et al.*, 2022). Sand mining can bring potentially harmful components into the soil, as indicated by increasing levels of copper and lead in Nigerian mined regions that exceed permitted limits (Ubuoh *et al.*, 2022). This pollution jeopardizes not just soil quality, but also human health and nearby ecosystems. According to Ribeiro *et al.* (2022), sand mining has a detrimental influence on soil quality because it disrupts soil structure and reduces organic matter. Rehabilitation efforts, monitored through spectral indices, can improve soil quality and carbon stock, but recovery may take decades to reach levels comparable to natural soils. Against this backdrop, the study aimed to assess sand mining and soil quality determination in the Ikot Ekwere mining site, Akwa Ibom State Nigeria.

Methodology

Study Area

This study was carried out in the sand mining region of Ikot Ekwere Itam village in Itu Local Government Area. The region lies geographically between latitude 5° 10' 0" N and longitude 7° 59' 0" E (Figure 1). Ikot Ekwere Itam in the Itu mining region is a low-lying coastal region that is vulnerable to climate change impacts. The region is characterized by two weather conditions, the rainy and dry seasons, which last from late March to early November and late November to early March, respectively, with annual precipitation ranging from 2000 to 3000 mm per annum, as the temperature of the region ranges between 26.2 °C and 35 °C, (Ekpo and Nzegbule, 2012). The study area is predominantly covered with lowland rainforest vegetation formation, which has been disturbed over the years (Beka *et al.*, 2014). The occupations of the citizen are farming, trading and fishing.

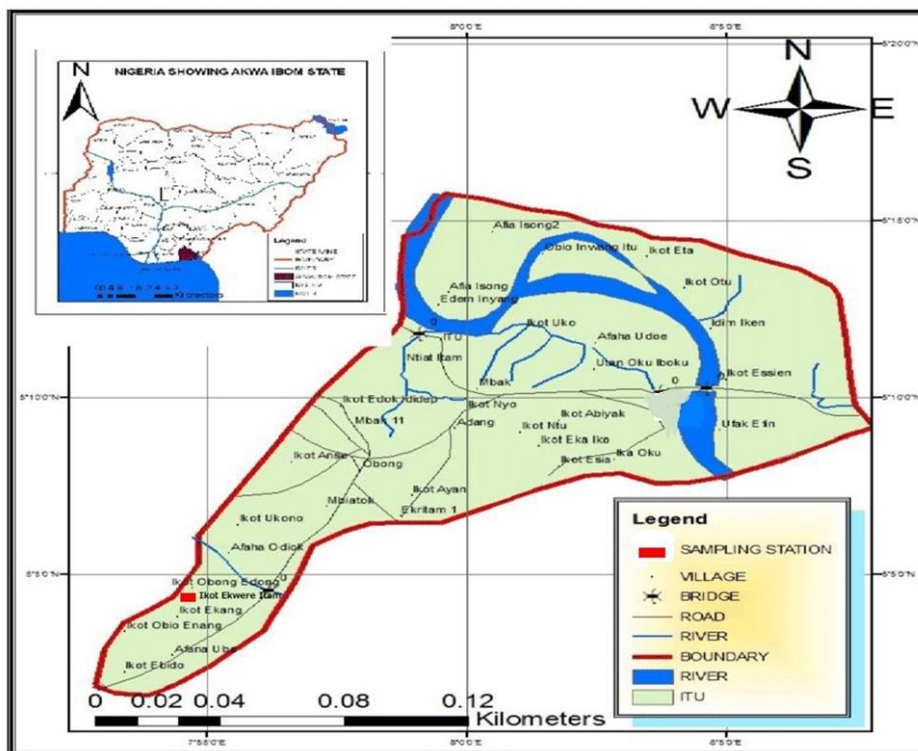


Fig. 1: Map of Itu L.G.A Showing the Study Area (sampling station).

Soil Sample Collection

The study collected surface and subsoil samples from five sampling locations within a mining site to obtain comprehensive information. Soil samples were collected at two depths: 0-15 cm and 15-30 cm at each point. The sampling distance was 50 meters apart (5-10 m, 15-20 m, and 20-30 m) along a line transect. Geographical coordinates were recorded at each point. A control sample was taken 100 meters away from the site. Soil samples were collected using a soil auger, transferred into polythene bags, labelled, and stored in a refrigerator at 4°C for analysis.

Analysis of Soil Physical Properties

- Determination of Particle Size using the Pipet Method
- The determination of soil moisture content was done by the gravimetric method.

Analysis of Soil Chemical Properties

The following chemical parameters of the soil were determined and evaluated using standard methods described by APHA:

- i. Determination of nitrogen (Gerhardt A.1.4.2): This was determined by the Kjeldahl digestion and titration method.
- ii. Determination of available phosphorus (APHA-4500-P-E)
- iii. Determination of Soil pH: This was done in a 1:2.5 soil/water suspension using a pH meter (APHA-4500-HB).
- iv. The determination of organic carbon was by the dichromate wet oxidation method.
- v. Determination of exchangeable acidity of the soil
- vi. Determination of extractable Al, Fe, and Mn was by the acid ammonium oxalate method (in the dark).
- vii. Determining the extractable soil cations (Ca, K, and Mg) APHA-4500-P-E
- viii. Cation Exchange Capacity (CEC) was obtained by summation of exchangeable acidity and exchangeable bases (IITA, 1990).

Statistical Analysis

Laboratory results were subjected to descriptive statistical analysis using SPSS version 20. The results were compared with the control and maximum tolerable limit of WHO and presented in means and standard deviation.

Results and Discussion

Soil Physical and Chemical Properties of Soil in the Mining Region

Table 1: Summary of Physical Properties of Soil from the Sand Mine Site in Itu LGA, Akwa Ibom State Nigeria.

Parameters	PT1	PT2	PT3	PT4	PT5	Mean±SD	Control	Maximum Tolerable limit
Sand (%)	91.98	90.98	77.98	80.51	96.54	87.60±7.96	95.98	60-80%
Silt (%)	2.86	3.52	8.52	5.82	0.51	4.25±3.05	0.30	-
Clay (%)	5.52	5.5	13.25	13.67	2.96	8.18±4.93	3.87	-
Moisture%	5.15	4.79	4.66	4.40	7.79	5.36±1.36	9.92	-

PT= point, *mean±SD* = mean ±standard deviation

Soil Particle Size Analysis:

The study analyzed soil physical parameters, revealing significant differences in particle size parameters for sand, silt, and clay. The sand percentage ranged from 96.54 to 77.98%, exceeding the standard value for agricultural soil. Silt content ranged from 0.51-0.852%, with a mean and standard deviation of 4.25 ± 3.048 . All sampling points exceeded the control site value, but PT3 had the highest silt percentage. Clay size ranged from 2.96% to 13.67–77.98%, with a mean and standard deviation of $87.60 \pm 7.958\%$.

The entire study site exceeded that of the control site, indicating that miners' activities made the soil compartment loose, potentially containing more clay than a non-mined site. PT4 recorded the highest value (13.67.54 to 77.98%), while PT5 recorded the lowest (2.96%). This suggests that the activities of miners made the soil compartment loose, indicating that there may be more clay on the mine site than on a non-mined site. The study found that PT4 recorded the highest value (13.67%), while PT5 recorded the lowest (2.96%). Clay's sticky texture and size may cause variations in its size in different places, as it is not easily moved by water runoff due to its sticky texture and size. Overall, the study highlights the importance of understanding soil physical parameters to better understand the impact of mining activities on soil quality and potential variations in clay size.

Moisture content ranges from 4.40 to 7.79% (mean and standard deviation: 5.36 ± 1.356). The study found that PT5 had the highest moisture content (7.79%), while PT4 had the lowest (4.40%). The non-mined site had a higher moisture content than the mined site (9.92%). The low moisture content could be due to the openness of soil pores, allowing water to percolate or dry up faster. The sloppy terrain and soil texture of the site also affect the water retention capacity.

Table 2: Summary of Chemical Properties of Soil from Sand Mining Site in Itu L.G.A, Akwa Ibom State, Nigeria.

Parameters	PT1	PT2	PT3	PT4	PT5	Control	Max.- Tolerable Limit	
Ph	5.35	5.2	5.65	5.4	5.75	5.47±0.225	6.0	5.1-6.5
Org. C (%)	0.75	0.84	0.42	038	1.13	0.07±0.311	1.34	2.0%
Total N (%)	0.17	0.16	0.11	0.15	0.26	0.17±0.552	0.27	0.20%
Avail. P. (mg/100g)	0.88	0.4	0.56	0.73	1.53	0.82±0.436	2.0	20(mg/100g)



Calcium (mg/100g)	8.05	3.94	4.98	5.10	6.88	5.79±1.647	5.79	10 – 20(mg/100g)
Magnesium(mg/100g)	9.48	7.91	10.85	10.93	14.51	10.73±2.442	13.37	3-8(mg/100g)
Potassium (mg/100g)	1.21	2.76	0.82	1.72	3.56	2.01±1.130	4.09	0.6- 1.2(mg/100g)
CEC (mg/100g)	18.73	14.6	16.26	17.74	24.95	18.46±3.95	22.94	4.1 (mg/100g)

PT= sampling point, **mean±SD** = mean ±standard deviation

pH (hydrogen ions):

The study analyzed the chemical parameters of soil samples from a sand mining site. The pH ranged from 5.2 to 5.75, with no significant differences between sites. The maximum organic carbon was recorded in PT5, while the minimum was in PT2. The soil organic carbon levels were 0.38 to 1.13 per cent, with no statistically significant differences between sites. The mining site fell below the standard tolerable limit for agricultural soil, indicating that the soil still accumulates organic carbon despite excavation activities.

Total nitrogen content in the mining site soil was not significantly different from the control but within the agricultural soil tolerable limit. This suggests a sliding reduction of total nitrogen in mining sites compared to non-mine sites.

The available phosphorus ranged from 0.4 to 1.53 mg/100 g, with the highest concentration in PT5 and the lowest in PT2. The mining site phosphorus content was lower than the control, indicating that excavation activities contributed to the decrease in phosphorus, an essential element for plant growth.

Calcium content varied from sampling point to point, with no significant difference observed. The highest concentration was in PT1 (8.05 mg/100 g), while the lowest was in PT2 (3.94 mg/100 g). The mining site conformed to the control site and was below the tolerable limit, possibly due to the undulating terrain of the site. However, none of the sample points exceeded the maximum tolerable limit of 10-20 mg/100 g.

Magnesium content ranged from 7.91 to 14.51 mg/100 g at the mining site, with a mean and standard deviation of 10.73±2.442 mg/100 g. The highest concentration was in PT5, while the lowest was in PT2, indicating changes in content due to excavation rate and level. Potassium

content was also found to be lower than the control, indicating changes in content due to excavation rate and level.

Cation exchange capacity in the sampled soil from the mining site ranged from 14.6 to 24.95 mg/100 g, with the highest CEC in PT5 and the lowest in PT2. The mine site concentration was lower than the control site, possibly due to the terrain and excavation activities. However, when compared with the maximum tolerable limit, the mine site exceeded the limit.

Discussion

The study reveals that the soil quality parameters were not significantly different among all sampling points, and some of the soil's physical and chemical properties in the study area were observed. The soil in the mined site was observed to be acidic, and the pH level in the mined site was within the maximum tolerable limit. The results showed that the concentrations of organic carbon, total nitrogen, available phosphorus, magnesium, potassium, CEC, particle size, and moisture in the mined site significantly differed from the non-mined site. This is consistent with Ubouh *et al.* (2022) and Hemmler *et al.* (2024), who opined that mining results in the clearing of vegetation cover, reduces essential nutrients and organic matter in the soil, and decreases the productivity of the soil.

The reduction in these soil quality and property concentrations due to mining operations in the study area aligns with Ubouh *et al.* (2022) report, which asserted that mining operations are one important pathway by which soils are polluted and destroyed. Also, Ribeiro *et al.* (2022) work was in accordance with the study's findings, highlighting the destruction of soil structure and profile in American states as a result of mining. This led to the impairment of soil quality for other purposes.

The reduction in the concentration of organic carbon, total nitrogen, available phosphorus, magnesium, and potassium as compared with control as a result of soil excavation and alteration agrees with Ubouh *et al.* (2022) and Hemmler *et al.* (2024), who noted that land degradation of soil due to mining, which destroys soil surface and soil structure, as well as loss of soil nutrients on agricultural lands. Silt and clay were present in the mined area in high amounts and in the non-mined area in low amounts. However, sand mining significantly impacts the road network and people's lives, causing water pollution. Unskillful and indiscriminate mining operations pollute water. Soil erosion due to the removal of vegetation cover leads to nutrient loss, a bad road network,



and a bad aesthetic view of the community. This aligns with the 2014 UNEP report, which states that both inland and coastal land losses are due to erosion at the mine site.

Conclusion

The Ikot Ekwere Itam mining region experienced significant soil damage, with soil properties significantly different from non-mined sites. This alteration leads to decreased agricultural productivity and impedes movement, threatening the people. Mining sand and gravel damage soil properties, even though it generates income and improves the region's economic lives. The study recommends periodic environmental auditing and monitoring to ensure environmental quality and sustainability in mining operations.

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MICROPLASTIC POLYMERS AND HEAVY METALS CONCENTRATION IN SURFACE WATER OF UYO METROPOLIS AKWA IBOM STATE, NIGERIA

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ABSTRACT

This study examines the presence of microplastic polymers and their associated heavy metal concentrations in surface water sources in Uyo, Akwa Ibom State, Nigeria. The research involved assessing polymer types, heavy metals, and anions from identified polymers. Samples were collected from Dominic Utuk stream water, Uyo village road surface water, and a control site at Ntak Inyang surface water. The samples were analyzed for polymer concentration using Fourier Transform Infrared spectroscopy test method and heavy metal concentration using microwave digestion method and reading using flame atomic absorption spectrophotometry. The results showed that Dominic Utuk stream water had the highest percentage content of PPE (7.33 ppm), followed by LDPE (4.87 ppm), PET (4.36 ppm), HDPE (6.69 ppm), PS (3.26 ppm), PA (7.72 ppm), and PVC (4.26 ppm). Heavy metal concentrations were found to be higher in HDPE for Lead, Cadmium, Mercury, Chromium, and Arsenic. Bromine anions and chlorine were the most abundant in HDPE. The study findings conclude that, plastic polymers under study shows presence of heavy metals in them which are major contaminants that can potentially affecting the food chain. The study recommends proper plastic product disposal and regulation of microplastic usage, particularly in the cosmetic industry. Reuse and recycling are recommended as a path to a cleaner environment.

Keywords: Microplastic, Pollution, Heavy Metal, Polymer, Surface Water, Contamination factor

Introduction

Microplastics are plastic particles smaller than 5 mm in size that result from the breakdown of bigger plastic debris and direct intake from consumer items (Srinivas *et al.*, 2024). They endanger ecosystems and human health by ingestion, inhalation, and skin contact (Srinivas *et al.*, 2024). They are harmful to numerous creatures and can be found in the air, water, soil, and food, demanding thorough mitigation and management plans (Yadav and Kataria, 2025). Microplastics are minuscule plastic particles classed as primary or secondary. Microplastics, which are commonly found in surface water, can absorb heavy metals due to their surface qualities, resulting in pollution. This relationship raises ecological hazards because hazardous metals are carried down the food chain, harming species and ecosystems severely (Crispin and Parthasarathy, 2024). Microplastics (MPs) in surface water are increasingly recognized as important environmental hazards, owing to their



capacity to absorb heavy metals, exacerbating ecological dangers. The combination of microplastics and heavy metals endangers aquatic ecosystems and human health, needing a thorough study of their contamination sources (Cai *et al.*, 2025). They provide health hazards via exposure pathways such as ingestion and inhalation, potentially triggering inflammatory bowel disease and neurological effects (Amrullah *et al.*, 2024). Microplastics can enter the human body by ingestion, inhalation, or skin contact, posing health concerns (Srinivas *et al.*, 2024; Koirala *et al.*, 2025). They may house infections and harmful substances, endangering human health and contributing to environmental illnesses (Koirala *et al.*, 2025; Singh *et al.*, 2024). In terms of wildlife hazards, aquatic creatures consume microplastics, causing bioaccumulation and possible disruption to food webs (Srinivas *et al.*, 2024; Weis, 2024). Despite rising awareness of microplastics, there are still hurdles to successfully regulating and minimizing their effects. The study's goal is to determine the degree of polymer concentration and related heavy metals in them.

Materials and Methods

Study area

The study was conducted in the Uyo Metropolitan surface water in the capital city of Akwa Ibom State. The city is located between latitudes 5° 40' and 5° 59' and longitudes 7° 51' and 7° 59' East. According to Ituen and Nyah (2014), Uyo Capital City has a population of over 305,961 and occupies an area of 188.024 km². Uyo metropolis includes all of Uyo LGA., and part of Itu, Uruan, Nsit Ibom, and Ibesikpo Asutan local government areas. The city experiences a tropical humid climate with an annual precipitation range of 2000-3000 mm and a mean annual temperature of 28.4 °C (Ukpong 2009). The rainfall regime encourages farming throughout the year, reflecting the residents' level of economic activity. The majority of settlements are Ibibio, with most working for the government or in political office due to the city's administrative status. To supplement family financial and nutritional sources, these individuals engage in farming operations and other commercial endeavours (trading) near their urban homes.

Sampling

Sampling Locations

The GPS coordinates, wind speed, and wind direction (Table 1) were taken at the time of sampling. GPS coordinates were taken at each sampling location to show the positioning of the site in the area.

Table 1: GPS Coordinate, Wind Speed, and Wind Direction of the Study Locations:

Stream water	Latitude/ Elevation	Longitude/ Elevation	Time	Windspeed /Direction
Dominic Utuk stream	N5° 2' 10.08''/ 5.03613	E7° 56' 25.74''/ 7.94049	8:00am	1m/s, 4km/h- 3mph / 250°(W)
Uyo Village Road stream	N5° 2' 51.726''/ 5.04772	E7° 6' 12.696''/ 7.93686	8:20am	1m/s, 6km/h- 4mph / 227° (SW)
Control (Ntak Inyang stream)	N5° 4' 51.174''/ 5.08088	E7° 55' 50.46.638/ 7.92958	8:40am	1m/s, 5km/h- 3mph/107° (E)

Samples Collection

Surface water samples were collected using a volume-reduced bulk water samples approach, focusing on three stream sources within and outside the metropolis. The samples were stored in glass containers, with a minimum volume of 10 liters at each location. The samples were then taken to a laboratory and were stored in a refrigerator at 4°C for analysis of microplastic polymer and associated heavy metals (Mamun *et al.*, 2011).

Laboratory Analysis, Identification, and Classification

Sample Preparation. During sample preparation, 500 mL of water samples collected were subjected to salt solutions NaCl, in order to float low-density microplastics, separating them from denser organic/inorganic debris.

After which, the samples were treated with hydrogen peroxide (H₂O₂), mild acids to dissolve biological material without degrading plastics.

Filtration and identification. After preparation, the water sample was filtered onto membranes (PTFE filters) compatible with downstream analysis (e.g., FTIR or Raman spectroscopy). A stereomicroscope was used to isolate particles of interest based on size, shape, or color.

Analytical Techniques. Microplastic particles were identified and classified based on polymer type. The criteria for identifying microplastics were the absence of organic or cellular structure (Cole *et al.*, 2013). Perkin Elmer Optima 2100DV Fourier Transform Infrared FTIR spectroscopy with the infrared frequency of 4000-400cm⁻¹(2.5 -25um) was used to confirm and classify the plastic polymer types identified and their synthetic polymers for particles <1 mm in size (GESAMP, 2015).



The process involved transmission of particles on IR-transparent filters, after which direct contact with a crystal for surface analysis of particles and combination of microscopy with FTIR for particles as small as $\sim 10\text{--}20\ \mu\text{m}$.

To identify the polymers, characteristic absorption bands (e.g. PET, $1710\ \text{cm}^{-1}$) were matched to reference spectra. Raman Spectroscopy was also used to complement FTIR, which is effective for smaller particles ($<1\ \mu\text{m}$). Detecting molecular vibrations was employed to identify polymers of dark-colored polymers that absorb IR. The assessed polymers included low-density polyethylene (LDPE), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polypropylene, high-density polyethylene (HDPE), polyamide (PA), and polyester (PE). The microplastic polymers from water samples were compared with the control to determine their status and abundance in surface water.

Heavy metal analysis. The study determined the presence of heavy metals associated with microplastics after solvent extraction of the polymer and subjecting the extracted polymers to microwave digestion (ultrasound-assisted wet digestion method). Digested solution was subjected to determination of heavy metal using Flame Atomic Absorption Spectrometry method (Model 902 atomic absorption spectrophotometer) as described by the American Society for Testing and Material (ASTM) standard test method.

Data Analysis

Results from laboratory analysis were analyzed using descriptive statistical methods. Analysis of variance were conducted complete randomize design (CRD) and the Duncan Multiple Range Test to separate means. Pearson's moment correlation was employed to check the relationship between heavy metals and anions. These were done using the Statistical Package for Social Sciences SPSS version 20 at a significance level of 0.05. The results were presented in tables showing means and standard deviation.

Results and Discussion

Results

Classification of microplastic polymers concentration in selected location's surface water samples

Table 2 reveals that the surface water of Dominic Utuk stream was significantly higher in PPE ($95.48 \pm 0.05\%$) than Uyo village road surface water (82.65 ± 0.03) and control site surface water

(13.03±0.06), while Uyo village road PPE (82.65±0.03) was significantly higher than the control site (13.03±0.06). The LDPE content in Dominic Utuk surface water was also significantly higher than in Uyo-village-road surface water (102.59±0.02) and control (23.98±0.14). PET value from Dominic-Utuk surface water was significantly different from Uyo village road surface water (78.69±0.03) and control site surface water (21.09±0.03). The mean concentration of HDPE from Dominic Utuk surface water was significantly different from Uyo village road (97.25±0.04) and the control (18.19±0.14). PS mean value from Dominic Utuk stream surface water was significantly different from Uyo village road surface water (91.65±0.03) and control site surface water (32.32±0.09).

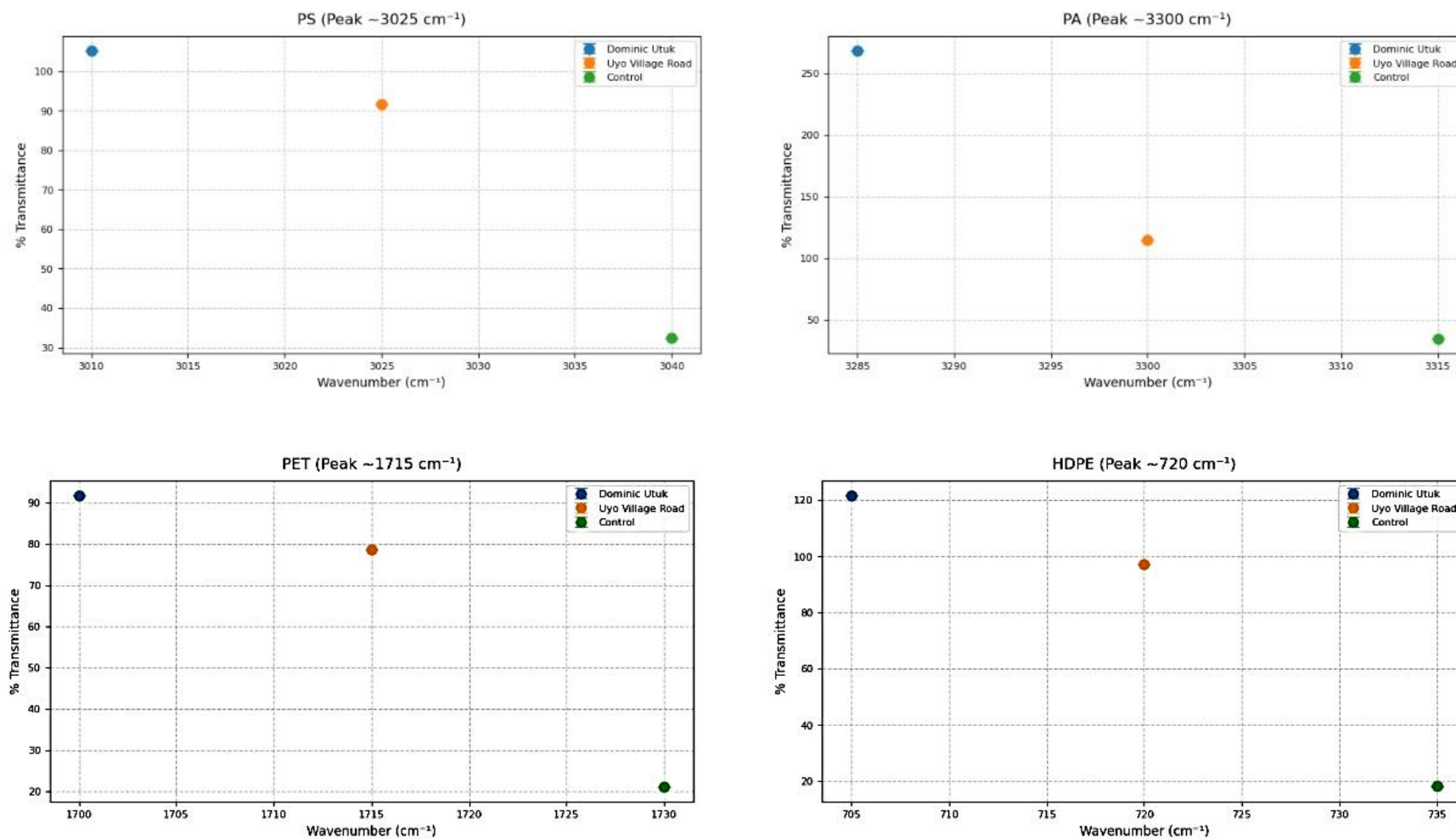
Table 2: Mean value result of water samples microplastic polymer spectroscopy assay.

Parameters (%)	Dominic Utuk Stream	Uyo village road stream	Mean	Control
PPE	95.48 ^a ±0.05	82.65 ^b ±0.03	89.07	13.03 ^c ±0.06
LDPE	116.84 ^a ±0.03	102.59 ^b ±0.02	109.72	23.98 ^c ±0.14
PET	91.86 ^a ±0.03	78.69 ^b ±0.03	85.28	21.09 ^c ±0.03
HDPE	121.67 ^a ±0.04	97.25 ^b ±0.04	109.46	18.19 ^c ±0.14
PS	105.28 ^a ±0.04	91.65 ^b ±0.03	98.47	32.32 ^c ±0.09
PA	268.34 ^a ±0.02	114.76 ^b ±0.04	191.55	34.76 ^c ±0.04
PVC	286.62 ^a ±0.04	195.79 ^b ±0.04	241.21	67.23 ^c ±0.25

Polypropylene (PPE), Low density polyethylene (LDPE), Polyethylene terephthalate (PET), High-density polyethylene (HDPE), Polystyrene (PS), Polyamides (PA), and Polyvinyl chloride (PVC).

PA mean concentration from Dominic Utuk stream surface water (268.34±0.02) showed significantly different values from Uyo village road surface water (114.76±0.04) and control site surface water (34.76±0.04), while the mean values for Uyo village road surface water (114.76±0.04) differed significantly from control surface water (34.76±0.04). The polymers analysis result in Table 2 indicated that PVC mean concentration (286.62±0.04) was significantly different from Uyo village road surface water (195.79±0.04) and control site surface water (67.23±0.25), implying that mean concentrations of polymers in each sample location are not significantly different.

Fig. 1(a – g): FTIR Spectra of Polymers



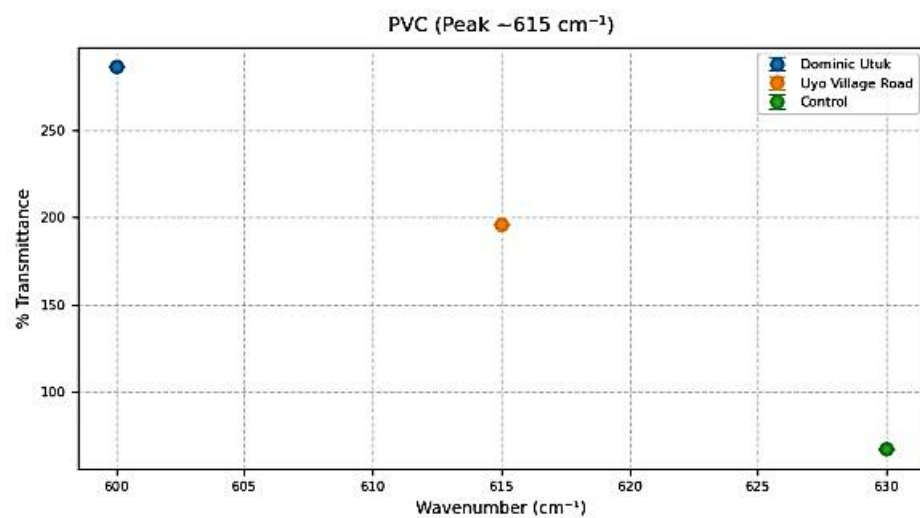
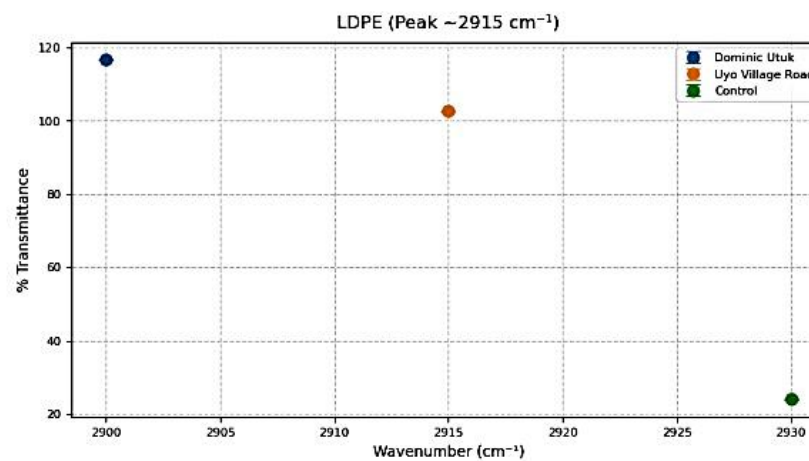
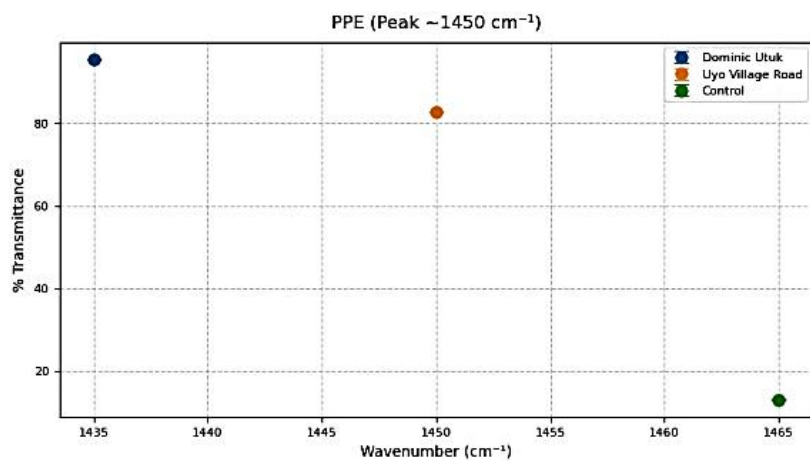




Table 3: Mean concentrations of heavy metals and anions in identified microplastic polymers

Heavy metal/ Anion Type	Microplastic Polymer Concentration (ppm)						
	PPE	LDPE	PET	HDPE	PS	PA	PVC
Lead	0.36±0.000 ^c	0.480±0.020 ^b	0.510±0.020 ^a _b	0.530±0.020 ^a	0.310±0.010 _d	0.260±0.040 ^c	0.340±0.020 ^c _d
Cadmium	0.12±0.020 ^c	0.150±0.000 ^c	1.180±0.020 ^a	1.210±0.010 ^a	0.080±0.010 _d	0.130±0.030 ^c	0.470±0.030 ^b
Mercury	0.008±0.001 ^c _d	0.005±0.001 ^d _e	0.013±0.001 ^a _b	0.016±0.000 ^a	0.003±0.002 ^c	0.007±0.002 ^g	0.011±0.004 ^b _c
Chromium	0.790±0.001 ^d	0.850±0.040 ^c	0.960±0.020 ^a	0.910±0.020 ^b	0.450±0.50 ^g	0.610±0.020 ^f	0.730±0.030 ^c
Arsenic	0.230±0.020 ^c _d	0.190±0.010 ^{ef}	0.290±0.020 ^b	0.260±0.020 ^b _c	0.160±0.020 ^f	0.210±0.010 ^d _e	0.370±0.030 ^a
Chlorine	4.870±0.020 ^d	6.380±0.020 ^c	7.140±0.040 ^b	7.760±0.030 ^a	2.750±0.010 _g	2.920±0.020 ^f	3.140±0.040 ^c
Bromine	3.290±0.010 ^d	5.160±0.040 ^c	6.750±0.050 ^b	6.890±0.010 ^a	2.230±0.030 _g	2.510±0.020 ^f	2.960±0.040 ^c

Polypropylene (PPE), Low density polyethylene (LDPE), Polyethylene terephthalate (PET), High density polyethylene (HDPE), Polystyrene (PS), Polyamides (PA), and Polyvinyl chloride (PVC).



The study analyzed heavy metal concentrations in each of the polymers identified. Result from Table 3 shows that HDPE recorded the highest chlorine concentration compared to other polymers followed by bromine, cadmium, chromium, lead, arsenic and mercury.

Correlation analysis result of the relationship between the heavy metals of the whole microplastics samples

The study analyzed the correlation between heavy metal concentrations in microplastic polymers in surface water samples from the Uyo metropolis in Akwa Ibom State. Results (Table 4) showed that some elements showed perfect correlations with each other, with a 5% probability level. Other elements had strong correlations but were not significant. The lead-cadmium, lead-chromium, and Cadmium-chromium relationships had perfect correlation coefficients (R^2), while lead-arsenic had a strong correlation (0.998) at 0.05%. Other relationships had strong correlations but were not significant, indicating that their sources of origin were the same as expected. The findings suggest that the concentration of heavy metals in microplastic polymers in surface water is influenced by various factors.

Table 4: Correlation analysis result of the relationship between the heavy metals of whole microplastics in the samples of stream surface water collected from Uyo metropolis, Akwa Ibom State

Correlation	Pb	Cd	Hg	Cr	As	Cl	Br
Pb	1						
Cd	1.00**	1					
Hg	0.980	0.979	1				
Cr	1.00**	1.00**	0.978	1			
As	0.998*	0.998	0.963	0.998	1		
Cl	0.976	0.997	0.913	0.978	0.989	1	
Br	0.947	0.948	0.864	0.949	0.967	0.994	1

*Correlation is significant at 0.05 percent

Source: Computed by the researcher from research result of the water samples collected from Uyo metropolis.



Discussion of Findings

This study reveals the presence of various types of microplastic polymers and associated heavy metals in surface water in selected locations within the Uyo metropolis of Akwa Ibom State. The presence of these polymers is attributed to run-off water, which carries waste particles from land and tributaries, such as nylons and rubber packages, and deposits them in the surface water bodies. The number of polymers found in the study could be linked to the various types of polymer products manufactured and used as a single used plastic. They contribute to its abundance in the environment because they are not properly disposed.

The highest polymer recorded in the study sample was PVC (286 %) in Dominic Utuk surface water and 195.79% in the Uyo village road stream. This polymer is used to manufacture many plastic products such as disposable materials (cups, plates, cutlery, fast food wraps, video cases, and so on). These products, after used are disposed of daily and indiscriminately by humans either directly or indirectly ending up in the environment. This finding is consistent with the findings of Srinivas *et al.*, (2024); Koirala *et al.*, (2025), who discovered that the majority of our daily plastic waste ends up in landfills (if properly disposed off).

Furthermore, Polyamide in Dominic Utuk stream recorded a high amount of heavy metal in it, possibly due to its products being used and discarded in the environment after PVC. Microplastics, such as containers, packaging, and netting from single-use items, are a significant source of contamination in the water. Their fragmentation on land leads to their presence in the water through run-off, which is further enhanced by sunlight. The impact of these polymers is higher within the metropolis. Microplastics absorb a significant amount of heavy metals from surface water, which are exposed during the long-term weathering process. Other environmental factors contribute to the additional quantity of metals and anion molecules added to the microplastic surface area.

Generally, elements like arsenic were found to be significantly high in the studied samples, possibly due to the sorption process by the surface area and other components generating these metals in the water as reported by He *et al.* (2015) and Crispin and Parthasarathy (2024). The research findings show that microplastic heavy metals in the studied environments exceeded the



WHO's regulatory limit, and this could pose a serious threat and risk to the aquatic organisms living in the water and human beings through the food chain.

Conclusion

The study concludes that surface water microplastic polymers and heavy metal concentrations in the Uyo metropolis of Akwa Ibom State, Nigeria were high. It identified polymers like PPE, LDPE, PET, HDPE, PE, PA, and PVC with high contents compared to control samples, which possess a severe risk to the environmental aspect. The study further draws attention that the surface water quality in the Uyo metropolis is unsafe for consumption by living organisms, as it can negatively affect the food chain due to the presence of heavy metals in microplastic particles. The study recommends recycling and reuse plastic products and packaging products, reducing single-use plastics production, and constructing drainage systems to filter plastic materials from entering streams, rivers, or the ocean. The research recommends further studies on the health risks of these plastic polymers, resins, and additives on human life and the ecosystem.

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SUB-THEME 4:

Energy Transition and Renewable/alternative Energy Solutions and Imperatives for the Domestic, Agricultural and Industrial Sectors



ENERGY SPECTRUM OF QUANTUM DOT SUPERLATTICES (QDSL)

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Abstract

Quantum Dot Superlattices and their huge potential applications in nano photonic devices covering a broad spectrum has attracted tremendous interest in the emerging field of nanotechnology from both theoretical and experimental perspectives. In this work, the Kronig Penny model is employed to resolve Time Independent Schrodinger equation and Bloche's theorem to theoretically formulate the dispersion equation for a quantum dot superlattice. The obtained equation describes the motion of electron with periodic motion and provides condition on the allowed energies of the electrons in the periodic structure. A virtue of this model is that it is possible to analytically determine the energy eigenvalues, eigenfunctions and to find analytical expressions for the dispersion relation among others.

Keywords: Quantum dots, Superlattices, Kronig Penny model.

Introduction

Quantum dots are tiny particles, typically between 2-10nm in size, made of semiconductor materials (Imran, 2018). They have unique optical and electronic properties due to quantum confinement effect i.e. electrons are confined in all three-dimensions, leading to discrete energy levels (Liu, 2017). Semiconducting quantum dots have garnered tremendous research interest due to their special optical properties, which arise from the quantum confinement effect (Onyekwere, 2021). They are used in solar cells, where they can improve the efficiency of energy conversion, biological imaging (Bayer, 2016), where they can be used as fluorescent probes, electronic displays (Ikeri, 2019), and quantum computing, where their ability to trap and manipulate individual electrons can be exploited (Lacarenkova, 2015).

A quantum dot superlattice is a periodic layer of quantum dots in a three dimensional structure. This artificial crystal structure exhibits unique electronic and optical properties due to the interactions between the quantum dots (Luque, 2018). Quantum-dot QD superlattices hold great potential for designing new materials (Nozik, 2018) through the combination of numerous geometrical arrangements (Onyekwere, 2021) and size-dependent electrical and optical

properties of QDs caused by quantum confinement effects (Oriaku, 2017). The applications of semiconductor QD superlattices are promising in various fields including electronics, (Peng, 2010) quantum and nonlinear optics (Yeda, 2022) and quantum computing (Wang, *et al.*, 2014). QDs embedded in a material matrix are particularly interesting due to their strong size-tunable electronic properties, (Shockley, 2018), strong photo- and electroluminescence, (Oriaku, 2017) and large optical nonlinearity (Pan, *et al.*, 2020).

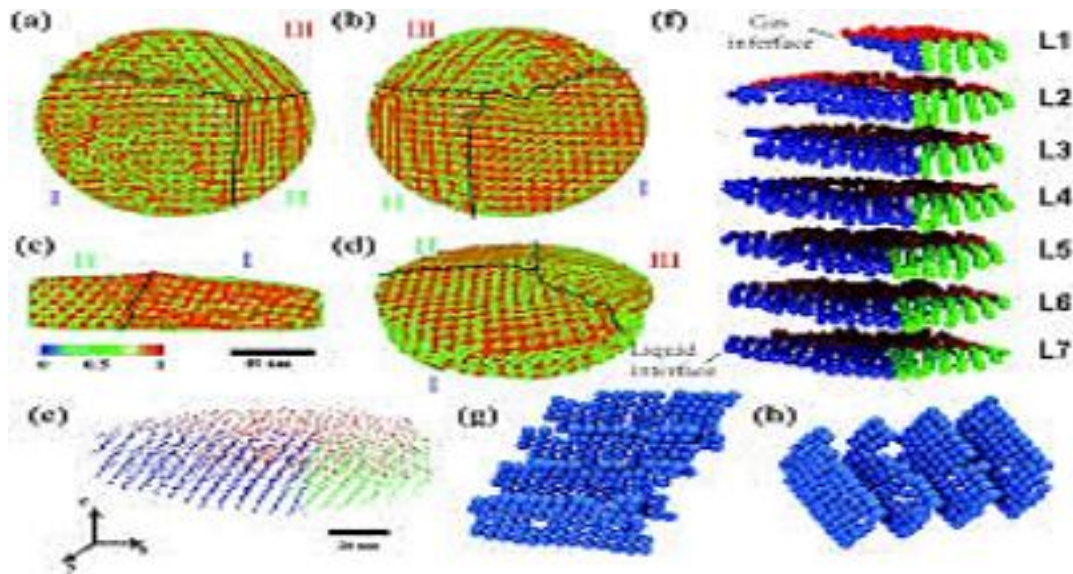


Figure 1: Quantum superlattice (google images)

The formation of semiconductor three-dimensional 3D QD superlattices has perhaps been most frequently observed during the growth of multilayered structures (Nozik, 2018) but always in crystalline matrices. Multilayers in such systems are grown mainly by Stranski-Krastanow heteroepitaxial growth mode (Yeda, 2022) where thin crystalline layers of a semiconductor material are grown on a crystalline substrate. The main driving force for the self-organization in those systems is the misfit of the lattice constants of the growing layer and the layer below it. This misfit causes strain fields in the growing layer, which leads to the self-organized growth. In this paper, we formulate theoretically a quantum dot superlattice structure using kronig penny model.

Theoretical Formulation of Quantum Dot Superlattice

The QDs superlattice is based on the resemblance between the QDs and atoms in which QDs play the role of atoms in a real crystal. The QD superlattice model comprise of alternating semiconductors with different bandgaps such that smaller bandgap semiconductor is sandwiched between two layers of higher bandgap materials. The smaller band gap material becomes a potential well while larger bandgap materials form potential barriers. Thus two potentials are formed; the well (QDs layer) depth for electrons called conduction band offset due to the difference between the conduction band edges of the well and barrier materials. Similarly the potential depth for holes called valence band offset is formed.

The QDs and barrier materials are periodically repeated in space to form a kind of periodic lattice shown in the Figure below:

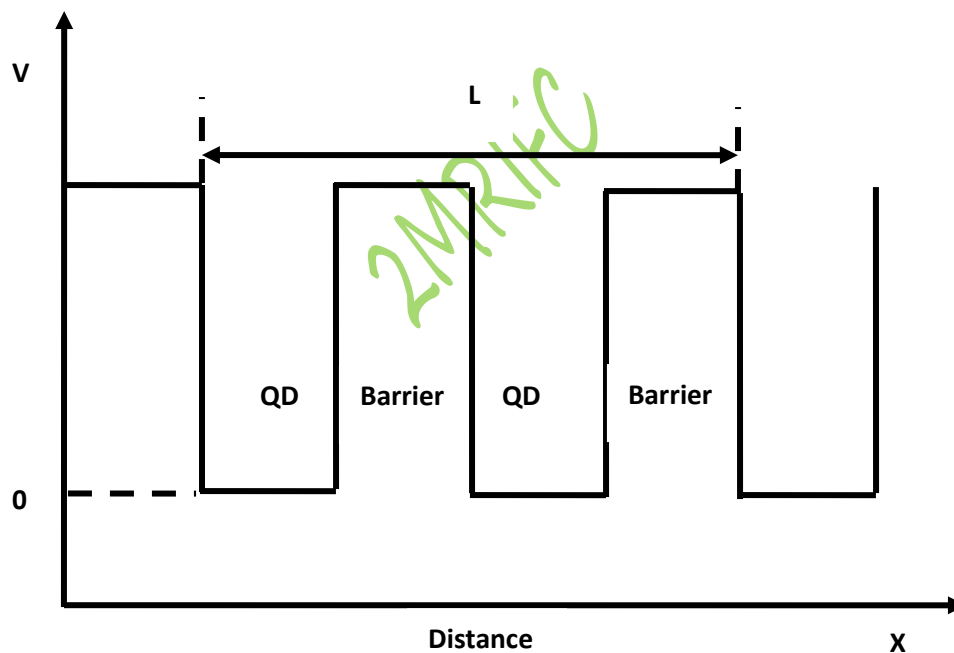


Figure 2: Quantum Dot Superlattice schematic diagram

The time independent Schrodinger equation for the motion of electrons along x-direction in both regions can be written as:

$$\frac{d^2\varphi(x)}{dx^2} + \frac{2m}{\hbar^2} \{E - V(x)\}\varphi = 0 \quad (1)$$

where, $\frac{2mE\varphi(x)}{\hbar^2} = K_Q^2$ and $\frac{2mE-V_0\varphi(x)}{\hbar^2} = K_B^2$ can be introduced

The periodic potential can be represented as:

$V(x) = 0$ for quantum dot region and

$V(x) = V_0$ for barrier region

where, $V(x) = V(x + a)$; $a = L_Q + L_B$ (2)

We suppose the general solution of the form:

$$\varphi_Q(x) = Ae^{ik_Qx} + Be^{-ik_Qx} \quad (3)$$

$$\varphi_B(x) = Ce^{ik_Qx} + De^{-ik_Qx} \quad (4)$$

where, A, B and C, D are the constants in the dot and barrier region respectively and can be obtained by applying the continuous and periodic boundary conditions.

For a periodic potential lattice with, $V(x) = V(x + a)$, its wave-function satisfies Bloch's theorem of the form:

$$\varphi(x) = u(x)e^{ikx} \quad (5)$$

Now applying the boundary conditions obeyed by Bloch functions, we obtain four homogeneous equations with four unknowns (A, B, C and D). In order to have a non-trivial solution ($A = B = C = D = 0$) to the four equations, the determinant of their coefficient must be zero:

$$\begin{vmatrix} 1 & 1 & -1 & -1 \\ ki_Q & -ki_Q & -k_B & k_B \\ e^{ik_QL_Q} & e^{-ik_QL_Q} & -e^{-ik_QL_Q+ikL} & -e^{ik_QL_Q+ikL} \\ ik_Qe^{ik_QL_Q} & -ik_Qe^{-ik_QL_Q} & -ik_Be^{-ik_BL_B+ikL} & k_Be^{ik_BL_B+ikL} \end{vmatrix} = 0 \quad (6)$$

By solving and simplifying the 4 x 4 determinant, we obtained:

$$\left(\frac{K_B^2 - K_Q^2}{2K_B K_Q}\right) \sinh(K_B L_B) \sin(K_Q L_Q) + \cosh(K_B L_B) \cos(K_Q L_Q) = \cos ka \quad (7)$$

This is the dispersion relation for electrons in the quantum dot superlattice. It describes the relationship that exists between the wave number K and the energy E on the *RHS* and *LHS* respectively.

Results and Discussion

We have succeeded in formulating theoretically the energy dispersion relation of free electron energies for semiconductor quantum dot superlattices using Kronig Penny model in very simple and non-tedious way.

The one-dimensional Kronig Penney (KP) potential is approximated as a periodic array of square-well shape. The Schrodinger equation for an electron in this potential has a solution in the form of the Kronig Penney equation (KPE), which illustrates the formation of electronic energy bands. The KPE is routinely found from the determinant of a 4×4 matrix resulting from four boundary conditions on the wavefunction and its derivative.

This model describes the motion of electron with periodic motion and provides a definite relationship between the energy E through K_Q on the *LHS* and the wave vector k on the *RHS*. It provides condition on the allowed energies of the electrons in the periodic structure. If the *LHS* of the equation is expressed as $F(E)$, we have $F(E) = \cos ka$. It is clear trigonometrically that for a solution to exist $\cos ka$ can only take values between -1 and 1 and the values of ka on these limits are respectively 0 and $\frac{\pi}{a}$.

Furthermore, it follows that the function on the *LHS* is bounded in the region $[-1, 1]$ since it is equal to $\cos ka$. This imposes limit on the amount of k . This in turn means there are values of ka for which valid k values occur (solution exists) and energies corresponding to this ka values are allowed. Also, there will be some values of ka which there are no real values of k and hence no proper solution exists, in which case there will be forbidden gap in the spectrum of energies.

That is, if energy E is in the allowed energy region the Schrodinger equation for the superlattice has a solution and if E is not in an allowed energy band there is no solution.



The difference between this model to that of the conventional case is that this model is artificial material and the energy band can be controlled by varying the width of different layers. In other words for real value of k the magnitude of $\cos ka$ should be less than 1 which corresponds to the allowed energy band, also the value of energy for which $\cos ka$ is greater 1, only the imaginary values of k are possible which correspond to the forbidden regions.

Conclusion

The Kronig Penney model play significant and unique role in the deep understanding of the electronic states in one-dimensional crystals. An interesting point of the Kronig Penney model is that not only the band structure of a Kronig Penney crystal can be analytically obtained as well known in the solid state physics community but also the function formalisms of all solutions, both in the permitted and forbidden energy ranges, can be analytically obtained and explicitly expressed.

Also, the carrier confinement effect can dramatically enhance the emission efficiency of optoelectronic devices. The confined structure exploits the principle of quantum confinement to engineer carrier states which makes QDSLs excellent candidates for near infrared IR photo detectors due to tunable band gap.

This work is of great significant as in theoretical physics, physics and involved mathematics are treated on equal footings.

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CLEAN ENERGY TRANSITION AND THE NIGERIAN OIL AND GAS INDUSTRY: THE IMPERATIVES

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ABSTRACT

Climate change and current environmental concerns arising from the utilization of fossil fuels as the global prime source of energy are issues that require concerted efforts from different nations of the world. Nigerian oil and gas companies produce fossil fuels consumed for national economic activities, with high emission levels of greenhouse gases (GHGs), majorly, from transportation, power and industrial sectors. To reposition Nigeria's economy in line with global efforts towards low-carbon society, the Nigerian oil and gas industry should queue into the Net-Zero, 2050, the global flagship for the clean energy transition programme to achieving net-zero carbon emission by 2050. Oil and gas are the revenue base of Nigeria and the industry is at a critical juncture, facing the challenges of clean energy transition and the need to diversify its economy. This paper examines the drivers of the clean energy transition, the relevance of the Nigerian oil and gas industry, the clean energy transition efforts of Nigeria, and the imperatives for the Nigerian oil and gas industry for a more sustainable and prosperous economy. Clean energy transition is critical for the industry towards a sustainable future with a diversified energy mix, leveraging alternative/renewable energy sources, while reducing dependence on fossil fuels.

INTRODUCTION

Global warming and the associated climate crisis are the current undesirable phenomena of our times that have been attributed to the fossil fuels consumptions for different global economic activities. These economic activities release GHGs, mainly, CO₂ and methane that cause global warming. To protect our environment from these emissions, There should be drastic cut in fossil fuels use by embracing and adopting clean energy transition (CET) policies and programmes targeted at keeping the average global temperature to 1.5°C (Alagoz & Alghawi, 2023).

Over the years, the energy sector utilizes fossil fuel and accounts for about three-quarters of global GHG emissions (IEA Report, 2021). Oil and Gas Companies are the major players in this sector for years, supplying the liquid and gaseous fossil fuels for various national economic activities (Zhong & Bazilian, 2018). Their operations emit enormous GHGs, and as such, can play key roles towards achieving a low-carbon society by repositioning its operations. Strategic



development policies and plans for the de-carbonization of this sector are certainly required alongside the adoption of new approaches to the operations of Oil and Gas Industries (OGIs). Nigeria's economy is largely fossil fuel-driven, and with Nigeria as the largest oil producer and the holder of the largest gas reserves in Africa, the operations of NOGI evidently impact the environment. Nigeria is also the twelfth largest oil producer in the world of which the Nigerian Oil and Gas Industry (NOGI) operation is the cornerstone of the country's economy, accounting for over 85% and 65% of export and government revenue earnings, respectively (EITI, 2025). Moreover, with the projected Nigeria's population of 329 million by 2030, and by 2050, up to over 400 million (International Energy Agency, 2019), and the associated rise in energy demand, NOGI will still be in operation with increased GHG emissions which will be felt in the near future.

To curb this, and for Nigeria to align itself to the global efforts, such as Net-Zero 2050, Nigerian oil and gas industry is compelled to operate under the global low-carbon society transition policies and Roadmaps. Due to the government policies on clean energy transition, the industry is currently facing significant challenges, including shift towards renewables, declining oil reserves and demand, increasing competition from other oil-producing countries, growing concerns about climate change and the associated risk, and environmental sustainability. The rising emission of heat-trapping greenhouse gases, mainly carbon dioxide and methane from fossil fuel (crude oil, shale oil, natural gas and coal) use for over a century is the major factor responsible for the rise in earth's average temperature (global warming) and climate change (Client Earth, 2022; IPCC, 2022; Global Carbon Project, 2023; NASA, 2024). The frequencies and intensities of extreme weather conditions, such as flooding, drought, and wildfire witnessed globally point to the imminent dangers of climate change to energy production and distribution (Alagoz & Alghawi, 2023). Climate change seriously negates the global efforts geared towards the achievement of any of the 17 interrelated Sustainable Development Goals (SDGs). The 17 SDGs, which were adopted on September 25, 2015, by the United Nations General Assembly, were meant to build upon the 8 goals of the expired Millennium Development Goals (MDGs) which were directed towards reducing poverty. The SDGs set a year 2030 agenda for addressing pressing global economic, social and environmental challenges like poverty; food security;



health; water and sanitation; inclusive and equitable education, inclusive economic growth; environmental degradation, sustainable development and climate change (UN, 2015).

Climate change can have negative effects on biodiversity (species composition, productivity, and quality); quantity, demand, and quality of water; the fight against poverty, illness, and hunger due to its effects on agricultural production and environmental quality; with potential effects on grasslands' other ecological roles in addition to forage production (Moser and Ekstrom, 2015; Nyong, 2015; FAO, 2018). Clean energy transition is like going back to nature in which natural carbon cycle is sustained by the global move to transform the energy sector from one dominated by fossil fuel sources with high carbon emissions to one dominated by cleaner or low to zero-carbon emission (alternative and renewable) energy sources (UN, 2021; Iledare, 2024). With the public awareness of the impacts of GHG emissions and the advocacy for the use of renewable energy resources as corrective strategy, the NOGI is compelled to align its operations to the global best practices. This calls for all stakeholders in the energy sector to explore and innovate new strategies for reducing the deleterious effects of greenhouse gas emissions and the resulting climate change effects. In view of this, the paper outlines the drivers of the clean energy transition (CET), the challenges, the strategies, and the imperatives for the NOGI for possible adoption and sustainability.

THE NEED FOR CLEAN ENERGY TRANSITION

For over a century, fossil fuels have been the driver of global economic activities since the industrial revolution. These activities destabilized the natural carbon cycle, left enormous carbon footprint in our environment, thus, resulting in extreme weather conditions with its deleterious effect on life and environment. The perceived danger by different governments of the world led to the adoption of measures to tackle activities that contribute to high carbon footprint. This global effort towards reducing emissions and transitioning to a low-carbon society is driven by political, economic, and environmental factors. However, clean energy transition aims at reducing carbon emissions from energy, transportation, and industrial sectors drastically or eliminating them by adopting renewable energy technologies that utilize carbon-neutral, renewables and clean energy sources for energy production. It has been established that carbon



emissions in power, transportation, and industrial sectors of the global economy are the critical areas responsible for global warming (IEA, 2021). Cutting down carbon emissions from these sectors means transitioning to low-carbon or Net-Zero society. Therefore, exploiting renewable energy resources as energy drivers in these sectors will go a long way in reducing global warming. In addition, an alternative and clean energy resource can also be utilized. An alternative energy resource is one that is used to supplement or replace the conventional energy resource used to drive human activities. A renewable energy resource is a natural resource that can be replenished or replaced at the same rate at which it is used or which is replenished through natural processes e.g. biomass (biological materials), wind, freshwater, geothermal and solar power (Nnaji and Uzoekwe, 2018). Renewable resources are regarded as infinite or inexhaustible due to their ability to be replenished. All renewables are alternative energy resources but not all alternatives are renewable. For instance, nuclear energy is an alternative energy, but not renewable since the materials like radioisotopes used to generate nuclear power are non-renewable (Just Energy, 2024). Biomass energy may also be considered as non-renewable if the plants utilized to generate energy are not replanted at the same rate as they are being used. A non-renewable energy resource is one that is replenished at a much slower rate than it is consumed e.g. petroleum, natural gas and coal. With the exception of biomass, renewable energy resources are called clean or green energy resources since their use does not lead to the emission of heat trapping greenhouse gases (GHGs) which are responsible for global warming. Fossil fuel energy resources which were formed by geologic action (like anaerobic decomposition) of the remains of ancient plants and animals millions of years ago are implicated in negative environmental impacts like global warming (due to GHG emission), ozone layer depletion, pollution and acid rain. The energy sector is currently the main emitter of greenhouse gas emissions (GHGs). To meet the goals of the Paris Agreement, GHG emissions from that sector need to be reduced quickly and eliminated by mid-century by deploying renewables, energy-efficient devices, transport switching, and material efficiency gains.

The pace at which clean energy (CE) is entering the global energy system is unprecedented with over 560 gigawatts (GW) of new renewables capacity added in 2023 with investments in CE



projects averaging about USD 2 trillion yearly higher than the amount spent on investments in coal, oil and gas (IEA, 2024a). Global renewable power generation capacity is projected to rise from 4,250 GW in 2023 to about 10,000 GW in 2030 with China accounting for 60% of this capacity in 2023. All these global efforts are targeted at achieving net-zero GHG emissions by 2050 (Net-Zero, 2050).

RELEVANCE OF OGI OPERATIONS TILL 2050

Primary energy refers to energy which is harvested or captured directly from natural resources while secondary energy refers to energy that is produced from the transformation of primary or secondary energy sources. Primary energy resources include fossil fuel, nuclear fuel, hydro and renewable resources (firewood, wind, solar, geothermal and hydro) while secondary energy resources include petroleum products like petrol, electricity, heat and biofuels (Overgaard, 2008). Fossil fuels are by far, the major source of energy in the Anthrosphere driving human activities like transportation, electricity and manufacturing (OPEC, 2024). The world is in the midst of an energy transition from non-renewable to renewable energy resources but fossil fuels still dominate the world energy market. This is partly due to petrochemical products derived from petroleum and natural gas, which their replacement have not been readily found in renewable resources, like biomass. However, within the decade, 2013-2023, the share of fossil fuels in the global energy mix decreased from 82% to 80% (IEA, 2024).

According to OPEC (2024), global primary energy demand is projected to increase by 24% from 301 million barrels of oil equivalent a day (mboe/d) in 2023 to 374 mboe/d in 2050 (Table 1.) with the growth driven by energy demand by developing countries (non-members of the Organization for Economic Cooperation and Development, OECD).

Tabel 1: World primary energy demand by fuel type, 2023–2050

Energy source	Levels (mboe/d)							Growth (mboe/d)	Growth (% p.a.)	Fuel share (%)	
		2023	2030	2035	2040	2045	2050			2023	2050
Oil	Oil	92.9	103.1	106.0	107.4	108.5	109.6	16.7	0.6	30.9	29.3
Coal	Coal	78.0	71.6	66.1	60.0	54.4	49.1	-28.9	-1.7	25.9	13.1
Gas	Gas	69.1	75.9	80.6	84.8	87.9	89.6	20.5	1.0	23.0	24.0
Nuclear	Nuclear	14.8	17.0	18.9	20.9	22.7	24.3	9.6	1.9	4.9	6.5



Hydro	Hydro	7.6	8.6	9.2	9.9	10.7	11.6	4.0	1.6	2.5	3.1
Biomass	Biomass	29.1	32.1	34.0	35.5	36.5	37.4	8.2	0.9	9.7	10.0
Other renewables	Other renewables	9.6	19.0	27.1	35.1	43.6	52.4	42.9	6.5	3.2	14.0
Total	Total	301.1	327.3	342.0	353.7	364.4	374.1	72.9	0.8	100.0	100.0

(Source: OPEC, 2024)

Demand for all forms of primary energy sources except coal is projected to increase from 2023 to 2050.

The largest increase is projected to come from other renewables (from 9.6 mboe/d in 2023 to 52.4 mboe/d in 2050) with natural gas and nuclear energy demands rising 69.1 – 89.6 and 14.8 – 24.3 mboe/d respectively. Oil and gas demands will increase 92.9 – 109.6 and 69.1 – 89.6 mboe/d respectively. The share of oil and gas in the energy mix is projected to be above 53% up to 2050 with oil having the largest share of 29.3%. In Nigeria there is yet no significant decarbonization effort noticeable in NOGI.

However, the global energy landscape is ever-evolving and the main drivers are climate change, energy access/security, finite nature of non-renewable energy resources, increase in population, increase in industrial output and economic size and technological advancements (Alita *et al.*, 2023; Nalule *et al.*, 2024; IEA, 2024). IEA (2020b) analyzed the role of oil and gas companies and concluded that oil and gas companies should not only be the major problem with regards to GHG emission (global warming and climate change) but should be a critical factor in the solution. The EIA Report noted that:

The oil and gas industry faces the strategic challenge of balancing short-term returns with its long-term licence to operate

No oil and gas company will be unaffected by clean energy transitions, so every part of the industry needs to consider how to respond

Current investments by oil and gas companies outside their core business areas has been less than 1% of total capital expenditure

There is a lot that the industry could do today to reduce the environmental footprint of its own operations



Electricity cannot be the only vector for the energy sector's transformation

The oil and gas industry will be critical for some key capital-intensive clean energy technologies to reach maturity

A fast-moving energy sector would change the game for upstream investment

A shift from “oil and gas” to “energy” takes companies out of their comfort zone, but provides a way to manage transition risks

National Oil Companies (NOCs) face some particular challenges, as do their host governments

The transformation of the energy sector can happen without the oil and gas industry, but it would be more difficult and more expensive

These clearly indicate the need for oil and gas companies to fully join the CET efforts and the CET pathways recommended for the global oil and gas industry include; energy efficiency, hydrogen system, carbon capture, use and storage (CCUS) and low-carbon fuels (Fig. 1). International oil companies (IOCs) are rebranding to international energy companies (IECs). Total rebranded to TotalEnergies in order to achieve net-zero carbon by 2050; British Petroleum (BP) rebranded to Beyond Petroleum and Statoil to Equinor. This is in tandem with global trends and commitments geared towards a sustainable energy future with gradual divestment, diversification and transition from fossil fuels (Nitte, 2023).

STATUS OF NIGERIA'S CLEAN ENERGY TRANSITION EFFORTS

Clean energy transition is a global measure to control global warming and the associated climate impact on the environment by reducing CO₂ and methane emissions through mitigation and adaptation pathways. To tackle global warming, the United Nations Framework Convention on Climate Change, Net-Zero (NZ), 2050 developed roadmaps at COP26, 2021, in which different nations are allowed to develop and adopt its Roadmap to suite achieving Net-Zero, 2050. Nigeria signed the Agreement and pledge her commitment to attain net-zero carbon emission by 2060 (AbouSeada & Hatem, 2022). In pursuant of this, Nigeria signed into law a new climate bill that created a five-year emission budget that would span through 2050 to 2070, targeting GHG emissions cut by 50% in 2050 (2050 Long-Term Vision for Nigeria, Federal Republic of Nigeria, 2021 Report).

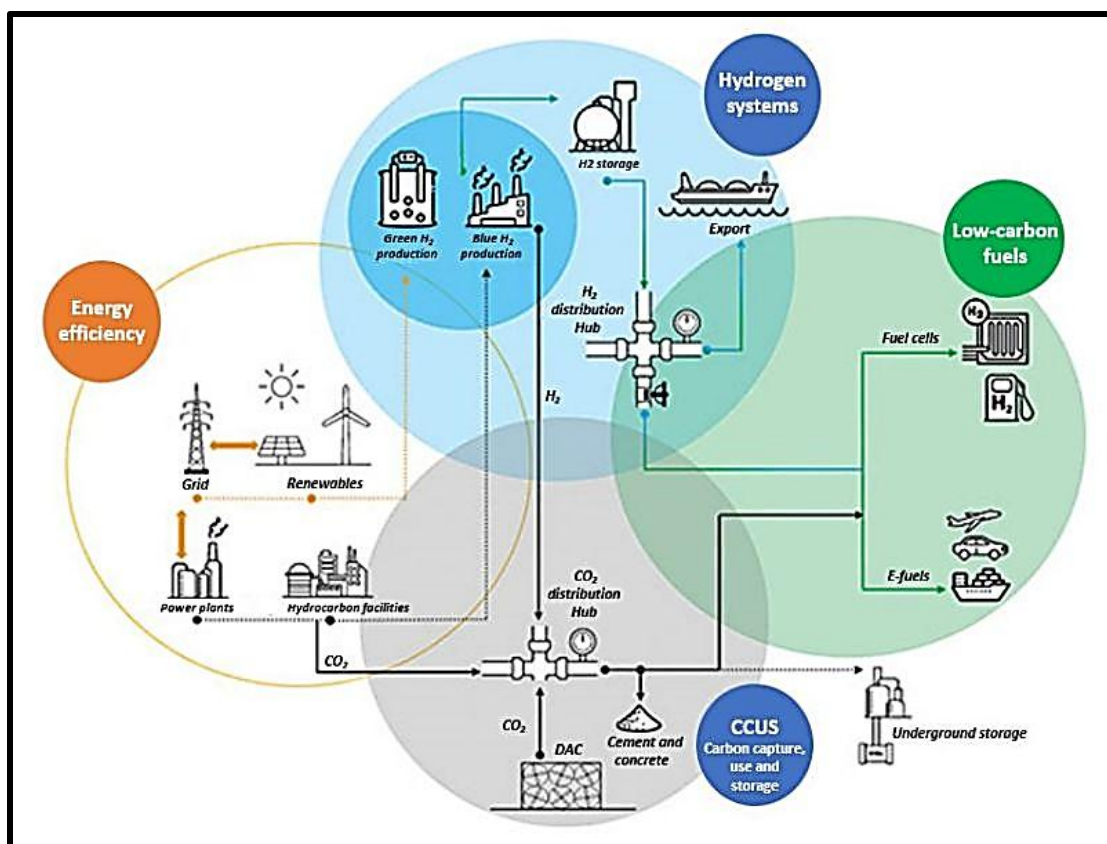


Fig. 1: Pathways to CET for the Oil and Gas Industry (Source: Kovacs, 2024)

The energy sector is Nigeria's biggest emitter of GHGs accounting for over 60.2% of total national GHG emissions and the country has developed several policies and regulations to curb emission and support its energy transition efforts. The **National Energy Policy** and the **Renewable Energy Master Plan (REMP)** are key documents that outline the country's strategy for transitioning to cleaner energy sources (ECN, 2021). These policies aim to reduce greenhouse gas emissions, promote renewable energy, and ensure energy security. Nigeria is also a party to international agreements such as the **Paris Agreement** and the **United Nations Framework Convention on Climate Change (UNFCCC)**. These agreements set targets for reducing greenhouse gas emissions and promoting sustainable energy (UNFCCC, 2018). Nigeria's **Nationally Determined Contributions (NDCs)** outline the country's commitments to achieving these targets.



In addition, the **Nigerian Upstream Petroleum Regulatory Commission (NUPRC)**, which is an outcome of the 2021 Petroleum Industry act, has introduced the **Upstream Petroleum Decarbonisation Template (UPDT)** to promote sustainability in upstream oil and gas operations (NUPRC, 2024). This template mandates the integration of decarbonisation strategies into field development plans and project engineering. It also requires NOGI operators to implement methane management programs and eliminate routine gas flaring.

Nigeria's **Energy Transition Plan (ETP)** was also unveiled in 2021 and it outlines the country's roadmap to achieve carbon neutrality by 2060 (NETP, 2021). The plan focuses on reducing emissions in key sectors such as power, cooking, oil and gas, transport, and industry (NETP, 2021). It aims to lift 100 million Nigerians out of poverty, provide modern energy services to the entire population, and manage job losses in the oil sector due to reduced fossil fuel demand.

Nigeria has made some progress in CET with the aim of increasing the share of renewable energy in its energy mix. A target of generating 30% of electricity from renewable energy sources by 2030 has been set by the government but the current share of renewable energy in the energy mix is about 10% which is a far cry from the stated target. Indeed, Nigeria faces major challenges in CET which include the need for a significant investments, upgrade and expansion of its energy infrastructure to support the integration of renewable energy sources. Adequate awareness creation among the populace, policy and regulatory frameworks for renewable energy are also critical and still evolving, and require further development to support the growth of the sector.

STRATEGIC CLEAN ENERGY TRANSITION IMPERATIVES FOR NIGERIA AND NOGI

Nigeria's OGI is bedeviled by a perception of low interest in eco-friendly operations emanating from widespread pollution (oil spillage and gas flaring) of the environment especially in the Niger Delta. There is little evidence that NOGI companies are investing in renewables. Nigeria seems fixated on oil and the trend is towards the discovery and exploitation of new oil and gas fields despite the fact that revenues from fossil fuels can be used to finance profitable clean energy projects (Nalule *et al.*, 2024). However, there is noticeable shift to cleaner energy (gas).



The next frontier of economic and technological development is renewable and alternative energy and energy efficiency i.e. Energy Transition. Imperatives for Nigeria as a country and NOGI companies as business entities include:

(a) Drastic increase in Investments in other Sectors. To reduce dependency on oil and gas revenues, Nigeria must diversify its economy and this involves the development of other sectors like agriculture, manufacturing, tourism and solid minerals (Leadership, 2025). The government should implement policies that encourage investment in other critical sectors and provide support for small and medium-sized enterprises (SMEs).

(b) Commitments to CET. Government at all levels and the NOGI needs to show sure footed commitment to energy transition. Governments need to create favourable policy and investment environments that will lower perceived risks for investments in renewables (EIA, 2024). **NOGI needs to show in word and in deed that she is** committed to reducing her carbon footprint by investing in renewable energy projects, implementing carbon capture and storage (CCS) technologies and eliminate gas flaring. Gas flaring is a major of GHGs emission and Nigeria flared 430.97bcf (equivalent to 1,720 GW of electricity) from March 2019 – February, 2021 (NNPC, 2021). There is little evidence of massive interest in moving towards sustainability, Carbon capture and Carbon neutrality in NOGI.

(c) Major Investments in Renewables. Nigeria has significant potential for renewable energy, particularly solar and wind power. The government should prioritize investments in renewable energy projects and create incentives for private sector participation. This includes establishing public-private partnerships and providing subsidies for renewable energy initiatives. Some international oils companies (IOCs) operating in Nigeria have started investing in renewables. **Chevron Nigeria Limited** is investing in renewable energy projects, such as solar and wind farms, to diversify the energy mix. **Shell Nigeria** is developing natural gas infrastructure to support cleaner energy sources while **TotalEnergies Nigeria** is investing in natural gas projects to reduce reliance on oil. IEA (2024b) projected that the global energy investment at over USD 3 trillion for the first time in 2024 with USD 2 trillion going to clean energy technologies and infrastructure (Fig. 2). Africa is expected to account for a paltry USD 40 billion (2%) of these investments.

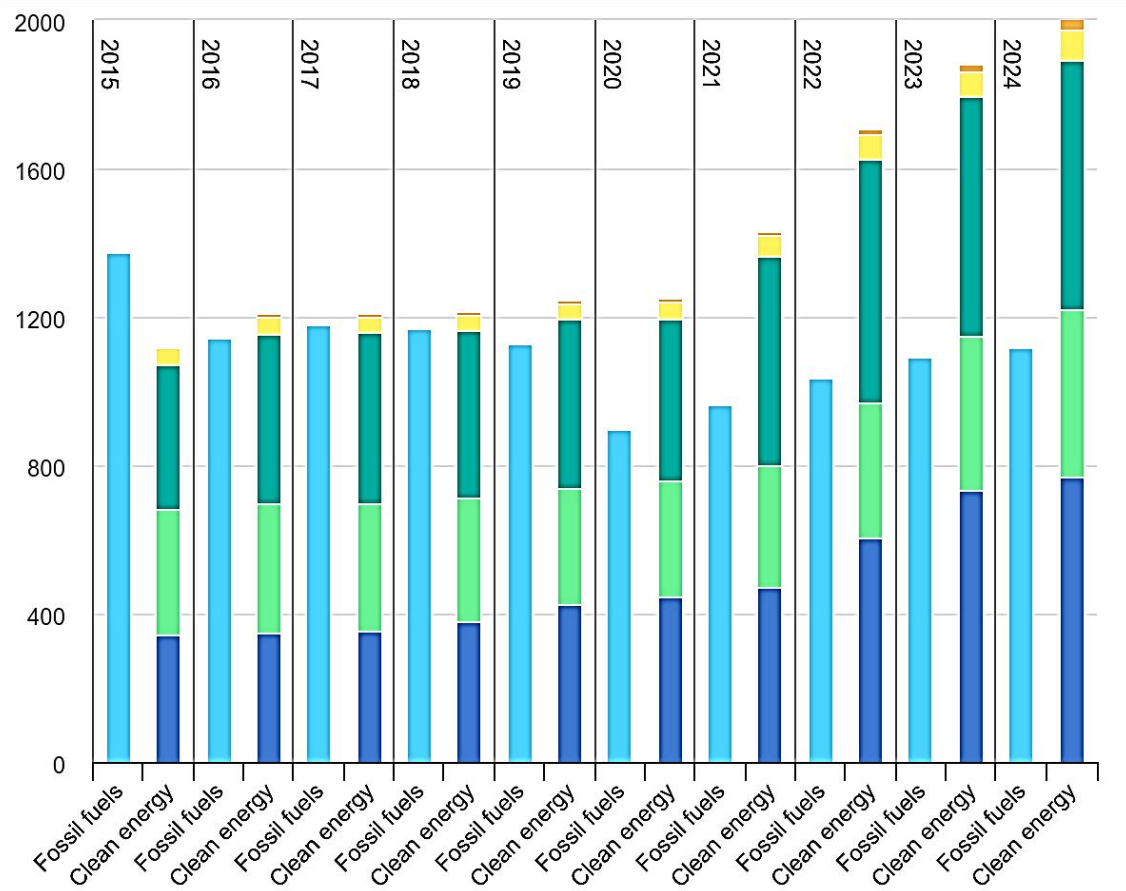


Fig. 2. Global investment in clean energy and fossil fuels, 2015-2024 (IEA, 2024b)

(d) Research and Development and deployment of technologies and infrastructure for CET.

This is critical for Nigeria's energy transition. Investments in research and development for cleaner energy production, energy storage solutions, and carbon capture and storage (CCS) technologies are needed. The government should collaborate with international organizations and research institutions to drive innovation in the energy sector. NOGI companies should partner with local and international research institutions to conduct research and develop locally generated technologies and solutions that will promote the energy transition.

(e) Adequate Regulatory Frameworks. This is essential to enable appropriate support for energy transition. Regulatory processes should be harmonized in order to enhance transparency and implement policies that will promote renewable energy adoption. This includes revising the



National Energy Policy and the Renewable Energy Master Plan to align with global energy trends.

(f) Awareness Creation and Capacity Building. Awareness of the imperatives of CET should be created among the Nigerian populace. Adequate capacity building aimed at the development of skills and expertise needed to support CET is also crucial. The government should invest in education and training programs for the workforce, focusing on renewable energy technologies and sustainable practices (NETP, 2021). This includes partnering with universities and other research and vocational institutions to create specialized training programs. IOCs and indigenous Oil and Gas companies should also fully engage in awareness creation campaigns and in building capacity in their companies and communities on energy transition and sustainable practices. Other important ways of doing this include the mounting of community outreach programs educational programs to promote energy transition efforts and raise awareness about carbon footprints reduction.

CONCLUSION

Nigerian oil and gas industry has over the decades played a key role in the economy and energy mix of Nigeria, with visible environmental impacts. To arrest the impacts with focus on a sustainable business, clean energy transition is an imperative for the Nigerian oils and gas companies. It is also crucial to Nigeria realizing her Net-zero, 2060 and consolidating her revenue base for a stronger economy. There are some strategies for NOGI to navigate the clean energy transition, which comprise a variety of areas, such as, achieving operational emission reductions, utilizing renewable energy, developing low-carbon transportation fuels through R&D, commercializing carbon capture and storage (CCS), and developing technologies for using hydrogen in power generation and in transportation. Nigeria should support the clean energy effort of the NOGI by creating enabling policy frameworks for the NOGI to implement the strategies.

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SUB-THEME 6:

Circular Economy, Administration, Green Accounting and Financing Approaches for Sustainable Transformation of Education, Agriculture and Industry



CONUNDRUM BETWEEN FINANCIAL ECOSYSTEM AND INDUSTRIAL OUTPUT SUSTAINABILITY IN NIGERIA

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Abstract

This study examined the conundrum existing between financial ecosystem and sustainable industrial production in Nigeria for the period between 1981 and 2023. Industrial output and its sustainability are expected to be financed by the financial sector. Yet the extent this has been achieved is a topic of debate as industrial production in the country within the reviewed period has been low. The study addresses this problem. Research design was Ex-Post Facto. Data was obtained from the Central Bank of Nigeria (CBN) Annual Reports and Statistical Bulletin of 2023. The data were analyzed using descriptive statistics and inferential statistics. Results indicate the existence of a long run relationship between the financial ecosystem and the industrial output sustainability; exchange rate depicts strong negative insignificant effect on the dependent variable in the long run while in the short run it depicts a weak positive insignificant effect; the banking financial institutions exhibit weak positive insignificant effect in the long run but strong negative significant effect in the short run; non –banking financial institutions show strong positive significant effect in the long run but strong positive insignificant effect on the dependent variable in the short run; among others. Policy implication of findings is that there is a conundrum between the financial ecosystem and industrial output sustainability and therefore the Dual Gap Theory is inapplicable in Nigeria. Recommendations include that government is to implement additional financial sector reforms to improve the efficiency of the domestic financial sector, also appropriate measures should be taken to eliminate the constraints and challenges that face industrial funding and financing such as soaring rate of exchange; high lending rate of inflation.

Keywords: Conundrum, ecosystem, financial ecosystem, industrial output, industrialization.

Introduction

Industrialization unarguably is identified as a critical component in developing countries' growth and development. This fact is supported by one of the United Nations Sustainable Development Goals of inclusive and sustainable industrialization. This Global Development agenda stresses the need for industrialization (UNO 2015). That is to state that the level of industrialization of a country is a determinant factor and driver of its economic, technological, political and socio-cultural development and advancement. Hence developed nations are known by their high level



of industrialization. Olokoyo et al (2016) noted that industrialization plays a pivotal role in economic growth and development globally. Afolabi et al (2019) opine that industrialization is generally acknowledged to be instrumental for stimulating economic growth and development. The industrial production sector provides a medium for producing goods and services, facilitating good jobs, and earning handsome rewards for economic agents (Sola et al, 2013). However, this is attainable if the said industries obtain the necessary financing through credit creation which remains the cardinal function of the financial system. The United Industrial Development Organization (UNIDO) stated in its Industrialization Report: "Industrialization is essential to economic growth and development; scarcely any country has grown without industrialization" (Ogunsakin, 2014).

Although industrialization is regarded as an important indicator of modern economic growth and development, the Nigerian industrial sector has suffered from decades of low productivity. Industrialization is widely regarded as capable of accelerating economic growth and ensuring rapid structural economic transformations. This is more worrisome despite the seemingly robust financial system expected to provide finances to the industries for sustainable output.

Agbo and Nwankwo, (2018) opine that the financial ecosystem notably influences the process of allocating resources across space and time as it exists to alleviate market frictions. The financial system statutorily performs two functions- mobilization of deposits and creation of credit. It comprises of the banking financial institutions and non- banking financial institutions. Banks enable that improved information acquisition about firms and managers will undoubtedly alter credit allocation. This stimulates financial contracts thereby increasing investors' confidence that firms will repay them and this no doubt influences how people allocate their savings. Because of the development of liquid stock and bond markets, for example, people who are hesitant to give up control of their savings for extended periods of time can trade claims to multiyear projects on an hourly basis. Melicher and Norton, (2011) therefore concludes that this could have a noticeable effect on how much and where people save.

From the foregoing, it becomes pertinent to note that the financial ecosystem should drive industrial output and production.



However, despite relative growth and robust performance of the financial ecosystem, this appears not to be translated to a corresponding remarkable growth of the industrial sector. Thus the industrial sector has been characterized with low production, and is constrained by poor infrastructure (Dada, 2003). It is against this backdrop that this study seeks to determine the conundrum existing in the relationship between financial ecosystem and industrial sector performance in Nigeria. There exist scanty studies on financial ecosystem and industrial performance nexus. This study attempts to fill the existing knowledge gap by focusing on the conundrum existing between the financial ecosystem and industrial performance using extended data points in Nigeria.

The rest of the paper is comprised of Literature review in Section 2, while Section 3 is the methodology, Sections 4 and 5 deal on the results and discussion, the recommendation and conclusion respectively.

Literature Review

Conceptual Review

Financial Ecosystem

Financial ecosystem encompasses a complex network of entities, systems, processes and procedures that intertwine commonly with the aim of attaining the functions of the financial industry. It is pertinent to pinpoint that the role of the financial system are two-fold; mobilization of deposit and creation of credit. This ecosystem includes- banking and non-banking financial institutions. This can be categorized as long term, medium term and short –term price markets. It extends to the commodity and derivatives markets (markets for trading assets such as gold, currencies and others); brokerage, exchanges and clearing house markets- for buying and selling of financial products; affordable banking services- for low cost structure accounts and no-frills savings account that help people that are unbanked participate in the financial system; embedded finance- include non-financial institutions that integrate financial services directly into the platforms allowing customers pay without third –party providers; block- chain technology –a decentralized, transparent and service tool that can revolutionize payment system and promote financial inclusion; insurance providers- sell insurance and assurance products and services for



protecting customers for losses and unforeseen conditions; neo-banks- including Fintech companies that offer technological and innovative solutions to bridge the gap in the traditional banking operations; digital payments- a vital medium that have optimized the financial sector.

Industrialization and Industrial output sustainability

Industrial production involves the creation of goods for sale, consumption or further production or use via the use of tools, machines, labor, chemical and biological formulation, and so on. Adofu et al, (2015) opine that industrialization involves the combination of human handicraft and high technology by changing and or transformation of unfinished goods into finished goods. Olamade et al, (2014) opine that in today's economy, the development of industries (industrialization) is heavily reliant on technological advancements in productive strategies.

Economic development theories recognize industrialization as an integral and fundamental part of economic structural transformation. Many economists and institutions still regard it as a necessary condition for increasing GDP per capita and improving people's livelihoods.

Relationship between Financial Ecosystem, Industrialization and Industrial output

Industrial output is sustained when the increasing output of the industries are maintained for a long time period without any interruptions. This remains cardinal for growth. This also is where the financial system performs its financing functions effectively and efficiently. However, a conundrum exists where this is not achieved or very difficult to be achieved.

Theoretical Review

Suffice to state that the study is anchored on how the financial system can drive industrialization, which can be attained by way of provision of credits, loans, and grants as well as augmenting domestic resources so as alleviate deficiencies in pooling savings or foreign exchange earnings. In the light of the above, the study theoretical underpinning is based on the theory of two-gap (Dual Gap Theory) model of economic development. This was espoused by Chenery and Strout (1966). To enable investigate the conundrum between financing and industrialization in Nigeria, it is noteworthy to hinge the nexus on the Dual Gap Theory. The major tenet of this model is that



many developing nations are engulfed with either domestic savings scarcity to take care of investment opportunities or unavailability of foreign exchange earning to fund the expected imports of capital and intermediate products and services. The financial system is expected to bridge this yawning gap.

Empirical Review

Awe (2022) studied investigated the relationship between stock market performance and manufacturing growth in Nigeria for the period covering 1985 to 2020. The vector auto-regression (VAR) model was adopted for data analysis. The stationary test results from Augmented Dickey-Fuller (ADF) and Phillip Peron (PP) confirmed the use of VAR. the study revealed that stock market performance has a significant impact on manufacturing growth.

Okunade (2018) examined the effect of capacity utilization on manufacturing firm output using time series data for the period covering 1981 to 2016 for Nigeria. the Autoregressive Distributed Lag (ARDL) model approach was adopted for data analysis. The study discovered a positive but insignificant relationship between capacity utilization and manufacturing firm output since capacity was grossly underutilized in virtually every productive firm in Nigeria. In conclusion, the study states that there was significant underutilization of capacity in Nigerian manufacturing firms, making the positive effect of capacity utilization less significant in explaining manufacturing firms' output growth in Nigeria.

Oui (2019) in a study of the impact of capital market indicators (industrial loan, equity, and market capitalization) on Nigerian industrial sector financing, employed ordinary least squares and multiple regression statistical techniques. Findings depict the existence of a significant relationship between industrial loans and the expansion of industrial sector financing in Nigeria. Furthermore, there is a significant impact between market capitalization and the growth of industrial sector financing in Nigeria, but there is no significant impact between equity and the growth of industrial sector financing in Nigeria.

Emmanuel and Adegboyega (2014) employed a linear regression function identifying real GDP, which is a measure of economic activity, is a function of bank credit to the economy, which is a



measure of banks' contribution. The estimated model results show that banks have a positive impact on economic growth in Nigeria.

Iheanacho (2016) investigated the relationship between financial intermediary development and economic growth in Nigeria from 1981 to 2011 using annual data. The real GDP per capita is used to measure economic growth.

Methodology

Research Design

The study seeks to ascertain if there is a conundrum relationship between financial ecosystem and industrial output sustainability in Nigeria for the period spanning from 1981 to 2023. The research is an *ex post facto* and adopts a time series data. Data collection is by secondary sources gotten from the Central Bank of Nigeria (CBN) Statistical Bulletin of various issues. The results of the tests is interpreted which forms the basis of the research findings and enable the recommendations to be proffered in the study.

The following augmented model is estimated or adopted:

$$L\Delta INDGDP = \beta_0 + \beta_1 LBFI + \beta_2 LEXR + \beta_3 INF + \beta_4 LLR + \beta_5 LN BFI + \epsilon_t \dots \quad (1)$$

where,

L = logarithm, Δ = rate of variations in the employed variables

INDGDP = Industrial output sustainability and the dependent variable, β_0 = constant, β_1, β_2 = explanatory power of the variables, BFI representing Banking financial institutions, EXR is exchange rate of the Naira to the United States of America dollar, INF is the rate of inflation, LR is the lending rate and NBFI is the non-banking financial institutions.; ϵ_t = stochastic error term.

Methodology

To achieve the objective of the study, the following tests were run; -the descriptive statistics – mean, median, mode etc. in order to

The unit root test (URT)- the Augmented Dickey Fuller (ADF) to test the stationary of the variables. When the variables are integrated of the mixed order, we move a step further to employ the ARDL. The ADF test is based on the following equation

$$\Delta X_t = \alpha_0 + \alpha_1 t + \beta X_{t-1} + \sum_{j=1}^m Y_j \Delta X_{t-j} + \mu_1 \quad \dots (2)$$

where

X_t is integrating series (independent variable), β is coefficient, Y_j is integrating series (dependent variable), Δ is the first difference operator; t is the time trend; α_0 is a drift; t represents the linear time trend; m is the lag length; μ_1 is a white noise process.

The following econometric tests are performed-

-the correlation test;

- the autoregressive distributed lag ARDL test; this is performed in order to find the long run relationship among variables which are mixed such that some are stationery at level and some are stationery at first difference.

Results and Discussion

Results

Table 1 Descriptive Test Result

	INDGDP	BFI	EXR	INF	LR	NBFI
Mean	150404.4	19770.02	136.0281	20.38605	23.38977	849.8140
Median	128417.0	20778.00	118.5669	13.70000	22.51000	586.0000
Maximum	345621.0	41098.00	786.0000	72.80000	38.70000	2134.000
Minimum	71968.00	1229.000	0.610000	5.400000	10.00000	185.0000
Std. Dev.	67252.77	11858.72	163.7417	15.95363	7.081668	554.2028
Skewness	1.236189	0.118235	1.922104	1.502468	0.101173	0.902817
Kurtosis	3.873990	1.949186	7.297199	4.691698	2.551142	2.608038
Jarque-Bera	12.32042	2.078562	59.56190	21.30557	0.434331	6.116657
Probability	0.002112	0.353709	0.000000	0.000024	0.804797	0.046966
Sum	6467390.	850111.0	5849.206	876.6000	1005.760	36542.00
Sum Sq. Dev.	1.90E+11	5.91E+09	1126077.	10689.77	2106.301	12899913
Observations	43	43	43	43	43	43

Source: Researcher's computation (2024)

The above values depict strong evidence that these variables have reasonable values of relationship in totality. It can then be opined that dynamics in trends may affect variable

normalcy distribution. Therefore the findings are to be subjected to further econometric tests to confirm such results or reject it.

Table 2. Unit Root test result

Variable	Intercept Only	Decision	Trend and Intercept	Decision
<i>LINDGDP</i>	2.9237 (-7.3466)*	I(0)	3.5107 (-4.8593)*	I(0)
<i>LBFI</i>	-2.9237 (-2.4639)	I(1)	-4.9614 (-3.3580)*	I(0)
<i>LEXR</i>	-2.9266 (1.4900)	I(1)	-3.5063 (-0.6036)*	I(1)
<i>LR</i>	-2.9314 (-3.1808)	I(1)	-3.5180 (-1.6175)	I(1)
<i>LInf</i>	-3.1830 (-3.0061)*	I(0)	-0.9237 (-3.4743)*	I(1)
<i>LNBF1</i>	-3.5207 (3.8861)	I(1)	-2.9331 (9.2701)*	I(1)

Source: Researcher's computation (2024)

The unit root tests results - The Augmented Dickey Fuller unit root test depicts that the variables are integrated of order I(0) and order 1 that is, I(1) at 1%, 5% and 10% level of significance respectively as the case may be. Since variables are mixed where some are stationery at level and some are stationery at first difference, we adopt the Auto regressive Distributive Lag ARDL. In the time series domain, ARDL co- integration bounds test can be used to find the long run relationship among variables which are mixed such as some are stationery at level and some are stationery at first difference.

Table 3 Correlation Test Result

	INDGDP	BFI	EXR	INF	LR	NBFI
INDGDP	1.000000	0.920037	0.951385	-0.015794	0.741928	0.860802
BFI	0.920037	1.000000	0.851128	-0.111252	0.745070	0.889899
EXR	0.951385	0.851128	1.000000	-0.012567	0.696548	0.730259
INF	-0.015794	-0.111252	-0.012567	1.000000	0.220111	-0.151912
LR	0.741928	0.745070	0.696548	0.220111	1.000000	0.592884
NBFI	0.860802	0.889899	0.730259	-0.151912	0.592884	1.000000

Source: Researcher's computation (2024)



The explanatory variables except inflation depicted strong positive relationship with the dependent variable. This is so as BFI, EXR, LR and NBFI with values of 92 %, 95%, 74% and 86% respectively while inflation showed a weak negative relationship of -1% relationship with the dependent variable.

Table 4 Autoregressive Distributed Lag Test Result

Dependent Variable: INDGDP

Method: ARDL

Date: 12/26/24 Time: 14:58

Sample (adjusted): 1985 2023

Included observations: 39 after adjustments

Maximum dependent lags: 4 (Automatic selection)

Model selection method: Akaike info criterion (AIC)

Dynamic regressors (4 lags, automatic): EXR BFI INF LR NBFI

Fixed regressors: C

Number of models evaluated: 12500

Selected Model: ARDL(1, 4, 4, 0, 4, 4)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
INDGDP(-1)	0.398331	0.119264	3.339900	0.0042
EXR	-19.99938	35.10944	-0.569630	0.5768
EXR(-1)	-23.42161	72.37469	-0.323616	0.7504
EXR(-2)	189.6425	96.52245	1.964750	0.0671
EXR(-3)	-62.62948	90.65624	-0.690846	0.4996
EXR(-4)	212.5558	73.04459	2.909946	0.0102
BFI	0.284037	0.942115	0.301489	0.7669
BFI(-1)	-3.006390	1.030738	-2.916734	0.0101
BFI(-2)	0.645825	1.055412	0.611917	0.5492
BFI(-3)	1.329615	0.954088	1.393598	0.1825
BFI(-4)	-1.727138	0.969704	-1.781098	0.0939
INF	-386.1590	88.90417	-4.343542	0.0005
LR	722.1759	346.8321	2.082206	0.0537
LR(-1)	240.4925	319.4247	0.752893	0.4624
LR(-2)	1316.224	383.2242	3.434607	0.0034
LR(-3)	346.6124	337.6433	1.026564	0.3199
LR(-4)	403.1571	308.9672	1.304854	0.2104
NBFI	18.49351	8.273603	2.235242	0.0400
NBFI(-1)	9.408953	8.198929	1.147583	0.2680
NBFI(-2)	12.88079	9.411188	1.368668	0.1900
NBFI(-3)	-16.79120	11.68310	-1.437222	0.1699
NBFI(-4)	26.22429	9.900649	2.648745	0.0175



C	10217.37	8199.903	1.246036	0.2307
R-squared	0.997728	Mean dependent var	157570.5	
Adjusted R-squared	0.994604	S.D. dependent var	66544.84	
S.E. of regression	4888.124	Akaike info criterion	20.11552	
Sum squared resid	3.82E+08	Schwarz criterion	21.09659	
Log likelihood	-369.2526	Hannan-Quinn criter.	20.46752	
F-statistic	319.3872	Durbin-Watson stat	1.997308	
Prob(F-statistic)	0.000000			

*Note: p-values and any subsequent tests do not account for model selection.

Source: Researcher's computation (2024)

In Table 4 the R-squared of 99 percent implies that only 1 per cent of the conundrum between financial ecosystem and industrial output sustainability cannot be explained by the financial system. For adjusted R^2 only 98 percent of the nexus is explained by the explanatory variables. This also depicts significance.

On the long run relationship between the explanatory variables and dependent variable, the F-statistic of 319 at 0.00 probability depicts existence of a long run relationship.

The coefficient of the rate of exchange having a negative value of -19 has insignificant effect having a probability of 0.57. This implies that the exchange rate has negative insignificant effect on the industrial output sustainability; the BFI has a value of 0.76 and a probability of 0.57 implying a positive insignificant effect on the dependent variable. Inflation having -386 and probability of 0.0005 implies negative significant effect of industrial growth; while lending rate having a high positive value of 722 depict significance at 0.05 probability implying positive significant effect on the dependent variable; the NBFBI have a positive value of 18.4 at 0.04 significance, showing the it has a positive significant effect on the dependent variable.

For the short run, for there to be a long run relationship among the variables, the coefficients of the variables must be negative and also be significant at 5% level of significance. Using the one-lag period, the results depicts that some of the lagged variables are insignificant at 5% level.



For BFI it is -3 and probability of 0.01 depicting relationship; for LR it is 240 at 0.46 depicting no relationship; for NBFi it is 9.4 at 0.26 depicting no relationship.

Findings

1. There is the existence of a long run relationship between the financial ecosystem and the industrial output sustainability.
2. Exchange rate depicts strong negative insignificant effect on the dependent variable in the long run and short run depict weak positive insignificant effect strong.
3. Banking financial institutions exhibit weak positive insignificant effect in the long run but strong negative significant effect in the short run.
4. Non –banking financial institutions show strong positive significant effect in the long run but strong positive insignificant effect on the dependent variable in the short run.
5. In the long run inflation exhibit strong negative significant effect on the dependent variable
6. In the long run lending rate exhibits a strong positive significant effect on the dependent variable.

Implication

There is a conundrum between the financial ecosystem and industrial output sustainability and therefore the Dual Gap Theory is inapplicable in Nigeria within the reviewed period. Scarcity of domestic savings had impeded taking care of investment opportunities or unavailability of foreign exchange earning to fund the expected imports of capital and intermediate products and services. The financial system has not bridged this yawning gap.

Conclusion and Recommendations

Conclusion

The study investigated the conundrum existing between the financial ecosystem and industrial output production in Nigeria for a period between 1981 and 2023. Both descriptive and econometric statistics were adopted.



The paper adopted the auto-regressive distributed lag (ARDL) approach for co-integration analysis. Three control variables (exchange rate, inflation and lending rate) are included to capture other components of the Nigerian macroeconomic environment that could influence the ability of the financial ecosystem to lend to the industrial sector and the industrial sector to pay back the loans as well as service them. The auto-regressive distributed lag (ARDL) approach is employed. The findings depict that a long run relationship exists between the dependent and independent variables, however there is a conundrum in such nexus between the financial system and industrial output sustainability in Nigeria.

Recommendations

The following policy implications can be implied-

1. The most important task for the Nigerian government is to implement additional financial sector reforms to improve the efficiency of the domestic financial sector, which is a prerequisite for achieving industrial development. The financial sector's inefficiency is to blame for the negative impact on industrial production.
2. Appropriate measures should be taken to eliminate the constraints and challenges that face industrial funding and financing such as soaring rate of exchange; high lending rate; as these businesses are the backbone of the Nigerian industrial sector.
3. Inflation rate should be monitored to single digit to enhance industrial production

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EFFECT OF ASSET STRUCTURE ON ECONOMIC VALUE ADDED OF LISTED INDUSTRIAL GOODS FIRMS IN NIGERIA

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Abstract

The study examines the effect of asset structure on economic value added of listed industrial goods firms in Nigeria. Non-current asset and current asset were used to measure asset structure while residual income, market value added and return on invested capital were used to measure economic value added. It adopts the ex-post facto research design. The population of the study consists of the 13 listed industrial goods firms on the Nigerian Exchange group. Data was collected from 9 listed industrial goods firms which were judgmentally sampled for the period of ten years (2013 to 2022). The study adopted the panel regression model in testing the six stated hypothesis. It is found that noncurrent asset has a significant effect on residual income of listed industrial goods firms in Nigeria. Secondly, current asset has a significant effect on residual income of listed industrial goods firms in Nigeria. Thirdly, noncurrent asset has no significant effect on market value added of listed industrial goods firms in Nigeria. Fourthly, current asset has no significant effect on market value added of listed industrial goods firms in Nigeria. Fifthly, noncurrent asset has a significant effect on return on invested capital of listed industrial goods firms in Nigeria. Finally, current asset has no significant effect on return on invested capital of listed industrial goods firms in Nigeria. The study recommends that, listed industrial goods firms' non-current asset structure should be monitored and evaluated on a regular basis by the respective company managements to ensure that the composition meets the strategic requirements of the firms in order to increase the economic value added of listed industrial goods firms in Nigeria. Furthermore, management of the firms should ensure that adequate current assets are maintained to enhance the liquidity base of the firms. This will further improve the firms' ability to meet up with short term obligations and ensure a significant change in their respective economic value added.

Keywords: Non-current asset, current asset, Residual income, Market Value Added, Return on invested capital.

Background to the study

Firms need to acquire raw materials, enough to keep the production line running until the finished goods produced are turned into cash and/or debts, and then inventories replenished. Firms also need to grow their assets by increasing the amount of assets at its disposal and also by



adopting new technologies in order to be competitive so as to increase the future flow of economic benefits to the firms (Aguiar, Tortoli, Figari&Tabajara, 2021). One aspect that requires attention to ensure this objective is met by the firm is control of the firms' asset structure.

Asset structure determines firms' ability to undertake investment and meet its obligations (Aguzzi& Payne, 2007). Assets are resources used for production as well, it measures a firm's ability to survive and compete with competitors effectively (Ceryova, Turcekova, Adamickova & Moravcikova, 2018). Firms are created with the goal of maximizing owners' wealth. In pursuance of this goal, they consider asset structure that involves combination of various asset components to allow them undertake investments and meet business obligations. In view of this, the management must review financing activities and associate strategies that strike a balance between asset and capital financing. Assets structure are grouped into current assets, noncurrent assets (Farkoosh, Farkoosh & Naseri, 2012) and intangible assets (Hanran & Wenshu, 2014). These categories of asset structure provide suitable asset mix to be used by firm managers. As such firms can decide when to increase the noncurrent asset and lower current assets or increase the level of intangible assets and vice versa. This will ensure that the company has enough resources thus can take on any form of production or term investments (Ionita & Dinu, 2020).

According to Koh (2012) organizations also accumulate assets to establish security that is used to acquire financial services such as loans and bid bonds. Furthermore, assets are used to borrow money from creditors to finance business activities. Assets are also used to determine the future existence of a company and its ability to meet its intended obligations. Investors are also concerned about the company's assets to promise them the safety of their investments and the likelihood of generating returns. This specific business goal determines the asset structure of firms and enhances the firm overall financial performance.

Finding a superior evaluation tool for firm performance is considered as one of the most important fundamentals of recent accounting and finance researches. However, accounting performance measures such as profit and earnings have been criticized (Duru, 2014) due to their incapability to reflect an organization full cost of capital, thus relying on profitability alone cannot be applied in measuring corporate performance and cannot be considered as a consistent



interpreter of firm value (Maeenuddina, Hussain, Hafeez Khan & Wahi, 2020). Consequently, in order to overcome this drawback through finding a realistic firm financial performance measure, researchers like Md. Zahedul, Md. Thasinul, and Md. Sharif (2019; Maeenuddina *et al.*, 2020) made great effort for revealing a best possible corporate financial performance measurement tool. For that reason, they launched the Economic Value Added (EVA) metric as a superior measurement for economic profit and the best driver of shareholder value. Following EVA, Olonite and Okoro (2021), proposed that EVA is a performance measure that incorporates but accounting financial performance metrics and the overall value of the firm. This makes it valuable for measuring the economic contribution of the firms' activities in a more generic perspective (Omneya, Ashraf & Eldin, 2021).

The theory of constraints (TOC): The basic theory of this study is the throughput accounting theory of constraints, propounded by Tiyahu and Goldratt (1986). The Theory of constraints is based on the precept of using scientific principles and Logic in guiding human based organizations in carrying out their decision making processes. The main aim of the TOC is to assist organizations in achieving their goals, as well as helping them to continue doing so through changing times. In a nutshell, TOC is a recipe for change. The TOC is based on the assumption that every organization has, at any given time, at least one limiting factor (or constraint) that reduces its performance and prevents it from accomplishing its goals. This could be in term of sufficient noncurrent and current assets investment. Insufficient investment in tangible and intangible assets may hinder management from achieving the degree of their desired economic value added.

The Link: The **Theory of Constraints** provides a framework for identifying and optimizing the use of assets, which is critical when studying the **effect of asset structure on EVA**. By focusing on removing bottlenecks and improving asset utilization, TOC helps businesses maximize throughput, reduce unnecessary costs, and ensure that capital is used efficiently—all of which contribute to improving **Economic Value Added**. Thus, TOC is directly linked to understanding how an organization's asset structure impacts its financial performance through EVA.



Conceptual Review

Concept of asset structure

Assets Structure is defined as those class of assets that are acquired presently that will bring returns in the future. Zhai (2019) defined asset structure as any owned physical object (tangible) or right (intangible) having economic value to its owners; an item or source of wealth with continuing benefits for future periods, expressed, for accounting purposes, in terms of its cost, or other value, such as current replacement cost. Martina (2015) defined assets structure as the disaggregation of assets into different structural components for purpose of classification. Her study described the disaggregation into noncurrent, current, intangible and tangible assets. This study adopts the definition of Martina (2015) of asset structure since it was explicitly disaggregated into its functions (noncurrent, current, intangible and tangible assets).

a) Tangible assets

Assets are generally classified in two big groups: current asset and non-current asset (Ishmael & Kehinde, 2013). Notwithstanding, noncurrent asset is classified into two groups: tangible non-current or intangible non-current assets (Iqbal & Wibowo, 2015). The former term usually called as fixed assets or in current standards named as property, plant, and equipment (PPE). There are two criteria to meet in order to categorize an asset as a tangible asset: it can be seen, held, and it is used in normal business operation, rental, administrative of goods and services, and it is intended to be held and used for more than one period (Weygandt et al. 2015). Examples of tangible assets include land, building, structures, and equipment (Famil, Hasim& Yusuf, 2014).

b) Intangible assets

Over the last decades, globalization and the development of information technology have intensified competition between firms (Li, 2001). Therefore, those intangible assets have gained prominence in this scenario, being important determinants of differentiation and contributing to obtain competitive advantages (Mawih, 2014). The intangible assets are subjective in terms of availability of goods and rights, and their value is attributed by the market (Bratland&Hornbrinck, 2013). According to Barlev, Fried, Haddad and Livnat (2018), intangible assets are sources of future advantages that do not have physical or financial characteristics, generated by innovations, human competences, or singular organizational structures. Badertscher,



Collins and Lys (2012) corroborate that singular attributes are those enhancing intangible assets in generating value for firms.

c) Current Assets

These are assets that can be converted into cash during the normal production cycle. A normal production cycle is one year, that is, twelve months. Current assets are sometimes referred to as convertible assets. These are physical assets such as stock of raw materials, stock of work-in-progress, stock of finished goods, and goods held for resale. (Yan & Wang, 2016).

Assets that can be converted into cash during the normal production cycle are current assets. A normal production cycle is one year, that is, twelve months. Current physical assets are sometimes referred to as convertible assets. These are physical assets such as stock of raw materials, stock of work-in-progress, stock of finished goods, and goods held for resale. Current assets in one business may be a fixed asset in another business. An example of such asset would be real estate held in inventory by a real estate investment firms and sales organization or builder, the same real estate would be a fixed asset for other firm that procure it for use in a production line. Also computers that are manufactured for sale are current assets in the books of the computer manufacturing firms, the same computers are fixed assets in the books of other firms that procure them for use in their production line.

Chen Yao and Zhang (2008) states that net operating assets generally make up a substantial portion of firms' total assets and that these accounts share much common variation. Secondly, asset growth can take a variety of forms (growth in cash, current assets, or long-term assets). Previous work has not generally distinguished between different forms of asset growth and their effects on stock prices. At the very least, one potentially important distinction is between internally generated expansion in assets ("organic" growth) and acquisitions of other firms and their assets. Wisegeek (2015), states that acquiring firms over experience leads to disappoint in stock returns.

d) Noncurrent assets

These are the non-current assets that cannot be converted into cash during a year of running a business. Non-current assets include the property, plant and equipment: land, buildings, furniture and fitting, computers, equipment of manufacturing and other assets like Patent, Godwill which



can last for longer periods of time. These assets are more revenue generators than the current assets but the risk involvement is more than in the current assets as it is difficult to convert them into cash and also this involves huge initial capital outlay (Xuan & Hong, 2016).

Non-current assets are those assets that cannot be converted into cash during a year of running a business (Scott, 2003). It includes the land, buildings, furniture and fitting, computers, equipment of manufacturing and other assets which can last for longer periods of time. Non-current assets are more revenue generators than the current assets but the risk involvement is more than in the current assets as it is difficult to convert them into cash and also the involves huge initial capital outlay.

Economic value added

It is well recognized in finance literature that maximization of shareholders' wealth is the ultimate objective of a firm. Here, maximization of the share price makes a bridge with the maximization of the wealth. In this circumstance, a good performance measure helps to assess a firm's performance in terms of wealth maximization (ACCA Global, 2011). A number of firms still use profit based performance measures failing to take into account opportunity cost like cost of equity capital (ACCA Global, 2011). Moreover, profit based performance measure like accounting profit is altered due to accrual based earnings management and real earnings management. The accountants' discretion sometimes plays a role in altering the accounting profit due to use and implication of accounting standards (ACCA Global, 2011). Economic value added acts in fixing out the drawbacks embedded in traditional profit based performance measures and allows the firms meet the ultimate objective.

Value added refers to the increase in wealth of an organization. It is a popular concept in measuring income (Jamali&Asadi, 2012). It inherits underlying concept from macro-economics, especially related to the calculation of national income, measured by the performance of an economy known as National Product or Domestic Product (Marty, 2014). Other than the common usages, value added has also been used as a performance indicator in different areas of business administration (Olatunji&Adegbite, 2014).

Economic Value Added (EVA) is a performance metric that measures the value a company generates from its operations after accounting for the cost of capital. It is an indicator of a



company's financial performance and is used to assess how effectively a company is creating value for its shareholders. EVA is often employed by management to evaluate the performance of divisions or projects and to make informed financial decisions. Economic Value Added attempts to improve efficiency and value creation of firms. To measure the increase in value made by a firm, EVA uses data from accounting statements. It accounts all the relevant issues associated to growth of a firm including costs related to growth of the firm in terms of outlay of funds. It measures net benefits by taking into account what all the benefits cost (Barber & Lyon, 2018). EVA plays the role in establishing a clear and accountable links between capital investment, strategic thinking, operating decisions, and shareholder value. EVA works as a reliable gauge of a firm's growth in future as well as an effective measure of the quality of managerial decision (Azam & Haider, 2011).

Empirical Review

Sami (2022) explained the economic importance of intangible assets to make the right decision on how to use them in an optimal way. He measured the intangible assets, through an economic analysis of the characteristics of these assets, in addition to that his study explained the most important way to evaluate them. Based on a case study of Pfizer, the study calculated some indicators before and after deleting the intangible assets, to notice their impact in creating value on the company via a regression analysis. The study found that, intangible assets have a direct role in creating value in Pfizer, and by removing them from the financial statements, the company's performance will decline and cannot be dispensed with in the evaluation of the company.

Dancaková, Sopko, Glova and Andrejovská (2022) assessed the role intangible assets play in a firm's market valuation besides other firm-specific characteristics. The data used in this study comprises 250 publicly traded firms operating in four different business sectors in France, Germany, and Switzerland for the ten years from 2009 to 2018. Based on the panel data regression models, the study provides an extension of previous knowledge about the effect intangible assets may have on the investors' view of a company's value, where the value added of the paper is the empirical evidence of a possible link between the intangible assets' disclosure and the market value of German, French, and Swiss enterprises. The importance of their study



contribution lies in a comparative analysis carried out to reveal substantial differences in the impact of intangible assets and innovation activity on the market value firms in three European countries and across four industry sectors. Although their study result shows the positive impact of intangible assets on the firms' market value, they suggest that investors still assess firms based on their profitability rather than considering the information on intangible assets the enterprises disclose in their financial statements.

Zelalem and Abebe (2022) empirically examined the effect of intangible assets on the financial performance and policy of 17 commercial banks in Ethiopia from the year 2017 to 2020. Return on asset and equity were used to measure the financial performance and debt as a measure of financial policy. The intangible asset is used as the main explanatory variable and asset size and liquidity as control variables. Random effect estimation technique for panel data was used. The result revealed that intangible asset has positive effect on the financial performance measured both by ROA and ROE at 5% significance level while, negative effect on the financial policy of commercial banks in Ethiopia at 1% significance level. Moreover, the study found asset size has significant and positive effect on ROA and ROE at 1% and 5% significance level respectively. Liquidity ratio has also significant positive effect on the financial performance measured both by ROA and ROE at 5% significance level. Finally, the finding revealed asset size and liquidity ratio has significant positive effect on the financial policy of commercial banks in Ethiopia at 10% and 1% significance level respectively.

Kalusová and Badura (2022) analyzed the impact of selected external macro-environment and internal corporate factors on the capital allocation into fixed assets of enterprises. They analyzed 250 firms operating in six sectors from 2009 - 2018. The methods of correlation and multiple regression analysis were used as the main research methods. Their research results suggest that the investment activity of firms is influenced both by external factors of the macro-environment (economic cycle, inflation, interest rate and tax rate) and by internal corporate factors (especially by financial structure, non-debt tax shield and risk). They further found out that for enterprises operating in different sectors there were not just differences in the significance of selected factors but for some of them we found even a different direction of the effect; as for the investment activity and capital allocation into fixed assets of the company.



Jin and Xu (2022) examined the relationship between intellectual capital and firms' financial leverage by exploring whether firm profitability mediates this relationship, using a dataset of Chinese agricultural listed firms during the period of 2014–2020. Financial leverage is measured by the debt-to-asset ratio, and IC is measured via the modified value-added intellectual coefficient (MVAIC) model. By way of a regression result, the study found that, financial leverage is lower in firms with higher levels of intellectual capital, and intellectual capital positively affects firm profitability. In addition, firm profitability partially mediates the relationship between intellectual capital and financial leverage. When MVAIC is disaggregated into its four components, firm profitability has a partially mediating effect on the relationship between physical and human capitals and financial leverage.

Methodology

The study adopted the *ex-post facto* research design. *Ex-Post Factor* design was used where the researcher has no control or cannot manipulate already existing data.

The population of the study is made up of all the 13 listed industrial goods firms in Nigeria (Nigeria Exchange Group 2022) as at June 2023.

The sample size of the study is made up of nine (9) industrial goods firms listed in Nigeria exchange group. The sample size for the study is determined using a judgmental sampling technique. The firms are selected on the following basis:

- i. They must be listed and are consistent on the Nigerian Exchange Group from 2013 to 2022.
- ii. They must have their complete set of annual reports covering the study timeframe.

This study used the secondary data which is generated from annual reports and accounts of the listed industrial goods firms from 2013 – 2022.

The econometric technique adopted in this study is the panel regression techniques. The rationale for using this technique is based on the study's attempt to empirically analyze the four objectives stated and to test the four hypotheses outlined in the study, given that, the data that is collected have time and cross-sectional attributes.

The panel regression provides better results since it uses large observation and reduces the problem of degree of freedom; it avoids the problem of multicollinearity and help to capture the



individual cross-sectional (or company-specific) effects that the various pools may exhibit with respect to the dependent variable in the model. Hausman and Taylor in 1981 also recommended panel data estimation method because it enables a cross-sectional time series analysis which usually makes provision for a broader set of data points, but also because of its ability to control heterogeneity and endogeneity issues. Hence panel data estimation allows for the control of individual-specific effects usually unobservable which may be correlated with other explanatory variables included in the specification of the relationship between dependent and explanatory variables.

In evaluating the panel regression results, the Hausman specification test is used to select between fixed effect and random effect. The individual statistical significance test (T-test) and overall statistical significance test (F-test) is also used. Importantly, the goodness of fit of the model will be ascertained using the coefficient of determination (R^2). The panel analysis is done after descriptive statistics, normality test, diagnostic test, using the variance inflation factor test for multicollinearity.

The analyses is conducted at 5% level of significance using E-View 10 software. The normality test, in this case, the Skewness statistic test determines if the data series are normally distributed by evaluating the disparity of the skewness of the series compared with those from the normal distribution. Furthermore, the unit root test is conducted before adopting the panel regression for analysis.

Model Specification

The study adapted the model used in the study of Whittred and Chan (2017). The adapted model is stated as:

$$\text{Profitability} = f(\text{Noncurrent assets \& Current assets}) \dots \dots \dots (1)$$

The model is modified to become:

$$\log RI_{it} = \log \beta_0 + \beta_1 \log NCA_{it} + \beta_2 \log CA_{it} + U_{it} \dots \dots \dots (2)$$

$$\log MVA_{it} = \log \beta_0 + \beta_1 \log NCA_{it} + \beta_2 \log CA_{it} + U_{it} \dots \dots \dots (3)$$

$$\log ROIC_{it} = \log \beta_0 + \beta_1 \log NCA_{it} + \beta_2 \log CA_{it} + U_{it} \dots \dots \dots (4)$$

Where

RI = residual income



MVA =market value added

ROIC = return on invested capital

NCA = non-current asset

CA = current asset

β_0 = Intercept

β_1 to β_4 = Parameters to be estimated

U_i = Stochastic Variable

3.8 Measurement of Variables

VARIABLES	DEFINITION	TYPE	MEASURE
NCA	Non-current asset	Independent	Total reported value of noncurrent asset of a firm at a time
CA	Current asset	Independent	Total reported value current asset of a firm at a time
RI	Residual income	Dependent	Net income – (equity x cost of equity).
MVA	Market Value Added	Dependent	Market capitalization minus capital invested
ROIC	Return on invested capital	Dependent	Net income divided by total capital invested.

Data presentation

This section of the chapter presents the data extracted from the financial statement of the 9 listed industrial goods firms in Nigeria (2013-2022). The data were obtained from the Nigerian Stock exchange website and was presented in appendix 7.

Data Analysis

This section analyzes the data presented (Appendix 1-6) with the aid of E-View 9 (Econometric View). The analysis of data is presented in the subsequent sections:

Descriptive statistics

The descriptive statistics for both the dependent and independent variables are presented in table 4.1 below:



	CA	NCA	RI	MVA	ROIC
Mean	6.414009	6.537014	6.375660	4.869338	0.206321
Median	6.240653	6.197115	6.236095	4.916636	0.127195
Maximum	8.320745	8.927143	8.545803	6.505761	1.408151
Minimum	4.691506	5.023989	4.694359	3.482159	-0.058273
Std. Dev.	0.903670	0.932065	0.867889	0.785172	0.242909
Skewness	0.309160	1.378452	0.552533	0.156222	2.385915
Kurtosis	2.492032	3.838228	3.268383	2.301974	10.33635
Jarque-Bera	2.401317	31.13681	4.795620	2.193232	287.2213
Probability	0.300996	0.000000	0.090917	0.333999	0.000000
Sum	577.2608	588.3312	567.4337	438.2404	18.56888
Sum Sq. Dev.	72.67913	77.31825	66.28438	54.86813	5.251432
Observations	90	90	89	90	90

Table 4.1 showed the result of the descriptive or summary statistics of various variables (CA, NCA, RI, MVA and ROIC). The summary statistics were used to compare the measures of central tendency, the measures of dispersion and the measures of normality of the data set. The measures of central tendency compared the mean and median values of the data set. While the mean considered the average values of the variables the median looked at the middle distribution of the data set. From the result, it could be observed that the mean values of CA, NCA, RI, MVA and ROIC were respectively, 6.414009, 6.537014, 6.375660, 4.869338 and 0.206321. The measures of dispersion considered how widely spread the dataset was from their mean values. The measures of dispersion considered in this study were the minimum value, the maximum values and the standard deviation. From the E-view output, the dataset for minimum for CA, NCA, RI, MVA and ROIC ranged respectively from 4.691506, 5.023989, 4.694359, 3.482159 and -0.058273. However, the maximum values are 8.320745, 8.927143, 8.545803, 6.505761 and 1.408151 for CA, NCA, RI, MVA and ROIC respectively. The standard deviation measures how far the observations are from their sampled averages. From the summary output of the data set, the standard deviation were 0.903670, 0.932065, 0.867889, 0.785172 and 0.242909 respectively for CA, NCA, RI, MVA and ROIC.

The normality test measures whether the data set is normally distributed or otherwise. The measures of normality considered by this study were skewness and kurtosis. Skewness measured the degree of asymmetry of the series. The series may be normally skewed, positively skewed or

negatively skewed. A skewness value of zero is said to be normal and implies that the distribution is symmetry around its mean; a positive skewed value implies that the distribution has a long right tail, implying that the skewness value is higher than the sampled mean. A negative skewness implies that the distribution has a long left tail with lower values than the sampled mean. From the E-view result, the skewness values of 0.309160, 1.378452, 0.552533, 0.156222 and 2.385915 respectively for CA, NCA, RI, MVA and ROIC. All the variables have positive values, implying that they have a long right tail.

Kurtosis measures the peakedness or flatness of the data relative to the normal distribution. Kurtosis could be mesokurtic, leptokurtic or platykurtic. A kurtosis value of 3.0000 is mesokurtic, meaning that the distribution is normal. A kurtosis value greater 3.0000 is said to be leptokurtic or positive kurtosis, meaning that it has a peaked curve and produces higher values than the normal. A kurtosis value less 3.0000 is platykurtic or negative kurtosis, meaning that it has a flatted curve and that it produced lower values than the sample mean. From the result obtained in table 4.1 for the dataset, the kurtosis values of 2.492032, 3.838228, 3.268383, 2.301974 and 10.33635 respectively for CA, NCA, RI, MVA and ROIC. However, NCA, RI and ROIC were less greater than 3.0000 required for a normal distribution. It, therefore, means that they were leptokurtic, meaning that they produced higher value than the normal. While CA and MVA values were less than 3.0000 meaning that they produced lower value than the normal

The Jarque-Bera (JB) test measures the difference of the skewness and kurtosis of the series with those from the normal distribution. The null hypothesis for the JB statistics is that the series is normally distributed. Given the result in table 4.1 above, the JB values of 2.401317, 31.13681, 4.795620, 2.193232 and 287.2213 with their respective p-values of 0.300996, 0.000000, 0.090917, 0.333999 and 0.000000 respectively for CA, NCA, RI, MVA and ROIC. Therefore, NCA and ROIC have P-values less than 0.05 (5 per cent) meant that they did not meet normality assumption. While that of CA, RI and MVA have p-values greater than 0.05 meaning that they meet normality assumption.

Data validity test. In order to ensure that the results are robust, several diagnostic tests are conducted to enhance the validity of data and model specified for analyses. As such, data

diagnostic test such as; the Unit root test is computed. Before that, the correlation analysis is done.

Correlation analysis

This section of the chapter presents in the table below the result of the correlation analysis between the independent variables to further validate the Tolerance statistic.

Table 4.2 Correlation matrix

	CA	NCA	RI	MVA	ROIC
CA	1.000000	0.669012	0.621986	0.234300	0.070304
NCA	0.669012	1.000000	0.683604	0.523512	-0.277752
RI	0.621986	0.683604	1.000000	0.239889	0.002689
MVA	0.234300	0.523512	0.239889	1.000000	-0.131455
ROIC	0.070304	-0.277752	0.002689	-0.131455	1.000000

Table 4.2 shows the Pearson correlation for all the independent variables to ensure the test for multicollinearity of the independent variable since they consist of unranked data. Correlation considers two variables at a time to determine how they relate to each other. These types of checks are necessary because high correlation cause problems about the relative contribution of each predictor to the success of the model (Gujarati & Sangeeta, 2007). The correlation matrix above shows the absence of multicollinearity among the explanatory. All the variables show a low correlation with the highest correlation estimated at 0.669012. Correlation statistics that are above 0.75 is considered harmful for the purpose of analysis (see Gujarati and Sangeeta, 2007) but this is not the case with the current studies.

Stationarity/unit root tests

To avoid running a spurious regression, unit root test is carried out to ensure that the variables employed in this study are mean reverting i.e. stationary. For this purpose, the Levin, Lin & Chu test and Augmented Dickey Fuller (ADF) test are employed to test for stationary of data. The result of the test is presented in the table below.

**Table 4.3: Unit Root Test Table**

Variable	LLC (Common P-value)	ADF	Difference	Order
CA	0.0000	22.1418	Level	1(0)
NCA	0.0000	60.8337	Level	1(0)
RI	0.0000	34.2864	Level	1(0)
MVA	0.0011	26.8371	Level	1(0)
ROIC	0.0147	21.3479	Level	1(0)

The Table above shows the result of the first test required to know the common and individual stationarity of the variables. For the common stationarity test, the Levin Lin Chu (LLC) test for common stationarity was used which considers lags in data series. A variable is stationary if the ADF p-value is less than or equal to 0.05 level of significance. The result from the table shows that all the variables (CA, NCA, RI, MVA and ROIC) are stationary at level. Since the unit root test results for all series in models are integrated at level ie 1(0) hence panel OLS can be used without cointegration tests as the technique has no evidence of producing spurious results.

Regression of the Estimated Model Summary

Effect of current and non-current asset on residual income of listed industrial goods firms in Nigeria

Model Summary 1

Correlated Random Effects - Hausman Test

Equation: Untitled

Test cross-section random effects

Test Summary		Chi-Sq. Statistic		Chi-Sq. d.f.	Prob.
Cross-section random		28.266034		2	0.0000
Variable	Coefficient	Std. Error	t-Statistic	Prob.	
C	2.772301	0.364792	7.599680	0.0000	
CA	0.293655	0.066687	4.403508	0.0000	
NCA	0.262740	0.068352	3.843917	0.0002	



R-squared	0.950937	Mean dependent var	6.375660
Adjusted R-squared	0.944647	S.D. dependent var	0.867889
S.E. of regression	0.204191	Sum squared resid	3.252131
F-statistic	151.1783	Durbin-Watson stat	1.169095
Prob(F-statistic)	0.000000		

Table 4.4, presents the regression result on the effect of asset structure (CA and NCA) on residual income (RI). From the model summary table above, the following information can be distilled.

To enable the study chose between the fixed effect model and the random effect model, a Hausman Test is conduct with the comparable results placed in the appendix 4. The result of the Hausman correlation test above shows a cross sectional random probability value of 0.0000 with a Chi-square statistic of 28.266034 which is significant thus informs the study decision to choose the fixed effect model in other to capture other asset structure components not included in this study that might cause variations in the model specified.

The R^2 which measure the level of variation of the dependent variable caused by the independent variables stood at 0.950937. The R^2 otherwise known as the coefficient of determination shows the percentage of the total variation of the dependent variable (RI) that can be explained by the independent or explanatory variables (CA and NCA). Thus the R^2 value of approximately 0.951 indicates that 95.1% of the variation in the RI of listed industrial goods can be explained by a variation in the asset structure while the remaining 4.9% (i.e. $100-R^2$) could be accounted by other factors not included in this model.

The adjusted R^2 of approximately 0.945 indicates that if other factors are considered in the model, this result will deviate from it by only 0.006 (i.e. $0.951 - 0.945$). This result shows that there will be a further deviation of the variation caused by the independent factors to be included by 0.006%.

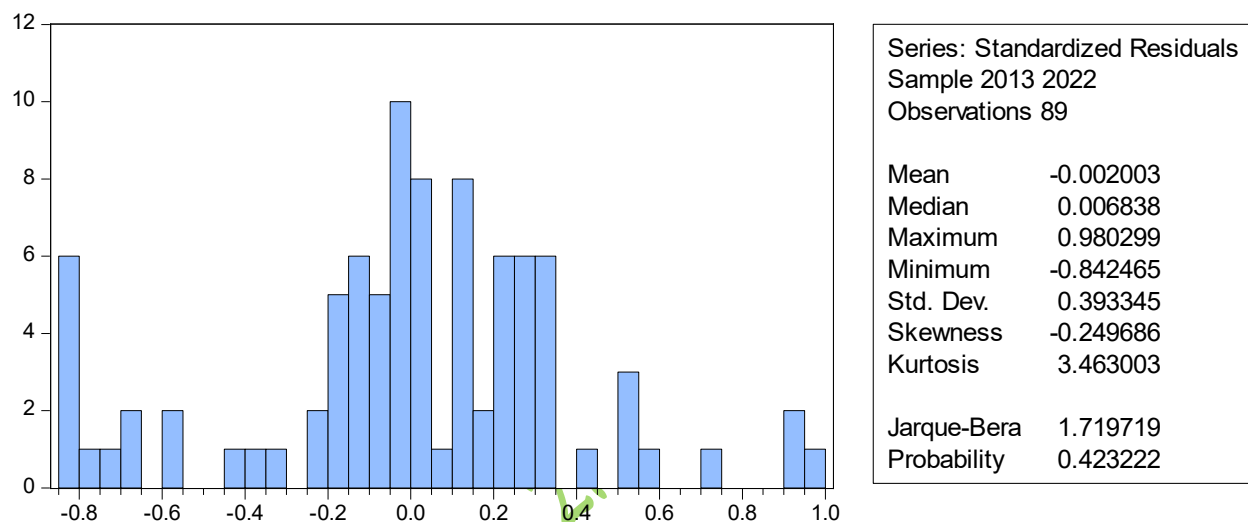
The regression result as presented in table 4.4 above to determine the relationship between CA, NCA and RI shows that when all the independent variables are held stationary; the RI variable is estimated at 2.772301. This simply implies that when all independent variables are held constant, there will be an increase in the RI of listed industrial goods firms up to the tune of 2.772301% occasioned by factors not incorporated in this study. Thus, a unit increase in CA will lead to an

increase in RI by 0.293655%. For NCA, a unit increase in NCA will lead to an increase in RI by 0.262740%.

Finally, the result shows that there is a significant variation of Fisher's statistics (151.1783) with P-value of 0.00000 which means the model as a whole is statistically significant at an autocorrelation level of 1.169095 (Durbin-Watson), which is less than 2.5.

Post Estimation Diagnoses

Table 4.5: Histogram normality test



The variable autocorrelation and multicollinearity were searched for using the test for histogram normality. The Jarque-Bera value is 1.719719 and the probability value is 0.423222, both of which are more than 0.05 (5%), based on the results of the normality test. The null hypothesis, which states that the model does not show multicollinearity or autocorrelation, will thus be accepted by the inquiry.

HO₁: Noncurrent asset has no significant effect on residual income of listed industrial goods firms in Nigeria.

Since the calculated probability value 0.0002 is less than the accepted probability value of 0.05. The null hypothesis is rejected and the alternative accepted thus; Noncurrent asset has a significant effect on residual income of listed industrial goods firms in Nigeria.

HO₂: Current asset has no significant effect on residual income of listed industrial goods firms in Nigeria.



Since the calculated probability value 0.0000 is less than the accepted probability value of 0.05. The null hypothesis is rejected and the alternative accepted thus; Current asset has a significant effect on residual income of listed industrial goods firms in Nigeria.

Effect of current and non-current asset on market value added of listed industrial goods firms in Nigeria.

Table 4.6: Model Summary 2

Correlated Random Effects - Hausman Test

Equation: Untitled

Test cross-section random effects

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	9.228945	2	0.0099
Variable	Coefficient	Std. Error	t-Statistic
C	3.821949	0.856297	4.463345
CA	0.187225	0.156861	1.193574
NCA	-0.023478	0.160861	-0.145951
R-squared	0.667422	Mean dependent var	4.869338
Adjusted R-squared	0.625324	S.D. dependent var	18.24792
S.E. of regression	0.480610	Sum squared resid	3.252131
F-statistic	15.85384	Durbin-Watson stat	1.856071
Prob(F-statistic)	0.000000		

Table 4.6, presents the regression result on the effect of asset structure (CA and NCA) on market value added (MVA). From the model summary table above, the following information can be distilled.

To enable the study chose between the fixed effect model and the random effect model, a Hausman Test is conduct with the comparable results placed in the appendix 5. The result of the Hausman correlation test above shows a cross sectional random probability value of 0.0099 with a Chi-square statistic of 9.228945 which is significant thus informs the study decision to choose the fixed effect model in other to capture other asset structure components not included in this study that might cause variations in the model specified.

The R^2 which measure the level of variation of the dependent variable caused by the independent variables stood at 0.667422. The R^2 otherwise known as the coefficient of determination shows



the percentage of the total variation of the dependent variable (MVA) that can be explained by the independent or explanatory variables (CA and NCA). Thus the R^2 value of approximately 0.667 indicates that 66.7% of the variation in the MVA of listed industrial goods can be explained by a variation in the asset structure while the remaining 33.3% (i.e. $100-R^2$) could be accounted by other factors not included in this model.

The adjusted R^2 of approximately 0.625 indicates that if other factors are considered in the model, this result will deviate from it by only 0.042 (i.e. $0.667 - 0.625$). This result shows that there will be a further deviation of the variation caused by the independent factors to be included by 0.042%.

The regression result as presented in table 4.6 above to determine the relationship between CA, NCA and MVA shows that when all the independent variables are held stationary; the MVA variable is estimated at 3.821949. This simply implies that when all independent variables are held constant, there will be an increase in the MVA of listed industrial goods firms up to the tune of 3.821949% occasioned by factors not incorporated in this study. Thus, a unit increase in CA will lead to an increase in MVA by 0.187225%. For NCA, a unit increase in NCA will lead to a decrease in MVA by 0.023478%.

Finally, the result shows that there is a significant variation of Fisher's statistics (15.85384) with P-value of 0.00000 which means the model as a whole is statistically significant at an autocorrelation level of 1.856071 (Durbin-Watson), which is less than 2.5.

Summary of Findings

This study examines the effect of asset structure on economic value added of listed industrial firms in Nigeria for a period of 10 years covering 2013 to 2022. To achieve the study's specific objectives, data are collected from annual reports of the firms and tested with the panel regression model. From the regression analysis, the following findings are made;

- i. The first hypothesis tested revealed that, noncurrent asset has a significant effect on residual income of listed industrial goods firms in Nigeria.
- ii. The second hypothesis tested revealed that, current asset has a significant effect on residual income of listed industrial goods firms in Nigeria.



- iii. The third hypothesis tested revealed that, noncurrent asset has no significant effect on market value added of listed industrial goods firms in Nigeria.
- iv. The fourth hypothesis tested revealed that, current asset has no significant effect on market value added of listed industrial goods firms in Nigeria.
- v. The fifth hypothesis tested revealed that, noncurrent asset has a significant effect on return on invested capital of listed industrial goods firms in Nigeria.
- vi. The sixth hypothesis tested revealed that, current asset has no significant effect on return on invested capital of listed industrial goods firms in Nigeria.

Conclusion

The study examined the effect of asset structure on economic value added of listed industrial goods in Nigeria. Non-current asset and current asset were used to measure asset structure while residual income, market value added and return on invested capital were used to measure economic value added. The data were generated from the selected industrial goods firms listed in Nigeria Exchange Group. The data collected were analyzed using panel multiple regression analysis and the following findings were revealed;

- i. Noncurrent asset has a significant effect on residual income of listed industrial goods firms in Nigeria.
- ii. Current asset has a significant effect on residual income of listed industrial goods firms in Nigeria.
- iii. Noncurrent asset has no significant effect on market value added of listed industrial goods firms in Nigeria.
- iv. Current asset has no significant effect on market value added of listed industrial goods firms in Nigeria.
- v. Noncurrent asset has a significant effect on return on invested capital of listed industrial goods firms in Nigeria.
- vi. Current asset has no significant effect on return on invested capital of listed industrial goods firms in Nigeria.

Recommendations

In line with the findings of this study, the following recommendations are made;



- i. Firms' non-current asset structure should be monitored and evaluated on a regular basis by the respective company managements to ensure that the composition meets the strategic requirements of the firms in order to increase the economic value added of listed industrial goods firms in Nigeria.
- ii. The management of the firms should ensure that adequate current assets are maintained to enhance the liquidity base of the firms. This will further improve the firms' ability to meet up with short term obligations and ensure a significant change in their respective economic value added.
- iii. Managers of the listed industrial firms should increase their allocation of resources towards long term investments and funds in noncurrent asset in order to improve on their overall market value added to the company.
- iv. In order to enhance the market value added of firms, industrial goods firms should pay more attention to their current asset and ensure that there is cash and other cash equivalents available for current transactions of the business.
- v. Industrial goods firms should evaluate their noncurrent asset properly and engage in investment that would bring greater return to the business and company.
- vi. Industrial goods firms should evaluate their liquidity level through current asset assessment and ensure that the available current asset can yield performance that would enhance return on invested capital in the future.

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ENHANCING BUSINESS EDUCATION STUDENTS SKILLS ACQUISITION FOR SELF-RELIANCE IN PREVAILING ECONOMIC UNCERTAINTY IN ABIA STATE, NIGERIA

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Abstract

The study examined Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State, Nigeria. The study was guided by three research questions and three hypotheses. The design of the study was survey research design. The population of the study was 75 comprising 62 final year Business Education students 13 Business Education lecturers in three institutions in Abia State. There was no sampling, the entire population was used by the researcher since it was manageable. The instrument for data collection was structured questionnaire developed by the researcher and validated by three experts, two from Business Education in the Department of Agricultural and Vocational Education and one from Measurement and Evaluation in Science Education Department all in College of Education, Michael Okpara University of Agriculture, Umudike. The overall reliability coefficient of the instrument was 0.83. The data collected were analysed using mean to answer the research questions and standard deviation to determine the closeness or homogeneity of the respondent's responses, while t-test statistic was used to test the null hypotheses at 0.05 level of significance. The findings revealed that to high extent Business Education enhances students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State. Also, the constraints to students skills acquisition were: inadequate availability of training facilities, poor participation of Business Education students in industrial attachment training programmes, poor funding of Business Education programme, poor attitude of some Business Education students towards skills acquisition, poor remuneration of business educators in tertiary institutions, excess workload of the business educators, and inadequate provision of modern technology to enhance students skills acquisition among others while the mechanisms for enhancing Business Education students skills include: Adequate funding of Business Education programme, provision of adequate training facilities for enhancing students skills acquisition, adequate participation of Business Education students in industrial attachment training programmes, provision of enabling environment to enhance students positive attitude towards skills among others. Based on the findings, it was recommended that: there is need for both the federal and Abia state Government to pay adequate attention to education by providing the needed funds, facilities, modern equipment and tools to enhance students' skills acquisition in Business Education for self-reliance in prevailing economic uncertainty.

Keywords: Business Education, Skills Acquisition and Economic Uncertainty



Introduction

Business Education involves teaching students the rudiments, fundamental, concepts, theories and processes of business. It is an important part of the general education which emphasizes on skills acquisition for offices and business related occupation (Okenwa, 2018). Business Education represents a broad and diverse discipline that is included in all types of educational delivery which are primary, secondary and tertiary institutions. It includes education for office occupations, distribution and marketing, accounting, business teaching, business administration and economic understanding. This assertion indicates that all citizens need Business Education as an entry level of employment or as an entrepreneur particularly in this period where unemployment and economic uncertainty have become the order of the day in Nigeria and Abia state in particular (Olowu, 2019).

The objectives of Business Education according to Njoku (2018) include: to produce qualified graduates who can teach business subjects in secondary schools and other educational institutions, instill vocational aspects of business education to the students and equip graduates with skills for office work and self-employment among others. This implies that skills acquisition is important aspect of Business Education gear towards self-reliance of Business Education graduates. Skills as described by Uchendu (2019) referred to the abilities, capabilities, aptitude and expertise acquired through deliberate, systematic and sustained training necessary to adaptively perform job functions effectively. It is also described as the learned ability to carry out a task with pre-determined results often within a given amount of time, energy or both. Meanwhile, skill acquisition is the process of organizing effective and relevant knowledge in building up aptitude and ability in a particular craft. It entails the development of novel ideas, practice or a way of doing things which is attained by constant practicing (Eze, 2023).

According to Ekong and Ekong (2018), skill acquisition is the process of demonstrating the habit of active thinking or behaviour in a specific activity. It can further be seen as the ability to do or perform an activity that is related to some meaningful exercise, work, or job. Therefore, for skill to be acquired, appropriate knowledge, attitudes, habits of thought and qualities of character are learnt to enable the learner to develop an intellectual, emotional, and moral character which



prepares him or her for a brighter future. Thus, skill acquisition is the manifestation of idea and knowledge through training geared towards instilling in the students the spirit of entrepreneurship needed for meaningful development (Ebodili & Eze, 2022).

Effective skill acquisition in Business Education is an indispensable tool towards producing a self-reliant national and dynamic economy. Acquisition of relevant skills remains a panacea in the fight against economic hardships and unemployment in Nigeria as this will curtail crime rates through effective engagement of the youth in meaningful economic activities (Adedeji & Ibironke, 2022). This is to say that possession of relevant skills is an antidote to social problems. Skill acquisition in Business Education has become necessary in that it helps to shape and reshape the mentality of the youths for self-reliance and overcoming economic uncertainty.

Economic uncertainties in the submission of Siavash (2023) can be defined as situations in which the future economic environment is challenging to predict and there is a high degree of risk or unknowns involved. Ebodili and Eze (2022) added that in economic uncertainties, Business Education can help the youths to create jobs for themselves through vocational skills acquired. However, Ubulom and Enyoghasim in Adedeji and Ibironke (2022) stated that Business Education programme equips its recipients with skills such as communication skills, computation skills, economic adaptability skills, organizational effectiveness skills, managerial and business decision-making skills among many others through training and practical experiences in form of group projects and industrial training (IT) (Macintosh et al., 2017).

Consequently, Adeola (2024) stated that despite the perceived benefits of Business Education in Nigeria, there are numerous challenges that affect effectiveness of Business Education which impede the extent of students' skills acquisition. These challenges according to Adeola (2024) may include: inadequacy of instructional resources to commensurate with the need of the students, poor implementation of Business Education in some schools, poor funding of the programme and inadequate number of educators required for effectiveness of Business Education in different schools among others. Eze (2023) maintained that despite government effort to fund education programme, there is still inadequate fund in the implementation of the programme. The inadequate funding of education has become a hydra-headed monster that



cannot be conquered by government quarterly subventions but with sufficient and regular funding of the programme together with training and development of educators and development of viable curriculum among others as strategy for enhancing students' skills acquisition among others. To this end, the extent to which Business Education can be used for youths' sustainable employment and livelihood in economic uncertainties remain uncertain. Thus, it is on this background that necessitated this study on enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State, Nigeria.

Statement of the Problem

Business Education is an aspect of vocational and technical education meant to equip the learners with skills and competencies required to be gainfully employed or self-employed in order to be self-reliant and to overcome economic uncertainty. But it is worrisome to find out that most Business Education graduates lack necessary skills for self-reliant. This development in Nigeria and Abia State in particular in which Business Education graduates roam the streets looking for very scarce white-collar jobs instead of creating their own jobs seems to indicate that there is problem with the standard of the delivery of the programme and our economic development. This may be attributed to Government lip-service and nonchalant attitudes in the implementations of Vocational Education policies and programmes in term of provision of needed funds, facilities, workshops and equipment in addition to competent educators and adequate remuneration of the educators with regular training and development required to enable the learners to be equipped with adequate skills without depending solely on theory to the detriment of practical activities. This tends to affect students' acquisition of adequate skills for self-reliant and sustainable livelihood in economic uncertainty. (Eze, 2023). Consequently, it is on this backdrop that this study focused on enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State, Nigeria.

Purpose of the Study

The study focused on enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State, Nigeria. Specifically, the study sought to:



1. examine the extent Business Education enhances students skills acquisition for self-reliance in prevailing economic uncertainty in Abia State,
2. determine the constraints to Business Education students skills acquisition for self-reliance in prevailing economic uncertainty in Abia State and
3. find out the mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.

Research Questions

The following research questions were posed to guide the study:

1. To what extent does Business Education enhances students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State?
2. What are the constraints to Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State?
3. What are the mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State?

Hypotheses

The following null hypotheses were formulated and tested at 0.05 level of significance.

- H0₁:** There is no significant difference between the mean responses of students and Business Educators on the extent Business Education enhances students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.
- H0₂:** There is no significant difference between the mean responses of students and Business Educators on the constraints to Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.
- H0₃:** There is no significant difference between the mean responses of students and Business Educators on the mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.



Methodology

The design of the study was a survey research design. According to Ali in Madu (2023), survey can be described as a research design which seeks or uses the sampled data of an investigation to document, describe and explain what is in existence, or non-existence, or present status of a phenomena being investigated. The study was conducted in Abia State with the population of 75 comprising 62 final year Business Education students 13 Business Education lecturers in three institutions in Abia State. There was no sampling, the entire population was used by the researcher since it was manageable.

The instrument for data collection was structured questionnaire developed by the researcher titled: Enhancing Business Education Students Skills Acquisition for Self-reliance in Prevailing Economic Uncertainty Questionnaire (EBESSASPEUQ) and was validated by three experts, two from Business Education in the Department of Agricultural and Vocational Education and one from Measurement and Evaluation in Science Education Department all in College of Education, Michael Okpara University of Agriculture, Umudike. The reliability coefficient of the instrument was 0.82, 0.83 and 0.84 and overall reliability of coefficient of 0.83 was obtained and considered adequate for the study. A total of 75 copies of questionnaire were distributed to the respondents with the help of two briefed research assistants and 68 copies were retrieved completely filled including 57 final year Business Education students 11 Business Education lecturers representing 91% return rate. The data collected were analysed using mean and standard deviation to answer the research questions while t-test statistic was used to test the null hypotheses at 0.05 level of significance. The mean scale for research question one was obtained by real limit value of numbers as Very Low Extent (VLE) 1.00 – 1.49, Low Extent (LE) 1.50 – 2.49, High Extent (HE) 2.50 – 3.49 and Very High Extent (VHE) 3.50 – 4.00. Meanwhile, for research question two and three, the mean cut-off mark of 2.50 and above was considered as agreed while the mean cut off below 2.50 was considered as disagreed. The standard deviation was used to ascertain the homogeneity of the respondents' response to the items in the instrument. The decision rule in testing the hypotheses; the t-calculated values were compared with t-calculated values at 0.05% level of significance. The hypotheses of no significant difference was accepted for items whose t-calculated value are less then t-table values and rejected or otherwise.



Results

Research Question 1: To what extent does Business Education enhances students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State?

Table 1: Mean and Standard Deviation of the Respondents' Responses on the Extent Business Education Enhances Students Skills Acquisition for Self-reliance in Prevailing Economic Uncertainty in Abia State

N=68											
S/N	ITEM STATEMENT				\bar{X}_1	S.D ₁	\bar{X}_2	S.D ₂	\bar{X}_g	S.D _g	Rmks
Business Education:											
1	provide	students	with	effective	3.14	0.74	3.09	0.83	3.11	0.78	HE
	communication	skills									
2	enable	students	acquire	office	3.05	0.63	3.00	0.89	3.02	0.76	HE
	management	skills									
3	facilitates	planning	skills	acquisition	3.01	0.74	2.90	0.70	2.95	0.72	HE
	among	students									
4	provide	students	with	effective	3.10	0.72	3.00	0.63	3.05	0.67	HE
	marketing	skills									
5	equips	students	with	different teaching	2.98	0.74	2.90	0.83	2.94	0.78	HE
	skills										
6	provide	students	with	computation	3.08	0.78	3.00	0.77	3.04	0.77	HE
	skills										
7	facilitates	organizational		skills	2.96	0.70	2.81	0.75	2.88	0.72	HE
	acquisition	among	students								
8	equips	students	with	accounting	3.05	0.71	3.00	0.77	3.02	0.74	HE
	skills										
9	Inculcate	in the	students	critical	3.12	0.73	3.09	0.83	3.10	0.78	HE
	thinking	skills									
10	provide	students	with	human relation	3.03	0.75	3.00	0.77	3.01	0.76	HE
	skills										
	Cluster Mean				3.05	0.72	2.97	0.77	3.01	0.75	HE

Keys: \bar{X}_1 = mean of Business Education students, SD_1 =standard deviation of Business Education students, \bar{X}_2 = mean of Business Educators, SD_2 =standard deviation of Business Educators, \bar{X}_g = Grand mean of Business educators and students, SD_g = Grand standard deviation of Business Educators and students, Rmks. = Remarks.



The data presented on Table 1 shows that the mean responses of the respondents on items 1 to 10 ranged from 2.88 - 3.11 which fall within the real limit of 2.50 – 3.49. This implies that the respondents agreed to a high extent that Business Education enhances students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State. Also, the standard deviation of the 10 items ranged from 0.67 to 0.78 including the cluster mean and cluster standard deviation of 3.01 and 0.75 respectively indicating that the responses of the respondents were close to one another and to the mean.

Hypothesis 1: There is no significant difference between the mean responses of students and Business Educators on the extent Business Education enhances students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.

Table 2: t-test Analysis of the Mean Responses of Students and Business Educators on the Extent Business Education Enhances Students Skills Acquisition for Self-reliance in Prevailing Economic Uncertainty in Abia State

Variables	\bar{X}	SD	N	Df	t-calculated	t-tabulated	Decision
Students	3.05	0.72	57	67	0.31	1.99	Not Significant
Business Educators	2.97	0.77	11				

The data in Table 2 shows that the calculated t-value is 0.31 while the t- tabulated value is 1.99 at 0.05 level of significant and at 67 degree of freedom. Since the calculated value is less than the t-tabulated value, the null hypothesis was accepted. Therefore, there is no significant difference between the mean responses of students and Business Educators on the extent Business Education enhances students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.

Research Question 2: What are the constraints to Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State?



Table 3: Mean and Standard Deviation of the Respondents' Responses on the Constraints to Business Education Students Skills Acquisition for Self-reliance in Prevailing Economic Uncertainty in Abia State N=68

S/N	ITEM STATEMENT	\bar{X}_1	S.D ₁	\bar{X}_2	S.D ₂	\bar{X}_g	S.D _g	Rmks
1	Inadequate availability of training facilities for enhancing Business Education students skills acquisition	3.38	0.81	3.36	0.80	3.37	0.80	Agreed
2	Poor participation of Business Education students in industrial attachment training programmes	3.07	0.56	3.00	0.89	3.03	0.72	Agreed
3	Poor funding of Business Education programme in tertiary institutions	3.14	0.71	3.09	0.83	3.11	0.77	Agreed
4	Poor attitude of some Business Education students towards skills acquisition	3.03	0.68	3.00	0.63	3.01	0.65	Agreed
5	Poor numeration of business educators in tertiary institutions	3.19	0.61	3.18	0.87	3.18	0.74	Agreed
6	Excess workload of the business educators	3.22	0.59	3.27	0.78	3.24	0.68	Agreed
7	Inadequate business educators training and development	3.31	0.78	3.27	0.90	3.29	0.84	Agreed
8	Poor supervision of instructional activities in Business Education	3.12	0.68	3.09	0.83	3.10	0.75	Agreed
9	Inadequate provision of modern technology to enhance students skills acquisition in Business Education	3.10	0.64	3.09	0.83	3.09	0.73	Agreed
10	Inadequacies in the curriculum content of Business Education	3.08	0.71	3.00	0.77	3.04	0.74	Agreed
11	Inadequate number of experienced manpower in Business Education programme	3.12	0.62	3.09	0.70	3.10	0.66	Agreed
12	Poor industry and academic linkage	3.26	0.69	3.18	0.75	3.22	0.72	Agreed



Cluster Mean	3.16	0.67	3.13	0.79	3.15	0.73	Agreed
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Keys: \bar{X}_1 = mean of Business Education students, SD_1 =standard deviation of Business Education students, \bar{X}_2 = mean of Business Educators, SD_2 =standard deviation of Business Educators, \bar{X}_g = Grand mean of Business educators and students, SD_g = Grand standard deviation of Business Educators and students, Rmks. = Remarks.

The data presented on Table 3 shows that the mean responses of the respondents on the 12 items range from 3.01 - 3.37 which are all above 2.50 acceptable benchmark for the study. This implies that the respondents agreed that the 12 items are the constraints to Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State. Also, the standard deviation values of the 12 items ranged from 0.77 to 0.94 which indicates that the responses of the respondents were close to one another and to the mean.

Hypothesis 2: There is no significant difference between the mean responses of students and Business Educators on the constraints to Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.

Table 4: t-test Analysis of the Mean Responses of students and Business Educators on the constraints to Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State

Variables	\bar{X}	SD	N	Df	t-calculated	t-tabulated	Decision
Students	3.16	0.67	57				
				67	0.11	1.99	Not Significant
Business Educators	3.13	0.79	11				

The data in Table 4 shows that the calculated t-value is 0.11 while the t- tabulated value is 1.99 at 0.05 level of significant and at 67 degree of freedom. Since the calculated value is less than the t-tabulated value, the null hypothesis was accepted. Therefore, there is no significant difference between the mean responses of students and Business Educators on the constraints to Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.



Research Question 3: What are the mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State?

Table 5: Mean and Standard Deviation of the Respondents' Responses on the Mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State

		N=68							
S/N	ITEM STATEMENT	\bar{X}_1	S.D ₁	\bar{X}_2	S.D ₂	\bar{X}_g	S.D _g	Rmks	
1	Adequate funding of Business Education programme in tertiary institutions	3.29	0.90	3.27	0.78	3.28	0.84	Agreed	
2	Provision of adequate training facilities for enhancing Business Education students skills acquisition	3.03	0.59	3.00	0.89	3.01	0.74	Agreed	
3	Adequate participation of Business Education students in industrial attachment training programmes	3.12	0.73	3.09	0.83	3.10	0.78	Agreed	
4	Provision of enabling environment to enhance students positive attitude towards skills acquisition in Business Education	3.01	0.69	2.90	0.70	2.95	0.69	Agreed	
5	Adequate numeration of business educators to enhance their commitment towards students skills acquisition	3.17	0.63	3.09	0.83	3.13	0.73	Agreed	
6	Recruitment of business educators to reduce their workload for effective instructional delivery	3.21	0.61	3.18	0.87	3.19	0.74	Agreed	
7	Adequate training and development of business educators	3.29	0.80	3.27	0.90	3.28	0.85	Agreed	
8	Effective supervision of instructional activities in Business Education	3.10	0.69	3.09	0.83	3.09	0.76	Agreed	
9	Provision of modern technology to enhance students skills acquisition in	3.08	0.66	3.00	0.89	3.04	0.77	Agreed	



Business Education								
10	Review of curriculum content of Business Education to enhancing students skill acquisition	3.07	0.72	3.09	0.83	3.08	0.77	Agreed
11	Employment of professional and more experienced Business Educators	3.10	0.64	3.18	0.75	3.14	0.69	Agreed
12	Adequate industry and Business Education linkage to enhancing students skill acquisition	3.22	0.73	3.09	0.83	3.15	0.78	Agreed
Cluster Mean		3.14	0.69	3.10	0.82	3.12	0.76	Agreed

Keys: \bar{X}_1 = mean of Business Education students, SD_1 =standard deviation of Business Education students, \bar{X}_2 = mean of Business Educators, SD_2 =standard deviation of Business Educators, \bar{X}_g = Grand mean of Business educators and students, SD_g = Grand standard deviation of Business Educators and students, Rmks. = Remarks.

The data presented on Table 5 shows that the mean responses of the respondents on items 12 ranged from 2.95 - 3.28 which are all above the acceptable benchmark of 2.50. This implies that the respondents agreed that 12 items are the mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State. Also, the standard deviation of the 12 items ranged from 0.69 to 0.85 respectively which indicate that the responses of the respondents were close to one another and to the mean.

Hypothesis 3: There is no significant difference between the mean responses of students and Business Educators on the mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.

Table 6: t-test Analysis of the Mean Responses of students and Business Educators on the mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.

Variables	\bar{X}	SD	N	Df	t-calculated	t-tabulated	Decision
Students	3.14	0.69	57				
				67	0.15	1.99	Not Significant



Business Educators	3.10	0.82	11
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The data in Table 6 shows that the calculated t-value is 0.15 while the t- tabulated value is 1.99 at 0.05 level of significant and at 67 degree of freedom. Since the calculated value is less than the t-tabulated value, the null hypothesis was accepted. Therefore, there is no significant difference between the mean responses of students and Business Educators on the mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.

Discussion of Findings

The findings of the study were discussed in accordance with the research questions and hypotheses that guided the study.

From the findings of the study on research question one, it was revealed that to high extent Business Education enhances students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State. Also, the corresponding hypothesis tested revealed that there is no significant difference between the mean responses of students and Business Educators on the extent Business Education enhances students skills acquisition for self-reliance in prevailing economic uncertainty in Abia State. However, the findings relate to the study of Adediji and Ibironke (2022) that Business Education programme equips its recipients with skills such as communication skills, computation skills, economic adaptability skills, organizational effectiveness skills, managerial and business decision-making skills among many others. The findings also aligned with the study of Adeola (2024) stated that Vocational Education enhances students' acquisition of diverse skills.

The findings of the study on research question two revealed that the constraints to Business Education students skills acquisition for self-reliance in prevailing economic uncertainty in Abia State include: inadequate availability of training facilities, poor participation of Business Education students in industrial attachment training programmes, poor funding of Business Education programme in tertiary institutions, poor attitude of some Business Education students towards skills acquisition, poor numeration of business educators in tertiary institutions, excess



workload of the business educators, inadequate business educators training and development , poor supervision of instructional activities in Business Education and inadequate provision of modern technology to enhance students skills acquisition among others. There is no significant difference between the mean responses of students and Business Educators on the constraints to Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State. Consequently, this finding relates to the study of Adeola (2024) who revealed that the challenges that impede students skills acquisition include: inadequacy of instructional resources to commensurate with the need of the students, poor implementation of Business Education in some schools, poor funding of the programme and inadequate number of educators required for effectiveness of Business Education in different schools among others. Also, the findings relate the study of Eze (2023) that inadequate funding, inadequate training and development of educators and poor curriculum structure among others are the constraints to students' skills acquisition.

Lastly, the findings of the study on research question three shows that the mechanisms for enhancing Business Education students skills acquisition for self-reliance in prevailing economic uncertainty in Abia State include: Adequate funding of Business Education programme in tertiary institutions, provision of adequate training facilities for enhancing Business Education students skills acquisition, adequate participation of Business Education students in industrial attachment training programmes, provision of enabling environment to enhance students positive attitude towards skills acquisition in Business Education, adequate numeration of business educators to enhance their commitment towards students skills acquisition, recruitment of business educators to reduce their workload for effective instructional delivery, Adequate training and development of business educators, effective supervision of instructional activities in Business Education and provision of modern technology to enhance students skills acquisition in Business Education among others. Also, the corresponding hypothesis tested indicate that there is no significant difference between the mean responses of students and Business Educators on the mechanisms for enhancing Business Education students skills acquisition for self-reliance in prevailing economic uncertainty in Abia State. Thus, the findings relate to the study of Eze



(2023) who found that regular funding of education programme together with training and development of educators and development of viable curriculum among others are the strategies for enhancing students' skills acquisition among others.

Conclusion

It was concluded from the findings of the study that to high extent Business Education enhance students skills acquisition and the constraints to students acquisition of adequate skills were: inadequate availability of training facilities, poor participation of Business Education students in industrial attachment training programmes, poor funding of Business Education programme, poor attitude of some Business Education students towards skills acquisition, inadequate supervision of Business Education programme in tertiary institutions, inadequate provision of modern technology to enhance students skills acquisition and poor industry and academic linkage.

Recommendations

Based on the results of this study, it was recommended that:

1. There is need for Abia state Government to pay adequate attention to education by providing the needed funds, facilities, modern equipment and tools to enhance students skills acquisition in Business Education for self-reliance in prevailing economic uncertainty.
2. The Abia state Government should ensure that Business Education educators are adequately remunerated and also provided with required training especially on the use of modern technology for enhancing students acquisition of skills for self-reliance in prevailing economic uncertainty.
3. There is need for Abia State Government including institutions to ensure that there is proper linkage of Business Education with industries together with adequate supervision as mechanisms for enhancing Business Education students' skills acquisition for self-reliance in prevailing economic uncertainty in Abia State.



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GENDER DIFFERENTIALS IN MICRO-CREDIT USE AMONG PALM OIL ENTREPRENEURS IN SOUTH EAST NIGERIA

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Abstract

The study assessed gender differentials in micro-credit use among palm oil entrepreneurs in South East, Nigeria. Specifically, the study described the socio-economic characteristics of palm oil entrepreneurs by gender in South East Nigeria; identified the sources of credits available to palm oil entrepreneurs by gender and ascertained the level of use of micro-credit among palm oil entrepreneurs by gender. A multi-stage technique was used in the selection of 120 palm oil entrepreneurs (60 males and 60 females). Primary data were obtained from the selected samples using a structured questionnaire, which was administered to 120 respondents. Data were analyzed with descriptive statistics such as means, frequencies and percentages, as well as index of micro-credit utilization. Results showed that male palm oil entrepreneurs were mostly middle-aged, married, and had secondary education, while their female counterparts are relatively younger, mostly married, and had primary education. Both groups rely heavily on informal credit sources like family and cooperatives, though men tend to utilize more micro-credit for business expansion. The study recommended that government should partner with financial institutions to ensure that credit from formal financial institutions is directed to support both male and female palm oil entrepreneurs at low interest rate.

Keywords: Processors, marketers, sources, level, utilization, credit, index, government

Introduction

Gender is a socially constructed role difference between men and women to allocate powers, duties, status, responsibilities, and roles in any social context (Ekenta, Obabire, Otegwu, Adediran, Ahmed, and Abdullahi, 2023). Gender roles and expectations are learned and can change over time and vary within and between cultures. Systems of social differentiation such as political status, class, ethnicity, physical and mental disability, age, and more, modify gender roles (Ekenta et al., 2023). In palm oil value chain in South East, Nigeria, both men and women play crucial roles that can be complementary or supportive, maximizing productivity (Agwu, Oteh, and Amama, 2017). Therefore, cooperation and mutual support between men and women



are crucial for ensuring that palm oil entrepreneurs can access credit (loans or financial resources) and adopt improved technologies that enhance processing and marketing of palm oil.

Palm oil entrepreneurs specialize in processing, marketing, or selling palm oil products rather than cultivating palm oil trees. They include palm oil processors and marketers (Adejo, Opeyemi, Negedu, and Oyewole, 2023). Palm oil processors are specialized individuals that transform the harvested fruit of the oil palm tree into palm oil, using technologies like sterilizers, threshers, digesters, mechanical pressers, screw pressers, and centrifuges, among others (Alabi *et al.*, 2020). These technologies help palm oil processors increase efficiency, quality, yield and revenue/profit. Furthermore, palm oil processors play the intermediary role of taking the products from the processors to the final consumers. Palm oil marketers use technologies such as storage tanks, transportation technologies, e-commerce platforms, online marketplaces, and supply chain management software to optimize marketing, distribution, and customer engagement. However, both palm oil processors and marketers often rely on access to credit to enhance their operations, acquire modern technology, and expand their market reach (Alabi *et al.*, 2020).

Microcredit could be described as small loans provided to farmers who typically lack access to formal banking services. It includes loans, notes, bills of exchange, and bankers' acceptances, adapted to the specific financial needs of farmers, determined by planting, harvesting, and marketing cycles (Manteaw, Folitse, Swanzu, and Mahama, 2023). For processors, credit enables them to invest in costly processing equipment, such as sterilizers, digesters, and presses, which improve efficiency, yield, and product quality (Egwu, Odoh, and Eze, 2023). Access to financing also allows processors to cover the significant operating costs associated with scaling up production, hiring skilled labor, and implementing quality control measures. For marketers, credit is essential for funding logistics and distribution, maintaining inventory, and investing in digital marketing or supply chain technologies. With adequate financing, marketers can afford transportation equipment, warehousing solutions, and logistics software, ensuring a reliable supply of palm oil to meet demand in both local and regional markets (Egwu *et al.*, 2023).



Research on gender differentials in micro-credit use among palm oil entrepreneurs is important for enhancing the performance of both men and women in the palm oil business in Nigeria. However, most studies on palm oil entrepreneurship focused on the profitability of oil palm processing techniques (Okezie, 2020; Adejo *et al.*, 2023), the socioeconomic attributes and risk behavior of small-scale palm oil processors (Akpan *et al.*, 2023), effect of access to microcredit on food security status of farm households (Offor *et al.*, 2020) and gender differential in the intensity of adoption of oil palm processing technology (Bankole and Arifalo, 2022). Little or no known effort is made to assess gender differentials in micro-credit use among palm oil entrepreneurs in South East, Nigeria, which is the gap in literature that this study has filled.

Specifically, this study aimed to:

- i. identify the sources of credits available to palm oil entrepreneurs by gender in the study area;
- ii. ascertain the level of use of micro-credit among palm oil entrepreneurs by gender;
- iii. identify the socioeconomic characteristics of respondents

Methodology

The Study Area

The study was conducted in South Eastern Nigeria. The region lies in the humid tropical agro-ecological zone of Nigeria, between latitude 6° and 9°E and 4° north of the Equator and longitude 7°N east of the Greenwich Meridian. According to NPC (2018), the population of the South East Zone is estimated at 16, 381, 729 persons, disaggregated into 8, 306,306 males and 8, 075, 423 females with a population growth rate of 2.6% per year. The Zone consists of five states, namely, Abia, Anambra, Ebonyi, Enugu, and Imo. It has a bimodal rainfall pattern with the rains usually lasting on the average, for eight to nine months followed by a short dry season. The rains are usually heavy and start March and stop in November, peaking in July and September. The weather favours various crops all year round. The major crops grown include cassava, maize, fluted pumpkin, water leaf, okro, swamp rice, palm oil, cocoyam, oil palm and raffia palm. Cowpeas, cocoa, kola, mangoes and citrus are also grown but in lesser quantities. Cattle, goat,



sheep, pig, rabbit, fish, snail, bees and poultry are reared in the State. However, there are significant numbers of household specializing in the processing of palm oil.

Sampling Procedure and Sampling Size

A multi-stage technique was used in the selection of the respondents. The first stage involved the purposive selection of three states (namely- Abia, Imo, and Ebony States) from the five states of the Southeastern region based on the intensity of palm oil processing. Secondly, from each of the selected states, one agricultural zone was purposively selected based on the dominance of palm oil processing in the zones. Thirdly, from each agricultural zone, two Local Government Areas (LGAs) were randomly selected, giving a total of 6 local government areas for the study. The fourth stage involves a random selection of two communities each from the selected LGA, giving a total of 12 communities for the study. In the fifth stage, 1 village was selected randomly from the communities, giving 12 villages for the study. In the last stage, 10 palm entrepreneurs (5 males and 5 females) were randomly selected from the villages, giving 120 respondents (60 males and 60 females) for the study.

Data collection/Analytical Technique

Primary data were obtained from the selected samples using a structured questionnaire, which was administered to 120 respondents. Objectives, i and ii were analyzed with descriptive statistical tools such as means, frequencies and percentages. Objective iii was analyzed with Index of micro-credit utilization (IMU) as follows:

$$IMU_i = \frac{\sum_{j=1}^n T_{ij}}{n} \dots 3.1$$

IMU_i = Index of micro-credit utilization for respondent i.

T_{ij} = Binary variable indicating whether respondent i uses amount of micro-credit j (1=Yes, 0 = No).

n = Total amount of micro-credit available.



Results and Discussion

Socio-economic characteristics of palm oil entrepreneurs by gender in Southeast Nigeria

Table 1: Distribution of respondents according to socio economic characteristics

Variables	Male		Female	
	Frequency	%	Frequency	%
Age				
20-29	2	3.33	-	-
30-39	7	11.67	3	5.00
40-49	9	15.00	28	46.67
50-59	22	36.67	25	41.67
60-69	11	18.33	4	6.67
70-79	8	13.33	-	-
80-89	1	1.67	-	-
Total	60	100	60	100
Mean	53		47	
Marital status				
Single	17	28.33	6	10.00
Married	43	71.67	50	83.33
Widowed	-	-	4	6.67
Divorced	-	-	-	-
Total	60	100	60	100
Education				
No formal education	10	16.67	3	5.00
Primary education	20	33.33	17	28.33
Secondary education	21	35.00	2	3.33
NCE/OND	3	5.00	12	20.00
Degree/HND	5	8.33	11	18.33
Postgraduate education	1	1.67	15	25.00
Total	60	100	60	100

Source: Field survey, 2025

Age of the respondents

The result in Table 1 shows that most (36.67%) of the male palm oil entrepreneurs were within the age bracket of 50-59 years while that of the least proportion (1.67%) of the respondents was within the age bracket of 80-89 years. The mean age of the male palm oil entrepreneurs was 53years. From the distribution, it could be inferred that most of the male palm oil entrepreneurs were still in their active stage in life, a pointer to the fact that middle aged palm oil entrepreneurs are mostly involved in palm oil processing in the study area. More so, male palm oil



entrepreneurs are at their productive age in life and are likely to adopt innovations and palm oil processing technologies faster. This is true because age, as a proxy for experience, can enhance innovation adoption, business initiatives and efficient use of scarce resources. With respect to the female palm oil entrepreneurs, majority (46.67%) were within the age bracket of 40-49 years while the least proportion (5.00%) of the respondents were within the age 30-39 years. The mean age of the female palm oil entrepreneurs was 47 years, implying that large proportions of the young female palm oil processors are involved in palm oil processing in the study area. Relatively, female palm oil entrepreneurs are younger than their male counterparts in the study area. This finding is in tandem with Okezie,(2020) and Agbamu (2021), who reported that female palm oil entrepreneurs were younger than their male counterparts.

Marital status of the respondent

The result in Table 1 also shows that majority (71.67%) of the male palm oil entrepreneurs were married. This connotes that married individual constitute majority of the male palm oil entrepreneurs in the study area. The preponderance of married male palm oil entrepreneurs has huge implication for improved palm oil processing technologies adoption, enhanced productivity and profitability, and welfare. Married male palm oil entrepreneurs have high tendency of having children who could assist them in palm oil processing, thereby enhancing their productivity. Of course, family members often serve as a source of cheap or additional labor in palm oil processing and marketing activities like bunch quartering, striping, digesting, pulp pressing, storing, transporting and selling. Equally, majority (83.33%) of female palm oil processors were married and the likelihood of such households having children who could help in palm oil businesses is high. This is typical of Nigeria rural setting because family members often serve as a source of additional labor together with cultural value attached to marriage. More so, the preponderance of married female palm oil entrepreneurs in the palm oil industry could be attributed to high domestic responsibility and their desire to enhance their welfare needs and that of their family members. This finding corroborates with Idris-Adeniyi, Busari, Alabi, Olanrewaju, Wahab, and Ige, (2024), reported that majority of the respondents were married.



Education

The result in Table 1 also shows that majority (36.67%) of the male palm oil entrepreneurs had secondary education as their highest level of educational qualification while the least proportion (1.67%) had postgraduate education. A greater proportion (28.33%) of the female palm oil entrepreneurs obtained primary education. This presages that majority of male and female palm oil entrepreneurs in the study area are literates, thus can read and write and as well take advantages of the innovations in the palm oil industry. Their level of education is vital since it helps them to have good attitude, good understanding and communication skills needed in the adoption of improved palm oil technologies and its application for enhanced productivity, profitability and welfare. It also implies that most male and female palm oil entrepreneurs in the study area are better positioned to take advantage of new palm oil technologies that could lead to increased productivity and welfare. This finding aligns with that Worlu, Morris and Nyejiwu, (2023) reported that most of respondents had primary education.

The sources of credits available to palm oil entrepreneurs by gender

Table 2: Sources of credits available to palm oil entrepreneurs by gender

Sources of credit	Male		Female	
	Frequency*	%	Frequency*	%
Agricultural cooperatives	50	88.33	54	90.00
Microfinance banks	20	33.33	10	16.67
Government programmes/Banks	44	55.00	30	50.00
NGOs	15	25.00	5	8.33
Families/friends	55	91.67	49	81.67

Source: Field survey, 2025 *Multiple responses recorded

Results in Table 2 shows that majority (91.67%) of the male palm oil entrepreneurs sourced credit from families/friends, while 90.00% of the female palm oil entrepreneurs sourced credit from agricultural cooperatives in the study area. For the male palm oil entrepreneurs, sourcing credit from families/friends eliminates the need for stringent repayment terms or collateral requirements, making it a practical choice for those of them facing barriers to accessing formal



financial institutions. However, this reliance on informal sources may limit the amount of credit available for scaling up their operations. For the female palm oil entrepreneurs, cooperatives may have provided them with a more structured financial support and opportunities for shared resources and knowledge exchange. Results also points to the fact that majority of palm oil entrepreneurs in the study area sourced credit from informal sources other than formal sources. Reliance on informal credit sources by both male and female entrepreneurs highlights a gap in the accessibility and suitability of formal credit systems. This finding is in line with that Okezie (2020) who reported that Majority of the processors obtained credit from informal sources.

Level of use of micro-credit among palm oil entrepreneurs by gender

Table 3: Level of use of micro-credit among palm oil entrepreneurs by gender

Levels of Utilization of micro-credit (%)	Male		Female	
	Freq.	%	Freq.	%
0-25	1	1.67	-	-
26-50	-	-	-	-
51-75	1	1.67	4	6.67
76-100	58	96.66	56	93.33
Total	60	100	60	100
Mean	86.11		85.49	

Sources: Field Survey, 2025

Results in Table 3 shows that the level of utilization of micro-credit by majority (96.66%) of the male palm oil entrepreneurs was between 70-100% while 93.33% of the female palm oil entrepreneurs utilized 76-100% of credit obtained. The mean level of utilization of credit (86.11) by the male palm oil entrepreneurs was higher than that of the female counterparts (85.49). This high level of credit usage suggests that male entrepreneurs are maximizing the financial support they receive, likely directing it toward expanding operations, purchasing technologies/inputs, or improving production efficiency. For the female palm oil entrepreneurs, their level of utilization of credit reflects a commendable ability to put borrowed funds to productive use. The small difference in credit utilization between the two groups may stem from variations in business scale, investment opportunities, or financial management practices. This finding is in tandem



with Anigbogu, Uzundu, and Nduka (2018), that the level of utilization of credit among male farmers was higher than that of their female counterpart.

Conclusion

The male palm oil entrepreneurs in Southeast Nigeria are mostly middle-aged, married, and had secondary education, while their female counterparts are relatively younger, mostly married, and had primary education. Both groups rely heavily on informal credit sources like family and cooperatives, though men tend to utilize more micro-credit for business expansion.

Recommendations

Based on the findings and conclusion of this study, the following recommendations were proffered;

1. Government should partner with financial institutions to ensure that credit from formal financial institutions is directed to support both male and female palm oil entrepreneurs by reducing the interest rate.
2. Training programmes on financial management and credit utilization should be introduced, especially for female entrepreneurs, to help them better access and manage business funds while Palm oil entrepreneurs should form group/ cooperative for easy access of Micro credit and grassroot training.

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TRENDS ANALYSIS OF AGRIBUSINESS FINANCE IN NIGERIA FROM 1980 TO 2022

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Abstract

Agribusiness plays a crucial role in the Nigerian economy, bridging input supply, farm production, and output processing and marketing. The development and expansion of agribusiness largely depend on adequate financing, which can be sourced from personal savings, bank loans, government interventions, and other financial institutions. This study analyzed trends in agribusiness finance in Nigeria from 1980 to 2022. The research utilizes time-series data sourced from institutions such as the Central Bank of Nigeria (CBN), the National Bureau of Statistics (NBS), the Food and Agriculture Organization (FAO), and the World Bank. The analysis used descriptive statistics, trend analysis, and exponential and log-linear trend models. The key financial indicators examined include commercial bank loans to agriculture (CBLA), government expenditure on agriculture (GEAS), Agricultural Credit Guarantee Scheme Fund (ACGSF), agricultural foreign direct investment (AFDI), agricultural GDP (AGDP), and food security index (FSI). The study revealed significant downward fluctuations in agribusiness finance over the years. However, high variability in commercial bank loans and government expenditure suggests inconsistencies in agricultural financing policies. The study therefore recommended that the government create long-term policies supporting agribusiness financing, regardless of leadership changes.

Keywords: Credit, grant, interest rate, policies, government

Introduction

Agribusiness is a lucrative and vital aspect of Agriculture in Nigeria. It can best be described in line with Goldberg and Davis as a linkage between the input, farm, and output sectors. These cover farm input supply such as farm machinery, fertilizer, chemical, and seedling supply, etc. (input sector) crop, livestock, fishery, forest production (farm sector), and agro-processing, marketing, storage, and distribution (output sector) (Food and Agricultural Organization [FAO], 2023). The agribusiness sector is becoming popular given its profitability and emphasis on sustainability. Furthermore, agribusiness stirs up investment consciousness. Concerning Nigeria,



the sector covers subsectors such as crop, fishery, livestock, forestry production processing, and distribution (Mbelu and Ifionu, 2022).

All the growth and development of agribusiness depend on the monetary or financial infusion in the system which can be pooled through large-scale investments and so, agricultural financing is the acquisition and use of capital for agricultural activities (Odoemenem and Boinne 2022). This can be obtained from various sources including personal savings, bank loans, loans from friends/family, cooperative society and money lenders, government sources, charitable organizations, private companies, etc. According to Muftau (2023), agricultural credit (finance) is credit granted to farm and ranch operators to assist in planting and harvesting crops to support the feeding and care of livestock. Credit to the agribusiness sector could take the form of an overdraft, short-term, medium-term, or long-term depending on the purpose and gestation period of the project (CBN, 2014). Such credits granted to farmers to purchase inputs are paid directly to the suppliers who must furnish the bank with evidence of delivery. This is done to avert the diversion of funds, which is common among Nigerian farmers (Afolabi, 2021).

A major initiative within agricultural finance is the Commercial Agricultural Credit Scheme (CACS), launched in 2009. This program was designed to provide funding to large-scale commercial farmers through bonds worth ₦200 billion raised by the Debt Management Office (DMO) (CBN, 2014). The loans offered under this scheme come with a maximum interest rate of 9%, and the scheme covers all aspects of the agricultural value chain, including production, processing, storage, and marketing. In addition to the CACS, the Anchor Borrowers' Program (ABP), launched in 2015, was established to link smallholder farmers with large agricultural processing companies (CBN, 2015). The program has proven to be beneficial, as it has assisted millions of farmers across Nigeria, distributing significant funds through various agricultural commodities (Reuben *et al.*, 2020).

Despite the ongoing efforts to boost agricultural finance, many smallholder farmers in Nigeria still face significant challenges in accessing these resources. Smallholder farmers in the country often rely on family labor and possess small plots of land that are not typically sufficient to meet



market demands (Reuben *et al.*, 2020). More than 80% of Nigeria's farmers are classified as smallholders, and they often encounter issues with financing, which in turn impacts their productivity (CBN, 2015). Therefore, this study was conducted to analyse trends in agribusiness finance in Nigeria: An analysis from 1980 to 2022.

Methodology

The Study Area

The study was carried out in Nigeria in 2024. Nigeria is situated in West Africa, Africa – the largest black continent. Its capital is Abuja. The country gained independence in 1960 and been a republic in 1963. The country Nigeria lies on latitude $9^{\circ}04'39.90''N$ longitude $8^{\circ}40'38.84''E$. The country covers a geographical space of 923,768 square kilometres (CIA world fact book 2011) and a population size of 200 million (NBS, 2019). The country shares a border spanning 773 km in the west, 1690 km with Cameroon in the East, 1497 km and 87 km with Niger and Chad respectively in the north, and 790 kilometres with the Gulf of Guinea in the South. Nigeria is the most populous nation in Africa, currently ranked 7th most populous in the world with an estimated population of about 170,123,740 (consisting of 374 ethical groups with Hausa, Igbo Yoruba as the main ethnic group) with a population destiny of about 184 per square meter (Central Intelligence Agency (CIA), 2012). The water resources of the country are largely evidenced by River Niger and Benue which are 1174.6 km and 796.5 km long respectively. The rivers transverse in the confluence town of Lokoja, Kogi State (Muhammad, and Mohammed (2018).

In terms of economy, Nigeria economy is the 30th largest economy in the world based on GDP size (Organization of the Petroleum Exporting Countries (OPEC), 2019). Nigeria's economy is largely dominated by crude oil supply and it accounts for about 15% of the GDP of the country, 70% of the revenue of the Government, and over 83% of the nation's export revenue (OPEC, 2019). The industrial sector makes up 22.3% of the GDP, agriculture makes up 20.8% of the GDP, and 55.8% of the GDP is represented by service. The industrial sector comprises of mining and manufacturing. The agricultural sector comprises of crop, livestock, fishery, and forestry (CBN, 2018) the service sector comprises of banking, transport, communication, etc.



The climatic profile of Nigeria is tropical with two main seasons which are the dry season and the rainy season. The dry season begins in November and last till March and is categorized into the cool dry season and the hot dry season. The cool dry season is characteristically cold and affected by North-east trade wind blowing across the country from the Sahara. The hot dry season is characteristically hot with high temperatures. The rainy season begins in April and last till October. The raining reason is affected by the south-west trade wind which blows from the Atlantic Ocean across the country. According to NNPC (2019), rainfall decreases from about 1,5000mm in the south to about 500mm in the North. The average temperature in Nigeria is high, ranging between 22°C and 34°C . However, there is a case of exceptionally low temperatures in the Jos Plateau, the Mambila Plateau and the Obudu Plateau all year round. (NNPC 2019)

The agribusiness sector plays a crucial role in Nigeria's economy, contributing approximately 20.8% of the Gross Domestic Product (GDP) (CBN, 2018) and providing employment for over 35% of the labor force (NBS, 2021). The sector includes crop production, livestock, fisheries, forestry, agro-processing, and agricultural trade. Nigeria is a leading producer of cassava, maize, yam, rice, cocoa, oil palm, groundnut, and livestock products, making agribusiness a crucial contributor to food security and economic growth. In recent years, there has been growing emphasis on agriculture and agribusiness as key drivers of economic diversification and resilience. Government initiatives such as the Agricultural Transformation Agenda (ATA), Anchor Borrowers' Programme (ABP), and National Agricultural Technology and Innovation Policy (NATIP) have been introduced to enhance investment in agribusiness and strengthen food security (NBS, 2021).

Method of Data Collection

Time series data were used for this study. The period of the study was from 1980 – 2022. Data for this study were sourced from various sources as guided by existing literature. The sources of data were as follows: CBN statistical bulletin for various years, National Bureau of statistics for various years, FAO statistics for various years Nigeria Economic Summit Group (NESG) annual



report, the National Meteorological Center and World Development Indicator which acts as the primary World Bank database.

Analytical Technique

To achieve the trends in agribusiness financing in Nigeria within (1980 – 2022), descriptive statistics (tables) and trend analysis were used.

In modeling trend for this study, the exponential trend or log-linear trend was employed in line with Onyenweaku (2004). The exponential trend or log-linear trend equation is modeled as follows;

$$\text{LOGCBLA}_t = \beta_0 + \beta_1 t + \mu_t \dots 1$$

$$\text{LOGGEAS}_t = \beta_0 + \beta_1 t + \mu_t \dots 2$$

$$\text{LOGACGSF}_t = \beta_0 + \beta_1 t + \mu_t \dots 3$$

$$\text{LOGAFDI}_t = \beta_0 + \beta_1 t + \mu_t \dots 4$$

$$\text{LOGAGDP}_t = \beta_0 + \beta_1 t + \mu_t \dots 5$$

$$\text{LOGGDP}_t = \beta_0 + \beta_1 t + \mu_t \dots 6$$

$$\text{LOGFSI}_t = \beta_0 + \beta_1 t + \mu_t \dots 7$$

Where:

LOGCBLA_t = Commercial bank loans to agriculture (measured in Naira) at period t .

LOGGEAS = Government capital investment or government expenditure on agricultural sector (measured in millions of Naira) at period t .

LOGACGSF_t = Agricultural credit guarantee scheme fund (measured in millions of Naira) at period t

LOGAFDI_t = Agricultural foreign direct investment (measured in USD Dollars) at period t

LOGAGDP_t = Gross domestic product/economic growth (measured in billions of Naira) at period t

LOGFSI_t = Food security index (constructed by dividing the annual per capita calorie intake by the average recommended per capita calorie) at period t

β_0 = the constant in the regression line.

β_1 = the trend coefficient.

t = trend variable measured in years.

μ_t = the error term.



Results and Discussion

The summary statistics of the agribusiness finance components

The study variables' descriptive statistics are shown in Table 1. According to the Table, Gross Domestic Product (GDP) recorded over the period a mean value of \$223 billion with a maximum of \$574billion and minimum of \$44billion per annum with its standard deviation of \$168billion indicating high dispersion from the mean. This implies that economic growth has not been steady, potentially due to factors such as fluctuating oil prices, inconsistent government policies, inflation, and external economic shocks. This finding aligns with Odoemenem and Boinne (2022), who also highlighted the impact of economic volatility on GDP growth, emphasizing the role of policy instability and external shocks in shaping economic performance. In addition, the commercial bank loan to agricultural sector (CBLAS) recorded over the period a mean value of N81 billion with a maximum of N600 billion and minimum of N0.1billion per annum with its standard deviation of N140 billion indicating high deviation from the mean. In furtherance, government expenditure on agricultural sector (GEAS) recorded over the period a mean value of N45billion with a maximum of N322billion and minimum of N.01billion per annum with its standard deviation of N78 billion indicating low deviation or dispersion from the mean. On the other hand, the Agricultural Credit Guarantee Scheme Fund (ACGSF) had a mean value of N16 billion, a maximum value of N13billion and minimum value of N16 billion per year, and a standard deviation of N8 billion, suggesting a moderate level of dispersion.

Table 1: Summary statistics of agribusiness finance components in Nigeria (1980-2022)

VARIABLE	N	Minimum	Maximum	Mean	Std. Deviation
CBLA(₦'M)	43	100.00	600000.00	81304.7674	140942.08510
ACGSF(₦'M)	43	15642.000	45625.000	13240.06977	8328.363312
GEAS (₦'Billion)	43	.01	322.29	45.2493	77.73058
AFDI (\$'B)	43	18.73	25121.35	6508.3784	9709.01206

Source: CBN Statistical Bulletin, 2021



Trends in Agribusiness Finance Components/Variables

Figures 1, 2 and 3 represent a graphical illustration of the agribusiness financing components or variables under analysis. In particular, the figure demonstrates that these variables showed a great deal of inconsistency in their upward and downward movements throughout the research period. Specifically, commercial bank loan to agriculture (CBLA) showed somewhat stagnant growth from 1980 to 2005 then recorded a sharp increase in 2013 and maintained a consistent increase till 2022. The same is applicable to ACGSF that recorded a sharp increase in 2011 dropped in 2012 and increased again in 2013. The observed fluctuations in agribusiness financing components indicate a lack of consistency in financial support for the sector, which may have implications for agricultural productivity and investment planning. Figure 5 shows an impressive trend of AFDI following policies of the country at the time. The trend shows a good performance of agricultural FDI in the early 1980s and early 1990s. The trend recorded the highest value in 1990 and remained stagnant till the mid-1990s. It could be seen from the trend that the period when agricultural foreign direct investment performed better coincided with the period of military regime in Nigeria. According to Ibeagwa (2016) and Njogo (2013), the era of military rule in Nigeria was characterized by inconsistency in government policies. This resulted in political instability. Foreign investments are hampered by political instability but in Nigeria's case, it is different Wafure and Ahu (2010) in accentuating this point reported a direct relationship between the country's FDI inflow and political instability.

More so, the high performance of the AFDI in Nigeria was due to the fall in global energy supply. Hence investors were moving into sub-Sahara Africa in search of biofuel, food, etc to take to their home countries (Wafure and Ahu, 2010). Nigeria benefited from this largely despite the political instability by military dictatorship. The dominance of FDI over domestic investment in Agriculture within the period defined the policy inconsistency at the time but investors gradually withdrew their investment portfolio when they foresaw that military would not stop even soon. Hence AFDI remained stagnant even from 1986 to 1993. Nigerian government and policy makers favoured the SAP which helped to shore up local investment and ensured that domestic investment was give the pride of place and that helped ensure increased GDP and self-

sufficiency in food supply in Nigeria. Fluctuations in AFDI prevailed till 2001 when the least value was recorded.

AFDI picked up again after the military rule in 1999 and continued till 2005 following a revival in civilian administration and economic policies that favoured FDI in Nigeria. According to Ibagwa (2016) and Wafuru and Ahu (2010) this era marked a remarkable improvement in foreign policies and foreign investors took advantage of the peaceful democratic regime in Nigeria to increase their economic activities. However, a sharp drop in AFDI was recorded in 2009 following a change in democratic government. It picked up again from then when Nigeria was declared the best and highest economy in Africa.

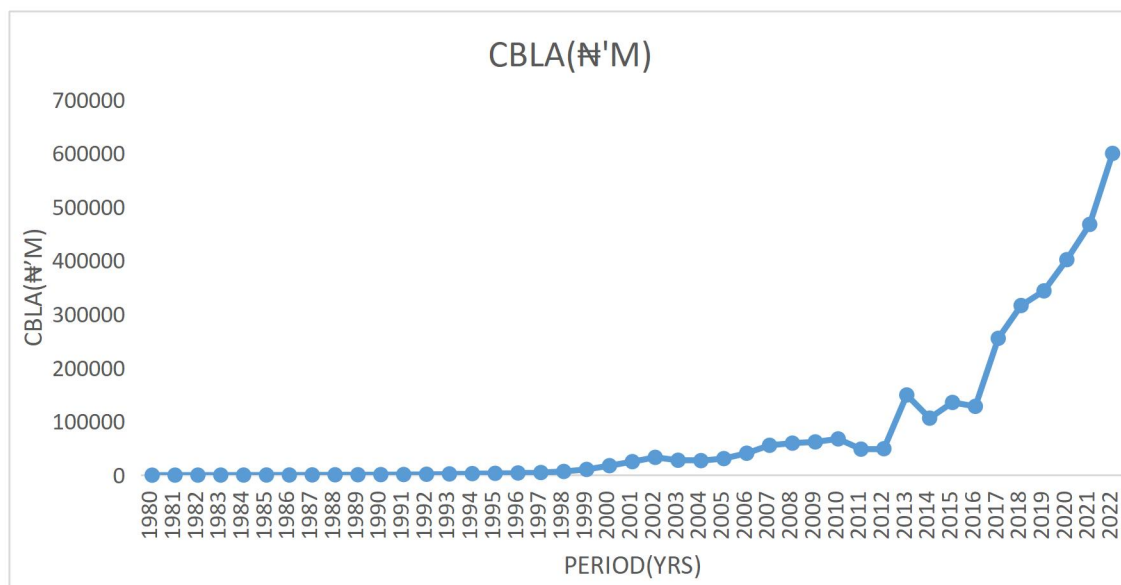


Fig. 1 Trend in Commercial Bank Loan to Agriculture (CBLA)

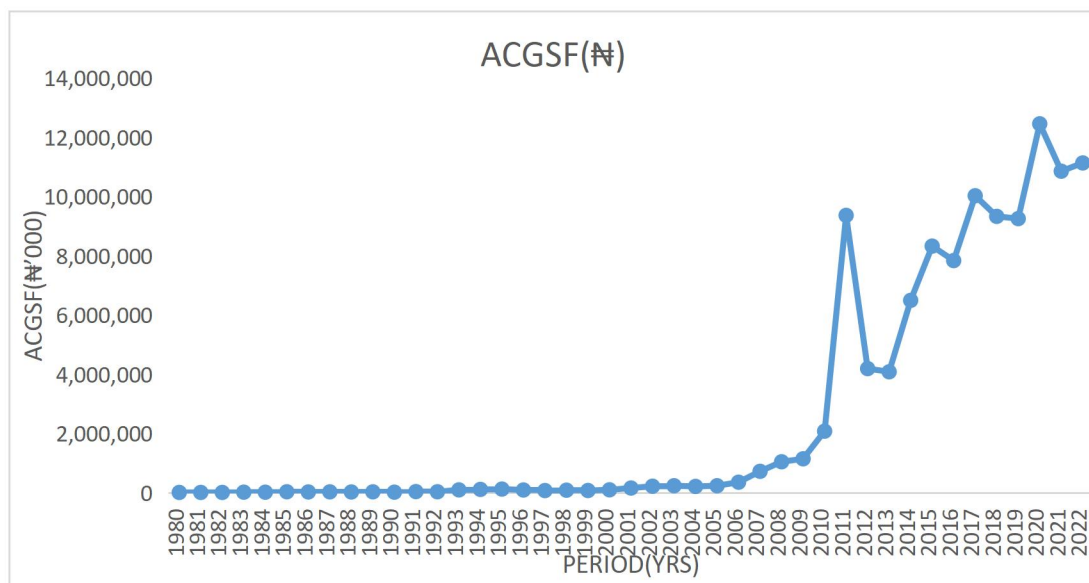


Fig. 2 Trend in Agricultural Credit Guarantee Scheme Fund (ACGSF)

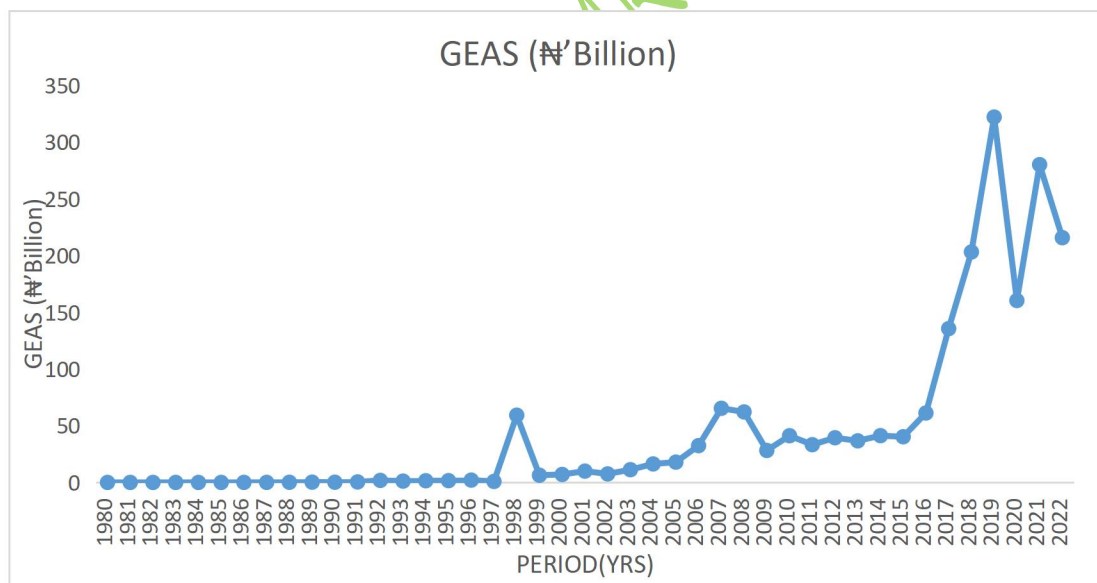


Fig. 3 Trend in Government Expenditure in Agricultural Sector (GEAS)

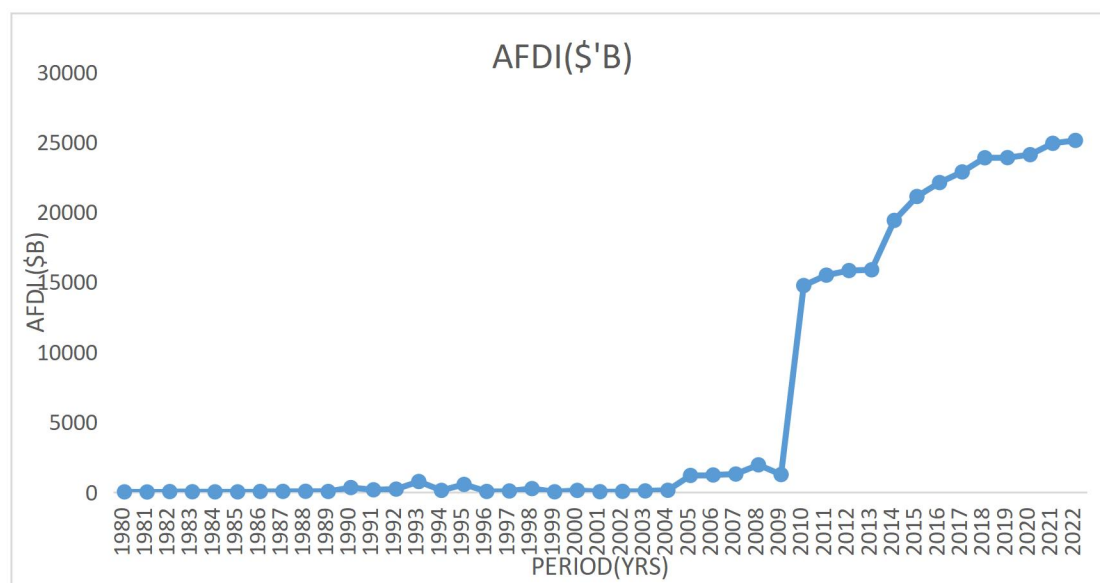


Fig. 4 Trend in AFDI

Conclusion

The study found that the availability of funds for agribusiness in Nigeria is influenced by government policies, changes in leadership, and global economic conditions. The study also showed that loans from commercial banks, government spending on agriculture, and credit programs for farmers have promoted agricultural growth, however, these financial supports have not always been consistent, which has affected the sector's stability.

Recommendations

Based on the findings and conclusion of this study, the following recommendations were proffered;

1. Changes in leadership influenced agricultural financing negatively, therefore, the government should create long-term policies that support agribusiness financing, regardless of changes in leadership.
2. The government and banks should make grants and loan available to agribusinesses by lowering the interest rates and making of repayment plan flexible.



3. The government should create incentives like tax reductions and loan guarantees to attract private investors to the agribusiness sector.

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PUBLIC SECTOR ACCOUNTING REFORMS AND PUBLIC FINANCIAL MANAGEMENT

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Abstract

Public sector accounting reforms, as part of public financial management (PFM) aims to ensure transparency, accountability, and efficiency in managing public resources. These reforms improve financial reporting, governance, fiscal transparency, and public investment through the adoption of international standards such as the International Public Sector Accounting Standards (IPSAS). The study examines global trends, implementation strategies, and outcomes, highlighting case studies from various countries, including Nigeria, New Zealand, India, and Ghana. The paper emphasizes the role of digital transformation, accrual-based accounting, and institutional frameworks in strengthening financial management systems. The theoretical frameworks that underpin study reviewed by the paper include institutional theory, rational choice theory, and public choice theory. The findings suggest that modernized accounting practices are essential for achieving fiscal discipline, economic development, and public trust.

Key words: Public Sector Accounting, Public Financial Management, Fiscal Transparency

Introduction

Public financial management (PFM) can be traced back to the early development of state finance systems in Europe during the late medieval and early modern periods as nation states consolidated power, the need for more structured and transparent financial systems became evident. Reforms have shaped by the changing demands of governance, economic complexity, and accountability requirements Resulted by the establishment of parliamentary oversight over public finances. Over time, similar initiatives were adopted in other parts of Europe, particularly with the rise of constitutional monarchies, where fiscal accountability to representative bodies became a central feature of governance.

Public Financial Management (PFM) refers to the set of rules, systems, and processes by which governments manage public resources to achieve their development and governance goals. PFM can also view as the processes and methods with which the government organises, allocates, and oversees public resources.



Key elements of PFM include budget preparation, execution, and monitoring; public procurement; debt management; and financial reporting. These processes ensure that public funds are used efficiently, effectively, and equitably to meet policy objectives (Cangiano et al., 2013). A strong PFM system supports good governance by reducing opportunities for corruption, ensuring fiscal discipline, and aligning resources with national priorities (World Bank, 2021). Today, PFM is shaped by globalization, technological advances, and international standards promoted by institutions like the International Monetary Fund (IMF) and the World Bank. Contemporary systems emphasize fiscal transparency, participatory budgeting, and digital innovation to enhance efficiency and inclusiveness (Andrews, 2010).

Public sector accounting reforms are a part of public financial management (PFM) reforms that help governments manage public resources. These reforms can improve the quality of financial reporting and help governments make better decisions. Public sector accounting reforms are initiative aimed to assist in improvement of quality and reliability of public financial information. The objective was to ensure public funds are utilized wisely and that public sector managers have information they needed in making right and prompt decision for the overall interest of all stakeholders. Given this, the paper aims to analyze the intersection of public sector accounting reforms and PFM, providing insights into their benefits, implementation strategies, and outcomes. By examining global practices and challenges, the study contributes to the discourse on strengthening governance through improved financial management. Also the paper is a literature review type, carrying review of relevant journals, authoritative books and standards and other resources relevant to the subject matter of the topic.

Benefit of Public Sector Accounting Reforms

Improve Financial Reporting

Financial reporting practices are critical for governments to foster transparency, accountability, and effective resource allocation. Financial reforms can standardize processes by ensuring that reports are consistent, comparable, and reliable across jurisdictions. It also boost trust among stakeholders which including citizens, investors, and international organizations.

One key element of reform involves adoption of International Public Sector Accounting Standards (IPSAS). These frameworks provide guidelines for accrual-based accounting that



enable governments to present a holistic view of assets, liabilities, revenues, and expenditures. Studies show that governments that implemented IPSAS reporting improved financial clarity and comparability to aligning national accounts with global benchmarks (Hassan et al., 2020). Reforms also help integrate technology-driven solutions, such as automated data systems and enterprise resource planning (ERP) tools. These innovations minimize human error, enhance data accuracy, and provide real-time updates to make financial reports more dependable (Smith, 2021). Adopting international standards and leveraging in technology governments can achieve more transparent and reliable financial reporting systems. Also Accurate and timely financial reports help policymakers make informed decisions on resource allocation, budgeting, and financial management which lead to Facilitates international cooperation, grants, and financial aid.

Improve Governance

Public sector accounting reforms play a critical role in fostering transparency, accountability, and efficiency in managing public resources enable policymakers and stakeholders to make informed decisions (Chowdhury & Hoque, 2019). Accurate and standardized financial reporting reduces opportunities for corruption by providing clear insights into how public funds are used (Cangiano *et al.*, 2013). Additionally, accountability is strengthened as these systems allow for more effective auditing and performance measurement with a view to make public officials to be held responsible for their decisions and actions (Pillay, 2020).

Furthermore, reforms in public sector accounting provide reliable data which helps in better planning, execution, and monitoring of public projects, leading to efficient use of funds resulted in building public trust and fostering economic stability (Eldenburg *et al.*, 2021). Public sector accounting reforms are vital for improving governance by ensuring transparency, accountability, and efficiency. They serve as foundational elements in strengthening the integrity of public financial management systems and fostering citizen trust.

Improve Fiscal Transparency

Reforms enable government provides clear, accessible, and timely information about their financial activities. It allowed citizens, investors, and international stakeholders to monitor the allocation of resources and assess fiscal responsibility (International Monetary Fund IMF 2022).



Governments can achieve this through the adoption of internationally recognized standards like the Fiscal Transparency Code, which outlines practices in budget reporting, public debt management, and fiscal risks (OECD, 2021). For instance, disclosing comprehensive budgets and making real-time updates available to the public reduces opportunities for corruption and misuse of funds (World Bank, 2020). Platforms like open budget portals and e-procurement systems ensure that citizens have access to spending details and public contracts. Countries such as Estonia and Brazil exemplify this by publishing government transactions online, fostering trusts in public institutions (Transparency International, 2023). However, successful reforms require political will and strong institutional frameworks. Ultimately, improving fiscal transparency not only strengthens governance but also enhances economic stability and public confidence.

Global Trends in Public Sector Accounting Reforms

Key trends include:

Adoption of IPSAS

IPSAS provides a framework that facilitates the production of comparable financial statements across jurisdictions which enable stakeholders, investors, donors, and citizens, to assess the financial health and performance of governments. IPSAS allows governments to present a comprehensive picture of their financial position and performance. This approach includes recognizing assets, liabilities, revenues, and expenses when they are incurred rather than when cash is received or paid. Studies show that IPSAS adoption help in fiscal discipline and improves the efficiency of resource allocation (PWC, 2020). The adoption of the International Public Sector Accounting Standards (IPSAS) has gained significant momentum globally as countries seek to enhance the quality and reliability of their financial reporting.

Transition to Accrual Accounting

The transition from cash-based to accrual-based accounting systems assists governments to improve financial management and transparency. While cash-based accounting records transactions only when cash is received or paid, accrual accounting recognizes revenues and expenses when they are incurred regardless of when cash flows occur. This shift allows governments to capture a more comprehensive view of their financial position by including



liabilities, assets, and contingent obligations in financial statements. As a result, accrual-based systems provide a clearer and more accurate picture of fiscal health and better decision-making and resource allocation (Heald & Hodges, 2015). Accrual accounting helps governments identify long-term obligations such as pension liabilities or infrastructure maintenance costs that might be overlooked under cash-based systems. This will help stakeholders such as policymakers, citizens, and investors to assess the true financial sustainability of government operations.

Public Sector Accounting Reforms in Nigeria

Public sector accounting reforms in Nigeria is driven by need to enhance transparency, accountability, and efficiency in government financial management. Over the years, Nigeria has transitioned from a traditional cash-based accounting system to the adoption of the International Public Sector Accounting Standards (IPSAS). This shift aligns Nigeria with global best practices, ensuring that public financial reports are standardized, comparable, and credible (Adamu, 2018). Another key aspect of these reforms is the Treasury Single Account (TSA), implemented in 2015, which consolidates government revenue into a single account to prevent leakages and mismanagement (Adebayo, 2020). Additionally, the Integrated Payroll and Personnel Information System (IPPIS) have streamlined payroll management, reducing ghost workers and ensuring financial discipline.

Budgeting and Budget Management Reforms

Budgeting and budget management reforms in Nigeria have been pivotal in addressing the nation's fiscal challenges. Budgeting involves planning and allocating financial resources to achieve specific objectives, while budget management ensures efficient implementation and monitoring. In Nigeria, these processes have faced significant challenges, including revenue shortfalls, corruption, and inefficiencies.

Historically, Nigeria's budgeting system has been plagued by a lack of transparency and accountability, characterized by overambitious revenue projections and a mismatch between plans and execution. According to Ojo (2012) this led to poor service delivery and stalled development. The Public Sector Financial Management Reforms (PSFMR) under the World Bank's support has been instrumental in restructuring Nigeria's budgetary process. A cornerstone of these reforms is the adoption of the Medium-Term Expenditure Framework (MTEF) in 2007,



which improved fiscal discipline by linking budgeting to national priorities and promoting a multi-year perspective (Okonjo-Iweala, 2014).

Nigerian government has also embraced digital technologies to enhance budgeting processes. The deployment of the Government Integrated Financial Management Information System (GIFMIS) has streamlined budget preparation and execution, ensuring real-time monitoring of expenditures (Agba *et al.*, 2021). Despite these strides, challenges remain, including delays in budget approval, weak oversight mechanisms, and reliance on volatile oil revenues. With ongoing reforms, Nigeria has the potential to establish a robust budgeting system that supports economic growth and social development.

Cash Management Reforms and Treasury Single Account

The Treasury Single Account (TSA) is a key reform under this initiative, introduced in 2015 to consolidate government revenue into a single account at the Central Bank of Nigeria (CBN). Prior to the TSA, public funds were fragmented across multiple accounts in commercial banks leading to inefficiencies and revenue leakages (Eme *et al.*, 2015).

The TSA ensures centralized management of government cash, reducing borrowing costs by optimizing idle funds and enhancing budgetary discipline. It also minimizes corruption by curbing unauthorized withdrawals and promoting real-time monitoring of public resources. This reform aligns with Nigeria's fiscal consolidation goals, enabling better planning and execution of national budgets. It provides policymakers with accurate cash flow data, facilitating informed decision-making (Obinna, 2019). TSA therefore help in cash management reforms, improve financial accountability and governance.

Impact of Public Sector Accounting Reforms on Public Financial Management

Public sector accounting reforms have significant implications for various dimensions of PFM:

Improved Resource Allocation

Unlike cash accounting which records transactions only when cash changes hands, accrual accounting recognizes revenues and expenses when they are earned or incurred regardless of when payment occurs. This approach allows for a more precise matching of costs and benefits over time. Accrual accounting enables decision-makers to evaluate the true cost of programs or projects and their anticipated benefits. For instance, in public sector budgeting, it helps assess the



future implications of current decisions such as the long-term costs of infrastructure investments or employee pensions. This level of transparency is critical for comparing alternatives and prioritizing initiatives that yield the highest value for resources expended (Bergmann, 2022). Additionally, accrual-based financial statements facilitate accountability by highlighting inefficiencies, prompting reallocations where resources are underutilized or misaligned with strategic goals.

Strengthened Fiscal Discipline

One of the key benefits of the reforms is improved financial reporting which provides stakeholders with accurate, timely, and comprehensive information about public finances. The reforms modernize accounting systems and align them with international standards such as the International Public Sector Accounting Standards (IPSAS). This allows policymakers to monitor budget execution and ensure adherence to fiscal rules thus minimize risk of overspending or fiscal slippage (Blöndal et al., 2009). This approach encourages efficient use of public resources and ensures compliance with budgetary constraints, ultimately strengthening fiscal sustainability (IMF, 2016). Governments can address challenges related to fiscal mismanagement, build public trust, and improve their overall economic stability through adoption of sound public sector accounting practices.

Theoretical Framework

Rational Choice Theory

Rational choice theory assumes that individuals make decisions by systematically evaluating the costs and benefits of various options to maximize their utility (Becker, 1976). This approach is grounded in the principles of methodological individualism, which holds that social phenomena result from the actions and decisions of individuals. Core assumptions in rational theory are **Utility Maximization** (Individuals act in ways they believe will provide the greatest benefit or satisfaction relative to their preferences Elster, 1989). Rational theory emphasizes systematic, logical, and evidence based approaches to decision making.

Rational choice theory provides a theoretical foundation for understanding decision-making in public sector accounting and PFM. Theory emphasized utility maximization, systematic analysis, and logical decision-making. Theory underpins many practices in public financial management.



These practices ensure that scarce public resources are allocated efficiently, transparently, and accountably to achieve societal goals which align with the principles of fiscal discipline, economic sustainability, and public accountability.

Public Choice Theory

Public Choice Theory applies economic principles especially the concept of self interest and behavior of political actors and institutions. Originated from the work of economists such as James Buchanan and Gordon Tullock, The theory challenges the assumption that government officials act purely in the public interest. Instead, it suggests that politicians, bureaucrats, and voters are guided by their own incentives and constraints (Mueller, 2003)

Theory posits that individuals in the public sector (voters, politicians, and bureaucrats) are motivated by self-interest rather than a purely altruistic desire to serve the public. This has direct consequences for public sector financial practices, as it can lead to inefficiencies like rent-seeking, budget maximization, and misallocation of resources. Public sector accounting and financial management systems are designed to address these issues by creating institutional mechanisms to promote accountability and transparency.

Conclusion

Public sector accounting reforms assist in strengthening public financial management through promoting transparency, accountability, and efficiency in resource allocation. Adoption of International Public Sector Accounting Standards (IPSAS) and digital transformation ensure that governments present accurate and comprehensive financial reports, reduce corruption and enhance government decision-making. The implementation of accrual-based accounting and integrated financial management systems as seen in countries like New Zealand, India, and Ghana has demonstrated the positive impact of these reforms on fiscal discipline and economic stability. In Nigeria, initiatives such as the Treasury Single Account (TSA) and the Government Integrated Financial Management Information System (GIFMIS) have significantly improved financial oversight, reducing leakages and strengthening governance structures.

Despite the progress made, challenges such as resistance to change, inadequate technical capacity, and infrastructure limitations remain significant barriers to full implementation. To maximize the benefits of public sector accounting reforms, governments must invest in



technology, and institutional frameworks that support sustainable financial management practices. Political commitment and stakeholder engagement are essential to ensure the long-term success of these reforms. Moving forward, a continuous review and adaptation of these strategies will be necessary to address emerging financial challenges and further strengthen public trust in government financial systems.

Recommendations

The paper therefore recommend as follows:

Phased Implementation

A gradual approach to reforming public sector accounting systems allows for greater flexibility and provides the time necessary to address challenges. Phased implementation helps to manage risk and ensure smooth transitions. This can be achieved pilot projects, incremental rollout, timeframe and benchmark.

Leveraging Technology

Technology plays a crucial role in modernizing public sector accounting systems. The integration of cutting-edge financial management systems can significantly enhance efficiency, transparency, and accountability. This involves: **Adopting Integrated Financial Management Information Systems (IFMIS), Data Analytics and Reporting Tools, Cloud-Based Solutions and E-Governance Integration.**

Stakeholder Engagement

For public sector accounting reforms to be successful, it is essential to engage all relevant stakeholders in a meaningful and inclusive manner. This helps to build a sense of ownership, minimize resistance, and enhance the legitimacy of the reforms. Key strategies include **Inclusive Dialogue, Public Awareness and Communication Campaigns, Engagement with International Partners and Collaboration with Civil Society.**

Monitoring and Evaluation

For public sector accounting reforms to be sustainable, a robust monitoring and evaluation (M&E) system is crucial. This ensures that the reforms are effective; that they achieve their intended outcomes and that corrective actions can be taken if needed. Steps to enhance M&E



include **Establishing Clear Performance Indicators, Regular Audits and Reviews, Feedback Mechanisms, and Sustainability Planning.**

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EFFECT OF GREEN ENTREPRENEURSHIP PRACTICES ON THE PERFORMANCE OF POULTRY-BASED ENTERPRISES IN ABIA STATE, NIGERIA

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Abstract

The study assessed the effect of green entrepreneurship practices on the performance of poultry-based enterprises in Abia State, Nigeria. The objectives of the study were to: describe the socio-economic characteristics, assess the level of involvement in green entrepreneurship among poultry-based enterprises, evaluate the cost of adoption/use of green entrepreneurship, determine the effect of green entrepreneurship on poultry-based enterprises performance. A purposive sampling technique was used in this study to select 120 poultry entrepreneurs practicing green entrepreneurship. Primary data was collected through structured questionnaire and personal interviews. Statistical tools such as Mean, Percentage, and Frequency distribution and Ordinary Least Square (OLS) regression were used in analyzing the data generated. The result showed that the majority (72.5%) of the respondents involved in the practice of green entrepreneurship were young, energetic, and enterprising with greater drive and passion for financial freedom through the adoption of sustainable eco-friendly practices. In addition, most (65%) of the respondents were male, literate (95%) having a large family size (85%) with essential experience for practicing green entrepreneurship. In addition, the result showed that there is a high level of involvement in pollution control (75%) and recycling/ reuse (85%) while the involvement level of respondents in solar energy use was 33% and could be said to be low since it is less than 50%. However, the overall average cost of adopting green entrepreneurship was ₦ 68913.67. This means that respondents can practice green entrepreneurship if they can save ₦ 5743.00 per month from their business returns. In addition, the result shows that there is a positive and significant 5% relationship between recycling/reuse of poultry waste and by products and poultry enterprise performance. It is recommended that the young, literate, and experienced individuals should be supported with the right tools/inputs/financial resources to be able to properly adopt green entrepreneurship practices especially recycling/reuse of waste/bye poultry products

Keywords: Green entrepreneurship, Practices, Performance, Poultry, Enterprise



Introduction

Green Entrepreneurship initiative is a practice of an entrepreneur which refers to all the related projects with a specific aim of helping businesses reduce the environmental impacts of their business operations as well as also helping them to save money. This means that they will use fewer raw materials, less natural resources, less energy, and less water which will lead to producing less waste and less cost of running the business. The concept of green entrepreneurship evolved because of environmental concerns such as pollution, global warming, climate change, and scarcity of natural resources which constitute strategic environmental concerns to stakeholders in business (Ataman, *et al.*, 2018; Sharma & Kushwaha, 2013; Enoch *et al.*, 2020).

According to Bakari (2013), green entrepreneurs create social value and business models for environmental and economic profitability. This results in green business with less adverse impact on the environment both globally and locally and it requires principles of sustainability in all business decisions to have a friendly environment for products and services (Gevrenova, 2015). Similarly, Huang (2010) opines that green entrepreneurship helps to address social and environmental needs using entrepreneurial ideas to assess the level of risk, financial sustainability, and the effect of environmental challenges on the natural environment. In the same vein, Bakari (2013) and Schapper (2016), note that the practices of green entrepreneurs are aimed at recycling, reducing, and reusing resources for the sustainability of the environment and economy. This requires actions directed at preventing waste, pollution, and energy saving. Hence, green entrepreneurs are innovative solution providers of goods and services produced and consumed based on business models that contribute to a greener economy (Demuth, 2015; Hossam, 2015).

On the other hand, business performance entails the outcome of business activities with the state of efficiency and productivity. It may be financial performance concerning growth, profitability etc, or non-financial performance with customer satisfaction, internal processes; efficiency, etc. Therefore, improved performance as a requirement for an organization's success is measured to determine the extent of the organization's achievement of set goals and objectives (Makanga and Paul, 2017; Eniola and Ektebang, 2014). In green entrepreneurship, business performance



consists of operational and competitive performance either in the manufacturing or service industry which are aimed at optimizing growth, expansion, and profitability for the stakeholders as organizations strategically engage in the short and long-term goals of the organization.

This study therefore assessed the effect of green entrepreneurship practices on the performance of poultry-based enterprises in Abia State. The specific objectives are to determine the socio-economic characteristics of respondents involved in green entrepreneurship, assess the level of involvement in green entrepreneurship (recycling, pollution control, and solar energy use) among poultry-based enterprises, evaluate the cost of adoption/use of green entrepreneurship, determine the effect of green entrepreneurship on agro enterprises performance.

Methodology

This study was carried out in Abia State which is in the southeastern part of Nigeria, the capital is Umuahia. Abia State occupies about 6,320 square kilometers and is bounded on the north and northeast by the States of Anambra, Enugu, and Ebonyi. To the west of Abia is Imo State, to the east and southeast are Cross River State and Akwa Ibom State respectively and to the south is Rivers State. The population of the study consists of 47767 poultry farmers (NBS/FMARD, Report). First, Abia State has 17 LGAs, and 6 LGAs were randomly selected for study. Second, from each of the selected LGAs, 20 poultry farmers were randomly selected from each of the selected LGAs ensuring a more representative sample and helped mitigate bias by ensuring that participants are selected based on chance rather than preconceived notions.

This gave a total sample size of 120 poultry farmers. Primary data were collected from the 120 respondents with the use of a well-structured questionnaire and complimented with an oral interview. Copies of the questionnaire were given to few experts for corrections and comments on the content of the questionnaire. To determine the reliability of the research instrument, a trial test of the instrument using 15 poultry farmers who were not part of the study were selected randomly and the study was conducted. The cronbach Alpha reliability test was conducted for internal consistency of the instrument. The cronbach Alpha reliability coefficient of 0.75, shows the instrument is highly reliable. Statistical tools such as mean, percentage, and frequency



distribution and Ordinary Least Square (OLS) regression were used in analyzing the data generated. The implicit form of the regression model is stated as follows;

$$Y = f(X_1, X_2, X_3)$$

Where,

Y= Performance of poultry farmers measured in quantity of birds sold in naira

X₁= Amount spent on recycling/reuse measured in naira

X₂= Amount spent on pollution control measured in naira

X₃= Amount spent on solar/renewable energy measured in naira

Results and Discussion

Socio-economic characteristics of respondents involved in green entrepreneurship

Distribution based on the socio-economic characteristics of respondents involved in green entrepreneurship is presented in Table 1

Table 1: Distribution based on the socio-economic characteristics of respondents involved in green entrepreneurship

Socioeconomic characteristics			
Age	Frequency	Percent	Mean
21-30	45	37.5	
31-40	42	35.0	
41-50	27	22.5	
51-60	6	5.0	
Total	120	100	35.3
Sex			
Male	78	65.0	
Female	42	35.0	
Total	120	100	
Level of education			
No formal education	6	5.0	
Primary	3	2.2	
Secondary	21	17	
Tertiary	90	75.0	
Total	120	100.0	
Marital status			
Single	66	55	
Married	54	45	
Total	120	100	
Household size			
1-3	18	15	
4-6	84	70	
7-9	15	12.5	



10-12	3	2.5	
Total	120	100	5.3
Years of Experience			
1-10	100	83.3	
11-20	17	14.2	
21-30	3	2.5	
Total	120	100	

Source: Field Survey, 2021

Table 1 shows that 72.5% of the respondents had ages ranging between 21-40 years. The mean age of the respondents was 35. This indicates that the majority of the respondents involved in eco-friendly practices were young, energetic, and enterprising. Being young, energetic, and enterprising could mean greater drive and passion for financial freedom through a sustainable eco-friendly practice.

More so, Table 1 shows that 65% of the respondents selected for the study were male while 35% were female. This means that the majority of the respondents were males. The high incidence of males in the study could be that males are the breadwinners of their homes and are regularly confronted with the management of poultry-based waste products to the advantage of the poultry enterprise without compromising the eco-standards.

Table 1 shows that 95% of the respondents involved in green entrepreneurship had one form of education or another. This means that the majority of the respondents are literate. Being literate could mean greater skill in handling eco-friendly practices and ideas effectively. Education is a vital quality for enterprise owners, as it gives them the ability to access useful technologies and information, as well as acquire new skills to develop their on- and off-farm activities that can improve their livelihoods (Ogbe, 2023).

Table 1 shows that 85% of the respondents had household sizes ranging between 1-6. The mean of 5 persons. This means that most of the respondents involved in poultry production had a large family size. This scenario implies that respondents had access to family labour which is useful in sourcing eco-friendly technologies and information.

Table 1 shows that 96% of the respondents had years of experience ranging between 1-10 years. The mean years of experience was about 5 years indicating that most of the respondents were



experienced individuals in poultry enterprise. Experience means that the respondents had practical knowledge of poultry enterprises and could have developed a pathway of managing poultry waste for the benefit of the enterprise and environment.

Level of Involvement in Green Entrepreneurship Practices

The level of involvement in green entrepreneurship practices among the respondents is presented in Table 2.

Table 2: Level of involvement in green entrepreneurship practices

s/n	Green entrepreneurship practices	Frequency	Percent
Pollution control			
1	Regular cleaning/clearing of drainage	80	66.7**
2	Burying of waste	72	60**
3	Burning of waste inside incinerator	75	62.5**
4	Drying and bagging of waste	73	60.8**
5	Storing liquid waste in septic tank	75	62.5**
	Total	375	75**
Solar energy use			
1	Use of solar inverters and panel	25	20.8*
2	Use of energy bulbs	44	36.7*
3	Use of solar energy security lights	30	25*
	Total	99	33*
Recycling/reuse			
1	Use of waste in vegetable farm	120	100**
2	Use of waste in generating maggot for feed inclusion	90	75**
3	Use of waste in feeding pigs	45	37.5*
	Total	255	85**

Source: Field Survey, 2021

Table 2 shows that majority of the respondents had a high level of involvement in pollution control and recycling/ reuse with the mean involvement level of 75% and 85% respectively. The high incidence of involvement of respondents in pollution control and recycling could be associated with the growing concern for the environment and a heightened awareness of the need for sustainable practices. Fastercapital (2024) enumerated the environmental concerns to climate change, pollution, and resource depletion which have become pressing issues in developed and developing economies that demand immediate attention.



Lastly, the involvement level of respondents in solar energy use was 33%. This could be said to be low since it is less than 50%. This result could be associated with the relatively high cost associated with solar energy procurement and setup.

Cost of adopting green entrepreneurship practices. Cost of adopting green entrepreneurship practices among the respondents is presented in Table 3

Table 3: Cost of adopting green entrepreneurship practices among the respondents

Green entrepreneurship practices	Mean cost (Naira)	Ranking on cost	Ease of adoption
Pollution control	73680	2 nd	2 nd
Solar energy use	103181	1 st	3 rd
Recycling/reuse	29880	3 rd	1 st
Average	68913.67		

Source: Field survey, 2021

Table 3 shows that the cost of adopting solar energy use came top among the respondents with a mean cost of ₦ 103181.00. This is followed by pollution control with the mean cost of adoption of ₦ 73680.00. Lastly, the mean cost of adopting recycling/reuse by the respondents was ₦ 29880.00. Furthermore, the ease of adopting recycling/reuse of poultry-based waste and other associated materials was higher with less associated cost (₦ 29880.00) than pollution control (₦ 73680.00) and solar energy use (₦ 103181.00). The adoption of recycling/reuse of poultry-based waste and other associated materials may be due to the smallness of financial involvement and minimum training/ skill for its adoption and practice. In addition, the ease of adopting pollution control was next in line with varying reasons ranging from the suitability of the business environment as attractants for potential business clients to less financial involvement in the health of the business operators. The overall average cost of adopting green entrepreneurship was ₦ 68913.67. This means that respondents can practice green entrepreneurship if they can save ₦ 5743.00 per month from their business returns.

Effect of Green entrepreneurship practices on poultry-based enterprise performance.

Effect of green entrepreneurship practices on poultry-based enterprise performance is presented in Table 4

**Table 4: Effect of green entrepreneurship practices on poultry-based enterprise performance**

Variables	Coefficient	Standard error	T value
Constant	89658.249	181152.41	0.495 ^{ns}
Pollution control	9.142	11.977	0.763 ^{ns}
Solar energy use	7.883	6.665	1.183 ^{ns}
Recycling/Reuse	4.267	1.526	2.796**
R ²	0.848		
R ⁻²	0.733		
F ratio	7.418***		

Source: Field survey, 2021 ** Significant at 5% ns-not significant

Table 4 shows that there is a positive and significant (5%) relationship between the recycling/reuse of poultry waste and bye products and poultry enterprise performance. This means that recycling/reuse increased, and performance also increased. The implication of recycling/reuse of waste poultry products could be associated with the little or no technical skill/training in its adoption. Pollution control had a positive but not significant relationship with the performance of poultry-based enterprises. This means that as pollution control increased, the performance also increased. The non-significance of pollution control could be associated with poor environmental consciousness. According to Egbu (2000), the environmental consciousness in the developed world has witnessed over the past two decades generally effective mechanisms for pollution abatement, the situation in many third-world nations including Nigeria is at best tepid. Solar energy had a positive but non-significant relationship with the performance of agroenterprise. This means that as solar energy use increased, performance also increased. Increased solar energy use could mean increased investment in clean energy and power supply. The more power supply, the more the effectiveness of poultry-based enterprise performance. However, the non-significance of solar energy use could be associated with high adoption costs. Amadi *et al.* (2024) confirm that the upfront costs of solar panel systems, inverters, and batteries can be a significant barrier, particularly for low-income households and businesses. The R² (coefficient of multiple determination) was 0.848 signifying that 84.8% of the total variation



observed in the performance (dependent variable) was accounted for by the independent variables included in the model. The F-value was 7.418 which is significant at 1% indicating that green entrepreneurship had an effects on the performance of poultry-based enterprises.

Conclusion/Recommendations

Based on the findings of this study, it was concluded that individuals involved in the practice of green entrepreneurship were young males, young, literate with the required years of experience and passion for financial freedom through the adoption of sustainable eco-friendly practices. In addition, there was a high level of involvement of respondents in pollution control and recycling/reuse. Furthermore, the study showed that the majority of the respondents can practice green entrepreneurship if they can save ₦ 5743.00 per month from their business returns. In addition, the result shows that there is a positive and significant 5% relationship between recycling/reuse of poultry waste and by products and poultry enterprise performance. Furthermore, 80%, 78%, and 76% of the respondents indicated that inadequate power supply, inadequate funding, and high cost of inputs/climate change as their main constraints to the adoption of green entrepreneurship practices. The study therefore recommends that young, literate, and experienced individuals should be supported with the right tools/inputs/financial resources to be able to properly adopt green entrepreneurship practices especially recycling/reuse of waste poultry products. This measure would ensure that respondents operate their poultry business in a healthy environment while producing eco-friendly poultry-based produce that commands the right market price. More so, poultry-based entrepreneurs should be encouraged to save a proportion of their returns monthly to sustain the practice of green entrepreneurship.

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ASSESSING INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT (IFAD) FINANCING AND ITS IMPACT ON AGROENTERPRISE CLIENTS IN ABIA STATE, NIGERIA

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Abstract

This study assessed International Fund for Agricultural Development (IFAD) financing and its impacts on agroenterprise clients in Abia State, Nigeria. The study's objectives were to: determine the socio-economic characteristics of agro-enterprise clients, assess the level of credit demanded and received among agroenterprise clients, and determine the type of agro practices adopted before and after IFAD credit received. A random sampling procedure was used in selecting respondents for the study. The study used the primary data and data were collected using a well-structured questionnaire. Also, sixty (60) agro enterprise clients were randomly selected for the study. Data were analysed using statistical tools such as percentages, and frequency distribution. The result of findings showed that most of the respondents were male, young, married, and educated with moderate household size. Clients received less than they demanded, but financing significantly boosted agroenterprise performance by 171%. The mean value of funds received could reflect the amount clients can effectively deploy. Moreover, the 171% increase in the mean value of performance among clients after IFAD financing goes further to show that IFAD financing among clients is impactful. Furthermore, the majority of the clients adopted and intensified useful agro-practices that are cost-effective and eco-friendly. Future IFAD financing programs should prioritize experienced, educated, and cooperative-affiliated farmers for improved financial sustainability. This measure would ensure the effective utilization of financing services provided by IFAD and enhance financial performance of clients. For a sustainable financial performance and adoption of eco-friendly agro enterprise practices with beneficial effects on farm produce, soil and the environment potential clients should be encouraged through awareness creation to join cooperative societies.

Keywords: Agricultural Development, Financing, Agroenterprise, Clients

Introduction

Agricultural credit is very important for sustainable agricultural development to be achieved in Nigeria (Ololade and Olagunju, 2013). In addition, rural credit has proven to be a powerful instrument against poverty reduction and development in rural area. Farmers are particularly in need of such instrument (i.e. credits), because of the seasonal pattern of their activities and the uncertainty they are facing. Agricultural credit enhances productivity and promotes standard of living by breaking vicious cycle of poverty of small-scale farmers. Access to credit facilities by



these poor rural people has the potential of making the change between crushing poverty and economically secured life as well as improving agricultural productivity (Ajah *et al.*, 2017). Limited availability of credit service has undermined rural income activities due to lack of capital for investment and has prevented farmers from adopting improved farming practices. To solve these problems, the Federal Government went into a funding agreement with International Fund for Agricultural Development for the funding of small-scale farmers in Nigeria. The International Fund for Agricultural Development (IFAD), a specialized agency of the United Nations, was established as an International Financial Institution in 1977 as one of the major outcomes of the 1974 World Food Conference. The conference was organized in response to the food crises of the early 1970s that primarily affected Sahelian countries of Africa. Therefore, IFAD was created to mobilize resources for programmes that alleviate rural poverty and improve nutrition. To achieve this objective, IFAD cooperates and collaborates with government agencies and parastatals such as Agricultural Development Programmes (ADP) and Ministries of Agriculture and Rural Development. The main objective of this study was to examine IFAD financing among agro enterprise clients in Abia State, Nigeria. The specific objectives includes to; determine the socio-economic characteristics of IFAD beneficiaries, determine the level of credit demanded and received among agro enterprise clients, determine the performance of IFAD financing before and after production and sales, determine the type of agro practices adopted before and after IFAD financing.

Methodology

Area of the Study

Umuahia North is a Local Government Area in Abia State, with administrative headquarters in the city of Umuahia. The Local Government Area has an area of 245km² and is bounded to the north by Isuikwuato Local Government Area, to the east by Bende Local Government Area, to the south by Ikwuano and Umuahia South Local Government Areas and to the west by Imo State. The result of the 2006 national population and housing census put the population of Umuahia North Local Government Area at 359,230. It lies between longitude 7 degrees and 60'E and



latitude 5 degrees 68'N. First, Umuahia North was purposely selected for study from all the IFAD project sites in the state due to high concentration of IFAD activities and its proximity. Second, four (4) communities with visible IFAD projects were selected for study were purposively selected. Third, 15 IFAD benefiting agroenterprise clients were randomly selected from each of the selected communities. This gave a total sampling size of 60 IFAD beneficiaries. The selected number of beneficiaries in each communities were limited due to the selection criteria. The lists of the IFAD benefiting agroenterprise clients were supplied by IFAD contact agent at Agricultural Development Authority (ADP), Mission Hill Umuahia, Abia State. This list formed the sampling frame for the selection of respondents. Primary data was used in this study. Structured questionnaire was used in data collection. Data were analyzed using means, percentages and frequency distribution,

Results and Discussion

Socio economic characteristics of crop enterprise clients involved in IFAD financing programme. Socioeconomic characteristics of crop enterprise clients involved in IFAD financing programme is presented in Table 1.

Table 1: Socio economic characteristics of crop enterprise clients involved in IFAD financing programme

Sex	Frequency	Percent
Female	29	48.3
Male	31	51.7
Total	60	100
Age		
21-30	24	40
31-40	22	36.7
41-50	8	13.3
51-60	6	10
Total	60	100
Mean	36.2	

Marital status



Single	20	33.3
Married	40	66.7
Total	60	100
Household size		
1-3	22	36.7
4-6	33	55
7-9	3	5
10-12	2	3.3
Total	60	100
Mean	4.48	
Membership of cooperative		
Members	32	53.3
Non-members	28	46.7
Total	60	100
Years of cropping experience		
1-5	15	25.0
6-10	28	46.7
11-15	12	20.0
16-20	5	8.3
Total	60	100
Mean	7.8	

Source: Field survey, 2019

Table 1 shows that 48.3% and 51.7% of the respondents are female and male respectively. This means that majority of the respondents are male. The high incidents of male in IFAD programme could be due to the fact that males have the responsibility to fend for their families and have shown the willingness to acquire relevant knowledge that promote their functionality and financial prosperity (Ogbe and Igwemadu, 2021).

Table 1 shows that 76.7% of the respondents had age ranging between 21-40 years. The mean age of the respondents was about 36years, this means that majority of the respondents were young, energetic, and enterprising. According to Mejeha and Ogbe (2010) being young could mean that respondents would not be constrained by physical energy in carrying out their agro-agro-entrepreneurial duties. Moreso, Ogbe and Igwemadu (2021) stated that young, energetic, and innovative individuals have the willingness to adapt financial innovations. This corroborates the work of Ogbe and Ejim (2019) that willingness to adopt financial innovation could position the respondents to access more financial intervention. The result on Table 1 shows that 33.3% of



the respondents were single while 66.7% of the respondents were married. This means that the majority of the respondents were married. The involvement of more married persons in IFAD agroenterprises/activities could be associated with the fact that agriculture is labour-intensive and requires the support of family members.

Furthermore, Table 1 shows that about 92% of the respondents had household size ranging between 1-6. The mean household size was about 4 indicating that the majority of the respondents has moderate household size. The implication of this could mean less diversion of IFAD financing to feeding family members but rather channeling a greater proportion of funds to agroenterprise activities.

Table 1 shows that 53.3% and 46.7% of the respondents are members and non-members of co-operative respectively. This means that the majority of the respondents are members of co-operatives. The high incidents of co-operative membership could be because co-operative society help in the facilitation of IFAD financing and provide mentorship activities for members that improves access to agricultural and non-agricultural knowledge needed for agribusinesses growth and sustainability. This study is in consonance with the Cooperatives Europe (2020) that cooperatives enables members to develop useful skills, and pass on, the business expertise for their overall benefits. Table 1 shows that about 72% of the respondents had years of experience ranging between 1-10 years while about 28% of the respondents had years of experience ranging between 11-20. The mean years of crop enterprise experience was about 5 years signifying that majority of the respondents had practical knowledge in agro-based practices. Ogbe (2023) reported that enterprise owners with more experience would have a better knowledge of efficient allocation of resources and market situations and are thus expected to run a more efficient and profitable enterprise.

The level of credit demanded and received among Agroenterprise clients

The level of credit demanded and received by the agro-enterprise clients is presented in Table 2

Table 2: Level of credit demanded and received among respondents

Amount (Naira)	Credit Demanded		Credit Received	
	Frequency	Percent	Frequency	Percent
10000-100000	46	76.7	42	70
110000-200000	7	11.7	17	28.3



210000-300000	-	-	1	1.7
410000-500000	7	11.6	-	-
Mean	658,550.00		434,733.33	

Source: Field survey, 2019.

Table 2 shows that about 77% of the respondents demanded amount ranging between ₦1,000- ₦100,000. While about 23% of the respondents demanded amount ranging between ₦110,000- ₦500000. On the other hand, only 70% of the respondents received amount ranging between ₦1000- ₦100000 representing a reduction of about 9% from the initial number of clients that demanded for funds. The reduction in the number of clients in this range could be associated to the fact that the respondents have capacity to manage more than what they applied for. More so, there is an increase of about 143% in the amount received over those that applied for funds ranging between ₦110,000- ₦200000. The reason for this could be linked to the creditworthiness of clients to utilize and repay funds. **Clients received less than they demanded, but financing significantly boosted agroenterprise performance by 171%.** The mean value of funds received could reflect the amount clients can effectively deploy into crop enterprise activities that can generate the necessary financial returns that can offset their loans and still ensure the sustainability of their crop enterprise.

Performance of respondents involved in IFAD financing before and After Production and Sales

Distribution of respondents based on their performance after production and sales is presented in Table 3

Table 2: Distribution of respondents based on performance after production and sales

Performance (₦)	Before		After	
	IFAD financing		IFAD financing	
	Frequency	Percent	Frequency	Percent
10,000-110,000	51	85.0	33	55
111000-211000	8	13.3	11	18.3
212000-312000	1	1.67	7	11.7
313000-413000	-	-	9	15



Total	60	100	60	100
Mean	32586.51		88283.33	

Source: Field survey, 2019

Table 3 Shows that 55% of the respondents had performance level ranging from ₦10,000 – ₦110,000 after IFAD financing which indicate a reduction of about 33% in the number of clients before IFAD financing. More so, there was about 38% increase in the performance of clients after IFAD financing over the clients before IFAD financing with performance range of ~~₦111000-~~ ₦211000. Also, the Table shows an increase of 600% in performance of clients after benefiting from IFAD financing with clients with performance range of ₦212000- ~~₦312000~~ before IFAD financing. In addition, 15% of the clients moved into the performance range of ~~₦313000-~~ ₦413000. The movement of clients into this performance range could strongly indicate sound financial returns from utmost utilization of IFAD financing. Furthermore, the mean performance of clients before IFAD financing was ₦32586.51 while the performance of clients after IFAD financing was ₦88283.33. This means that there was an increase of about 171% increase in the mean value of performance among clients after IFAD financing. This goes further to show that IFAD financing among agroenterprise clients is impactful. This could have been based on their effective use of cooperatives in disbursement and mentoring and monitoring for effective utilization of funds. This study corroborates the findings of LIFE-ND (2020), that agribusiness investment programme organized International Fund for Agricultural Development (IFAD) and Niger Delta Development Commission (NDDC) had at least 50% of beneficiary households have stable income for enhanced food security and sustainable livelihood.

Types of agro practices adopted before and after IFAD financing

The type of agro practices adopted before and after IFAD financing among the respondents is presented in Table 4.

**Table 4: The type of agro practices adopted before and after IFAD financing among agro enterprise clients**

Agro practices	Before financing		After financing		
	Frequency	Percent	Frequency	Percent	% change
Bush burning	47	78.3	26	43.3	-44.7
Fallowing	41	68.3	17	28.3	-58.5
Crop rotation	54	90.0	59	98.3	9.26
Weeding	56	93.3	44	73.3	-21.4
Storage	19	31.7	55	91.7	189.5
Mixed cropping	31	51.7	51	85.0	64.5
Soil enrichment (organic farming)	24	40.0	50	83.3	108.3
Irrigation	16	26.7	39	65.0	143.8
Pesticide	21	35.0	50	83.3	138.1

Source: Field survey, 2019.

Table 4 shows that there was about 45%, 59 % and 21% reduction in the practice of bush burning, fallowing and weeding. The reduction in the practice of bush burning after accessing IFAD financing could as a result of the knowledge gained on the harmful effect of its practice both on the soil, soil microorganisms and the environment in general. IFAD promotes sustainable agriculture and rural development based on inclusivity, resilience, and environmental sustainability (IFAD, 2025). In addition, the reduction in the practice of bush fallowing could be linked to the demand /competition for agricultural land for other purposes such as construction of houses, schools among others and would have rather been made to see the need to adopt land intensification practices such as crop rotation and mixed cropping. This exposure could have been instrumental in about 9% and 65% increase in the adoption of crop rotation and mixed cropping. Furthermore, there was about 190% and 108% increase in the adoption of storage practice and soil enrichment (organic farming). This is in addition to the benefits of crop diversification, effective soil utilization and nutrient maximization. According to Lamptey (2022) agronomic practices such as crop selection, mulching, soil enhancement and soil tillage has the



potential to improve soil water content for improved and sustainable crop production. Moreso, IFAD emphasizes that sustainable practices are crucial for food security and protecting natural resources (IFAD, 2025).

More so, the high rate of storage practice could be associated to the fact that most of their produce are perishable and need storage facilities for the preservation of their produce for a long time, increase their market value and reduce the scarcity of produce during off-season. On the other hand, the adoption of organic farming could be associated with the moderate price of purchase and eco- friendly effect of its use on the crop, soil and the environment. The result also shows that there was about 144% and 138 % of clients adopted the practice of irrigation and pesticide in their agroenterprise activities. The reason for the adoption of irrigation and pesticide use could be a deliberate effort by the clients to increase crop productivity to generate high financial returns. This findings is consistent with the mission of IFAD on the adoption of agroecological methods that enhance soil health, conserve water and reduce reliance on chemical inputs (IFAD, 2025)

Conclusion and Recommendations

Based on the findings of this study, IFAD operators in the state released financial resources that can be properly utilized to generate increases that can pay their loans and still sustain their agro enterprises. Moreover, the study showed that agro practices that require moderate price and eco-friendly effect of use on the crop, soil, and the environment with high productivity potentials were adopted while agro practices with negative impact were less practiced. It is therefore recommended that young males that are educated, married with moderate household size with required years of experience should be given priority in the future selection of beneficiaries of the IFAD financing programme in the state. This measure would ensure the effective utilization of financing services provided by IFAD and enhance the financial performance of clients. For a sustainable financial performance and adoption of eco-friendly agro enterprise practices with beneficial effects on farm produce, soil, and the environment potential clients should be encouraged through awareness creation to join cooperative societies.



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SUB-THEME 7:
Importance of
Stakeholder
Engagement, Policy
and Regulation for
enhanced
Agricultural/Industrial
production and
Environmental
Sustainability



ENVIRONMENTAL DISCLOSURE AND FINANCIAL PERFORMANCE OF QUOTED FAST-MOVING CONSUMER GOODS COMPANIES IN NIGERIA

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Abstract

This research empirically examined the association between environmental disclosure and performance of listed fast-moving consumer goods companies in Nigeria. The population of the study comprises of all food and beverage companies listed on the Nigerian Exchange Group. Ten food and beverage companies were selected as sample for the study. Secondary data used for the study were collected from annual reports of the companies for the period of five years from 2018 through 2022. Ordinary Least Square regression technique was employed to analyze the data. Content analysis was used for measuring quantitative environmental disclosure and unweighted approach was used to rank environmental disclosure indices for measuring qualitative voluntary environmental disclosure. Return on Assets (ROA), Return on Equity (ROE), and Earnings per Share (EPS) were used as proxies for measuring performance. The empirical result indicated that environmental disclosure quantitative (EDQN) has a positive insignificant impact on ROA and EPS at 0.707 and 0.616 respectively; it has negative insignificant impact on ROE at 0.756. On the other hand, environmental disclosure qualitative (EDQL) has positive significant impact on ROA at 0.025 and on EPS at 0.009. It however, has positive insignificant impact on ROE at 0.660. The control variable firm size (FRMS) has positive significant impact on EPS at 0.009. The study recommends inter alia that management of fast-moving consumer goods companies in Nigeria should develop a well-articulated environmental costing system so as to guarantee a conflict free corporate atmosphere for improved corporate performance.

Keywords: Environmental Disclosure, Fast-moving Consumer Goods, Firm Size, Performance, Voluntary Disclosure.

Introduction

Financial performance can be described as the level of achievement or performance of a business, expressed in terms of overall profits or losses, return on investment, return on equity, earning per share, value added usually shown in the financial statement of an organization in order to enable the decision makers to assess the various financial, managerial decisions and actions taken within the period under consideration.



Evaluating the financial performance of a business allows decision-makers to judge the results of business strategies and activities in objective monetary terms. Wikipidia (2021) defined financial performance as the act of performing financial activity, the degree to which financial objectives are being accomplished and the process of measuring the results of firm's policies and operations in monetary terms. It is used to measure firm's overall financial health over a given period of time and can also to compare similar firms across the same industry.

The rapid development in economic activities and globalization has caused serious environmental challenges in Nigeria among many other countries. Companies around the world are under more community inspection than ever before and are being forced to disclose information about their environmental activities. This issue has grasped the interest of researchers because of the increased knowledge and understanding of the environmental subject (Umoru-Oki, 2019). The vital environmental issues are air and water pollution, solid waste, water and wastewater management. This situation has resulted from economic growth and high degree of openness which indicate that economy is very sensitive to globalization process.

According to Abubakar, Moses and Inuwa (2017), environmental disclosure entails where a company voluntarily or statutorily provide in annual reports environmental management and environmental development cost. Different means have been used in a variety of countries to provide information on environmental performance. These include press releases, newsletters, annual reports, magazines and sustainability reports.

Environmental accounting is aimed at achieving sustainable development, maintaining favourable relationship with community and pursuing effective and efficient environmental conservation activities. Environmental information disclosure is important because it helps stakeholders to recognize the impact that the organization has on the environment and the impact that the environment has on the organization.

Currently, the demand for companies to apply environment disclosure is very high in order to save the world, it has also been proved that companies with environmental disclosure can achieve good performance (Nor, Bahari, Adnan, Kamal and Ali, 2015). Performance according



to Oxford Advance Learner's Dictionary is how well or badly something works. Put simply, performance is the act of putting into action, achievement or accomplishment of set objectives.

Firm performance which is often used in business as organizational performance, measures how efficient and effective a company is, in its dealings. In accounting financial performance which is a subset of firm performance, measures profitability of companies in terms of return on assets, return on investment and return on equity. It also measures market value which includes earning per share. Firms can best interact with their stakeholders through disclosing environmental information. This helps companies to appear as good citizens in the eyes of their stakeholders.

Prior studies conducted on environmental disclosure by various authors such as (Nor, Bahari, Adnan, Kamal & Au 2015; Ong, Tho, Goh, Thai & Teh, 2016; Malcom, Khadijah & Ahmad 2007; Clarkson, Li, Richardson & Vasvari 2007; Jia, Lianxiao & Adam 2011; Juhmani, 2014 & Agbadam, 2015) did not reach consensus on the effect environmental disclosure has on firm performance. Some found environmental disclosure to have negative effect on EPS, LEV while others found environmental disclosure have positive effect on EPS, LEV. There exist a mixed result and variation of the effects. This variation may be due to voluntary nature of environmental disclosure, where companies tends to disclose environmental information they so wish, it could be because of the variation in format, content or lack of consistent approach on environmental disclosure. Different authors use different approach to measure environmental disclosure in Nigeria, some used environmental disclosure checklist (indices), some content analysis. Therefore, this study tries to fill the gap that exists by using both content analysis and environmental disclosure indices to measure environmental disclosure. The study set out to examine the impact of environmental disclosure on the performance of listed fast-moving consumer goods companies in Nigeria. Specifically, the study intends to find out the impact of environmental disclosure on the following variables: return on assets; return on equity and earnings per share.



Literature Review

Conceptual Framework. Abubakar, Moses and Inuwa (2017) opine that environmental disclosure entails where a company is voluntarily or statutorily required to provide in annual reports, environmental management and environmental development costs. And these are costs incurred in preventing, reducing or repairing damage to the environment and conserving resources (Nwaiwu & Oluka, 2018).

Ong, Tho, Goh, Thai and Teh (2016) define environmental disclosure as a planned statement that depicts company's environmental burden and environmental efforts including company's objectives, environmental policies, environmental activities and impacts, reported and published periodically to the public. Through such reports that are published periodically to the public, companies seek to capture public perception toward their operations (Dibia & Onwuchekwa, 2015).

Environmental information serves as a medium of communication between the company and its stakeholders. Disclosure is necessary because of the importance of the environment to human existence and the devastating impact of companies' activities on the environment. Moreover, there is growing awareness globally about how companies' activities impact the environment. Since environmental protection has now become a global issue, managers have to focus their attention on creating biodegradable products that can be recycled.

In the opinion of Nwaiwu & Oluka (2018), corporate performance is no longer seen simply as being equivalent to and consequently measurable in terms of profitability alone. Information on accounting for environmental costs is now required. Each type of cost is to be considered as it arises so as to accord it the appropriate treatment in line with Generally Accepted Accounting Principles (GAAPs).

According to Nor et al (2015), the demand for companies to apply environment disclosure nowadays is very high in order to save the world and it is proved that company with environmental disclosure can achieve good performance. Based on the reviewed literature, improved disclosure by the companies reduces the gap between management and outsiders,



allow company to gain competitive advantage, improve corporate image, enhance the value of stock in the capital market and reduce cost of capital (Kanda 2010; Dye 2001, Akanet 2013).

While many developed countries have initiated mandatory disclosure in their reporting requirements, in most developing countries like Nigeria, Malaysia, Turkey among others, environmental disclosure still heavily rely on voluntary initiatives of reporting entities. Nwaiwu and Oluka (2018) note that environmental disclosures in Nigeria and many other developing countries are discretionary, suggesting that corporations exert unimaginable control over the preparation and disclosure of social and environmental information.

Mandatory disclosure consist of information that is been disclosed in order to meet the requirement of law and regulation. According to Burbu, Dumontier, Feleaga and Feleaga (2011), France and UK environmental disclosure is mandatory for listed and large non-listed companies. In France, environmental disclosure is regulated by 'Nouvelles Regulations Economiques' (New Economic Regulation). The regulation requires listed companies to disclose information on the firm environmental impact of their operations in their annual report.

In UK, the Company's Act of 1985 mandates all listed companies to publish a yearly operating and financial review that captures information on significant firm's environmental impacts. In 2006, non-listed companies were also required to disclose key environmental performance indicators in business review section of annual report (Burbu *et al.* 2011). In the United State of America, SEC regulations and accounting standards require American companies to disclose environmental information in annual reports (Ejoh, Duke & Acquah, 2014).

On the other hand voluntary disclosure entails where management discloses information about the environmental impact of their operation that is useful for the users in financial statements without statutory requirement. It can be seen as a willingness or free choice on the part of company to disclose information in the annual report. The main goal of voluntary disclosure is to communicate better the company's value to its potential investors. As information is available to investors, they can easily recognize the value and predict the future performance. This will increase investor's willingness to invest especially if they perceive the company a good



corporate citizen. Voluntary environmental disclosure has no content, format or consistent approach, the content or the format lies completely in the hand of management of the company. Based on prior research, developing countries heavily rely on voluntary environmental disclosure.

Empirical Framework. Prior research on environmental disclosure and its impact on firms' performance resulted to different conclusions. Dibia and Onwuchekwa (2015) examined the determinant of environmental disclosure in Nigeria. The study used a sample of 15 oil companies, data were collected from the companies' annual report from 2008-2013. Data were analyzed through the use of regression. Their results showed that leverage impact negatively on the decision to disclose information while profit after tax impact positively on the decision to disclose environmental information by quoted companies in Nigeria.

Olayinka and Oluwamayowa (2014) examined the impact of environmental information disclosure on market value of 50 quoted companies in Nigeria. Descriptive statistics was used to analyze the data; the results revealed that market value has positive correlation with corporate environmental disclosure.

Ong, Teh and Ang (2014) examined the impact of environmental improvement on the financial performance of leading companies listed in Bursa Malaysia. Sample size of 78 companies listed in Bursa Malaysia was used. Their study employed content analysis to verify the extent of information disclosed. The results revealed that firms will gain financially through environmental improvement.

Nor, Bahari, Adnan, Kamal and Ali (2015) examined the effect of environmental disclosure on financial performance in Malaysia. Based on their findings, there exists a negative relationship between environmental disclosure and firm financial performance indicators (ROA, ROE, and EPS). On the other hand, there exist a significant positive relationship between environmental disclosure and firm financial performance indicator (profit margin).

Ong, Tho, Goh, Thai, and Teh (2016) studied the relationship between environmental disclosure and financial performance of public listed companies in Malaysia. Data were analyzed through



the use of multiple regressions, and the study revealed that there is only a positive relationship between quality of environmental disclosure and EPS.

Jia, Lianxiao and Adam (2010) studied the relationship between environmental disclosure and firm performance in United States of America. Data were analyzed through the use of regression, and their results showed a significant negative impact on firm performance. Leverage also has significant negative impact on firm performance, while firm growth has significant positive impact on firm performance.

Theoretical Framework. For the purpose of this study, the Legitimacy Theory and the Stakeholder Theory are considered to explain environmental disclosure.

The Legitimacy Theory. Legitimacy theory, according Aghdam (2015), implies companies' consideration, concern and expectation of community to appear legitimate from stakeholders' point of view and to pledge that their activities are socially acceptable and safe. The legitimacy theory was propounded by John Dowling and Jeffrey Pfeffer in 1975.

The legitimacy theory provides a comprehensive viewpoint on corporate social disclosure as it clearly recognizes that organizations are bound by the social contract in which they agree to perform various socially desired actions in return for approval of their objectives which guarantee their continued existence and their successful operations (Guthrie & Parker, 1989; Brown & Deegan, 1998; Deegan, 2002).

From the foregoing theoretical review, legitimacy theory suggests a relationship between corporate environmental disclosure and community concerns so that management must react to community expectations and changes. Therefore, this study is anchored on the legitimacy theory because management must react to environmental issues concerning the environment in which they operate in order to gain acceptance of the society and ensure survival of their firm.

The Stakeholder Theory

The stakeholder theory was propounded by Edward Freeman in 1984. The theory is of the view that the community where the company operates has interest in knowing the company's effort



and concern toward reducing the devastating effect of their operations on the environment. This demand can only be satisfied through disclosure of environmental information in annual reports. Ong et al (2016) report that corporate environmental disclosure is being used as a tool for strengthening good relations with stakeholders. Environmental disclosure is seen as dialogue between the corporation and stakeholders. Corporate social and environmental responsibility encourages strong relationship between firm and society where it operates (Aggarwal, 2013). He further states that where a company ignores the stakeholders interest it may contaminate the organization's image, which would have a devastating effect on firm's financial performance.

The theory as used in the study, examines the conditions under which managers treat members of communities that host their companies as well as other stakeholders. That is, by their disclosure of environmental information, they present themselves as addressing morals and values such as those related to corporate social responsibility. To ensure that an environment of mutual benefit is created, stakeholders' needs should be considered in any action of the company.

Methodology

This research set out to look at the impact of environmental disclosure on performance of listed fast-moving consumer goods companies in Nigeria. The population of the study consists of all the food and beverage companies listed on the Nigerian Exchange Group, out of which ten (10) companies (Unilever Nigeria, Guinness Nigeria Plc, Nigeria Breweries Plc, Dangote Sugar Refinery Plc, Flour Mill of Nigeria Plc, Honeywell Flour Mills Plc, BUA Foods Plc, Dufil Prima Foods, Cadbury Nigeria Plc and Nestle Nigeria. Plc) were sampled based on data availability. Secondary data were used, and these were collected from annual reports of the sampled companies regarding their environmental information disclosure for the period of five years from 2018 through 2022.

In order to assess the impact of environmental disclosure on the financial performance of the sampled companies, quantitative and qualitative approach was used to measure the independent variable. For the quantitative approach, content analysis was employed; it has frequently been used by researchers such as Jerry, Teru and Musa (2015); Uwalomwa and Jafaru (2012);

Ebimobowei (2011). This research adopts sentence count as a unit of analysis. Sentence count as a unit of analysis is appropriate than other units because it provides complete and reliable data (Guthrie and Abeysekera 2006). Sentence is considered as the main unit of speech and writing (Walden and Schwartz 1997). Environmental disclosure checklist was adapted from Akenet (2013), Comier, Magnan and Velthoven (2005) to measure the qualitative disclosure. This study adopts the unweighted disclosure index approach in order to know whether the companies disclose in their annual report information regarding the impact of their operations on the environment. This formula is used to explain disclosure using unweighted approach:

$$EDQL = \frac{\sum di}{n}$$

Where EDQL = environmental disclosure qualitative

di = 1 if an item in the check list is disclosed in annual report, 0 if not disclosed

n = number of items in the disclosure check list.

In this study dependent variable is the firm performance which is expected to be influenced by environmental disclosure practices. In order to measure the firm performance, the following are chosen as indicators of performance of the companies: Return on Asset (ROA), Return on Equity (ROE) and Earning per Share (EPS) as it has been consistently used in the previous research. The control variables are firm size and leverage of a firm.

In order to examine the impact of environmental disclosure on performance of fast-moving consumer goods companies in Nigeria, three (3) regression models were developed as indicated below:

$$ROA = \beta_0it + \beta_1itEDQN + \beta_2itEDQL + \beta_3itLEV + \beta_4itFRMS + eit \dots \text{model 1}$$

$$ROE = \beta_0it + \beta_1itEDQN + \beta_2itEDQL + \beta_3itLEV + \beta_4itFRMS + eit \dots \text{model 2}$$

$$EPS = \beta_0it + \beta_1itEDQN + \beta_2itEDQL + \beta_3itLEV + \beta_4itFRMS + eit \dots \text{model 3}$$

Where:

ROA is return on assets, ROE is return on equity, EPS is earning per share, β is the intercept, EDQN is environmental disclosure quantitative, EDQL is environmental disclosure qualitative, LEV is leverage and FRMS is firm size. Our models were adapted from the model of Samiloglu, Oztop and Kahraman (2017).

Results and Discussion

Table 1: Correlation matrix of dependent and explanatory variables

	Edql	edqn	roa	roe	eps	lev	frms
edql	1.0000						
edqn	0.2326	1.0000					
roa	0.1999	0.2454	1.0000				
roe	0.4959	0.2163	0.5059	1.0000			
eps	0.6935	0.2438	0.3292	0.6105	1.0000		
lev	0.1700	0.4668	0.2507	0.2746	0.0024	1.0000	
frms	0.3196	0.2326	0.2140	0.3377	0.5629	-0.1114	1.0000

Source: Authors' computation using stata version 18.0

Table 1 shows the correlation coefficient results among dependent and the explanatory variables where all of them show positive correlation except leverage and firm size. The overall matrix shows that there is no multicollinearity among the variables.

Table 2: Summary of the multiple regression results

Equation	Obs	Parms	RMSE	"R-sq"	F	
roa	35	5	.2300868	0.1327	1.0023	0.4053
roe	35	5	.224105	0.3369	3.360029	0.0316
eps	35	5	2.703669	0.6169	7.832048	0.0005
	Coef.	Std. Err.	T	P> t	[95% Conf. Interval]	
roa						
edql	.0989556	.2227946	0.44	0.660	-.3560518	.5539629
edqn	.0004823	.0012724	0.38	0.707	-.0021162	.0030809
lev	.257052	.23265	1.10	0.278	-.2180826	.7321866
frms	1.75e-13	1.71e-13	1.02	0.314	-1.74e-13	5.24e-13
cons	-.1080561	.1087427	-0.99	0.328	-.3301384	.1140262
roe						
edql	.5132993	.2170024	2.37	0.025	.0701213	.9564773
edqn	-.0003894	.0012393	-0.31	0.756	-.0029204	.0021416
lev	.3406987	.2266015	1.50	0.143	-.1220833	.8034806

frms	2.59e-13	1.67e-13	1.55	0.131	-8.15e-14	5.99e-13
cons	-.1598963	.1059156	-1.51	0.142	-.3762049	.0564122
eps						
edql	12.40072	2.617981	4.74	0.000	7.054093	17.74735
edqn	.0075834	.0149513	0.51	0.616	-.229513	.0381181
lev	-1.821493	2.733787	-0.67	0.510	-7.404632	3.761646
frms	5.59e-12	2.01e-12	2.78	0.009	1.48e-12	9.69e-12
cons	-.7044411	1.277797	-0.55	0.586	-3.314052	1.905169

Source: Authors' computation using stata version 18.0

In Table 2, the r^2 shows the power of the independent variable in explaining the dependent variables. The r^2 value of the dependent variables ROA, ROE, and EPS are; 0.1327, 0.3369, and 0.6169 respectively. These indicate that about 13.3%, 33.7% and 61.7% of the variation in each of the respective dependent variables is being explained by the explanatory variables EDQL, EDQN, LEV, and FRMS.

At 5% level of significance ($p \leq 0.05$), the explanatory variable EDQL has positive significant impact on ROE. This reveals that EDQL is statistically significant at 0.025. It is also statistically significant at 0.00 with the dependent variable EPS. However, it has a positive insignificant impact on ROA at 0.660. The explanatory variable EDQN has positive insignificant impact on the dependent variables ROA and EPS at 0.707 and 0.616 respectively. It however has a negative insignificant impact on ROE at 0.756. The control variables LEV and FRMS have positive but insignificant impact on ROA and ROE. However the control variable LEV has a negative insignificant impact on the dependent variable EPS at 0.510. On the other hand, the control variable FRMS has positive significant impact on EPS at 0.009.

Conclusion

The study has empirically examined the impact of environmental disclosure on performance of listed fast-moving consumer goods companies in Nigeria for the period from 2018 to 2022. The results of the regression show that only the independent variable EDQL has positive significant impact on ROE and EPS with values 0.025 and 0.00. The control variable FRMS shows significant positive impact on EPS with value 0.009. This means that through disclosing environmental information qualitative that is when certain environmental information is



disclosed will impact positively on the return on equity and earnings per share of listed fast-moving consumer goods companies in Nigeria. Consequently, the firm size apart from the environmental disclosure qualitative also impact earnings per share.

Recommendations

Based on the findings, the following recommendations were put forward:

- i. Companies should practice environmental disclosure qualitative since it has positive impact on return on equity and earning per share. This is to guarantee a conflict free corporate atmosphere for improved corporate performance.
- ii. Management should carry out a cost benefit analysis of environmental disclosure.
- iii. Government should come up with clearly defined policy on environmental disclosure issues and should ensure its full implementation. This is because environmental management and disclosure activities help in raising the standard of living of communities based on the fact that the activities of companies affect the life of host communities.

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SOCIAL ACCOUNTING AND THE SUSTAINABLE DEVELOPMENT GOALS: PROSPECTS AND IMPLEMENTATION CHALLENGES

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Abstract

Social accounting has emerged as a pivotal tool for promoting accountability, transparency, and sustainable development by measuring and reporting the social and environmental impacts of organizations. This paper explores the prospects and implementation challenges of social accounting as a mechanism for achieving the Sustainable Development Goals (SDGs). It examines the conceptual underpinnings of social accounting, its role in advancing corporate accountability, and its integration into public governance and civil society engagement. The methodology imperative employed for the study is critical analysis of secondary sources. Thus, key prospects include fostering ethical practices, enhancing organizational transparency, and aligning stakeholder interests with global sustainability objectives. However, challenges such as the absence of standardized frameworks, inadequate capacity, and resistance to adoption hinder its effective implementation. The study highlights the implications of social accounting for businesses, governments, and civil society, emphasizing its potential to drive innovation, improve policymaking, and empower communities. Recommendations are provided to address these challenges, including harmonizing standards, leveraging technology, building capacity, and fostering multi-stakeholder collaboration. This study underscores the transformative potential of social accounting in achieving a more equitable and sustainable global economy.

Keywords: Social accounting, Sustainable Development Goals, Accountability, Transparency, Public Governance

1.0 Introduction

The global pursuit of sustainable development has gained unprecedented momentum since the adoption of the United Nations' 2030 Agenda for Sustainable Development in 2015 (Trends, 2017). This agenda, centered on 17 Sustainable Development Goals (SDGs), provides a comprehensive framework to address the world's most pressing challenges, ranging from poverty eradication and climate change to ensuring gender equality and fostering inclusive economic growth. Achieving these ambitious goals requires not only the commitment of



governments but also the active participation of businesses, civil society, and other stakeholders. In this context, transparency, accountability, and ethical decision-making have emerged as critical components for driving progress toward sustainable development (Abhayawansa, Adams, & Neesham, 2021).

"Despite ongoing efforts, many developing nations continue to face significant challenges in achieving the SDGs due to structural, economic, and governance-related barriers. The unique socio-economic and political contexts of each nation further complicate the implementation of sustainability initiatives."

Social accounting, a concept that integrates social, environmental, and economic performance into organizational reporting, has emerged as a powerful tool to align business activities with sustainability objectives. By moving beyond the traditional financial metrics, social accounting provides a more holistic view of an organization's impact on society and the environment (Mook, 2010). It enables organizations to measure, report, and improve their contributions to sustainable development, fostering trust among stakeholders and ensuring long-term value creation.

Despite its potential, the adoption of social accounting in achieving the SDGs is not without challenges. The lack of standardized frameworks, resource constraints, and resistance to change have hindered widespread implementation, particularly in developing economies. Thus, the disconnect between social accounting practices and the SDG targets underscores the need for more tailored strategies to bridge this gap.

This paper examines the prospects and implementation challenges of social accounting as a mechanism for achieving the Sustainable Development Goals. It explores how social accounting can enhance organizational accountability, promote ethical practices, and support decision-making for sustainable development while highlighting the barriers that organizations face in integrating these practices into their operations. By addressing these issues, this study contributes to the broader discourse on aligning corporate actions with global sustainability objectives and provides actionable insights for policymakers, practitioners, and scholars.



2.0 Literature Review

2.1 Theoretical framework

Theories provide a framework for understanding the motivations and consequences of social accounting practices and their potential to contribute to the achievement of the SDGs. By considering these theoretical perspectives, researchers and practitioners can gain a deeper understanding of the role of social accounting in creating a more sustainable and equitable world. The following theories can further explain the relationship between social accounting and achieving SDGs.

2.1.1 Stakeholder Theory

This theory posits that organizations have a responsibility to consider the interests of all stakeholders, including employees, customers, suppliers, communities, and the environment, and that decisions taken by organizations would have a direct or indirect impact on them (Freeman *et al.*, 2020). This theory emphasizes that organizations have a wider set of responsibilities that go beyond maximizing shareholders' wealth. Social accounting aligns with this theory by encouraging organizations to measure and report on their impacts on these stakeholders, fostering a more inclusive and sustainable approach to business. As observed by Lange *et al.* (2022), a stakeholder's utility is partially fulfilled by their perception of how firms treat stakeholders. Still, they note that the stakeholder literature has yet to sufficiently account for stakeholders' perceptions of how firms deal with stakeholders.

With SDGs, stakeholder theory offers valuable insights into how accounting practices can drive sustainable development. Franklin *et al.* (2024) emphasize the importance of including diverse stakeholders in decision-making processes related to financial resource allocation, reporting, and accountability (Freeman *et al.*, 2020). By considering the interests and expectations of various stakeholders, countries can better align their accounting and PFM practices with broader SDG objectives, promoting transparency and trust (Lange *et al.*, 2022). This alignment is crucial for ensuring that financial practices not only meet economic goals but also support social and environmental sustainability through contributing to the holistic achievement of SDGs (Goddard *et al.*, 2016).



2.1.2 Institutional Theory:

This theory emphasizes the influence of social norms and pressures on organizational behavior. It also provides a powerful tool for understanding how institutions affect economic outcomes (Meyer & Höllerer, 2014). It posits that institutions—including legal frameworks, organizational structures, and cultural norms—shape both individual and collective behaviors. The theory explores the deeper, more resilient characteristics of social structures, examining how certain systems become established as guidelines for social behavior. Additionally, it sheds light on why and how nations interact with their institutional environments (Suddaby, 2010).

Institutional theory provides a foundational framework for understanding how accounting practices adapt to institutional forces and influence the Sustainable Development Goals (SDGs) Franklin *et al.* (2024). This theory clarifies how both formal and informal rules, norms, and practices shape societal behavior, particularly in the context of accounting. It offers valuable insights into the institutional mechanisms that impact decision-making regarding resource allocation, reporting, and accountability in the pursuit of sustainability. Equally, the theory highlights the institutional pressures that can either promote or hinder the integration of SDGs into accounting frameworks and practices (Goddard et al., 2016).

The more societal expectations for corporate social responsibility increase, the more organizations are pressured to adopt social accounting practices to demonstrate their compliance with social and environmental norms.

2.3 Social Accounting and SDG Achievement: The Nexus

The Sustainable Development Goals (SDGs), established by the United Nations in 2015, represent a global call to action to address critical challenges such as poverty, inequality, climate change, and environmental degradation by 2030 (Friedman & Gostin, 2016). Achieving these goals requires a concerted effort from governments, businesses, and civil society. In this context, social accounting emerges as a vital mechanism for aligning organizational practices with the SDG framework. By integrating social, environmental, and economic metrics into reporting and decision-making processes, social accounting establishes a nexus between organizational accountability and sustainable development.



Social accounting enables organizations to evaluate and disclose their contributions to the SDGs in a structured and transparent manner (Nicholls, 2020). For example, through frameworks like the Global Reporting Initiative (GRI) and Sustainability Accounting Standards Board (SASB), companies can report on their progress toward goals such as clean energy (SDG 7), climate action (SDG 13), and decent work and economic growth (SDG 8). These frameworks provide standardized metrics that facilitate comparisons across organizations and industries, enhancing the credibility and reliability of sustainability reporting (Trends, Challenges and opportunities in the implementation of the Sustainable Development Goals, 2017).

Moreover, social accounting serves as a decision-making tool that helps organizations identify and prioritize areas where they can have the greatest impact. By analyzing data on their environmental and social footprints, organizations can align their strategies with specific SDG targets (Boyce, 2000). For instance, a manufacturing company might use social accounting to assess its water usage and implement measures to support SDG 6 (Clean Water and Sanitation), while a financial institution might evaluate its lending practices to promote SDG 10 (Reduced Inequalities) and SDG 5 (Gender Equality).

The nexus between social accounting and SDG achievement is further reinforced by its ability to promote ethical and responsible business practices (Bebbington & Unerman, 2020). Through regular monitoring and reporting, organizations can identify gaps in their sustainability efforts and take corrective actions. For instance, social accounting can highlight disparities in employee wages or unsafe working conditions, prompting businesses to adopt fair labor practices in line with SDG 8 (Decent Work and Economic Growth) (Rai, Brown, & Ruwanpura, 2019). Similarly, tracking carbon emissions can drive investments in renewable energy and energy-efficient technologies, directly contributing to SDG 13 (Climate Action) (Doni, Gasperini, & Soares, 2020). Social accounting fosters collaboration among stakeholders, which is critical for achieving the SDGs. By engaging governments, non-governmental organizations (NGOs), and local communities in their social accounting processes, organizations can align their objectives with broader societal needs. This collaborative approach not only enhances the effectiveness of sustainability initiatives but also strengthens stakeholder trust and partnerships, as emphasized in SDG 17 (Partnerships for the Goals) (Franco & Abe, 2020).



2.4 Prospects of Social Accounting for Achieving SDGs

The integration of social accounting into organizational strategies offers significant potential for advancing the Sustainable Development Goals (SDGs). As a framework that expands beyond traditional financial reporting, social accounting provides tools for measuring, analyzing, and improving the social, environmental, and economic impacts of organizational activities. Its adoption highlights several critical prospects that underscore its relevance to achieving the SDGs. Notably, social accounting enhances **accountability and transparency** by enabling organizations to systematically report on their contributions to the SDGs (Hess, 2007). Businesses are increasingly required to demonstrate how their operations impact areas such as environmental conservation (SDG 13), gender equality (SDG 5), and decent work (SDG 8). Through standardized frameworks like the Global Reporting Initiative (GRI) and Integrated Reporting (IR), social accounting ensures that organizations can disclose their sustainability efforts in a manner that fosters trust among stakeholders (Adams, Potter, & York, 2016). This transparency not only builds credibility but also drives internal and external accountability, ensuring that organizations remain committed to sustainable development goals.

Another critical prospect lies in **supporting evidence-based decision-making**. By providing comprehensive data on social, environmental, and economic performance, social accounting equips organizations with the information needed to prioritize their interventions effectively (Leuz, 2018). For instance, a company analyzing its water consumption metrics may identify inefficiencies and implement measures to align with SDG 6 (Clean Water and Sanitation). Similarly, social accounting reveals supply chain vulnerabilities, prompting businesses to adopt more sustainable sourcing practices that support SDG 12 (Responsible Consumption and Production) (Arora & Mishra, 2023). This data-driven approach ensures that organizational strategies are targeted and impactful.

Social accounting also plays a key role in **promoting ethical and responsible business practices**. By highlighting areas where organizations fall short such as unequal pay, unsafe working conditions, or excessive carbon emissions it motivates corrective action (Owen, Swift, & Hunt, 2001). For example, regular monitoring of employee welfare can lead to policies that



advance SDG 10 (Reduced Inequalities) by addressing disparities in wages or opportunities. Likewise, tracking emissions can encourage investments in renewable energy, directly contributing to SDG 7 (Affordable and Clean Energy). In this way, social accounting not only promotes compliance with ethical standards but also fosters a culture of responsibility and sustainability within organizations (Laufer, 2003).

Social accounting facilitates **collaboration across sectors**, a necessity for achieving the SDGs. The complexity of global challenges demands partnerships between governments, businesses, non-governmental organizations (NGOs), and communities (Barraket & Loosemore, 2018). Social accounting provides a shared framework that aligns organizational goals with societal needs, creating opportunities for collective action. By openly communicating their contributions and engaging with diverse stakeholders, organizations can foster the multi-stakeholder collaborations emphasized in SDG 17 (Partnerships for the Goals). This collaborative approach amplifies the effectiveness of sustainability initiatives, ensuring that no stakeholder operates in isolation.

Another promising aspect of social accounting is its ability to **drive innovation and sustainable practices**. By encouraging organizations to rethink traditional processes, social accounting inspires innovative solutions to societal and environmental challenges (Lopez-Valeiras, Gomez-Conde, & Naranjo-Gil, 2015). For example, a business seeking to reduce waste may adopt circular economy models that align with SDG 12 (Responsible Consumption and Production), while another may invest in green infrastructure to support SDG 9 (Industry, Innovation, and Infrastructure). This emphasis on innovation not only enhances organizational competitiveness but also accelerates progress toward sustainability goals.

Fostering internal change, social accounting contributes to **strengthening public trust and organizational reputation**. In an era where consumers, investors, and regulators increasingly prioritize sustainability, organizations that adopt transparent social accounting practices are better positioned to attract socially conscious stakeholders (DiPiazza Jr & Eccles, 2002). Demonstrating alignment with SDG objectives enhances public perception, solidifies stakeholder loyalty, and strengthens the organization's social license to operate. Over time, this translates into a competitive advantage, as sustainability becomes a key differentiator in global markets.



Alternatively, social accounting provides a foundation for **policy alignment and global accountability**. By integrating SDG metrics into their reporting, organizations can align their activities with national and international sustainability policies. This alignment not only ensures regulatory compliance but also positions businesses as active contributors to government-led development initiatives (Qian, Tilt, & Belal, 2021). On a global scale, the standardization of social accounting practices contributes to a cohesive database for tracking SDG progress, helping policymakers identify gaps, monitor trends, and design effective interventions. The prospects of social accounting for achieving the SDGs are both practical and transformative. Its ability to enhance accountability, foster ethical practices, promote innovation, and facilitate cross-sector collaboration underscores its vital role in advancing global sustainability. By embedding social accounting into their strategies, organizations can not only meet their social and environmental responsibilities but also contribute meaningfully to the collective effort to build a more inclusive and sustainable world.

2.5 Challenges in Implementing Social Accounting Standardized Frameworks

Implementing standardized frameworks for social accounting presents a range of complex challenges that hinder their widespread adoption and effectiveness. These challenges, rooted in technical, financial, cultural, and institutional factors, often create barriers that limit the potential of social accounting to advance organizational accountability and sustainability objectives.

A critical challenge lies in the **lack of universally accepted standards** for social accounting. Existing frameworks, such as the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB), offer varied approaches with differing priorities and metrics. This lack of harmonization creates confusion among organizations, making it difficult for them to select the most appropriate framework (Oxman, 1991). Furthermore, the absence of global uniformity undermines comparability across organizations and industries, diminishing the utility of social accounting for benchmarking and evaluating performance.

Another significant issue is the **complexity of measuring social and environmental impacts**, which are often intangible and difficult to quantify. For instance, assessing the social benefits of a community development program or the ecological impact of conservation initiatives involves



subjective interpretations that may vary across contexts (Bergman & Beehner, 2015). Without clear and universally applicable metrics, organizations struggle to produce reliable and consistent data, which can erode the credibility of social accounting practices.

The **high cost of implementation** further compounds these challenges. Social accounting requires substantial investment in data collection systems, specialized expertise, and external audits, which can be financially burdensome, particularly for small and medium-sized enterprises (SMEs) (Cannon & John, 2007). Larger organizations, while better equipped to absorb these costs, may still face difficulties justifying them in the absence of immediate financial returns. This financial burden often discourages organizations from adopting social accounting frameworks, especially in regions where regulatory enforcement is weak or stakeholder demand for transparency is limited.

A related obstacle is the **limited technical expertise** available for implementing social accounting practices (Gibbon & Affleck, 2008). Many organizations lack skilled personnel who can navigate the complexities of data collection, analysis, and reporting. Understanding the nuances of different frameworks and aligning them with organizational goals requires a level of expertise that is often unavailable, particularly in developing regions (Retolaza & San-Jose, 2021). This skill gap not only hinders effective implementation but also increases the risk of errors and inconsistencies in reporting. Resistance to change within organizations also poses a significant challenge (Kamla, Gallhofer, & Haslam, 2012). Many businesses remain focused on short-term financial performance and view social accounting as an unnecessary or burdensome addition to their operations. This resistance often stems from a lack of awareness about the long-term benefits of social accounting, such as enhanced stakeholder trust and competitive advantage (Millon, 2012). Overcoming this resistance requires a cultural shift within organizations, which can be a slow and difficult process.

Another critical challenge is the **limited availability and quality of data** required for social accounting. Organizations often encounter difficulties in accessing accurate and comprehensive data on social and environmental performance, particularly in areas like carbon emissions or community impact. The absence of standardized data collection methods exacerbates this issue, leading to inconsistencies that compromise the credibility and usefulness of social accounting



reports (Retolaza, San-Jose, & Ruíz-Roqueñi, Social accounting for sustainability: Monetizing the social value, 2016).

Institutional and regulatory barriers further complicate the implementation process. In many regions, governments and regulatory bodies provide little guidance or support for adopting standardized social accounting frameworks. The lack of clear policies, incentives, or enforcement mechanisms discourages organizations from investing in social accounting. In some cases, bureaucratic inefficiencies and corruption within institutional systems can further undermine efforts to implement these frameworks effectively.

The **cultural and contextual variability** across regions and industries also poses a challenge. Social accounting frameworks often fail to account for the differing priorities of organizations operating in diverse environments (Gelfand, Lim, & Raver, 2004). For example, while businesses in developed economies may focus on advanced environmental metrics, organizations in developing countries might prioritize addressing basic social issues such as poverty or education. Adapting frameworks to reflect these contextual differences without losing standardization remains a delicate balance.

Above all, the risk of **greenwashing and misrepresentation** threatens the integrity of social accounting practices. Without robust verification mechanisms, organizations may manipulate data or selectively disclose favorable information to portray a false image of their sustainability performance (Free, Jones, & Tremblay, 2024). This not only undermines the credibility of social accounting but also erodes stakeholder trust, making it more challenging for genuine efforts to gain recognition. The implementation of standardized frameworks for social accounting is constrained by a range of interrelated challenges, including inconsistent standards, technical complexities, financial barriers, and institutional weaknesses. Addressing these issues requires concerted efforts from policymakers, industry leaders, and other stakeholders to harmonize standards, build technical capacity, and create enabling environments for adoption. Only by overcoming these challenges can social accounting fulfill its potential as a transformative tool for accountability, transparency, and sustainable development.



3.0 Conclusion and Recommendation

3.1 Conclusion

The successful implementation of social accounting as a tool for sustainable development requires targeted strategies to address existing challenges while maximizing its potential benefits. This necessitates a coordinated effort from businesses, governments, and civil society, focusing on practical solutions to foster transparency, accountability, and collaboration. The current landscape is fragmented, with frameworks like the Global Reporting Initiative (GRI), Integrated Reporting (IR), and the Sustainability Accounting Standards Board (SASB) offering varied approaches. The poor or inadequate knowledge of the operations of such standards is visible within the implementers and other stakeholders of these goals. Lack of attraction to the adoption of such accounting frameworks is also not visible. Regulatory bodies are also not strengthened to monitor activities of organizations to ensure adoption and full compliance of sustainability reporting. There is a need for the stakeholders to ensure that. To address this, there is a need for international collaboration to establish unified and universally accepted standards. A harmonized framework would simplify adoption for organizations, enhance comparability across sectors, and improve the overall credibility of social accounting practices.

3.2 Recommendations

To maximize the potential of social accounting as a tool for achieving sustainable development and addressing its implementation challenges, the following recommendations are proposed for businesses, governments, and civil society:

- a. **Harmonization of Standards.** The lack of unified frameworks in social accounting creates confusion and inconsistency. Efforts should be directed at harmonizing global standards like the Global Reporting Initiative (GRI), Integrated Reporting (IR), and the Sustainability Accounting Standards Board (SASB). A unified standard will ensure comparability, simplify adoption, and enhance credibility across sectors. Governments, international organizations, and standard-setting bodies must collaborate to establish a universally accepted framework.



- b. **Capacity Building.** Organizations must invest in training and capacity-building initiatives to address the skills gap in social accounting. Training programs should target professionals in businesses, public institutions, and civil society to develop expertise in data collection, analysis, and reporting. Governments and academic institutions can collaborate to integrate social accounting into educational curricula, ensuring a steady pipeline of qualified practitioners.
- c. **Incentivizing Adoption.** Governments and financial institutions should offer incentives to encourage the adoption of social accounting frameworks. Tax breaks, subsidies, and grants can reduce the financial burden for small and medium-sized enterprises (SMEs) and nonprofit organizations. Additionally, linking access to funding or procurement opportunities to the implementation of social accounting practices can drive compliance.
- d. **Strengthening Regulatory Frameworks.** Governments should establish clear policies mandating the adoption of social accounting for organizations operating within their jurisdictions. Regulatory frameworks must include enforcement mechanisms, penalties for non-compliance, and support systems for organizations transitioning to these practices. Integrating social accounting requirements into broader corporate governance laws can also enhance adoption.

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SUB-THEME 8: Green and Resilient infrastructure for sustainable National Development



RESISTANCE OF QUARRY DUST-PERIWINKLE SHELL ASH-CONCRETE TO SULFURIC ACID ATTACK

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Abstract

The vulnerability of concrete to aggressive exposures has contributed largely to global structural failure. The growing concerns on the need for green and resilient infrastructure for sustainable national development, has prompted intensified effort for provision of alternative construction materials. To abate the high cost and environmental implications of cement production, this study employed quarry dust (QD) and periwinkle shell ash (PSA) as partial replacement materials for cement in concrete. PSA was constant at 5% while QD was varied at 5% intervals from 0 to 25% by weight of cement. For a total exposure duration of 28 days, sulphuric acid (H_2SO_4) solution of 5% concentration was adopted to examine the resistance of concrete specimens. The behaviour of the tested specimens was evaluated by measuring the strength loss. The optimum strength was obtained at 10% QD-PSA content, with a 28 days' compressive strength of 27.73 N/mm^2 , with 8.2% variation from the targeted strength of 30 N/mm^2 and 2.3% variation from that of the control mix. The optimum strength dropped to 26.54 N/mm^2 after immersion in 5% H_2SO_4 solution, a minimum strength loss of 4% was obtained. The inclusion of QD-PSA of not more than 10% was able to improve the resistance of concrete towards acid attack and it is therefore recommended for concrete production in acidic environments. The regression analysis proved that the outcome of this study is statistically significant. Hence, production of QD-PSA concrete is reliable for construction in environments prone to acid attack.

Keywords: Concrete, Acid resistance, Quarry dust, Periwinkle shell ash, Regression analysis

Introduction

The degree of infrastructural failure in developing nations is reoccurring due to deteriorations arising from acidic environment (Nwa-David, 2024; Nwa-David, *et. al.*, 2024) and the ability of concrete to withstand acidic attack is an index for its durability, deformation capacity, stiffness and strength (ACI Committee, 2001; Kumar, *et. al.*, 2022). On daily basis, concrete structures are subjected to unfavorable environmental conditions and their properties are affected by both external and internal factors. These external influences could be chemical attacks or mechanical damage caused by impact, abrasion, erosion or cavitation while internal factors consist of the chemical reactions involving concrete constituents (Neville, 2005; Iorshagher and Ocholi, 2023).



Concrete is regularly attacked by sulphuric acid produced by sewer systems, the oxidation of pyrite which is widely and abundantly available in the earth's sulfide minerals or the oxidation of sulfur oxides generated by industrial activities and automobiles (Kumar, *et. al.*, 2022). The durability of concrete is altered as the acid neutralizes the alkalinity of concrete by reacting with the hydration products of the concrete matrix to form gypsum, thaumasite and ettringite (Yuan, *et. al.*, 2013; Kulkarni, 2019). This leads to volume expansion, spalling, formation of cracks, internal pressures, and strength loss (Iorshagher and Ocholi, 2023).

Several techniques are being employed to improve the resistance of concrete in an acidic environment. One of the strategies that have proven to be very effective is the use of various supplementary cementitious materials such as fly ash, cassava peel ash, rice husk ash, sawdust ash, periwinkle shell ash, slag, micro silica, and calcite laterites (Roy, *et. al.*, 2001; Nwa-David, 2023a; Nwa-David, *et. al.*, 2023a; Nwa-David, *et. al.*, 2023b; Nwa-David and Ibearugbulem 2023).

Quarry dust (QD) is a by-product of the rock-quarrying process abundantly available and minimally employed in a quarry industry. Quarry dust has a rough surface which enhances the bond with other materials like coarse aggregates and cement. It also has some cementitious materials in its composition such as silicate and aluminium contents (Aliyu, *et. al.*, 2020). Periwinkle shells are agricultural wastes with small greenish-blue marine snails with spiral conical shell and round-aperture, whose fleshy portion are processed and consumed while the hard shells are stockpiled in open sites which constitute a menace to the environment. These shells can be adopted for construction purposes to extricate pollution effect (Olusola and Umoh, 2012; Nwa-David, 2023b)

The study carried out by Aliyu *et. al.* (2020) showed that the resistance of the concrete to acid increases as the percentage addition of quarry dust increased. The weight of concrete decreased with an increase in exposure duration and also decreased with an increase in quarry dust content. The authors adopted quarry dust as partial replacement of fine aggregate at 0, 15, 25, and 35 % at 7, 14 and 28 days curing in water and 7, 14 and 28 days curing in 5% solution of sulphuric acid. Obilade (2018) and Abubakar *et. al.*, (2020) investigated the effect of hydrochloric acid solution on the compressive strength of concrete at early ages. In the report of Abubakar et al., (2020),



concrete samples exposed to 5% and 10% HCl solutions decreased significantly at 28 days. The study of Obilade (2018) showed that the incorporation of sugar cane straw ash of not more than 10% was able to improve the resistance of concrete towards acid attack. However, the authors did not consider the sulfuric acid neither was QD nor PSA adopted.

Arun *et al.*, (2021) determined the acid attack resistance in terms of weight loss of controlled concrete (CC), sugar bagasse fibre reinforced controlled concrete (CCF) and geopolymer concrete (GPC) exposed to 5% HCL and H₂SO₄ concentrations. Their study proved that sulphuric acid environment is more severe because sulphuric acid causes more strength loss than hydrochloric acid. Kumar, *et al.*, (2022) determined the residual compressive strength of wood ash concrete cube specimens after immersion in 2% and 5% diluted sulfuric acid (H₂SO₄) solutions. Quarry dust and periwinkle shell ash were not adopted in their investigation.

Djerfaj *et al.*, (2023) studied the behaviour of high performance concrete (HPC) under the combined effect of sulfuric (H₂SO₄) and acetic (CH₃COOH) acid. They observed that the deterioration of HPC by the acid mixture was the most serious, with the maximum value of the mass loss reaching 6 times the mass loss due to acetic acid and almost twice the mass loss resulting from the sulfuric acid attack. The authors considered silica fume. There was no consideration for the materials used in this study.

Iorshagher and Ocholi (2023) investigated the effect sulphuric acid attack on concrete produced by partially replacing cement with limestone dust (LSD) and locust bean pod ash (LBPA). Based on their findings, a 10% LSD-LBPA (5% LSD + 5% LBPA) mix produces concrete with better H₂SO₄ acid resistance than the control mix. QD and PSA were not adopted.

This research is exceptional since previous authors studied the effect of attacks by strong acids, such as sulfuric (H₂SO₄), hydrochloric acid (HCl), carbonic acid (H₂CO₃), and phosphoric acid (H₃PO₄), on various cement materials, mortar, and concrete without the inclusion of the mineral materials used herein (quarry dust and periwinkle shell ash). Regression analysis was also not carried out in any of the antecedent studies. This gap in literature is worth addressing. Hence the necessity of this study.



Materials and Methods

Materials

The materials used for this study include, Ordinary Portland Cement, sharp-river sand, granite chippings, Quarry Dust (QD), Periwinkle Shell Ash (PSA), Sulphuric Acid (H_2SO_4) and water.

The *Dangote* brand of Portland Cement that is in accordance with the specification of BS 12 (1996) was used. The cement is a CEM II type of cement with strength grade 42.5 R and specific gravity of 3.02. It was procured from the Timber market at Ibeku in Umuahia North LGA, Abia State. The coarse aggregate and fine aggregates employed in the study are locally available. The sand was sourced from Imo River, Imo State of Nigeria. The granite was sourced from the quarry site at Ishiagu, Ebonyi State, Nigeria. The coarse aggregates were of angular-shape. The maximum size of the granite used for this work was 20mm diameter, which conformed to the requirements of BS 882 (1992). Fine aggregates were sieved through 10mm British Standard test sieve to eliminate cobbles to satisfy the requirements of BS 882 (1992).

The periwinkle shells were fetched from dump-sites at Ndioru Market in Ikwuano L.G.A in Abia State. The periwinkle was removed from the shells and the shells were calcined in a kiln at a temperature of 750 °C in 60 minutes in a controlled combustion set-up to avert befouling. The torrefied material was collected and sieved scrupulously with 75µm sieve. The quarry dust used in the research was obtained from a local quarry site at Okposi-Umuaghara Ezza, Ebonyi State. The sulphuric acid used in this study was obtained from Timber Market in Umuahia, Abia State. The water used for the experiment during mixing and curing operation was fit for drinking and it conformed to the stipulations in BS EN 1008: 2002. The water was obtained from the borehole at the concrete laboratory, Civil Engineering Department, Michael Okpara University of Agriculture, Umudike.

Methods

Sample Preparation

The batching was carried out by partially substituting cement with quarry dust (QD) and periwinkle shell ash (PSA) by weight in a proportion of 0% (control), 5% (0% QD + 5% PSA), 10% (5% QD + 5% PSA), 15% (10% QD + 5% PSA), 20% (15% QD + 5% PSA), 25% (20% QD + 5% PSA) and 30% (25% QD + 5% PSA). A total of seven (7) batches were made with



Dangote cement grade 42.5, with an average of three cube samples for each mix level cured at 3, 7, 14, 21 and 28 days, a 1:2:4 mix ratio and a 0.55 water cement ratio, with a target strength of 30 N/mm² at 28 days. The tests carried out on the specimens were compressive strength test and acid resistance test.

Experimental Tests

Compressive Strength Tests

The compressive strength test of the hardened concrete was determined in accordance to BS 1881, part 116 (1983) specifications. A total of one hundred and five (105) cubes were cast using 150 mm x 150 mm x 150 mm steel moulds and cured in water. The cubes were tested for compressive strength after 3, 7, 14, 21 and 28 days curing. The samples were crushed using the compressive testing machine of 2000 kN load capacity at a constant rate of 15 kN/s at the Civil Engineering Concrete Laboratory of Michael Okpara University of Agriculture, Umudike, Umuahia, Abia State. The compressive strengths of the concrete cubes measured in Newton per millimeter square (N/mm²) were obtained using Equation 1

$$\text{Compressive Strength } (Cs) = \frac{\text{Failure Load } (F)}{\text{Area of specimen } (A)} \quad (1)$$

Acid Resistance Test

The acid resistance test was done according to ASTM C 267-2001. A total of twenty-one (21) concrete cubes of size 150 mm x 150 mm x 150 mm were cast and cured in clean water for 28 days. After 28 days of curing in water, the specimens were air-dried for 72 hours and immersed completely in twenty-five (25) litres of water containing sulphuric acid (H₂SO₄) with a molar concentration of 0.937 M. These specimens were then tested after 28 days of curing in acidic solution using the compressive testing machine of 2000 kN load capacity at a constant rate of 15 kN/s at the Civil Engineering Concrete Laboratory of Michael Okpara University of Agriculture, Umudike, Umuahia, Abia State.

The percentage loss in compressive strength was calculated using Equation 2.

$$f_{cl} = \frac{f_{cb} - f_{ca}}{f_{cb}} \times \frac{100}{1} \quad (2)$$

f_{cl} = Loss in compressive strength; f_{cb} = compressive strength before acid immersion

f_{ca} = compressive strength after acid immersion

Results and Discussion

Properties of QD-PSA-Concrete Constituents

Table 1 shows that the chemical composition of the cement used in this study met the BS EN 197-1 (2000) standard. It also captured the oxide compositions in quarry dust and periwinkle shell ash. The combined acidic oxides ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$), met the requirement of ASTM C618-2008 for class C pozzolan with a value of 77.22 % and 80.73 % for QD and PSA respectively. QD and PSA met the requirement of ASTM C618 for loss of ignition (LOI) which stipulates a value of not more than 10%, with recorded value of 2.01 and 4.27 respectively.

Table 1. Oxide Composition of Cement, Quarry Dust (QD) and Periwinkle Shell Ash (PSA)

Oxides	% composition		
	Quarry Dust (%)	Periwinkle Shell Ash (%)	Cement (%)
SiO_2	53.34	48.78	19.13
Al_2O_3	16.43	25.85	7.43
Fe_2O_3	7.45	6.10	5.74
CaO	15.10	10.30	60.14
SO_3	4.57	2.28	3.81
MgO	1.10	2.68	2.23
LOI	2.01	4.01	1.52

Compressive Strength of QD-PSA Concrete

The outcome of the compressive strength of QD-PSA concrete presented in Figure 1, shows that the compressive strength reduced as the QD-PSA content increased but it increased with curing age. The increase due to the curing period is traceable to hydration of cement, while the reduction in strength with increase in QD-PSA content may be due to the dilution effect of

limestone. This trend is similar to the study carried out by Iorshagher and Ocholi (2023). The increasing strength is also traceable to the formation of strengthening gel (C-S-H) and bond (C-A-H) occurring from the reaction of QD-PSA's silica and alumina elements with the hydrating agents of OPC (Nwa-David, 2023c). The optimum strength was attained at 10% QD-PSA mix, with a 28 days' compressive strength of 27.73 N/mm². At 10% QD-PSA content, there was 90.11 %, 72.71 %, 40.25 %, 19.90 %, and 8.19 % variation from the targeted strength of 30 N/mm² and 13.91 %, 13.67 %, 13.30 %, 4.50 %, and 2.3 % variation from that of the control mix at 3, 7, 14, 21, and 28 days' compressive strength. For every rise in curing period, there was a corresponding reduction in percentage variation from both the targeted strength and control mix.

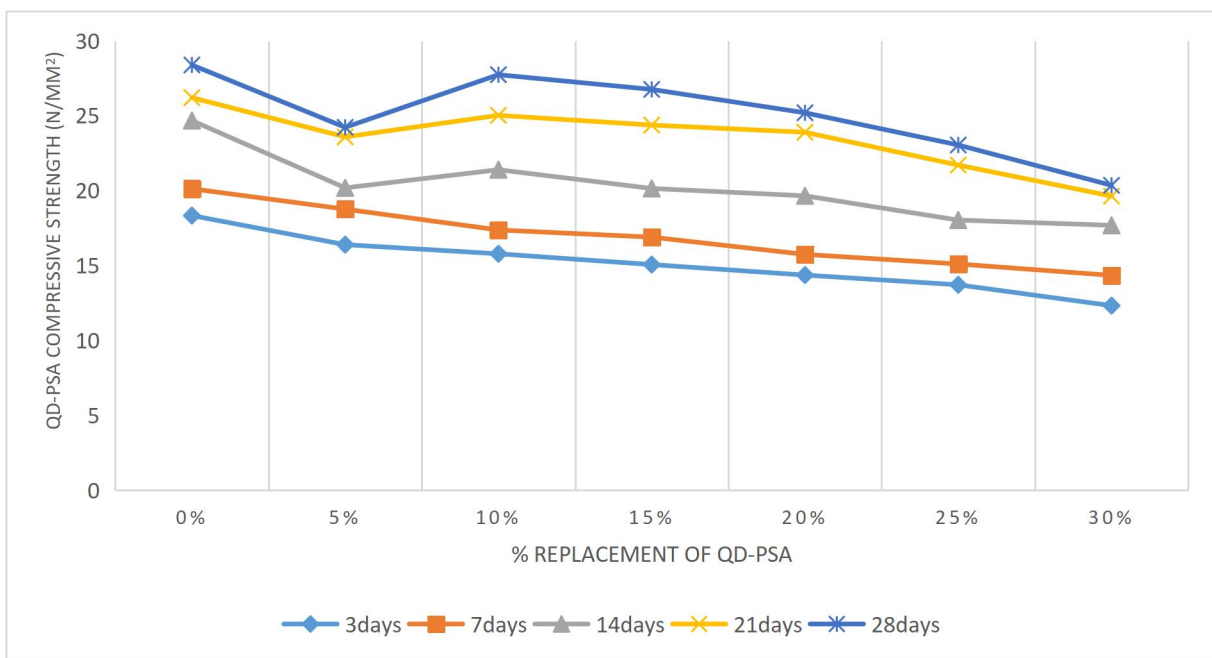


Figure 1: Compressive strength variation with percentage replacement

Effect of Sulphuric Acid on QD-PSA Concrete

The variation in compressive strength before and after immersion in a 5% sulphuric acid (H₂SO₄) solution for 28 days was presented in Figure 2, while Figure 3 describes the strength loss of concrete containing various percentages of QD and PSA after immersion in a 5% sulphuric acid (H₂SO₄) solution for 28 days. The best result with the least amount of strength loss was achieved

with 10% QD-PSA concrete. The control mix with no QD-PSA content lost the most strength. After 28 days of immersion in a 5% H_2SO_4 solution, the control mix's strength dropped from 28.38 N/mm² before immersion to 21.52 N/mm² after immersion in 5% sulphuric acid solution, a 32% reduction. At 10% QD-PSA, the compressive strength before immersion was 27.73 N/mm² which dropped to 26.54 N/mm² after immersion in 5% sulphuric acid solution, a minimum strength loss of 4% was obtained. Compared to the control sample, the samples with QD-PSA content showed little strength reduction as shown in Figure 3 because of the formation of a silicate gel by PSA during the hydration process, which coats and binds the matrix while also blocking acid action in the concrete structure, preventing acid damage. The excellent performance of the concrete resistance to acid attack is also influenced by the provision of more nucleation sites by quarry dust, which results in an acceleration of cement hydration rate. As the rate of hydration increases, the amount of hydrated products rises. This outcome is consistent with the work of Aliyu *et al.* (2020).

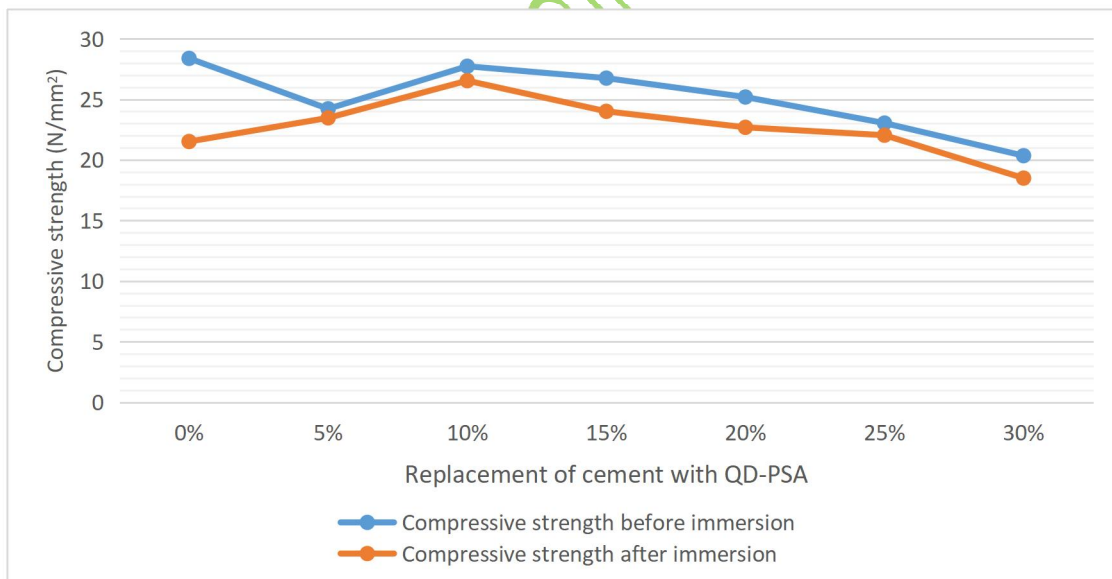


Figure 2: Variation of compressive strength before and after sulphuric acid immersion

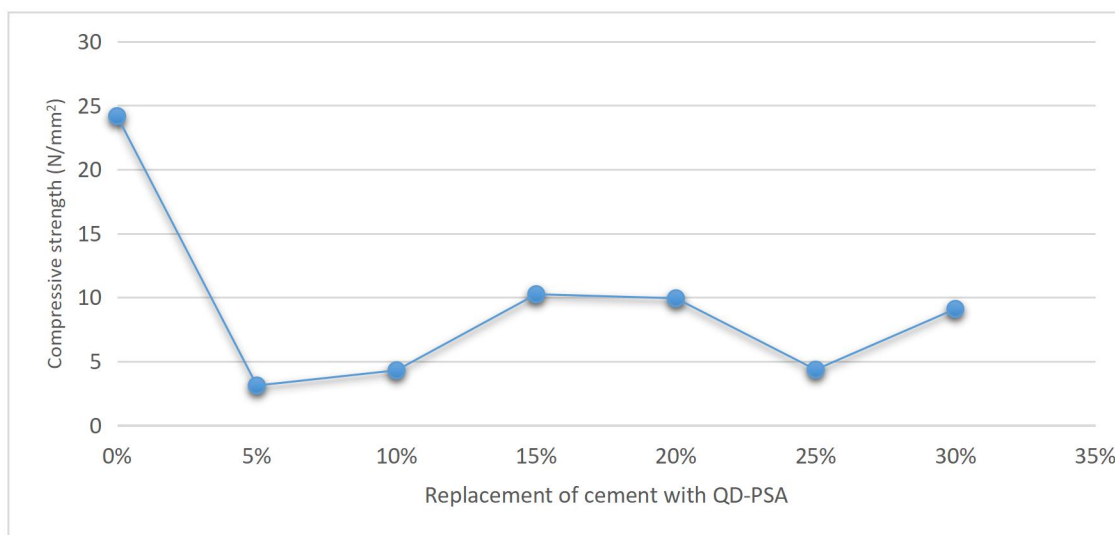


Figure 3: Variation of strength loss with addition of QD-PSA content

Statistical Analysis

The data analysis tool in Microsoft Excel was used to explore and study the interrelationship between the replacement percentage of cement with QD-PSA and the strength loss at 28 days' compressive strength before and after sulphuric acid immersion. The summary of the regression analysis was captured in Table 2. The correlation coefficient for strength loss values obtained from the sulphuric immersion was 0.40 as shown in Table 2, which indicates a moderate positive correlation. The R-squared values shows 15.9% of variance in strength loss values attributable to percentage replacement of cement with QD-PSA. The analysis showed that it has a favorable probability value of 0.38. The p-value of the strength loss in QD-PSA concrete being extremely small corresponds to a very large T-test and implies that its outcome is highly statistically significant such that the odds that the result was a product of chance is exceedingly low.

Table 2. Summary Output for Regression Analysis of the strength loss in QD-PSA concrete

<i>Regression Statistics</i>	
Multiple R	0.398168
R Square	0.158537
Adjusted R Square	-0.00976



Standard	
Error	7.229569
Observations	7

ANOVA

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	49.23703	49.23703	0.942035	0.376332
Residual	5	261.3333	52.26666		
Total	6	310.5703			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	13.28536	4.926121	2.696921	0.042942	0.622361	25.94835	0.622361	25.94835
Strength Loss	-26.5214	27.3252	-0.97058	0.376332	-96.7631	43.72024	-96.7631	43.72024

Conclusion

This study evaluated the effect of sulphuric acid (H_2SO_4) attack on concrete containing quarry dust and periwinkle shell ash as partial replacement of cement. The following conclusion can be drawn from this study;

- The compressive strength of QD-PSA concrete was negatively affected by the acidic curing environment.
- The incorporation of QD-PSA of not more than 10% was able to improve the resistance of concrete towards acid attack and it is therefore recommended for concrete production in acidic environments.
- The regression analysis proved that the outcome of the study is statistically significant. Hence, production of QD-PSA concrete is reliable for construction in environment prone to acid attack.
- The adoption of this quarry dust and periwinkle shells for concrete construction works will in turn reduce their impact as environmental pollutants thereby facilitating a sustainable environment.



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GREEN AND RESILIENT INFRASTRUCTURE FOR SUSTAINABLE NATIONAL DEVELOPMENT

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Abstract

This paper examines the intersection of green and resilient infrastructure as a transformative approach to sustainable national development. It explores strategies for mitigating climate risk, fostering economic growth, and ensuring environmental preservation. Drawing on global examples, especially Singapore's sustainable development framework, this study underscores the imperative for countries to integrate resilience and environmental stewardship into their infrastructure planning.

Introduction

Rapid urban development has caused so many significant alterations in the arrangement of the natural and artificial ecosystems including structure, pattern, and functions of the elements of the environment (Zahoor, *et al.*, 2023), leading to critical difficulties such as environmental degradation and health complications (Buijs *et al.*, 2016). There are numerous challenges facing urban ecology including; energy supply, drainage, waste pollution, air pollution, deforestation, carbon dioxide mitigation of natural disasters, transportation, construction, biodiversity, natural habitat, land use change and others (Zahoor, *et al.*, 2023).

Green infrastructure refers to a network of natural and environmental features that provides environmental, social and economic benefits available (Honeck *et al.*, 2020). It incorporates natural processes into urban and rural settings, including green roofs, urban parks, wetlands, forests and sustainable drainage systems. It aims to enhance biodiversity, improve air and water quality and provide spaces for recreation while mitigating climate change impacts.

Resilient infrastructure refers to systems designed to withstand, adapt to and recover from adverse events such as natural disasters, climate change or other disruptions. Biodiversity is the basis for establishing various resilient ecosystems that provide essential ecological services for



the protection of the natural environment and humans such as food, timber, rising global temperatures, urban climate change, natural disaster, and carbon mitigation as natural disasters, climate change or other disruptions (Zahoor *et al.*, 2023).

Importance of Green Infrastructure:

- Economic and social benefits: Green infrastructure invites investors and boots eco-tourism
- Job creation in sectors like sustainable design and urban planning.
- Social impact: Improved quality of life with better air quality and recreational spaces.

Why Green Infrastructure: SINGAPORE

Albert Einstein, one of the founders of modern physics, said, *"We can not solve our problems with the same level of thinking that created them."*

Singapore as a nation chose to embark on building a system of strategic thinking aimed at self-motivation and self-discipline that moved them from 3rd world status to one of the world's most developed nations today. Singapore's approach to green and resilient infrastructure (GRI) has positioned it as a global leader in urban sustainability, serving as a model for other nations.

Singapore actively involves citizens and businesses in sustainability efforts through public awareness campaigns, community gardening programs, and corporate sustainability initiatives.

Singapore implemented a carbon tax to encourage businesses to adopt low-carbon technologies. Also, a national blueprint outlining targets across energy, waste, water, transport, and green economy sectors.

Singapore invested heavily in research on sustainable urban solutions through institutions like the Singapore –ETH Centre.

Challenges

The challenges involved in green and resilient infrastructures include



1. High initial costs of implementing green technologies and resilient designs.
2. Institutional and policy including inadequate regulatory framework.
3. Resistance to change due to lack of awareness or short-term economic priorities.

However, wherever there is a will, there must be a way to get important projects executed.

Conclusion

Building sustainable and resilient infrastructure isn't just an option it is imperative for national development. Nations should embrace the policy of the European Union's chemical strategy for sustainability towards a toxic-free environment.

Recommendation

1. Policy reforms are encouraged. The government should establish clear guidelines and incentives for developing green and resilient infrastructure.
2. Private-public partnerships can mobilize and foster innovation.
3. Capacity building: Training programs for scientists, engineers, architects, and policymakers to adopt sustainable practices.
4. Community engagement: To ensure mangrove preservation and wetland as a buffer against coastal erosion and haven biodiversity.

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TECHNO ECONOMIC AND COST BENEFIT ANALYSIS OF PERIWINKLE SHELL REINFORCED CONCRETE GRINDSTONE

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Abstract

A techno-economic and cost-benefit analysis of periwinkle shell-reinforced concrete grindstone was conducted to evaluate its economic viability and sustainability compared to conventional concrete. The study employed multi-criteria decision measures, including net present value, benefit-cost ratio, payback period, and accounting rate of return, using prevailing economic indicators and market prices of materials in Nigeria. The analysis revealed that while periwinkle concrete grindstone demonstrates environmental advantages due to its use of renewable materials, its economic feasibility is affected by higher production costs, primarily driven by the high cement content and high cost of processing periwinkle shell to powder. Results showed that the payback period for periwinkle concrete grindstone is within 10 years, and its benefit-cost ratio is above the threshold of 1.0, indicating economic viability under current conditions. Conventional concrete grindstone exhibited a payback period of fewer than 2 years and a benefit-cost ratio above 1.5, making it also viable option for practical applications. To enhance the economic appeal of periwinkle concrete grindstone, material composition optimization and the use of alternative binders are recommended. This study underscores the significance of integrating environmental sustainability into construction materials while addressing economic challenges. It also provides a framework for evaluating innovative materials' economic and environmental trade-offs, contributing to the ongoing discourse on sustainable construction practices.

Introduction

The availability of raw materials is a key determinant of the feasibility of any construction innovation. The periwinkle shells are considered a waste material, predominantly found in coastal regions where periwinkle consumption is high (Umar *et al.*, 2019). This offers a significant advantage for regions that have access to these shells, as they represent a low-cost, locally sourced material that can reduce reliance on natural aggregates such as sand and gravel.

The techno-economic feasibility of periwinkle shells largely depends on the proximity of construction sites to areas where periwinkle shells are readily available. In coastal regions, the availability of periwinkle shells can significantly lower the cost of sourcing materials compared to inland regions where the costs of importing conventional aggregates or periwinkle shells might increase (Afolabi *et al.*, 2020). This localization can contribute to a reduction in the



environmental impact associated with transporting materials over long distances, aligning with the goals of sustainable development in construction.

Periwinkle shells being a byproduct of the seafood industry, these shells are generally disposed as waste, contributing to environmental pollution. Re-purposing them into grind stone production reduces this waste, providing an environmentally friendly alternative. Additionally, as the shells are essentially free or low-cost byproducts, their integration into construction materials can help reduce the overall production costs, offering significant economic benefits.

Processing periwinkle shells for use in concrete involves cleaning, crushing, and sieving to achieve the desired particle size and quality. While these processes are relatively straightforward, they do involve additional steps compared to the use of natural aggregate (Oyinloye *et al.*, 2019). The cost of these processing steps must be factored into the overall economic evaluation of periwinkle shells reinforced concrete (PSRC).

Efficient processing methods can help mitigate the costs associated with shell preparation. For instance, the use of automated or semi-automated crushing and sieving systems can reduce labor costs and improve consistency in particle size distribution. However, energy consumption and labor costs are critical elements that can influence the overall cost-effectiveness of PSRC.

In regions where labor is inexpensive and processing equipment is affordable, the additional steps required to prepare periwinkle shells may have a negligible impact on the cost of production. However, in regions with higher labor and equipment costs, the economic benefits of using PSRC may be diminished unless more efficient processing techniques are developed. Therefore, optimizing the processing of periwinkle shells remains a key area of focus to ensure the cost-effectiveness of PSRC.

The mechanical properties of PSRC play a significant role in determining its viability as a replacement for conventional concrete. Studies have shown that PSRC, when optimized, can offer mechanical properties comparable to those of traditional concrete, especially in terms of compressive strength (Akinyemi *et al.*, 2020). Partial replacement of fine aggregates with periwinkle shells (around 20%) has shown to have increased compressive strength by approximately 15% (Rafiq *et al.*, 2020). This improvement is attributed to the rough and angular



texture of the shells, which enhances bonding between the cement matrix and the aggregate particles.

From a cost-benefit perspective, this increase in compressive strength seems highly favorable. The enhanced strength of PSRC suggests that less material may be required for certain applications, leading to a reduction in material costs without sacrificing performance. Additionally, the durability of PSRC in aggressive chemical environments, such as sulfate-rich soils, indicates that the material can be used in environments where conventional concrete may require more frequent maintenance or replacement.

The high cost of conventional materials used in concrete production, such as sand, gravel, and cement, has driven the search for alternative, cost-effective, and sustainable materials. In many regions, there is a growing interest in utilizing locally available waste materials in construction to reduce environmental impact and production costs. One of such material is periwinkle shells, an abundant by-product from the seafood industry, which is often discarded as waste, leading to environmental concerns.

The construction industry is constantly seeking innovative and sustainable solutions to reduce costs, environmental impact, and reliance on conventional materials. By utilizing periwinkle shells as reinforcement in concrete grindstones, there is an opportunity to not only reduce costs but also promote the use of waste materials in construction applications. However, the feasibility and economic viability of this approach need to be thoroughly evaluated through a techno-economic and cost-benefit analysis. Therefore this research is centered on the techno-economic analysis of periwinkle shell reinforced concrete grindstone.

Materials

The following equipment's were used for the mixing of the aggregate: Mixing basin, hand Trowel, Shovel, Tape, Rubber gloves, Groove cutters, Manual hand compactor and Weighing scale.

Aggregates (fine gravel) Cement, Water, periwinkle shell and Sharp sand.

Methods

Preparation of the mixture:

Preparing the grinding wheel mixture begins with selecting precise quantities of abrasives, bond materials, and additives according to a specific formula.



The cement used in this work is a type of Portland cement called, **ordinary Portland cement (opc)** which is grey in colour. The cement type was selected because it is the most common type of Portland cement in general use around the world. Ordinary Portland cement was gotten from Dangote cement factory in Gboko, Benue State of Nigeria and was used as binding agent together with River Benue sharp sand. The periwinkle shells used in this work was obtained from Watt Market, Calabar Cross River State.

The periwinkle shells are the remains after the shells were cooked and the edible part removed. Impurities such as soil and other dirt were removed from the (PWS) by thorough washing. Hand-picking of further impurities was done before the project was carried out.

The periwinkle shell was then sun-dried thoroughly for about 2 months before it was taken for grinding. The periwinkle shell was grounded in the workshop in MOUAV with the help of periwinkle grinding machine to its fine aggregate.

Data was sourced from the production record of the Periwinkle shell reinforced concrete grindstone by (Ikechukwu *et al.*, 2020) which includes: Preparation of the mixture, Mixture of the grindstone, Construction of mold, Casting of the mixture and curing. Preparing the grinding wheel mixture begins with selecting precise quantities of abrasives, bond materials, and additives according to a specific formula. The composition is show in table 1

**Table 1: Composition of mixture**

Specimen	Water %	Sand %	Cement %	Fine aggregate %	Periwinkle shell %
A	8.34	7.63	36.69	32.45	14.89
B	7.63	9.13	33.07	32.45	17.43
C	7.00	7.00	45.00	31.00	10.00
D	7.00	8.50	39.50	35.00	10.00
E	8.50	10.0	30.00	35.00	16.51
F	7.00	8.50	34.50	30.00	10.00
G	7.00	10.0	43.00	30.00	10.00
H	8.00	7.00	30.00	35.00	20.00

The thickness and length of the mold cavity used is 35mm by 52mm while the outer is 37mm by 54mm. The mold was made air tight and sealed properly because of its slurry form it could pour out. Separate molds were constructed for specimen A to H.

After the mold was constructed the next step carried out was casting the mixture. Before the mixture was cast a releasing agent called In and Out releasing Agent was applied in the mold cavity. Before usage it was diluted with water. Mixing is done by hand; it is not shacked or agitated, as it could be foamy. How you dilute in and out is dependent on the concrete aggregate mixture and the form material that is been casted into. The entire mold cavity was cleaned to make it free from dust and well coated with the releasing agent. After applying the releasing agent on the mold, the mixture was poured from the mixing basin into the mold and then vibrated (shacked) as necessary to remove air bubbles. Failure in removing air bubbles leads to surface voids or bug holes. The grindstone was kept moist during curing in order to achieve optimal strength and durability. Curing was done at normal temperature. Depending on the level of curing, the cubes were removed at the end of 28 days from the day of casting and dried at room temperature for 2 hours before testing. Care was taken to avoid freezing or overheating due to the exothermic setting of cement. Improper curing could cause reduced strength, scaling, poor abrasion resistance and cracking. After curing the next step was finishing. Finishing involves smoothing and polishing the sample with brush to give it a smooth appearance.



Assessment of the Properties of Reinforced Grindstone

The following properties were evaluated: Compressive strength, Tensile strength, and hardness and Water absorption. Compressive strength or compression strength is the capacity of a material or structure to withstand loads tending to reduce size as opposed tensile strength which withstands loads tending to elongate (Ikechukwu, I. F *et al* 2020). This is the resistance of a material breaking under compression. Some materials fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures according to Beredugo (1990) as shown in equation (1).

$$\text{Comprehensive strength} = f/a \quad (1)$$

Where F =maximum load applied to the material at the point of failure; A =cross-sectional area of the material being tested. The compressive strength test was carried out in the mechanical laboratory at Proda, Enugu. The test was carried out with an automated compressive tester. The specimen was first placed on the plate. The specimen was aligned centrally on the base plate of the machine. From the top the handle was rotated in the clockwise direction so that it touches the top surface of the specimen. When the top and lower plate firmly holds the specimen load was applied gradually without shock till the specimen failed. The procedure was repeated for all samples. Readings were recorded from specimen A-H. Ultimate tensile strength (UTS), often shortened to tensile strength (TS), ultimate strength is the stress at which a force applied causes the material to lengthen then break. Ultimate tensile strength is measured by the maximum stress that a material can withstand while being stretched or pulled before breaking. For an axially load material the breaking strength in tension is given in equation (2) (Azam *et al.*, 2009)

$$S = p/a \quad (2)$$

Where: S = breaking strength; P = force that can cause it to break; A= cross-sectional area. The hardness test carried out in this project is Rockwell hardness test. The test was done with an automated hardness tester. The specimen was first placed on the anvil the test axis was within 2-degrees of perpendicular to ensure precise loading; there was no deflection of the test sample during the loading application from conditions such as dirt under the test specimen or on the elevating screw. The wheel was rotated in clockwise direction moving the load towards the



indenter. At the point where the indenter holds the specimen firmly, the start button is pressed. Readings are taken from the dial face and then recorded. This procedure was repeated for specimen A to specimen H. The hardness number was determined from equation (3) and (4) (Salau 1990).

$$HBW = Test \frac{force}{Surface} area of indentation \quad (3)$$

$$HBW = 00.102 * 2P/\pi D (D - \sqrt{D^2 - d^2}). \quad (4)$$

Where, p, d, D represent the load, diameter of indentation and diameter of indenter respectively

Durability Test: This was determined according to ASTM procedure (ASTM D96-06). Rectangular specimens were cut from each sample and weighed to the nearest 0.001g. The samples were immersed in water for 24 hours at room temperature. Excess water on sample surface was removed before reweighing. The percentage increase in mass during immersion was calculated to the nearest 0.01% using the following equation (Idris *et al.*, 2012):

ARWR (%) = $\frac{\text{Weight after 24 hrs} - \text{initial weight}}{\text{Initial weight}} \times 100$

Initial weight X 100

$$K = Q/A (Thickness of material/\Delta T). \quad (5)$$

Where K = thermal conductivity

$$Q = KA * dt/ds. \quad (6)$$

Mechanical Properties

Wear rate test and heat conduction test values were determined and the results shows that sample C has the minimum wear rate, of 0.012mm/min, 0.022mm/min and 0.036mm/min for contact force/pressure of 5KN, 10KN and 15KN respectively at 2500rev/min. Result of the hardness test showed that sample C with composition 7.00% water, 7.00% sand, 45.00% cement, 31.00% fine aggregate and 10.00% periwinkle shell had the lowest hardness test when compared to the control sample made. The control sample had the highest hardness number. In hardness test the lower the number the higher the hardness, increase in the value shows less hardness while decrease in the hardness number shows high hardness.

Result of the compressive strength showed that sample C with composition 7.00% water, 7.00% sand, 45.00% cement, 31.00% fine aggregate and 10.00% periwinkle shell had the highest

compressive strength when compared with the control sample made. Increase in the value shows increase in compressive strength. The tensile strength result showed that sample C with composition 7.00% water, 7.00% sand, 45.00% cement, 31.00% fine aggregate and 10.00% periwinkle shell had the highest tensile strength when compared to the control sample made. Increase in the value shows increase in compressive strength. All the values obtained from the samples were higher than the unmodified sample (control). It can be observed that water absorption increased with increase in all samples after immersing them in water, with the least values. Results showed that there is percentage increase in water absorption in sample C. As a result, water molecules could more easily penetrate.

Economic and Cost Benefit Analysis

The payback period (P_b), accounting rate of return (ARR), net present value (NPV) and benefit cost ratio (BCR) of the PSRC were computed from its financial data collected and optimal performance parameters determined in this study as given in tables 2 to 6 using the following relations in equation (7) to (12) given by Onwualu *et al.* (2002); Gerald and Marta (2015);

$$P_b = \frac{C_i}{B_n} \quad (7)$$

$$ARR = \frac{B_n}{C_i} \quad (8)$$

$$NPV = \sum_{t=1}^n \frac{B_{nt}}{(1+r_i)^t} - C_i \quad (9)$$

$$BCR = \frac{PVB}{PVC} \quad (10)$$

$$PVC = \sum_0^t \frac{C_i}{(1+r_i)^t} \quad (11)$$

$$PVB = \sum_0^t \frac{B_n}{(1+r_i)^t} \quad (12)$$

Where; C_i , B_n and B_{nt} constitute the initial investment cost, average annual net benefit (cash inflow) and net cash inflow at time, t respectively while PVC and PVB , are the respective present values of costs and benefits of the PSRC



Table 2 Material Cost For 10kg Concrete Mixture

Material	Periwinkle Concrete (PC)	Cost (₱)	Conventional Concrete (CC)	Cost (₱)
Cement (kg)	4.5	675.00	2.0	3000.00
Sand (kg)	0.7	0.88	3.013	3.76
Fine Aggregate	3.1	2.91	4.0	3.75
Periwinkle (kg)	1.0	0.50		
Water	Negligible	0.00	Negligible	0.00
Total Cost (₱)	-	679.29	-	3307.51

Table 3: Profit/Loss Analysis For 10kg Concrete

Concrete Type	Selling Price (₱)	Cost Price (₱)	Net Benefit (₱)
Periwinkle Concrete	4000	679.29	3,320.71 (profit)
Conventional Concrete	4000	3307.51	92.49 (Profit)

Table 4: Annual Profit/Loss Analysis (12,000kg/year)

Concrete Type	Net Benefits Per 10kg (₱)	Annual Net Benefit (₱)
Periwinkle Concrete	3,320.71	39,848.52 (Profit)
Conventional Concrete	92.49	11,098 (Profit)

Table 5: Investment Evaluation for PSRC

Metric	Value
Net Present Value (NPV)	₱ 4,108,255.22
Benefit Cost Ratio	2.52
Pay Back Period	0.48 years (~6 months)
Accounting Rate Of Return (ARR)	267.98%



Result and Discussion

Tables presented below represents the initial cost breakdown for 10 kg of periwinkle and conventional concrete.

Table 6: The total material costs calculated based on their specific compositions and current market prices Abia State Nigeria.

Concrete Type	Cement Cost (₦)	Sand Cost (₦)	Fine Aggregate Cost (₦)	Periwinkle Shell Cost (₦)	Total Cost (₦)
Periwinkle Concrete	675.00	0.88	2.91	0.50	679.29
Conventional Concrete	4000.00	3.76	3.75	-	4007.51

Table 7 : Salvage value of 10% of the initial production cost after 10 years:

Concrete Type	Initial Cost (₦)	Salvage Value (₦)
Periwinkle Concrete	679.29	67.93
Conventional Concrete	4007.51	30.75

The net cash flow was calculated by subtracting the annual costs (production and labor) from the annual revenue production of 12,000 kg/year and a selling price of ₦400/10 kg as shown in table 8. Table 9 evaluates the annual production costs and net benefits over the 10-year project period. The benefit-cost ratio (BCR) was calculated as the ratio of the present value of benefits to the present value of costs (using a 10% discount rate).as shown in table 10

. Table 8: Net Cash Flow Analysis

Concrete Type	Annual Revenue (₦)	Annual Cost (₦)	Net Cash Flow (₦)
Periwinkle Concrete	480,000	398,480.	81,480
Conventional Concrete	480,000	441,012	38,988

**Table 9: Annual Cost/Revenue Analysis**

Concrete Type	Annual Cost (₦)	Annual Revenue (₦)	Net Annual Benefit (₦)
Periwinkle Concrete	3,28,4800.	480,000	81,480
Conventional Concrete	441,012	480,000	38,988

Table 10: Evaluation of Benefit-Cost Ratio of PSRC And CC

Concrete Type	PVB (₦)	PVC (₦)	BCR
Periwinkle Concrete	480,0000.96	3,28,4800.	1.56
Conventional Concrete	6,817,593.96	2,709,338.74	2.52

Discussion

The analysis revealed that periwinkle concrete grindstone is economically viable. The high cost of cement (45% of the mix) significantly increases production costs, making the net benefit negative over the 10-year period. The BCR of 2.52 indicates that benefits outweigh costs. Additionally, the annual net cash flow is consistently negative, with no possibility of recovering the initial investment.

Conversely, conventional concrete grindstone proved to be economically viable. The lower cement content (20% of the mix) and absence of additional materials like periwinkle shells reduce production costs. The BCR of 2.52 indicates that the project yields benefits more than twice its costs. The short payback period (0.48 years) and a high accounting rate of return (ARR) of 207.98% further highlight its profitability.

While periwinkle concrete demonstrates potential in promoting sustainability through the use of renewable materials, its cost-effectiveness must be improved to compete with conventional concrete. Strategies such as optimizing material proportions and reducing reliance on cement could enhance its financial feasibility.



The findings underscore the importance of material selection in concrete production. Conventional concrete, with its established market and cost structure, remains a reliable option for cost-effective production. On the other hand, innovations like periwinkle concrete hold promise for sustainable construction but require significant cost optimization to achieve widespread adoption.

Conclusion

The unit cost of developing periwinkle shell-reinforced concrete and conventional concrete grindstones was calculated as ₦675.00. Salvage value of 10% of the initial production cost after 10 years was calculated as ₦67.93 as shown in table 7, Net Cash Flow of ₦81,480. The annual production costs and net benefits over the 10-year project period is shown in table 8. The analysis further revealed that while periwinkle concrete grindstone demonstrates environmental advantages due to its use of renewable materials, its economic feasibility is affected by higher production costs, primarily driven by the high cement content and high cost of processing periwinkle shell to powder. The payback period for periwinkle concrete grindstone did not exceed 10 years, and its benefit-cost ratio is above the threshold of 1.0, indicating economic viability under current conditions. Conventional concrete grindstone exhibited a payback period of fewer than 2 years and a BCR above 1.5, making it also a viable option for practical applications. To further enhance the economic appeal of periwinkle concrete grindstone, its material composition optimization and the use of alternative binders are recommended. This study underscores the significance of integrating environmental sustainability into construction.

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SUB-THEME 9: Community, Food, Environmental and Cyber security systems and strategies for National Development



SYNTHESIS AND BIOLOGICAL ACTIVITY OF HYDRAZONES AND THEIR METAL COMPLEXES: A REVIEW

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Abstract

Hydrazones and their derivatives along with their metal complexes are very important compounds in medicinal chemistry due to their reported biological and pharmacological activities for the treatment of several diseases, like alzheimer's, cancer, inflammation, and leishmaniasis. However, most of the investigations on hydrazones and their metal complexes available in literature today are directed to the synthesis of these molecules. With the purpose of bringing lights into this issue, we performed a revision of the literature and wrote this review based on some of the most current research reports of hydrazones and derivatives, making it clear that the synthesis of these molecules can lead to new drug prototypes. Our goal is to encourage more studies focused on the synthesis and evaluation of new hydrazones, as a contribution to the development of potential new drugs for the treatment of various diseases.

Keywords: Hydrazones, complexes, antimicrobial, chelation, inhibition

Introduction

Hydrazones are the derivatives of hydrazine ($R-NH-N=CRR$) and/or class of azomethine ($-C=N-N-$) and an essential group of drugs; synthesized through reduction reaction of hydrazine with carbonyl compounds (Uppal *et al.*, 2011; Hany *et al.*, 2015, Asuquo *et al.*, 2023, Otuokere *et al.*, 2024). Hydrazones are more reactive than carbonyl groups (aldehyde or ketone) due to the presence of alpha active hydrogen atoms. They are used as precursor in organic reactions (Florian *et al.* 2006; Asuquo *et al.*, 2023; Otuokere *et al.*, 2024), particularly in the preparation of Schiff base ligand (Zeyrek *et al.* 2006; Asuquo *et al.*, 2014, Otuokere *et al.*, 2024) which formed coordination through the $C=N$ bond with transition metals *in vivo*, with promising biological properties (Savini *et al.* 2004), and also used as ligands in coordination chemistry, organo-catalysis and synthesis of organic compounds.

The coordinating behavior of polydentate ligands, especially those with different donor atoms is of increased interest. The coordination cavity generated by oxygen, nitrogen and sulfur atoms gives a better fit in terms of size and flexibility for different transition metal ions. Their complexes with different metals showed anti-tuberculosis (Katyal and Dutt, 1975; Asuquo *et al.*,



2014) herbicidal, insecticidal, and nematocidal activities (Amrata *et al.*, 2014; Li-Fei *et al.*, 2012). It is also reported that hydrazones Schiff base and their metal complexes with various transition metals possess anti-analgesic, anti-inflammation, antibacterial, antifungal and anticancer activities (Hassan *et al.*, 2007; Jin *et al.* 2006; Otuokere *et al.*, 2019). Hydrazones are effective in inhibiting corrosion because their construction contains two nitrogen atoms and an imine bond which act as active adsorption centres (Turuvekere *et al.*, 2016). Hydrazones have proved to be useful intermediates in the conversion of ketones into thioketones, and have found particular application to the preparation of highly sterically hindered thioketones.

Hydrazones can be hydrogenated with a palladium or platinum catalyst. The addition of a Grignard reagent to one double bond of an azine followed by reduction of the resulting hydrazone with $\text{PtO}_2 / \text{H}_2$ gave hydrazines in 30–50 % yields, although the products had to be purified via their picrates. They act as reactants in various important reactions such as hydrazone iodination, Shapiro reaction and Bamford Stevans reaction to form vinyl compounds. They act as intermediate in Wolff-Kishner reaction (Rajarajan *et al.*, 2016).

Stereochemistry of the hydrazone is much decided by the steric effects of the various substituents in the hydrazone moiety and also favored by additional interactions such as intramolecular hydrogen bonding. It is observed that the *syn* (where two bulkier groups are on the same side) nature of the bond usually transforms to *anti* (the bulkier groups are on opposite side) geometry, while coordinating to metal ions. This phenomenon is assumed to be due to chelate effect, which results in an increased stability due to better electron delocalization in chelated ring system consisting of metal ions (Hany *et al.*, 2015; Asuquo *et al.*, 2014; Otuokere *et al.*, 2024).

Diversity in the chelating behavior of hydrazones

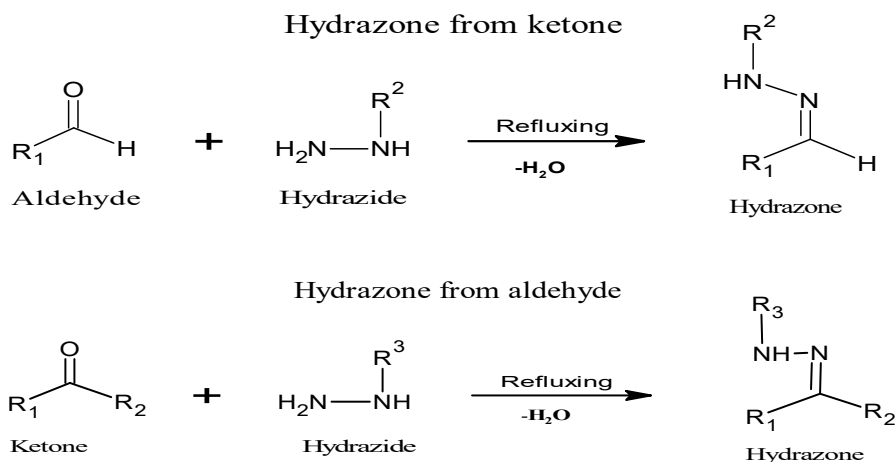
The chelating behavior depends on their amido-iminol tautomerism and in addition to this, the number and type of the substituents attached to the hydrazone framework also influences the coordination mode. The expected donor sites in simple hydrazones are the amide oxygen and azomethine nitrogen. In addition to this, if the carbonyl part contains a ring with a hetero atom, hetero atom can coordinate to metal centre thus behaving as a tridentate ligand. Due to



tautomerism in hydrazones the amide oxygen can be in neutral *keto* form or enolic form. The actual ionization state is dependent upon the condition (pH of the medium) and the metal salts employed. In basic solution amide oxygen get deprotonated and coordinates to the metal center in the enolic form whereas strongly acidic condition favor compounds formulated with a neutral ligand (Katyal and Dutt 1975; Rollas and Kucukguzel, 2007; Asuquo *et al.*, 2014; Otuokere *et al.*, 2024).

Synthesis and reactivity of hydrazones

Hydrazones possesses some particular properties which make them a potential candidate for designing new moieties. They contain a C=N bond in conjugated form with a functional nitrogen electron pair on the terminal nitrogen atom (N), these structural fragments are responsible for the physical and chemical properties of hydrazones. They are distinguished from other members of this class (imines, oximes) by the presence of two interlinked nitrogen atoms of different nature. These nitrogen atoms are nucleophilic but the amino nitrogen is more active, while the carbon atom of hydrazine has both an electrophilic and nucleophilic characteristics and further combination with numerous functional groups leads to the formation of products with unique biological properties (Kamal, *et al.*, 2015; Sayed *et al.*, 2018; Asuquo *et al.*, 2014, Otuokere *et al.*, 2024). For example, a ketone can be reduced down completely if made into a hydrazine and then treated with sodium ethoxide (Wolff-Kishner reduction). Hydrazones are very important intermediates in many reactions, such as the Fischer indole synthesis. This makes indoles, groups which are found in many drugs (Bingul *et al.*, 2016). Hydrazone formation is extensively used in the detection, determination and isolation of compounds containing carbonyl group (Can *et al.*, 2017). Photometric methods for determining aldehydes and ketones are based on their reaction with 2,4-dinitrophenylhydrazine to form corresponding hydrazones. The formation of aromatic hydrazone derivatives is used to measure the concentration of low molecular weight aldehydes and ketones, e.g. in gas streams. Hydrazones can also be synthesized by the Japp-Klingemann reaction (from β -ketoacids or β -ketoester's and aryldiazonium salts).



The N-N bond can be reduced to the –NH– group or the whole hydrazone molecule can be reduced to a hydrazide by reductive acylation. The C=N bond is susceptible to a nucleophilic attack. It can be hydrolyzed, oxidized or reduced—it willingly restores the C=O carbonyl group. It can undergo the nucleophilic addition of an organometallic compound (containing Li, Mg, Ce and Yb atoms), as well as of the intramolecular group –SH. Under appropriate conditions, hydrazones can react with α , β -unsaturated aldehydes, giving interesting dihydrazide connections with a lactam ring (Rollas and Kucukguzel, 2007; Asuquo *et al.*, 2014; Otuokere *et al.*, 2024).

Overview of transition metal ions

Transition metal ions have a great contribution in bio-inorganic chemistry and redox enzyme systems as they can be considered as the base of models for active sites of biological systems. Copper is one of the most abundant metallic elements in the human body. It plays a significant role in the action of a huge number of enzymes that catalyze a great variety of reactions. The bio-inorganic chemistry of nickel and cobalt has been rapidly expanded because of the increasing number of metal complexes of biological interest reported in the literature. Nickel (II) and cobalt (II) complexes showed antibacterial, antifungal and anticancer activities. Zinc is necessary to all forms of life and a large number of diseases and congenital disorders have been ascribed to zinc deficiency. Also, it is very important for cell growth, development and differentiation. Cadmium



is a very toxic element whose harmful actions affect the majority of human tissues and is often present in the environment. Ligands which can form stable complexes with cadmium could be used as detoxifying agents. Cadmium complexes have attracted great attentions because of their bioactivities including antibacterial, antitumor activities and DNA binding ability. There is a considerable interest in the coordination chemistry of actinides, especially dioxouranium (VI) complexes (Asuquo *et al.*, 2014; Mandewale *et al.*, 2015; Onyenze *et al.*, 2024)

Applications of hydrazones

1. Hydrazones in Non-Linear Optics

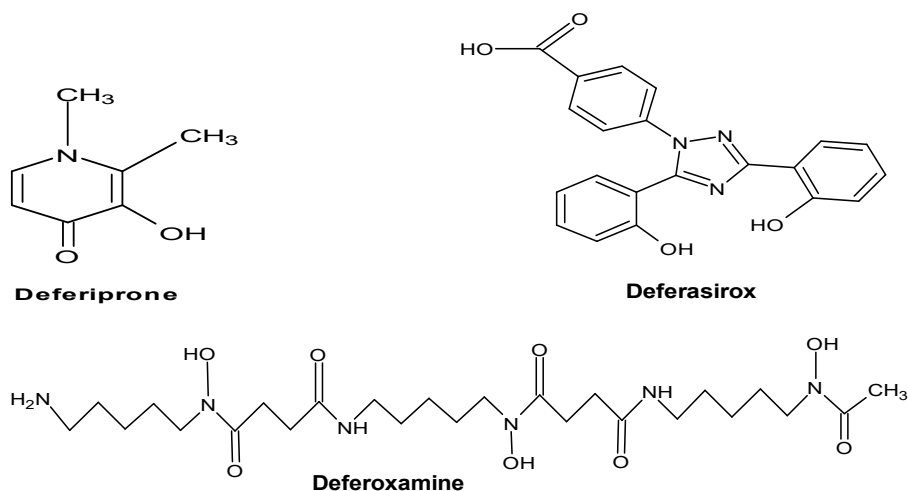
Non-linear optical materials are those materials or organic compounds that describe the behavior of light in non-linear medium. Such materials play a major role in modern technology in telecommunication, optical switching, data processing, ultra-short pulsed lasers, laser amplifiers, sensors, and many more. Metal coordination has been used in several ways to improve the behaviour of all organic push-pull chromophores for applications in second-order non-linear optics (NLO). The most common approach is the use of organometallic or metal coordinated fragments attached at the end of organic conjugated systems. To make the compound of potential interest in second-order non-linear optics, the ligand should be properly functionalized with strong electron donor (CH_3) acceptor groups (NO_2) and it should be non-centrosymmetric. Shing Wong *et al.* synthesized various hydrazone derivatives from aromatic aldehydes and 4-methoxyphenylhydrazine or 4-tolylhydrazine or 4-nitrophenylhydrazine and used them with powder test for second or third order non-linear optical devices.

2. Hydrazones and magnetochemistry

Investigation of magnetic properties of molecular materials has become a major goal of current research in the fields of condensed matter physics and material chemistry. Among the ligand systems, hydrazones occupy special place due to their well-known chelating capability and structural flexibility which can provide rigidity to the skeletal framework of the prepared multinuclear complexes. Considerable efforts have been applied to build and characterize such molecular architectures which can exhibit interesting magnetic properties.

3. Hydrazones as iron-chelating agents

- Iron is one of the important elements in our body which concentration is tightly controlled. Iron overload may occur due to several conditions like frequent transfusions, exploit consumption of iron (often as supplement) and chronic hepatitis. Iron overload causes formation of free radicals leads to the severe complications such as mental retardation, early neurological diseases (Alzheimer's, multiple sclerosis), reproductive system dysfunctioning, cardiac disorders (arrhythmia, cardiomyopathy), liver cirrhosis, liver cancer, hepatitis, and metabolism dysfunction (diabetes, thyroid disorders, parathyroid and low level of adrenal glands) (ref). Initially the search for effective iron chelators was primarily driven by the need to treat Fe overload diseases such as β -thalassemia. However, it has become clear that iron chelators may be useful for the treatment of a wide variety of disease states, including cancer, malaria and free radical mediated tissue damage (ref). Despite the synthesis and biological assessment of a diverse range of ligands, only a few compounds have ever been effective and safe enough to reach clinical trials. There are three drugs which frequently used in iron chelation therapy for treatment of iron overload and β -thalassemia condition, namely; Deferiprone (a pyridine derivative), Deferoxamine (naturally occurring trihydroxamic) and Deferasirox (chemically known as 4-[3,5-bis(2-hydroxyphenyl)-1H-1,2,4-triazol-1-yl]-benzoic acid) (Malik *et al.*, 2019; Attia *et al.*, 2018)



Hydrazones as molecular sensors

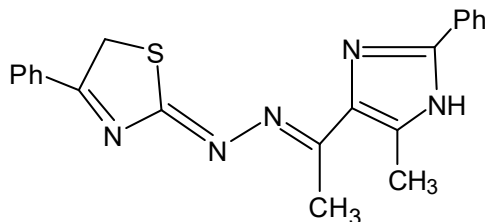
The development of molecular sensors has attracted a lot of research activities in recent years for their use in processes that include food, clinical and environmental analysis. Bi-stability, that is, the ability of the system (substrate plus surrounding molecules) to exist in two states (electronic or conformational) is essential for molecular recognition as the interconversion between states allows exploring their structural relaxation and interactions with their environment.

Biological activities of hydrazones

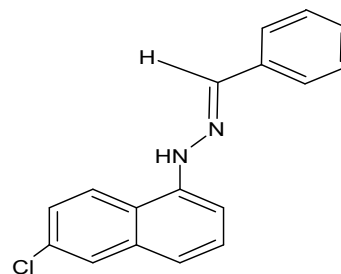
Hydrazones have been intensively investigated mostly because of their potential application as anticancer, antiviral, antibacterial and antifungal agents. These compounds display a versatile behavior in metal coordination and the biological activity is often increased by bonding to transition metals.

a. Antimicrobial activity

The overuse of chemicals against various infectious diseases has led to rapid emergence of resistivity against different bacteria. Therefore, the search for antimicrobials is a never ending task. Consequently, as an antibacterial agent, novel hydrazones containing aroylhydrazone, imidazoles, hydrazoneoyl substituted pyrimidinones, vanillin based hydrazine, 2-quinoxalinone-3-hydrazine derivative as well as selective inhibitors of *Staphylococcus aureus* β -ketoacyl carrier proteinsynthase III fighting against different bacterial strains as reported by Sharma *et al.* 2011; Jubie *et al.* 2010; Ozkay *et al.* 2010; Rane *et al.* 2010; Edress *et al.* 2010; Govindasami *et al.* 2011; Ajani *et al.* 2010 and Lee *et al.* 2012 with few examples as illustrated below.



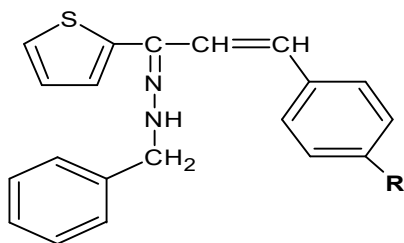
Hydrazone containing imidazoles



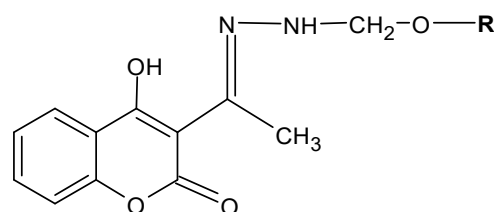
Benzylidene-Hydrazo derivatives containing Quinoline ring

b. Anti-oxidant activity

Oxidation reactions are crucial for sustenance of life but they can also be damaging. Oxidative stress is the cause of degenerative and pathological diseases viz. diabetes Mellitus, ischemic heart disease (IHD), atherosclerosis, cancer etc (ref). In recent years' anti-oxidant has an essential role as it can neutralize the ROS (reactive-oxygen-species) and free radicals. Hydrazone derivatives synthesized by Musad *et al.* (2011), Abdel-Wahab *et al.* (2011) (as illustrated below) are reported to have radical scavenging activity (RSA) promising antioxidant activity.



Hydrazone derivatives of thiophene

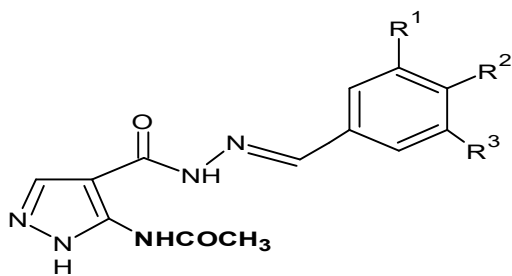


Hydroxycoumarin N-acylhydrazones

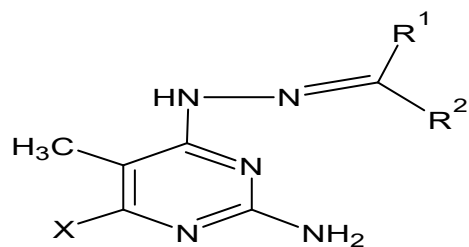
c. Anticancer activity

Cancer is a lethal group of diseases with a high level of penetrating potency affecting almost every organ of the body. Al-Said *et al.*, (2011) synthesized compounds active against human breast cancer cell lines MCF7. Hassan *et al.*, (2011) synthesized pyrazole based hydrazone derivatives with potential to treat breast carcinoma. Kendall *et al.*, (2012) evaluated some derivatives (70) as PI3K p110 α inhibitors. PI3K are signaling proteins in different cell types responsible for phosphorylation of lipids in cell membranes. Kumar *et al.*, (2012) synthesized various bis(indolyl) based hydrazones active against multiple cancer cell lines. Effenberger *et al.*, (2010) reported a hydrazone derivative with potent activity against HL-60 leukaemia and 518A2 melanoma. Acylhydrazones by Cui *et al.*, (2010) have been reported to have potent activity against the human promyelocytic leukemic cells (HL-60). Copper based hydrazone derivatives are reported to act against integrin β 4 in H322 lung carcinoma cell lines by Fan *et al.* (2010). Palladium based hydrazones by AbuSurrah *et al.* (2010) have been reported to be active against human head and neck squamous carcinoma cell lines SQ20B and SCC-25. 2-phenylindole based

hydrazone synthesized by El-Nakkady *et al.*, (2012) have been developed against breast carcinoma cell lines and reported to have an IC_{50} of 1.60nM (examples as illustrated in Figure 1 and 2)



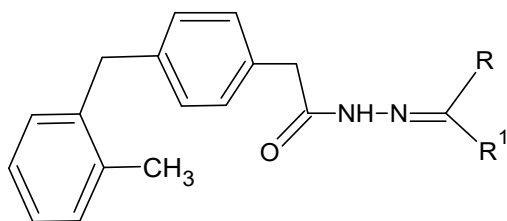
Hydrazino - pyrazoles derivatives



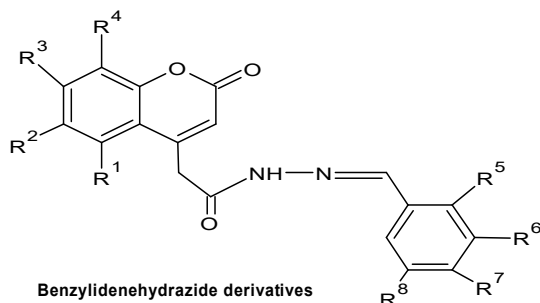
Hydrazino - pyrimidine derivatives

d. Antimycobacterial activity

Tuberculosis is a contagious bacterial disease, which is responsible for the mortality of nearly three million people every year worldwide. The drugs which are used to treat infections caused by Mycobacterium that include leprosy and tuberculosis (TB) are called as anti-mycobacterial or anti-tubercular agents. Some of the agents are rifampicin, isoniazid, ethambutol etc. Some novel approach has been attempted by the researchers (Dasgupta, 2012). The researcher put their efforts to synthesize several novel hydrazone derivatives that were assessed for the anti-mycobacterial activity. Among them, diclofenac acid hydrazones were synthesized from diclofenac, methanol, sulphuric acid with dichloro substituted phenyl amino phenyl acetohydrazides for the in-vivo antimycobacterial activities against mycobacterium tuberculosis (Sriram *et al.*, 2006) as well as coumarin-4-acetic acid hydrazides to synthesize benzylidene derivatives (Mamolo *et al.*, 2003).



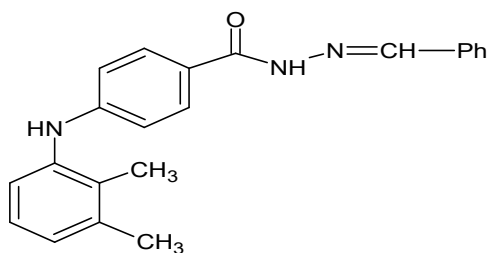
Diclofenac acid hydrazones



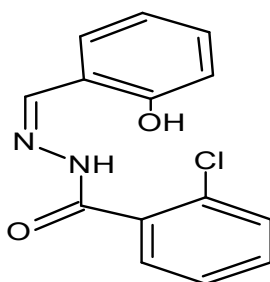
Benzylidenehydrazide derivatives

e. Anti-inflammatory activities

Inflammation is a localized physical, chemical or biological response of the immune system, understanding by injury any process able to cause tissue or cellular damages. Non-steroidal anti-inflammatory drugs (NSAIDs) of different classes were used as analgesics and hence used in the treatment of pain and inflammation. In the past years, aryl hydrazones were synthesized as the derivatives of mefenamic acid and were evaluated for the anti-inflammatory effects (Almasirad *et al.*, 2005). Much work has been done describing the analgesic and anti-inflammatory potential of hydrazides. Harnandez *et al.*, (2012) reported analgesic and anti-inflammatory activity of furoxanyl-N-acylhydrazones. Rajitha *et al.*, (2011) evaluated the anti-inflammatory activity of some aryl hydrazones and got good results. Moldovan *et al.*, (2011) synthesized various hydrazone derivatives and reported them to have promising in-vivo anti-inflammatory activity. El-Sayed *et al.*, (2011) and Isloor *et al.*, (2010) synthesized hydrazone derivatives with selective COX-2 inhibition of 50.2 % as shown below.



Arylhydrazones derivatives of mefenamic acid

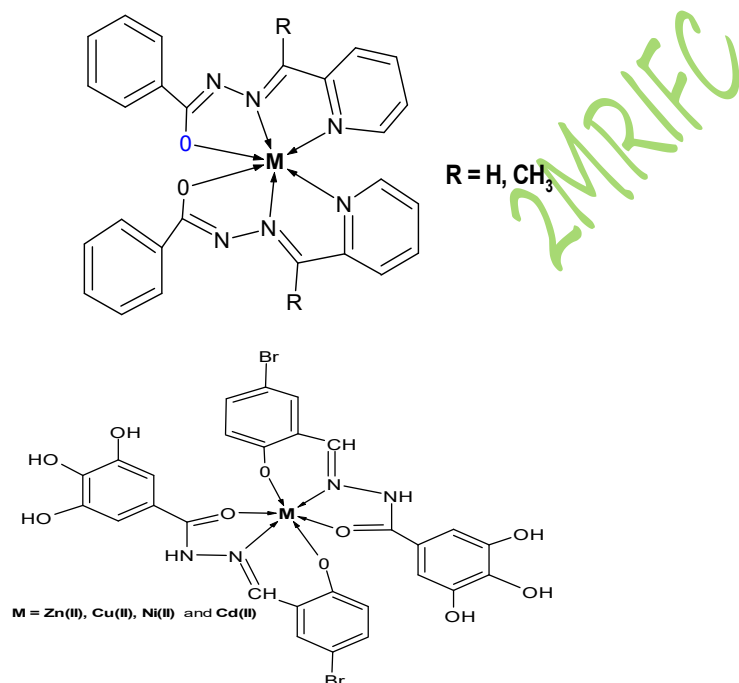


Salicaldehydechloro benzoylhydrazone derivatives

Metal complexes of hydrazones and their biological applications.

The coordination approach used by hydrazones is affected by different kinds of variables, which include tautomerism, different reaction conditions, nature of substituents on the hydrazone unit and the stability of the prepared complex. The change in the structure of the various species linked to hydrazones will have an impact on the coordinating ability of the ligands with metal ions, displaying exciting coordination modes and leading to the production of a variety of complexes. Metal ions in general and transition metals in particular are found to play an important role in industry, agriculture and plant nutrition, biological activities of living beings and medicines (Viswanatha and Chandrasekhar, 2013; Yu *et al.*, 2013; Otuokere *et al.*, 2015; Otuokere *et al.*, 2025). Hydrazones are reacted with many metal ions forming color complexes and act as chelating agents (Rao *et al.*, 2011), and these compounds contain an azomethine nitrogen atom and responsible for their reactivity with number of transition metal ions which form colored complexes (Ajani *et al.*, 2010; Bai *et al.*, 2010; Asuquo *et al.*, 2014; Eberendu *et al.*, 2025).

Hydrazone ligands and their complexes have been the subject of studies for many years due to their wide applications in different fields, such as liquid crystal and in catalytic processes (Hama *et al.*, 2009), extraction of some metals ions, micro determination of metals ions (Nawar *et al.*, 1999), determination of titanium bauxite, Portland cement, amphibolites granites (Gui *et al.*, 1998), and different biological activities, such as antimicrobial (Chohan *et al.*, 1996) which used iron chelators in the treatment of anemias and as antiviral drugs (Agulles *et al.*, 2004, Rollas and Kucukguzel, 2007), anti-inflammatory, anti-analgesic, antibacterial and anticancer applications, antifungal (Deepa *et al.*, 2001; Uppal, *et al.*, 2011; Ugochukwu *et al.*, 2024), antitumor (Iskander *et al.*, 2004), antidiabetic (Asuquo *et al.*, 2023) herbicidal, insecticidal, nematocidal and anti-tuberculosis activities. (Pokhariyal *et al.*, 1997). In addition, they have been studies also as a group of useful spectrophotometric reagents (Vallinath *et al.*, 2010, Kumar *et al.*, 2004, Vallinath *et al.*, 2010) as well as a Cytochrome C Peroxidase Inhibitors (Otuekere *et al.*, 2024).



Spectroscopic analysis of hydrazones and their metal complexes

For the determination of metal ion at micro levels, there are several analytical techniques such as:

- X-ray fluorescence spectroscopy
- atomic absorption spectrophotometry



- spectrofluorometric
- Infrared studies and other techniques

Among UV-Visible spectrophotometric methods are mostly been used because they are cheaper, easy to handle and highly sensitive. Derivative Spectrophotometry (DS) is an analytical technique of great utility for extracting both qualitative and quantitative information from spectral curves composed of unresolved bands. It is a very useful approach for determining the concentration of single component in mixtures with overlapping spectra as it may eliminate interferences. It is also useful technique, in the sense that, it decreases the interference i.e., increase the tolerance limit value of the foreign ions. This method is found to be rapid, sensitive, selective, reproducible and free from interference of a large number of common metal ions. The great interest towards derivative spectrophotometry is due to increased resolution of spectral bands, allowing the detection and location of the wavelengths of poorly resolved components of complex spectra and reducing the effect of spectral background interferences. In general, the technique of solvent extraction is widely used in the spectrophotometric determination of metal ions. However, organic solvents such as benzene and chloroform are often carcinogenic, toxic and cause environmental pollution. It is significant to develop a method which does not involve solvent extraction. The hydrazone moiety can be identified via spectroscopic methods.

- The IR spectrum shows signals at around 3050 cm^{-1} and 1550 cm^{-1} corresponding to the –NH- and C=N group, respectively.
- For ^1H NMR spectrum, Characteristic signals are visible in the form of a singlet with a chemical shift of δ 8.16 - 8.67 ppm for -CH= and a singlet with a chemical shift of δ 10.45 - 12.25 ppm for -NH- one
- In the ^{13}C NMR spectrum, there is a signal of carbon atoms from the –CH- in the range of δ 145–160 ppm.

Conclusion

The synthesis and application of medicines from bioinorganic complexes is a rapidly developing field due to the formation of stable compounds in coordination chemistry. The metal complexes and their parent ligands have a significant impact on clinical practice as diagnostic and



therapeutic agents. Advances and innovations in bioinorganic chemistry are essential for improving the design of compounds to maximize its therapeutic effects along with minimizing the toxic side-effects. As hydrazones and its metal complexes possess antibacterial, anti-oxidant, analgesic, anti-inflammatory, anti-cancer properties, so this write-up focuses the general review of hydrazones with proper designing, synthesis, spectroscopic analysis, biological applications of hydrazones and their metal complexes as well as general applications of hydrazones.

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***IN-SILICO* STUDIES OF HYDRAZONE LIGANDS AND METAL COMPLEXES AS INHIBITORS OF SARS-COV-2: A REVIEW**

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Abstract

In recent years, the spread of Corona Virus Disease (COVID-19) has become a major global public health challenge which poses a threat to people's physical and mental well-being. Effective therapeutics against COVID-19 are in high demand, therefore, there's persistent need for series of novel broad-spectrum inhibitors capable of curbing the spread of SARS-CoV-2 and slowing its replication within the cells. Hydrazones derivatives have been found significant by researchers for *in-silico* studies in the evolving landscape of modern drug discovery owing to their chelating ability, structural flexibility and diverse range of pharmaceutical applications. The synthesis and evaluation of hydrazone derivatives have emerged as a promising avenue for inhibiting SARS-CoV-2 main protease (Mpro); a crucial enzyme in the viral replication cycle, RNA polymerase and papain-like protease (SARS-CoV-2 PLpro). These reviewed studies collectively suggest hydrazones and their derivatives hold potential as drug candidates against SARS-CoV-2 virus, utilizing a variety of computational methods including density functional theory (DFT) studies, molecular docking, and absorption, distribution, metabolism, excretion and toxicity (ADMET) analyses. Structural modifications, including the introduction of various substituents and hybridization with other pharmacophores enhances the predictive accuracy and efficacy of hydrazones in computational models, thereby optimizing their potentials as therapeutic agents. This is particularly relevant considering one of the major challenges in drug development is the high mutation rate of the SARS-CoV-2 virus, which can give rise to new variants that may be more resistant to existing treatments. Ultimately, we highlight successful examples of SARS-CoV-2 inhibitory drug discoveries that have emerged from *in-silico* studies.

Keywords: SARS-CoV-2, Main protease (Mpro), Hydrazones, Inhibitors, *In-silico* studies; Molecular docking, DFT

Introduction

The emergence of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and its subsequent global spread have prompted intensive research efforts to identify effective therapeutic agents for combating the COVID-19 pandemic (Otuokere *et al.*, 2022; World Health Organization, 2020). The main protease (Mpro) of SARS-CoV-2, also known as 3C-like protease (3CLpro) (Liu *et al.*, 2020; Zumla *et al.*, 2016), plays a pivotal role in viral replication and maturation, and has been reported as a valuable target for drug development against COVID-19



(Oubahmane *et al.*, 2021). Numerous researchers and physicians from all over the world have been joining their resources to slow down the virus's spread, developing new antiviral drugs for SARS-CoV-2 and/or testing the anti-COVID efficacy of old drugs by a drug repurposing approach (Punekar *et al.*, 2022; Kato *et al.*, 2022; Marciano *et al.*, 2021). In this regard, small molecule inhibitors (Amaka *et al.*, 2020) are of particular interest due to their potential to selectively target viral proteins essential for replication and mitigate the severity of COVID-19 symptoms (Wu *et al.*, 2021; Adem *et al.*, 2020; Cui *et al.*, 2020).

Among the diverse array of chemical compounds under investigation, hydrazones ligands and their metal complexes have emerged as promising candidates for effective antiviral agents for tackling SARS-CoV-2 infection and replication (Akinyele *et al.*, 2023). Hydrazones are azomethines (Otuokere *et al.*, 2024) containing a triatomic group $>C=N-N<$. They differ from other members of this class (the imines and oximes) by the presence of two interlinked nitrogen atoms (Avaji *et al.*, 2008). Various substitutions on the aromatic or aliphatic rings of the hydrazones can significantly alter their physicochemical properties, such as lipophilicity, solubility, and bioavailability, which can affect their pharmacokinetic and pharmacodynamics properties (De Oliveira *et al.*, 2020).

Hydrazones and their derivatives are considered as versatile class of compounds in organic chemistry with interesting biological properties, such as antiapoptosis (Otuokere *et al.*, 2024), anti-inflammatory (Reddy & Kathale, 2017), analgesic (Rajitha *et al.*, 2014), anti-cancer (Nasr *et al.*, 2014), anticonvulsant (Jain *et al.*, 2018), antituberculous (Mandewale *et al.*, 2018), antiprotozoal (Coa *et al.*, 2015; Inam *et al.*, 2014), antitumor (Alberca *et al.*, 2021), anti-HIV (Shah *et al.*, 2018), antimicrobial activities (kamal *et al.*, 2019), and antiviral (Yang *et al.*, 2018). Researchers have observed that numerous transition metals, owing to their capacity to bind with nucleophilic (electron-rich) components such as proteins and DNA, exert various effects on biological processes (Otuokere *et al.*, 2022; Otuokere *et al.*, 2020). This significant finding has prompted investigations into the incorporation of metal ions, particularly transition metals, into drug structures to facilitate controlled interactions with biological systems, thereby promoting therapeutic effects (Asogwa & Otuokere, 2024; Loginora *et al.*, 2020). Research also indicates that the complexation of hydrazones with metal ions, including copper (Cu), Magnesium (Mg)

and Mn (Mn), significantly enhances their antiviral efficacy (Carcelli *et al.*, 2018). This enhancement is attributed to improved stability, solubility, and binding affinity of the hydrazone-metal complexes, which may facilitate better bioactivity against viral targets.

Presently, molecular docking is being employed particularly in drug discovery to gain insight into the interaction between a ligand and a protein (Adeboye *et al.*, 2021; Mermer *et al.*, 2020; Ikpeazu *et al.*, 2020; Igwe *et al.*, 2020). The goal of molecular docking simulations is to predict how strongly a ligand will bind to its target protein and to identify the most stable ligand-protein complex. A more negative binding free energy value indicates a stronger interaction and an increased likelihood of effective binding (Otuokere *et al.*, 2022; Otuokere *et al.*, 2022). Combined with ADMET properties, molecular docking can offer useful insights into the drug-like properties of compounds and the biochemical pathways and molecular mechanisms of drug-protein interactions (Asogwa *et al.*, 2024; Olanrewaju *et al.*, 2020; Metibemu *et al.*, 2020).

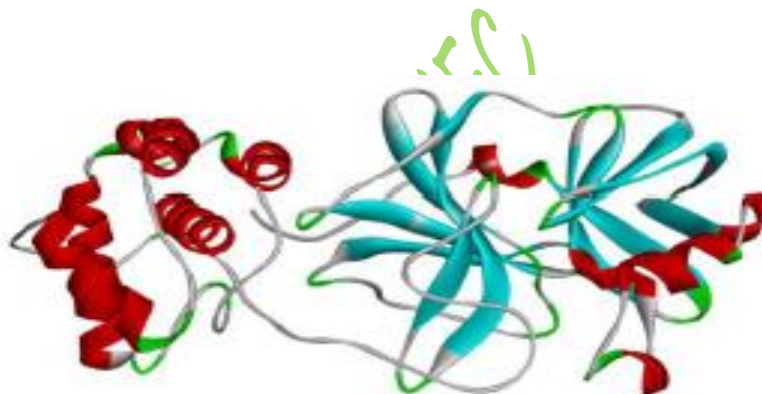


Figure 1: Crystal structure of SARS-CoV-2

***In-Silico* Studies and Computational Approaches of Hydrazone Derivatives as Inhibitors of SARS-CoV-2**

In-silico methodologies have become crucial in drug discovery, enabling researchers to identify potential pharmacological inhibitors by offering insights into the dynamic nature of molecular interactions. These computational techniques enhance the understanding of binding affinities (Otuokere *et al.*, 2022) and conformational dynamics, leading to more accurate predictions regarding the efficacy and selectivity of therapeutic candidates.

Three hydrazone derivatives HYDZ-1, HYDZ-2 and HYDZ-3 were synthesized via the condensation of 4-hydrazinylbenzoic acid with three aromatic aldehydes: thiophene-2-carbaldehyde, thiophene-3-carbaldehyde and 2-furaldehyde. The predicted ADME-T properties and pharmacokinetic parameters indicated that these compounds exhibit favourable oral bioavailability alongside significant biological activity. The calculated binding energies for HYDZ-1 (**figure 2**) indicated the ability to inhibit main protease of SARS-CoV-2. Finally, the docking simulations demonstrated that these investigated hydrazone derivatives possess potential as therapeutic agents against SARS-CoV-2 (Adjissi *et al.*, 2022).

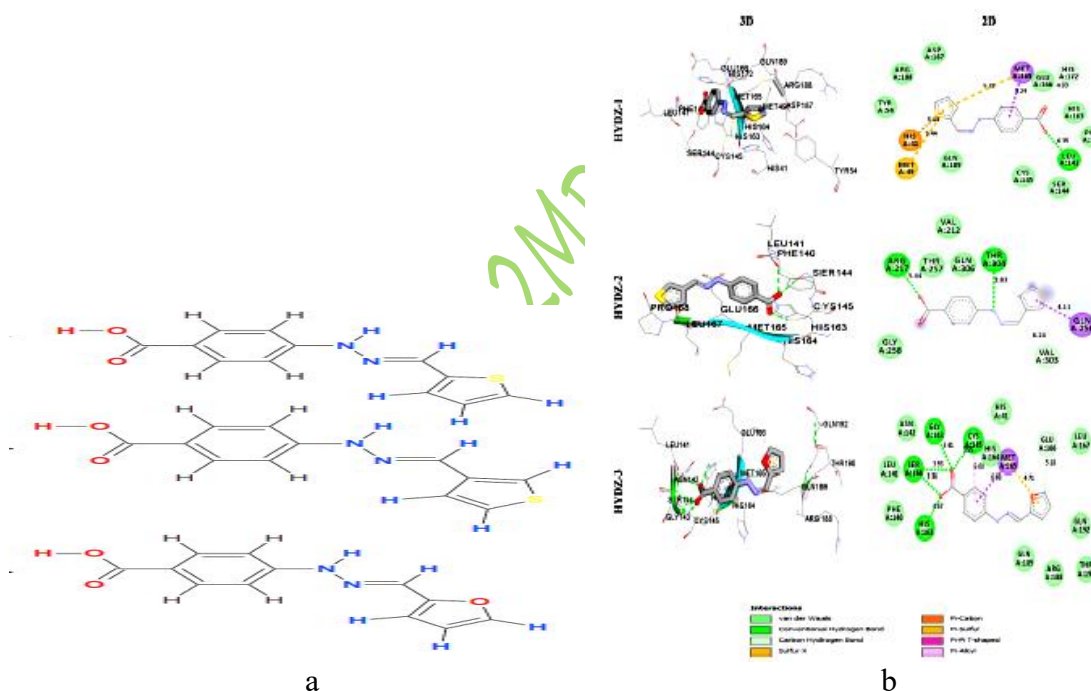


Figure 2: The structure of the studied hydrazone derivatives (a) Binding-interaction diagrams of the studied molecule with SARS-CoV-2 main protease (b)

Additionally, a new hydrazone ligand (DNEAA) and its Mn(II) complex [Mn-(DNEAA)] were synthesized. The *in-silico* analyses including molecular docking dynamics, and ADMETox simulations revealed high binding affinities and optimal conformation poses when they interact

with the NSP1 of the SARS-CoV-2 protease, suggesting their viability manifestations of the virus. Therefore, the ligand and its Mn(II) complex (**figure 3**) were proposed as effective inhibitors of the NSP1 protease (Eberendu *et al.*, 2024).

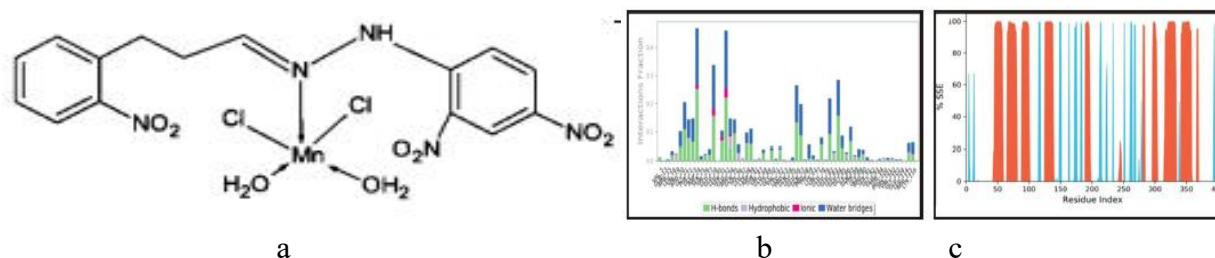


Figure 3: The structure of the synthesized hydrazone derivative [Mn-(DNEAA)] (a), the Protein-ligand contact histogram of protein structures complexed with DNEAA (b) and Protein Secondary Structure element (c).

New dual inhibitors of main protease (Mpro) and nonstructural proteins (NSP10)/(NSP16) were synthesized from the condensation of (4-chloro-3-methylphenyl)hydrazine with 2-pyridine-carboxaldehyde along with their corresponding Schiff-base metal complexes (Ni(II), Pd(II), Zn(II), and Hg(II)). *In-silico* molecular docking of Ni(II) and Zn(II) showed excellent binding energies ranging from -5.9 to -7.2 Kcal/mol and -5.8 to 7.2, highlighting their potential as inhibitors of the MPro and NSP16/NSP10 methyltransferase complex. All the synthesized complexes and the ligands exhibited good membrane permeability (BBB) and strong gastrointestinal absorption (GI), conforming to the Lipinski rule, indicating drug-like properties (Aljanabi *et al.*, 2023) (**figure 4**).

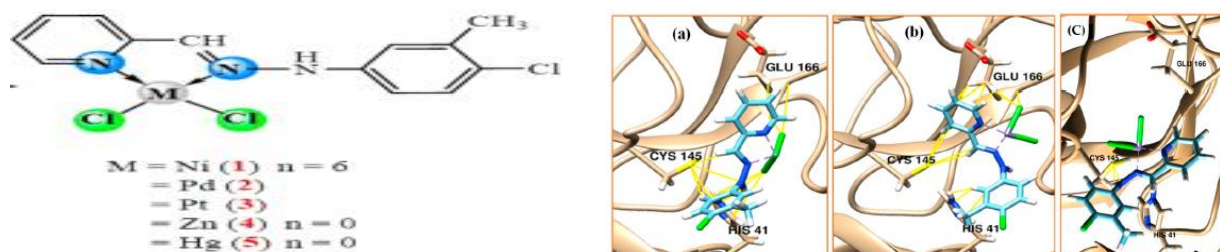


Figure 4: The structure of the studied hydrazone metal complex (left) and the ligand complexes docked with the active site of the main protease of SARS-CoV-2; (a) nickel complex, (b) and (c) zinc complex

Furthermore, a new bis hydrazone characterized as (1*z*,2*Z*)-1,2-bis(3-ChlorophenylHydrazino)Benzil(3-Cl BHB), derived from benzil (1,2-diphenylethanedione), showed promising inhibitory activity against SARS-CoV-2 main protease (-8.90 Kcal/mol) and RNA polymerase (-8.60 Kcal/mol) (**figure 5**) as evidenced by molecular docking studies comparing its binding energies with established antiviral compounds (Tabbiche *et al.*, 2022).

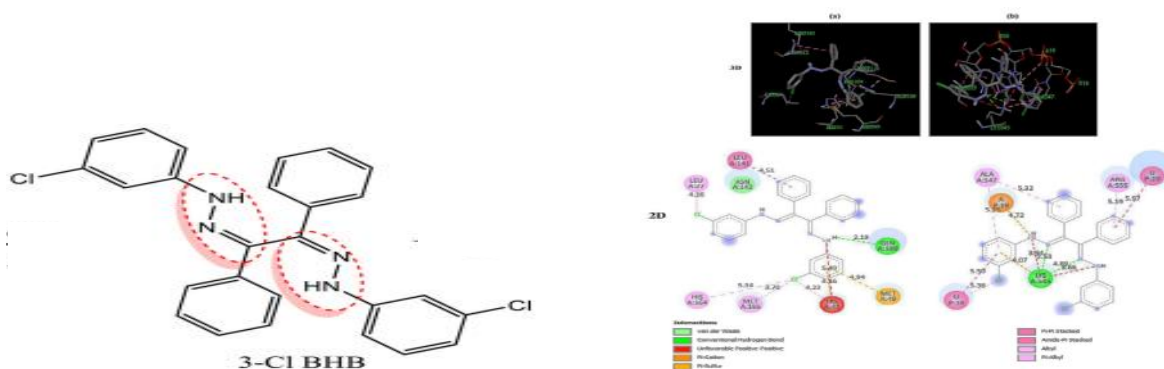


Figure 5: The structure of the hydrazone derivative (1*Z*,2*Z*)-1,2-bis (3-Chlorophenyl Hydrazino) Benzil (left) and 3D and 2D Binding-interaction diagrams of the studied molecule with SARS-CoV-2 main protease (a) and RNA dependent RNA polymerase (b).

Shellenberger *et al.* (2024) synthesized seven furanochromene-quinoline derivatives containing a hydrazone linker by condensing a furanochromene hydrazine with various quinolone carbaldehydes. The 3-, 5-, 6-, and 8-substituted derivatives exhibited moderate inhibition of SARS-CoV-2 M_{pro}, with IC₅₀ values ranging from 16 to 44μM. These derivatives showed strong interaction within the substrate binding pocket of the M_{pro}, with docking energy scores ranging from -8.0 to -8.5 Kcal/mol. *In-silico* ADME profiles further confirmed their favourable drug-like properties, highlighting the potential of the furanochromene-quinoline hydrazone scaffold as a viable M_{pro} inhibitor (**figure 6**).

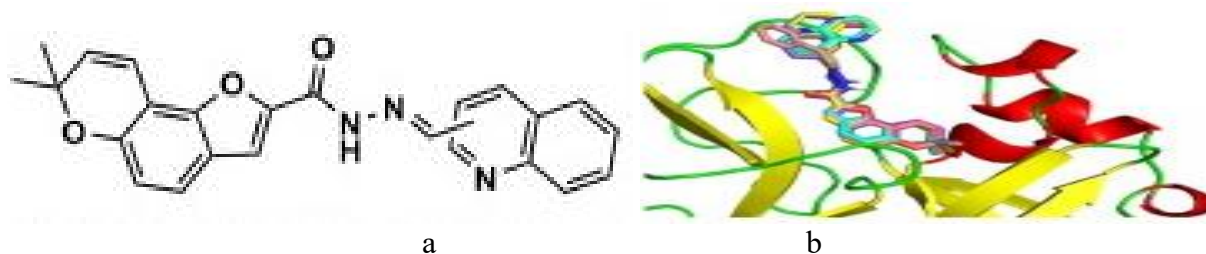


Figure 6: The structure of furanochromene-quinoline hydrazone (a), and the docked active site of M_{pro} protein of SARS-CoV-2 (b)

Schiff base compound with a hydrazide-hydrazone moiety, N'-(5-nitro-2-(piperidin-1-yl)benzylidene)benzohydrazide was reported by Sahin & Dege (2023). The docking studies were performed on tau fibrils (5V5C and 3OVL) and Mpro (6LU7) of SARS-CoV-2 accordingly. The title molecule is compatible with the known druglikeness rules, such as Lipinski, Ghose, Weber, Egan, Muegge, and Pfizer. The drug-likeness score of the compound was calculated to be -0.42 which places it within a range indicative of potential therapeutic relevance with binding energy values evaluations; tau segments (**figure 7**), (-5.68 and -6.90 kcal/mol, ref EGCG; -3.90 and 5.00 kcal/mol) and Mpro (-9.73 kcal/mol, ref inhibitor N3; -7.11 kcal/mol) respectively showing promising values for developing effective inhibitors.

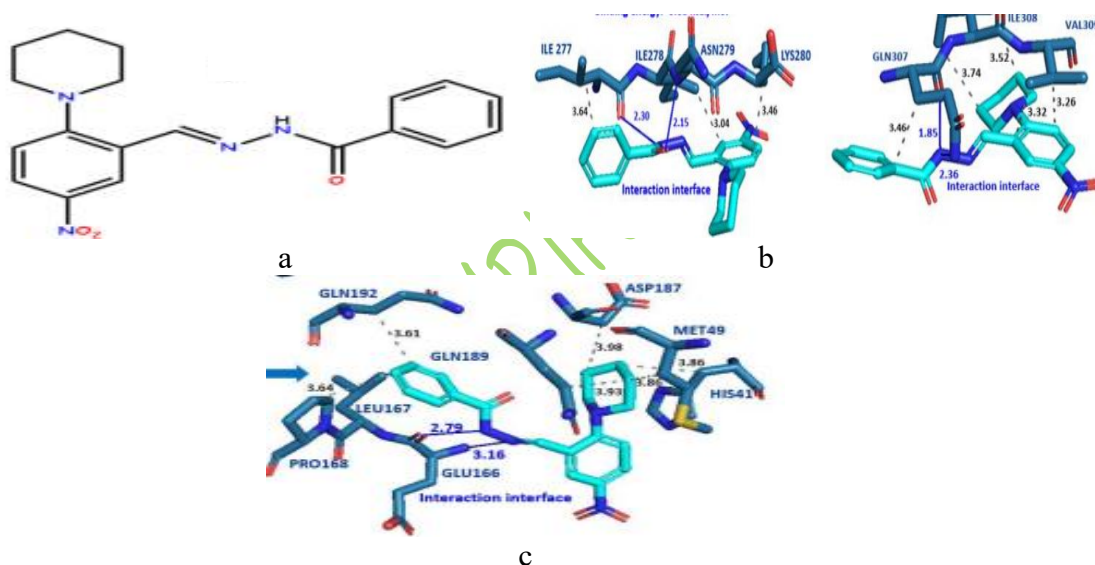
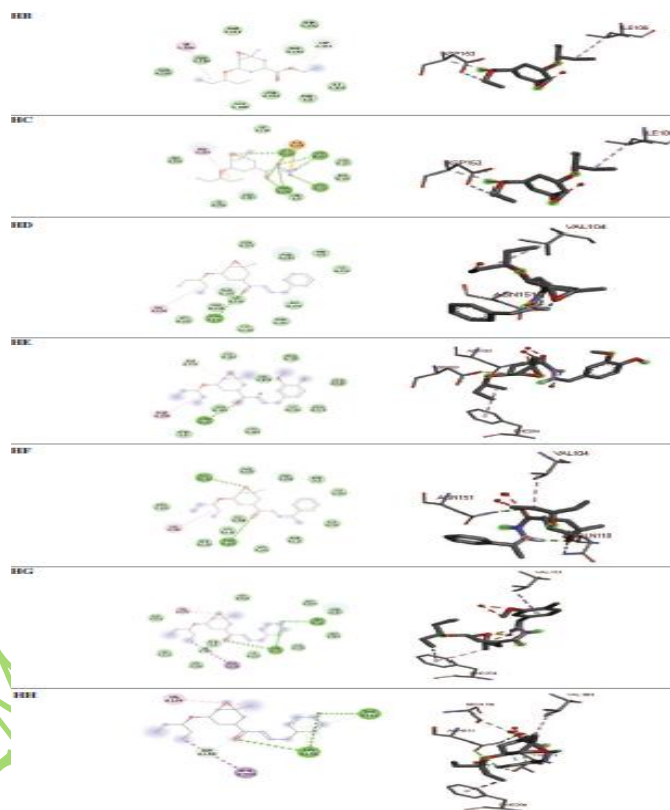


Figure 7: The structure of the synthesized hydrazone N'-(5-nitro-2-(piperidin-1-yl)benzylidene)benzohydrazide (a) and the Interaction interface of the query compound with tau segments, (b) and the active pockets of Mpro, (c)

Akinyele *et al.* (2023) employed density functional theory (DFT) and molecular docking to evaluate methyl-5-(pentan-3-yloxy)-7-oxabicyclo[4.1.0]hept-3-ene-3-carboxyhydrazide derivatives. The docking results demonstrated superior binding affinities and the interactions were primarily mediated by hydrogen bonds and pi-alkyl interactions, facilitating stable binding

within the active site of Mpro (**figure 8**) highlighting their potential inhibitors of Mpro. All the compounds conform. Vebers and Lipinski's rule to indicating oral drug candidates.



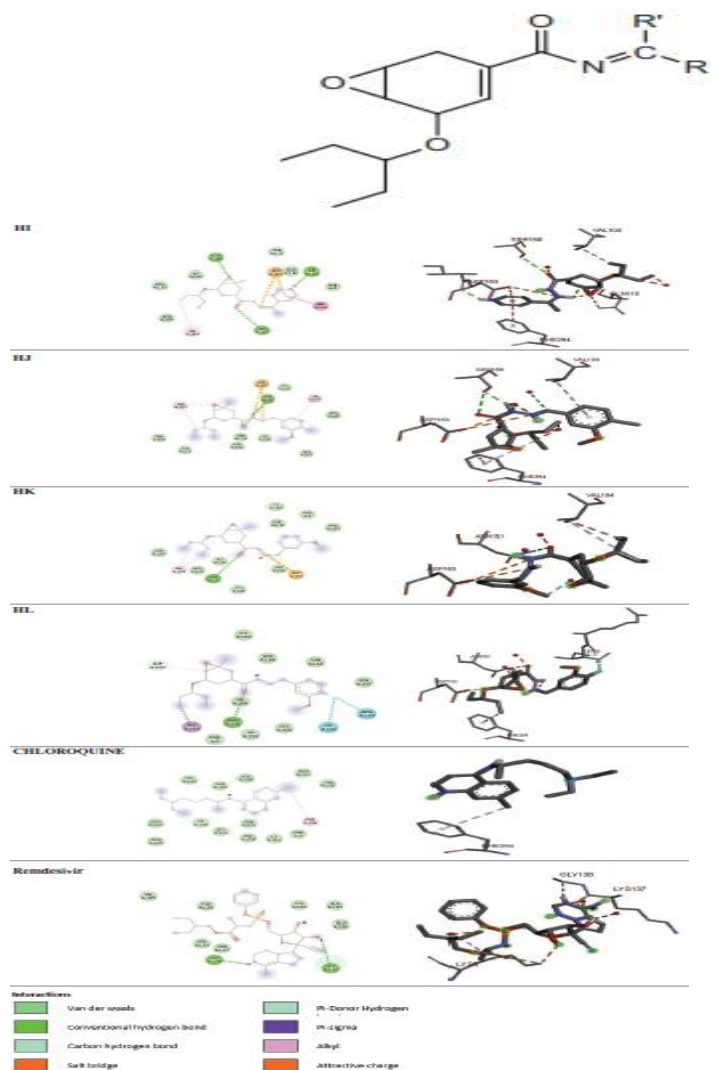


Figure 8: Hydrazones derived from oseltamivir intermediate, methyl 5-(pentan-3-yloxy)-7-oxabicyclo[4.1.0]hept-3-ene-3-carboxylate (a) and Interaction diagrams of amino acid residues of the corresponding hydrazones, chloroquine, and remdesivir (b).

Abu-Melha *et al.* (2020) focused on hydrazones, pyrazoles, and pyrazines bearing thiazole moieties as potential Mpro inhibitors. Molecular docking studies demonstrated that selected hydrazone compounds achieved binding affinities of approximately -8.0 kcal/mol, outperforming the positive control, Nelfinavir, which had a binding affinity of -6.9 kcal/mol. The hydrazone derivatives (compounds 11a-c) engaged with Mpro through multiple hydrogen bonds and

hydrophobic interactions, particularly targeting the Glu166 residue, which is pivotal for substrate binding and enzyme stability (**figure 9**).

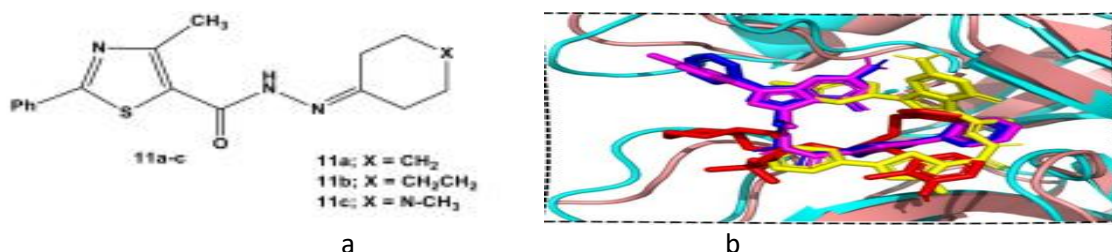
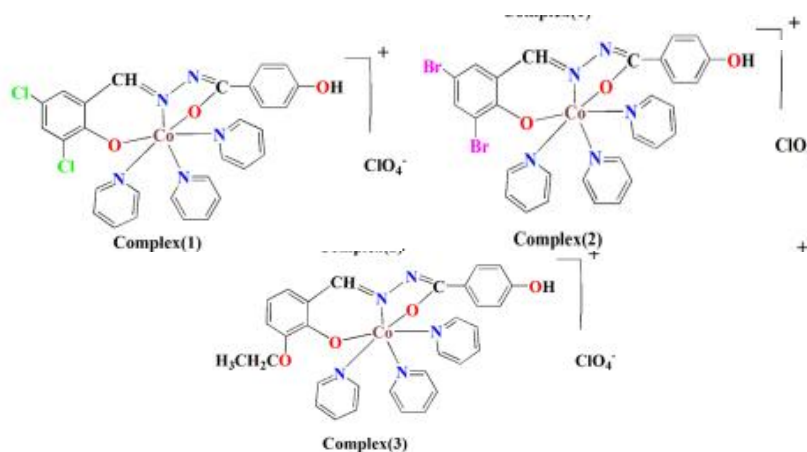


Figure 9: The structure of the synthesized hydrazone derivative (a) and the docked active site of Mpro of the SARS-CoV-2 (b)

Cobalt(III) complexes of hydrazone derivatives were synthesized and evaluated as multi-target inhibitors of SARS-CoV-2. Molecular docking revealed that these complexes interacted with the active site of Mpro through coordination bonds involving the hydrazone ligands (**figure 10**). Compound (2) exhibited the highest binding affinity, forming stable complexes via hydrogen bonding and pi-stacking interactions with residues such as His41 and Cys145, which are crucial for the catalytic activity of Mpro. The study underscored the potential of metal-coordinated hydrazones in enhancing binding specificity and inhibitory potency (Parvarinezhad *et al.*, 2022).



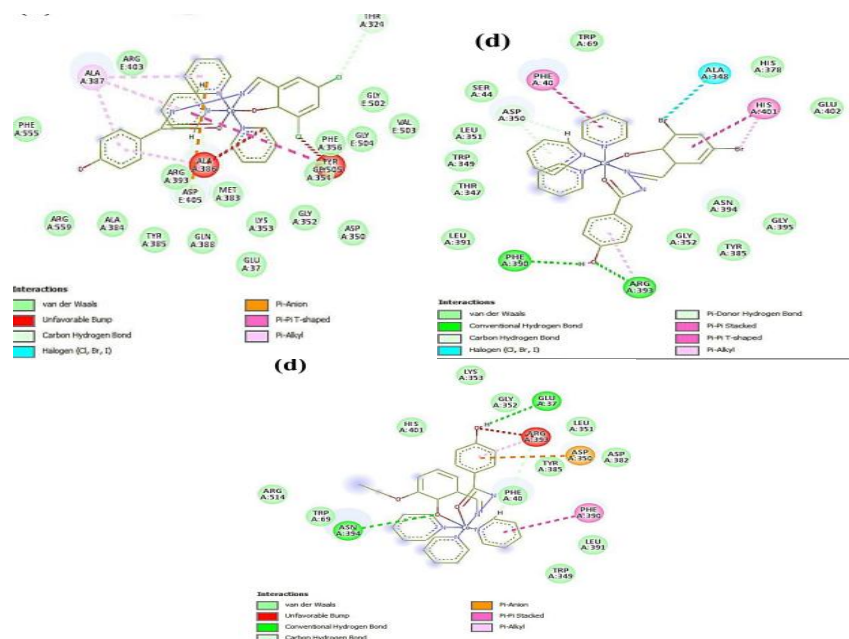
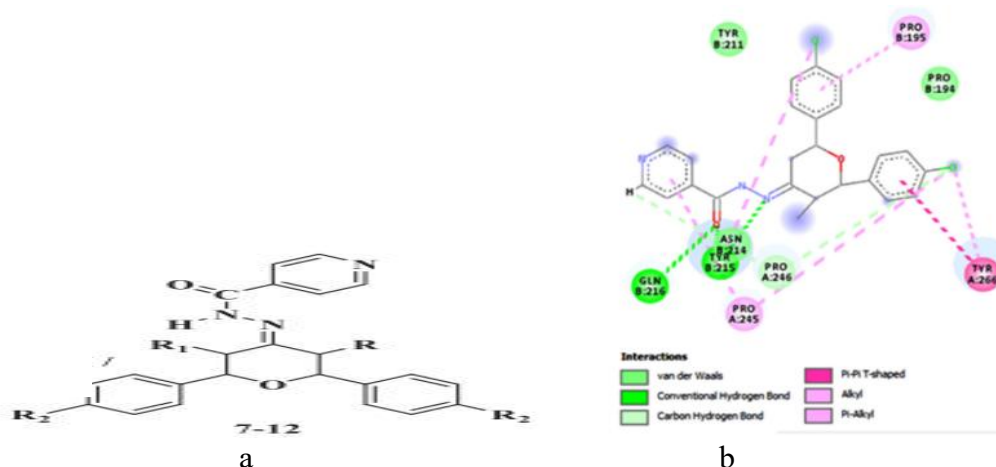


Figure 10: Structures of the studied hydrazone complexes (top) and the binding method of the corresponding respective receptor inhibitor of the important amino acids (down)

A new series of pyran-4-one bearing hydrazone derivatives were synthesized and evaluated as a potential binder for papain-like protease (SARS-CoV-2 PLpro) (**figure 11**). The docking studies demonstrated binding affinities in the range of -6.8 to -7.8 kcal/mol, with significant interactions involving the hybrids 9, 10, 33 and 34. Furthermore, ADMET predictions indicated favorable pharmacokinetic profiles, supporting the potential of these derivatives as viable drug candidates (Ravisankar *et al.*, 2023).



Dahms *et al.* (2021) explored the inhibitory effects of guanylhydrazone-based compounds on furin, a host protease involved in the activation of the SARS-CoV-2 spike protein. X-ray crystallography revealed that these hydrazones bind specifically to the OFF-state conformation of furin, engaging uniquely within the S1 pocket, distinct from substrate-like ligands that trigger a conformational shift to the ON-state. The compounds demonstrated selective inhibition of furin over related pro-protein convertases (PC5/6 and PC7), with up to a 7-fold lower potency for PC7, highlighting their specificity. Enzymatic assays confirmed potent inhibition of furin's proteolytic activity, critical for spike protein priming and subsequent viral entry into host cells (**figure 12**). The structural insights provided by crystallography affirmed the allosteric modulation by hydrazones, offering a targeted mechanism to impede viral maturation processes.

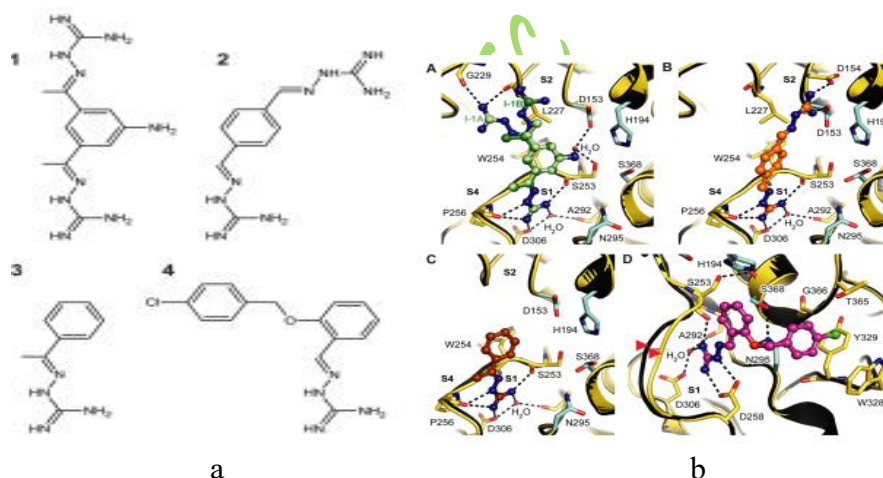


Figure 12: Structures of guanylhyazone-based compounds (a) and the binding mode of the off-state-specific furin inhibitors (b)

Future Directions and Perspectives

The covid-19 pandemic has shown a critical void in effective antiviral therapies, emphasizing the need for innovative strategies in combating viral infections. To address this gap, it is essential for researchers and industry experts to harness advanced computational methodologies, particularly AI-driven molecular modelling and machine learning techniques. These tools can enhance the predictive precision of *in-silico* studies and facilitate the identification and development of potent



SARS-CoV-2 inhibitors, which could significantly mitigate the spread of future pandemic outbreaks. A multitarget approach, which involves simultaneously inhibiting multiple viral proteins, may also be advantageous, as it could lower the likelihood of resistance emergence and thereby augment the therapeutic efficacy of hydrazone ligands and their metal complexes.

Moreover, encouraging interdisciplinary collaborations is crucial to integrating computational and experimental expertise. This collaboration will be instrumental in advancing hydrazone derivatives and their metal complexes into clinically relevant antiviral agents against SARS-CoV-2.

Conclusion

The synthesis and evaluation of hydrazone derivatives have shown promising potential for the inhibition of the SARS-CoV-2 main protease (Mpro), a pivotal enzyme in the viral replication cycle and. The inhibition of Mpro and RNA polymerase directly hinders the virus's ability to process polyproteins necessary for its lifecycle thereby preventing effective viral entry into host cells. The high binding affinities observed in molecular docking studies are substantiated through *in vitro* enzymatic assays, bolstering the therapeutic potential of these hydrazone compounds. Additionally, the incorporation of electron-donating or coordinating functional groups further enhances binding affinity and stability, which also improve overall ADME profiles.

However, it is critical to note that despite these encouraging findings, clinical validations and *in vivo* studies are necessary to fully evaluate the efficacy and safety of hydrazone derivatives as therapeutic agents. Future research should also consider the potential synergistic effects of hydrazone derivatives in combination with existing antiviral therapies to enhance their therapeutic efficacy and counteract resistance development.

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ANTIDIARRHEAL AND ANTIOXIDANT ACTIVITIES OF ETHYL ACETATE LEAF EXTRACT OF *ERYTHRINA SENEGALENSIS* (D.C) IN MICE

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Abstract

Erythrina senegalensis commonly known as “coral tree” is widely used in ethnomedical practices for the treatment of various ailments including diarrhea. The study investigated the antidiarrheal and antioxidant property of ethyl acetate leaf extract of *Erythrina senegalensis*. The antidiarrheal activity of the extract was investigated using castor oil induced diarrhoea, enteropooling and small intestine transit models. The test groups received various doses (75, 150, and 300 mg/kg) of the extract, whereas positive controls received Loperamide (5 mg/kg) and negative controls received distilled water (10 ml/kg). The ethyl acetate leaf extract of the plant significantly ($P < 0.05$) prolonged the onset of diarrhea up to 62.75 ± 15.76 minutes at the highest dosage (300 mg/kg) as against the control (50.50 ± 1.55 minutes) and reduced the number of wet faeces among the castor oil induced mice from 23.76 ± 1.45 to 14.50 ± 1.29 for the least dose, 12.50 ± 2.38 for the medium dose, and 8.00 ± 4.76 for the highest dose. In charcoal meal intestinal transit models, extract doses (75 mg/kg, 150 mg/kg and 300 mg/kg) also elicited dose dependent anti-diarrheal activity, evidenced by reduction in distance travelled by charcoal meal. With the middle and high dose producing a remarkable decrease of 10.68 ± 3.63 and 10.03 ± 5.04 as compared to the standard which was 11.88 ± 6.60 at a dose of 5 mg/kg body weight. Furthermore, the extracts produced a significant ($P < 0.05$) reduction only in the volume of intestinal contents in the enteropooling model when compared to the control. The antioxidant potential of the extract was determined using different *in vitro* antioxidant screening methods. The extracts produced concentration dependent increase in antioxidant effect in all the assays with lipid peroxidation inhibitory effect and DPPH radical scavenging assays producing 65.80 ± 2.29 and 64.83 ± 3.61 at 100 mg respectively while the standard drug (vit C) produced a better scavenging activity of 92.03 ± 2.93 for lipid peroxidation and 85.53 ± 3.31 for DPPH as revealed in the results of the study. The findings of this study indicates that *E. senegalensis* possesses antioxidant and antidiarrhoeal activities, and thus lend pharmacological credence to the suggested folkloric use of the plant as a natural remedy for the treatment of the ailments.

Key words: Antidiarrheal activity, antioxidant property, *Erythrina senegalensis*, ethyl acetate leaf extract

Introduction

Diarrheal diseases continue to be one of the main cause of morbidity and mortality in the world in general and sub-Saharan Africa in particular. Almost three-quarters of these mortalities among children occur in the first two years of life (Dairo *et al.*, 2017). In fact, diarrhea has remained the



second leading cause of mortality worldwide among children under five years of age next to respiratory infections and kills more young children than AIDS, malaria, and measles combined Liu *et al.* (2012). Its high prevalence rate in this region is greatly fueled by vicious cycles of poverty, ignorance, malnutrition and poor hygiene.

Diarrhea is characterized by increased frequency, fluidity, and bowel movement of three or more times per day as well as inflammatory response and oxidative stress (Agbor *et al.*, 2014). The condition, if persistent and/or without intervention, may lead to several complications and even death, due to dehydration and electrolyte loss (Dairo *et al.*, 2017). It is associated with viral, bacterial and fungal infections, food poisoning and other disease conditions as well as inflammatory response and oxidative stress (Suleiman *et al.*, 2008; Agbor *et al.*, 2014). Presently, the management of diarrhea involves the use of anti-motility agents, anti-secretory agents, anti-fungal and anti-bacterial agents and /or oral rehydration therapy (ORS). (Otimenyin and Uzochukwu, 2010). However, use of these conventional drugs has some limitations as some present with undesirable effects such as vomiting, fever, constipation, bronchospasms, dry mouth, and abdominal pains among others (Formiga *et al.*, 2017). More so, most infectious diarrhea is treated with a course of antibiotics, which currently is faced with massive drug-resistant challenges (Tadesse *et al.*, 2014; Nwabunike *et al.*, 2018) in addition to being expensive and not easily accessible to ordinary poor rural communities. A number of medicinal plants have been evaluated for their antidiarrheal properties and usefulness in the treatment, management and/or control of diarrhea (Ayalew *et al.*, 2022).

Antioxidants are chemical substances that protect the body cells from injury caused by free radicals. It is defined as any substance that when present at low concentrations compared to those of an oxidizable substrate, significantly delays or prevents oxidation of that substrate (Ikumawoyi *et al.*, 2017). Oxidative stress is a reflection of an imbalance between the systemic manifestation of reactive oxygen species and a biological system's ability to readily detoxify the reactive intermediates or to repair the resulting damage (Chandra *et al.*, 2015). Research works have been carried out to validate the potency of medicinal plant as antioxidant agent with few reports on *Erythrina senegalensis* (Yahaya *et al.* 2020; Njayer *et al.*, 2010; Gunda *et al.*, 2016).



Erythrina senegalensis DC. commonly called coral tree is a medicinal plant belonging to the family of Leguminosae. It is widely grown and used in the West African tropical and sub-tropical regions such as Nigeria and in other tropical and subtropical areas of the world (Feleke, 2021). Different parts of *E. senegalensis* have been documented to possess some pharmacological activities, for instance, the stem bark has been shown to possess antimicrobial activities (Doughari, 2010), hepatoprotective activities (Donfack *et al.*, 2008) and also inhibits HIV-1 protease (Lee *et al.*, 2009). The bark and root decoction is used for stomach disorder and hepatoprotective properties (Tepogning *et al.*, 2013). The plant has also been documented (Ahue *et al.*, 2017) to be used in the management of mental disorders and cognitive impairments. Some biological active compounds, including terpenoids, alkaloids, tannins, steroids, glycosides, phenolics, saponins, flavonoids etc. have been isolated in the different plant parts (Lai, 2014).

To the best of my knowledge no work has been documented on the antidiarrheal activities of *Erythrina senegalensis*. Therefore, as a part of our broad-based search for African medicinal plants with antidiarrhoeal properties, the present study was undertaken to examine the possible usefulness of *Erythrina senegalensis* leaf extract in the treatment, management and/or control of diarrhoea as well as their antioxidant potentials.

Materials and Methods

Plant Collection and Identification.

The fresh leaves of *Erythrina senegalensis* were collected from its natural habitat from Mbala Isuochi, in Umunneochi, L.G.A. of Abia State, Nigeria. The plant specimen was authenticated by Dr. Timothy Oluwafemi Ajiboye of National Center For Genetic Resources and Biotechnology (NACGRAB), Moore Plantation, Apata, Ibadan, Oyo State, Nigeria with herbarium reference number 775.

Chemicals, Drugs and reagents

Distilled water, ethyl acetate, sodium nitroprusside, tripyridyltriazine 1,1-diphenyl-2-picrylhydrazyl (DPPH) (Sigma-Aldrich, Germany) loperamide hydrochloride (Xian-Janssen Pharmaceutical Ltd., China), castor oil (Amman Pharmaceutical Industries, Jordan), charcoal, gum acacia (Merck, Germany) e.t.c. were analytical grade chemicals used for this study.



Extraction of Plant Materials

The plant materials were cleaned, air dried at room temperature to prevent direct effect of sun, which may likely affect the chemical constituents in the extract and then crushed into powdered form using electrical blender. The powdered material was weighed using an electronic balance (PI 303 model, China), stored in airtight containers and kept under normal room temperature until required. One hundred grams (100g) of the ground leaves of each plant was measured with an electronic balance and then submerged in the solvent (80% ethyl acetate) for 48 hours with intermittent shaking every 3 hours to ensure maximum extraction. The resulting mixture was filtered with a Whatman No. 1 filter papers and was dried in a hot air oven at 40 °C. After drying, percentage yield of ethyl acetate leaf extract of *E. senegalensis* was determined to be 15.27% w/w. The dried plant extract was reconstituted with distilled water for oral administration.

Animals

Three months old Swiss albino mice of both sexes weighing 26-32 g were obtained from the Animal Production Unit of the College of Veterinary Medicine, Michael Okpara University of Agriculture, Umudike. They were housed in metallic cages (four in each cage) at room temperature under natural light/darkness cycles and acclimatized to the animal housing storage unit and laboratory conditions for 2 weeks before the commencement of the experiment under specific pathogen free conditions. During this period, the animals were fed with standard commercial pelleted grower feed (Vital Feed, Nigeria) and clean water (*ad libitum*). They were maintained in accordance with the recommendations of the Guide for the care and use of laboratory animals (Hammond, 1994).

Antidiarrheal Study

Castor oil induced diarrhea

The method of Onoja and Udeh (2015) was used with slight modifications. Briefly, 20 mice were allowed to fast for 18 hours with free access to water and randomly divided into 5 groups of 4 animals each as follows:

- a) Group one (1) received distilled water (10 ml/kg) through oral gavage and acted as a negative control group.



- b) Group two (2) received reference drug loperamide (5mg/kg) and acted as a positive control.
- c) Groups 3–5 received orally increasing doses of ESE (75, 150 and 300 mg/kg).

After 1 hour of this administration, 1 ml/kg bwt of castor oil was administered orally to each animal to induce diarrhea. The animals were kept in separate metallic cages lined with filter paper placed beneath the cage to collect the faeces. The cages were then observed for 6 h for the presence of characteristic diarrheal droppings and the filter paper was changed every hour. Time for the onset of diarrhea and total number of wet droppings was recorded for each cage during the 6 h period of observation. The time for onset was measured as the time interval between the administration of castor oil and the first appearance of wet droppings in minutes. The absence of wet droppings was considered as protection from diarrhea, and the percentage protection was calculated according to the formula described by Umukoro and Ashorobi (2005) as follows:

$$\% \text{ inhibition of diarrhea} = \frac{\text{Mean number of diarrheal stools of (negative control-treated group)}}{\text{Mean number of diarrheal stools of control group}} \times \frac{100}{1} \quad (1)$$

Intestinal Transit of Charcoal Meal

This was done according to the method proposed by Mujumdar (1998) using charcoal meal as a diet marker. The Rats were divided into 5 groups of 4 animals each.

- a) Group one (1) of the first group will receive distilled water through oral gavage (distilled water 10 ml/kg)
- b) Group two (2) received reference drug loperamide (5mg/kg)
- c) Groups 3–5 received orally increasing doses of ESE (75, 150 and 300 mg/kg).

Half an hour later, each animal was given 1 ml of charcoal meal orally (10% activated charcoal in 5% gum acacia) and 1 ml of castor oil. Thirty minutes after this treatment, the animals were sacrificed by cervical dislocation and the intestines immediately isolated, then the pylorus and ileocecal valve were surgically ligated and the small intestine removed and outstretched on the surface of a petri dish. The total length of the intestine from pylorus to caecum (total length of small intestine) and the distance traveled by the charcoal (length traveled by charcoal meal) were measured using a ruler in centimeters (cm). The peristaltic index (PI) for each rat was calculated and expressed as a percentage (%) of the distance traveled by the charcoal meal relative to the



total length of the small intestine. The PI and percent inhibition relative to control were calculated according to Degu *et al.*, (2016) as follows:

$$\text{Peristaltic index (PI)} = \frac{\text{Intestinal length travelled by the charcoal meal}}{\text{Total length of the small intestine}} \quad (2)$$

$$\% \text{ inhibition} = \frac{(A-T) \times 1}{A} \times \frac{100}{1} \quad (3)$$

Where A=Distance traveled by charcoal meal in control group and T=Distance traveled by charcoal meal in treated groups.

Castor Oil Induced Enteropooling and Electrolyte Secretion

Intra-luminal fluid accumulation was determined by the method of Robert *et al.* (1976). Rats were divided into 5 groups of 4 animals each.

- Group one (1) of the first group will receive distilled water through oral gavage (distilled water 10 ml/kg)
- Group two (2) received reference drug loperamide (5mg/kg)
- Groups 3–5 received orally increasing doses of ESE (75, 150 and 300 mg/kg).

After 1 h mice in each group were orally administered 1 ml/kg/bwt of castor oil. 30 min later, each mice was sacrificed by cervical dislocation, and its abdomen was opened by midline incision, and the small intestines were surgically removed after ligation of the pylori and the ileocecal valves before it was isolated. The intestines were then weighed before and after removal of the intestinal content in order to determine intestinal secretion (mass in grams). The intestinal contents were squeezed and emptied into the graduated measuring cylinder, and the volume of contents was recorded. The intestine was reweighed without the intestinal contents, and the difference between the full and empty intestines was calculated, and percent inhibition was determined using the formula.

$$\% \text{ reduction in volume of intestinal content} = \frac{MVICC - MVICT}{MVICC} \times \frac{100}{1} \quad (4)$$

where, MVICC – mean volume of intestinal content (ml) of the negative control group, MVICT – mean volume of intestinal content (ml) of the treated group,

$$\% \text{ reduction in weight of intestinal content} = \frac{MWICC - MWICT}{MWICC} \times \frac{100}{1} \quad (5)$$



where, MWICC – mean weight of intestinal content (g) in the negative control, MWICT – mean weight of intestinal content (g) in the treated group.

***In vitro* Antioxidant Studies**

Determination of 1, 1, diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activities

DPPH radical scavenging capacity of the ethyl acetate leaf extract was determined according to the modified method described by (Repon *et al.*, 2013). The antioxidant activity was determined by decrease in the absorbance of methanol solution of DPPH which determine the antioxidant capacity of the plant extracts with a change in colour from deep violet to light yellow. Different concentrations of the extracts each 12.5 - 100 µg/ml were added to an equal volume of 10 ml of methanol solution of DPPH (400 µg/ml). Vitamin C was used as the standard reference compound in the concentration of 100 µg/ml. The absorbance values were measured at 517 nm on a spectrophotometer. The reaction mixture was shaken well and incubated in the dark for 15 min at room temperature. Percentage inhibition was determined using the equation:

$$\text{Percentage inhibition} = \frac{\text{Absorbance of Control} - \text{Absorbance sample}}{\text{Absorbance of Control}} \times \frac{100}{1} \quad (6)$$

Determination of Nitric Oxide Radical Scavenging Activity

Sodium nitroprusside (SNP) automatically generates nitric oxide, in aqueous solution at physiological pH, which intermingles with oxygen to generate nitrite ions that can be anticipated by Griess reagent [1% sulfanilamide, 2% phosphoric acid and 0.1% naphthyl ethylene diamine dihydrochloride (NED)]. Scavengers of free radicals result in the reduced production of nitric oxide radicals. In this assay, sodium nitroprusside (10 mM) in phosphate buffered solution (pH=7.4) was mixed with different concentrations of extract (12.5–100 µg/ml) dissolved in 10% DMSO and incubated at room temperature for 150 min. The same reaction mixture without the extract but the equivalent amount of the solvent used served as the control. After incubation, 0.5 ml of Griess reagent (1% sulfanilamide, 2% H₃PO₄ and 0.1% N- (1- naphthyl) ethylenediamine dihydrochloride) was added. The absorbance was measured at 546 nm against a blank (Bajpai *et al.*, 2015). All the tests were performed in triplicate. Vitamin C was used as the standard reference compound in the concentration of 100 µg/ml. The percent inhibition activity was calculated by the same formula as used for determination of DPPH radical scavenging activity.



$$\text{Percentage inhibition} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of blank}} \times \frac{100}{1} \quad (7)$$

Determination of lipid peroxidation inhibitory effect

The reaction mixture, in the absence and presence of the extracts (12.5-100 µg/ml) or reference compound, (100 mg/ml), 1 mM FeCl₃ and 1 mM ascorbic acid in 20 mM phosphate buffer with a final volume of 330 µl, was incubated at 37°C for 1 h. The hydroxyl radicals generated in the reaction initiated the lipid peroxidation, resulting in malondialdehyde (MDA) production that was measured by the TBA reaction. All tests in this assay were performed three times. Vitamin C was used as the reference compound.

$$\text{Percentage inhibition} = \frac{\text{Absorbance of control} - \text{Absorbance of sample} \times \frac{100}{1}}{\text{Absorbance of control}} \quad (8)$$

Statistical Analysis

The results were analyzed using SPSS software version 23 and expressed as mean ± standard error of the mean (SEM). The comparisons between group means were made using One-way Analysis of Variance (ANOVA) followed by Tukey HSD Post-hoc test. The differences between the group means were considered statistically significant at p-value < 0.05.

Results

Effects on castor oil-induced diarrhea

The result in Table 1 showed that the ethyl acetate leaf extract of *E. senegalensis* significantly (P<0.05) slowed the onset of diarrhea in a dose dependent manner with the maximum dose showing an appreciable delay in the onset of diarrhea among the treated animals (62.75±15.76^{abc}) which is comparable to loperamide, the standard drug (78.00±18.64^a). The plant extract also dose dependently and significantly decreased (P<0.05) the frequency of diarrhea drops. The highest decrease in the frequency of diarrhea drops was observed in the groups treated with loperamide (6.50±4.76^d) followed by the highest dose of *E. senegalensis* (8.00±4.76^{cd}). The percentage inhibition of the serial doses of the extract (75, 150 and 300 mg/kg) were 38.95, 47.37, 66.32% respectively. The standard drug (loperamide) produced a better effect on all the parameters (onset of diarrhea, frequency of diarrhea faeces, and percentage inhibition) compared to the negative control and plant treatments.



Effects on castor oil-induced enteropooling

From the result in Table 2, there was no statistically significant difference in the weight of the animals treated with the serial doses of *E. senegalensis*, the control as well as the standard drug. A significant difference in the volume of the stool of the animal was only observed in the control group, whereas there was no significant difference between those treated with the standard drug and the different doses of the extract. The percent reductions in the volume of intestinal contents of *E. senegalensis* were 43.00, 50.92, and 54.32% at 75, 150, and 300 mg/kg doses respectively. Similarly, the standard drug, loperamide (5 mg/kg) showed a significant reduction in the volume ($p < 0.05$) of intestinal fluid accumulation and decreased the volume of intestinal fluid by 53.51%, relative to the negative control. There was no statistically significant difference between the effects of all doses of *E. senegalensis* on the weight of the intestinal content of the animal.

Effects on intestinal motility

In Table 3, all the serial test doses of the leaves of *E. senegalensis* significantly decreased ($p < 0.05$) the intestinal transit of charcoal and peristaltic index compared to the negative control. The 300 and 150 mg/kg doses of the plant extract showed significant reduction ($p < 0.05$) in the intestinal transit of charcoal meal and peristaltic index compared to 75 mg/kg. The 75, 150, and 300mg/kg doses of the *E. senegalensis* leave extract produced, 29.25, 53.19 and 67.50 % reductions in the gastrointestinal transit of the charcoal meal, respectively. The standard drug, significantly reduced ($p < 0.05$) intestinal transit and peristaltic index compared to the negative control. The effect of the highest doses of the ethyl acetate extract of the plant against gastrointestinal transit, peristaltic index and percentage inhibition were all greater than the standard drug.

Table 1: Effects of the Ethyl Acetate Leaf Extract of *Erythrina senegalensis* on Castor Oil-induced Diarrhea in Mice

group (treatment)	dose (mg/kg)	onset	no of wet faeces	percentage of inhibition (%)
Group 1 (Distilled water)	10	50.50±24.77 ^{bcd}	23.75±1.55 ^a	0
Group 2 (Loperamide)	5	78.00±18.64 ^a	6.50±1.73 ^d	72.63
Group 3(ESE)	75	41.25±7.27 ^{cd}	14.50±1.29 ^b	38.95



Group 4 (ESE)	150	48.25±11.35 ^{bcd}	12.50±2.38 ^{bc}	47.37
Group 5 (ESE)	300	62.75±15.76 ^{abc}	8.00±4.76 ^{cd}	66.32

ESE (*Erythrina senegalensis* extract)

Values are presented as mean ± standard deviation (n= 4); standard deviation with different super script alphabet are significantly different at 5 % probability.

Table 2: Effects of the Ethyl Acetate Leaf Extract of *Erythrina senegalensis* on Castor Oil-induced Intestinal Fluid Accumulation

Group (Treatment)	Dose (mg/kg)	Total length of small intestine	Distance moved by the charcoal meal	Peristaltic index	Percentage inhibition of transit
Group 1 (Distilled water)	10	53.00±7.44	30.85±5.05 ^a	58.21 ^a	0
Group 2 (Loperamide)	5	52.18±5.04	11.88±6.60 ^{cd}	23.32 ^{cd}	61.51
Group 3 (ESE)	75	52.38±7.11	21.83±3.07 ^b	41.67 ^b	29.25
Group 4 (ESE)	150	53.13±3.75	10.68±3.63 ^d	27.18 ^c	53.19
Group 5 (ESE)	300	52.83±4.13	10.03±5.04 ^d	18.98 ^d	67.50

Values are presented as mean ± standard deviation (n=4); standard deviation with different super script alphabet are significantly different at 5 % probability.

Table 3: Effects of the Ethyl Acetate Leaf Extract of *Erythrina senegalensis* on Castor Oil-induced Enteropooling

Treatment	Dose (mg/kg)	Weight of intestinal content (g)	Volume of intestinal content (ml)	% reduction
Group 1 (Distilled water)	10	2.51±0.78	1.90±0.49 ^a	0.00
Group 2 (Loperamide)	5	2.07±0.40	0.86±0.18 ^b	53.51
Group 3 (ESLE)	75	2.30±0.67	1.06±0.61 ^b	43.00
Group 4 (ESLE)	150	2.02±0.43	0.91±0.57 ^b	50.92
Group 5 (ESLE)	300	2.35±0.74	0.85±0.18 ^b	55.32

Values are presented as mean ± standard deviation (n=4); standard deviation with different super script alphabet are significantly different at 5 % probability.



Determination of *In Vitro* Antioxidant Activity

1, 1, Diphenyl- 2-picrylhydrazyl DPPH radical scavenging activity

The highest values of scavenging DPPH radicals for the *E. senegalensis* was 64.83 ± 3.61^b (Table 4). The mean of the various treatments of *Erythrina* plant extract ranges between 6.07 ± 5.25^e - 64.83 ± 3.61^b for DPPH. Though the antioxidant potential of the extracts were found to be lower ($P < 0.05$) than those of vitamin C with 85.53 ± 3.31^a , the study revealed the plant extracts have antioxidant activity in a concentration dependent manner.

Anti-lipid peroxidation radical scavenging activity

The results in Table 5 showed that approximately all the plant sample dose dependently, inhibited lipid peroxidation. With the standard drug showing a very high inhibitory activity of (92.03 ± 2.73^a), while the extract of *E. senegalensis* produced an inhibitory activity of (65.80 ± 2.29^b).

Nitric oxide radical scavenging activity

The scavenging effect of the leaf extracts of *E. senegalensis* on nitric oxide was also concentration-dependent as seen in Table 6 with the highest concentration of the plant extract producing an inhibitory effect of (59.57 ± 1.89^b), whereas, the standard drug produced a higher inhibitory activity of (78.70 ± 4.57^b).

Table 4: Determination of 1, 1. Diphenyl- 2-picrylhydrazyl (DPPH) Radical Scavenging Activity

Treatment	<i>E. senegalensis</i>
Vit C	85.53 ± 3.31^a
100mg	64.83 ± 3.61^b
50mg	54.13 ± 3.63^c
25mg	20.57 ± 1.91^d
12.5	6.07 ± 5.25^e

Values are presented as mean \pm standard deviation ($n=3$); standard deviation with different super script alphabet are significantly different at 5 % probability.

**Table 5: Determination of lipid peroxidation inhibitory effect**

Treatment	<i>E. senegalensis</i>
Vit C	92.03±2.93 ^a
100mg	65.80±2.29 ^c
50mg	42.73±6.97 ^d
25mg	18.23±5.94 ^e
12.5	0.00±0.00

Values are presented as mean ± standard deviation (n=3); standard deviation with different super script alphabet are significantly different at 5 % probability.

Table 6: Determination of Nitric Oxide Radical Scavenging Activity

Treatment	<i>E. senegalensis</i>
Vit C	78.70±4.57 ^a
100mg	59.57±1.89 ^b
50mg	33.30±3.90 ^c
25mg	19.03±3.63 ^d
12.5	0.00±0.00 ^e

Values are presented as mean ± standard deviation (n=3); standard deviation with different super script alphabet are significantly different at 5 % probability.

Discussion

In the castor oil induced diarrhea model, the plant extract of *E. senegalensis* significantly ($P < 0.05$) delayed the onset of diarrhea at the maximum dose (300 mg/kg) and reduced the frequency of diarrheal drops in the 4-h observation period at all serial doses (75-300 mg/kg) compared to the negative controls. The significance ($P < 0.05$) dose-dependent reduction in the number of wet faeces excreted by mice treated with extracts of *E. senegalensis* when compared to the



control mice treated with distilled water showed that the extracts possess antidiarrheal activity. This is comparable to the reports of Otimenyin and Uzochukwu, (2010) on the spasmolytic and antidiarrhea effects of the bark of *E. senegalensis* and root of *K. Africana* and also similar to the results reported from the ethyl acetate leaf extract of *Morinda morindoides* (Meite *et al.*, 2009).

In general, the oral administration of *E. senegalensis* like loperamide, a drug widely used against diarrhea disorders which effectively antagonizes diarrhea induced by castor oil, prostaglandin and cholera toxin (Kan *et al.*, 2006) and which the antidiarrheal activity results from its antispasmodic and antisecretory properties on the intestine (Gandhnamathi *et al.*, 2009) lead to a significant dose-dependent increase in the latency time, a significant decrease in the frequency of defecation with a subsequent increase in the percentage of inhibition of defecation in castor oil treated animals.

Furthermore, castor oil-induced enteropooling model revealed that there was no significant reduction in the weight of the stool of the animals. However, there was only a significant reduction in the control groups when compared to the treated animals while a similar report of (Adeyemi and Akindele, 2008) on the extract of *Baphia nitida* showed that the extract reduced the number and weight of wet stools but did not have any significant effect on intestinal fluid accumulation and gastric emptying. Mengesha *et al.* (2022) reported a reduction of both volume and weight of the intestinal content in the ethyl acetate fraction of *Acacia seyal* in a similar work. In the charcoal meal study, the different doses of the extracts (75, 150 and 300 mg/kg, p.o.) decreased propulsive movements. The extract was found to decrease intestinal motility as shown by significant reduction ($p < 0.005$) in the progression of charcoal meal and peristaltic index compared to the negative control. This is in consonance with similar study on *Erythrina indica* (Sonia *et al.*, 2011). The result in this model also showed that the anti-motility effect of the highest dose of the extract was higher than the standard drug. Ihekwereme *et al.*, 2016 also reported similar findings on *Napoleona imperialis*.

The pathophysiologic mechanisms that causes diarrhea include altered intestinal motility that results in a shorter intestinal transit time, increased luminal osmolality and electrolyte release, and decreased electrolyte absorption (Kelly *et al.*, 2018). Castor oil has been commonly employed to induce diarrhea in antidiarrheal activity studies because of its ability to alter water



and electrolyte permeability changes in the intestinal mucosal membranes, resulting in fluid and watery luminal contents that flow rapidly through the small and large intestines (Mbagwu and Adeyemi, 2008). This is as a result of its ability to release ricinoleic acid, a metabolite that causes diarrhea, upon metabolism in the gut (Niemegeers *et al.*, 1984). Ricinoleic acid causes diarrhea by irritation and inflammation of the GI mucosa and promoting the release of prostaglandin, which in turn accelerates gastrointestinal motility and electrolyte secretion and lowers electrolyte absorption from the small intestine and colon thus inducing an increase in the peristalsis and an intestinal hyper secretion of fluid (Rajat *et al.*, 2013). The inhibition of prostaglandins biosynthesis prolongs the time of induction of diarrhea by castor oil (Lenika *et al.*, 2005).

Although the exact mechanism of the antidiarrheal action of the extracts could not be established in this study, various studies have shown that phytochemicals such as alkaloids, flavonoids, phenol, terpenes, tannins, saponins, steroids and glucosides) and other polyphenolic compounds possess antidiarrheal properties in various experimental animal models (Akindele and Adeyemi, 2006; Suleiman *et al.*, 2008; and Mbagwu and Adeyemi, 2008) and may be principally responsible for the antidiarrheal effects of the extract.

In general, it can be opined that the extracts probably produce antidiarrheal activity through a combination of its antimicrobial property and its ability to inhibit gastrointestinal acetylcholine release. The antidiarrheal effects of these plants may also be associated with its potent antioxidant potential as observed in this study. Umukoro and Ashorobi (2005) reported that ascorbic acid and α -tocopherol reduce prostaglandin level through the inhibition of peroxidation of phospholipids and thus ameliorate castor oil-induced diarrhea. However, further studies are required to clarify this speculation.

Several *in vitro* examination techniques are taken into consideration for assessing antioxidant activities (Mwihia, 2017). The *in vitro* antioxidant tests used in the present study include, lipid peroxidation inhibition capacity (LPIC), the nitric oxide scavenging assay, and DPPH scavenging effects.

In the DPPH radical scavenging activity model it was observed that *E. senegalensis* possess an appreciable anti-lipid peroxidation activity which was also evidenced at the highest



concentration of the extract with an inhibition activity of (64.83%) while the percentage scavenging activity of ascorbic acid was higher (92.03%) and this is in support of previous reports of (Patil *et al.*, 2009) and (Vivek *et al.*, 2013) in extracts of *Ageratum conyzoides* and *Caesalpinia pulcherrima*, respectively. Whereas, the ethyl acetate extract of *E. senegalensis* and vitamin C. showed percentage nitric oxide scavenging activities of 59.57% and 78.70% respectively at the highest concentration tested. However, it was also observed that *E. senegalensis* possess an appreciable anti-lipid peroxidation activity which was also evidenced at the highest concentration of the extract with an inhibition activity of (65.80%,) while the percentage inhibition of ascorbic acid was higher (92.03%).

Conclusion

Man has benefited from the exploitation of medicinal plants over the years for curing of diseases even before the discovery of antibiotics. From the obtained results, it was concluded that the ethyl acetate leaf extracts of *Erythrina senegalensis* possess appreciable antioxidant and antidiarrhea capacity. Hence, the findings of this study may be used as the basis to conduct further studies in the area including chemical characterization and molecular-based mechanism of actions of the plant for its confirmed pharmacological effects. More so, further studies that aimed at isolating and characterizing the pure phytoactive principles for enhancement are recommended.

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PROXIMATE COMPOSITION OF FLOUR FROM BLENDS OF UNDEHULLED AFRICAN BREAD FRUIT SEED (*Treculia africana*) AND WATER YAM (*Dioscorea alata*) WITH DEFATTED COCONUT GRITS (*Cocos nucifera*)

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Abstract

Proximate composition of flour from blends of unhulled African bread fruit seed (*Treculia africana*) and water yam (*Dioscorea alata*) with defatted coconut grits (*Cocos nucifera*) was evaluated using standard methods. The flour samples African bread fruit seed, water yam with defatted coconut grits flours were blended in the ratios of 70:20:10, 60:30:10, 50:40:10, 45:45:10 and 40:50:10 while 100% wheat flour was used as a control. The crude protein, ash, crude fibre, fat, moisture and carbohydrate contents of the flour blends were significantly different ($p < 0.05$) with the values ranging between 8.92-12.8%, 1.21-2.74%, 0.68-1.98%, 1.31-7.35%, 6.85-9.01% and 60.68-76.21% respectively. Composite flour of good qualities were obtained from flour blends of African breadfruit seed, water yam and defatted coconut flours and would find application in confectionaries and pastries which will reduce the over dependency in wheat flour in food processing.

Introduction

As of late, the utilization of indigenous flours with high fibre has picked up significance in the detailing of different nourishment items (El-Sharnouby *et al.*, 2012). This may be on the grounds that dietary fiber brings down serum cholesterol, heftiness and the solid state of the digestion tracts (Odom *et al.*, 2013; Rehinan *et al.*, 2014). The use of composite flours have a few advantages for developing countries such as Nigeria in terms of enhancement of nutritional quality of food, utilization of under-exploited crops, thus, preventing them from going into extinction and reduction in the importation of wheat flour, thereby saving of foreign exchange (Hugo *et al.*, 2000; Hasmadi *et al.*, 2014).

African breadfruit (*Treculia africana*) comprises a significant save of basic nourishment supplements that are accessible at certain basic times of the year when dependable wellsprings of



these supplements are under development and are rare (Nwabueze and Okocha, 2008). African breadfruit are wealthy in fiber (Okoye and Obi, 2017), protein, starch, fat, nutrients and minerals (Okorie, 2013).

Water yam (*Dioscorea alata*) a significant type of the *dioscoreacea* family developed in certain pieces of Nigeria for its huge roots with fine eatable flesh (Ezeocha and Oti, 2013). Water yam additionally alluded to as "winged yam" or "more noteworthy yam" as a rule has tubers that are white, dark colored or earthy red in shading (Riley *et al.*, 2006). Additionally, water yam is a harvest with potential for expanded customer request because of its low sugar content essential for diabetic patients (Ezeocha and Ojimelukwe, 2012). Notwithstanding the staggering dietary advantages of water yam, they are less famous when contrasted with different assortments of yam and is regularly viewed as nourishment for poor people (Nwike *et al.*, 2017).

Coconut (*Cocos nucifera*) is the stone of the drupes borne by the coconut palm, an individual from the monocotyledonous family Palmae. Coconut is known as the "wonder nourishment" and is viewed as impeccable eating routine since it contains practically all fundamental supplements required by the human body (Rehman *et al.*, 2004). It is named a "practical nourishment" since it gives numerous medical advantages past its healthful substance (Ramaswamy, 2014).

The aim of this work was to evaluate the proximate composition of flour blends from un-dehulled African bread fruit seed and water yam with defatted coconut grits.

Materials and Methods

Sources of raw materials

African breadfruit seeds, coconut and water yam tubers for the work were procured from National Root Crop Research Institute Umudike. All reagents that were used for analysis was obtained from the analytical laboratory of the Department of Biochemistry, National Root Crop Research Institute Umudike, Abia State.

Formulation of composite flour

The flours were blended into composite as shown in Table 1

**Table 1: Flour blends formulation (%)**

Sample codes	Wheat flour	African breadfruit seed flour	Water yam flour	Defatted coconut grits
101	100	0	0	0
102	0	70	20	10
103	0	60	30	10
104	0	50	40	10
105	0	45	45	10
106	0	40	50	10

Method of Analysis

Proximate composition of flour samples were determined according to methods described by Onwuka (2018).

Results and Discussions

The results of proximate composition of composite flour from African bread fruit and water yam with defatted coconut grits is presented in Table 2.

Table 2: Proximate composition of flour from blends of undehulled African bread fruit seed and water yam with defatted coconut grits

Sample	Crude protein	Ash	Crude fibre	Fat	Moisture content	Carbohydrate
101	11.58 ^b ±0.01	1.21 ^f ±0.01	0.68 ^e ±0.01	1.31 ^f ±0.01	9.01 ^a ±0.01	76.21 ^a ±0.01
102	12.83 ^a ±0.01	2.16 ^e ±0.01	11.98 ^a ±0.01	7.35 ^a ±0.01	7.92 ^b ±0.01	57.76 ^f ±0.01
103	11.56 ^c ±0.01	2.31 ^d ±0.01	11.47 ^b ±0.01	6.44 ^b ±0.01	7.54 ^c ±0.01	60.68 ^e ±0.01
104	10.28 ^d ±0.01	2.47 ^c ±0.01	11.09 ^{bc} ±0.01	5.58 ^c ±0.01	7.20 ^d ±0.01	63.04 ^d ±0.03
105	9.64 ^e ±0.01	2.52 ^b ±0.01	10.81 ^c ±0.01	5.17 ^d ±0.01	7.02 ^e ±0.01	64.85 ^c ±0.01
106	8.92 ^f ±0.01	2.74 ^a ±0.01	10.48 ^d ±0.01	4.74 ^e ±0.01	6.85 ^f ±0.01	65.97 ^b ±0.01

Values are means ± standard deviation of duplicate determinations. ^{a-f} means bearing different subscript on the same column are significantly (p<0.05).

Where 101 = 100% wheat flour; 102 = 70% =African breadfruit flour, 20% water yam flour & 10% defatted coconut grits; 103 = 60% a=African breadfruit flour, 30% water yam flour & 10% defatted coconut grits; 104 = 50% a=African breadfruit flour, 40% water yam flour & 10% defatted coconut grits; 105 = 45% a=African breadfruit flour, 45% water yam flour & 10%



defatted coconut grits; 106 = 40% a=African breadfruit flour, 50% water yam flour & 10% defatted coconut grits

Crude protein content of the flours ranged from 8.92 to 12.83 %. It was observed that increase in African breadfruit flour caused a significant increase ($p < 0.05$) in crude protein of the flours. Sample 106 (Flour from 40% African breadfruit flour, 50% Water yam flour and 10% Defatted coconut grits) recorded the least crude protein (8.92%) while sample 102 (Flour from 70% African breadfruit, 20 Water yam flour and 10% Defatted coconut grits) had the highest crude protein (12.83%). Higher value of crude protein content recorded in sample 102 (Flour from 70% African breadfruit seed, 20 % Water yam flour and 10% Defatted coconut grits) could be attributed to higher quantity of African breadfruit seed flour in the sample. This is in agreement with the report of Okorie (2013) that African breadfruit seed being a legume is rich in protein. Uluocha *et al.* (2016) affirmed that African breadfruit seed have substantial amount of protein content which helps to meet inadequate consumption of protein food; especially in rural parts of Nigeria. Significant increase in crude protein (5.19 to 20.98 %) with corresponding increase in the proportion of flour from a legume (pigeon pea) in composite flours produced from blends of water yam, pigeon pea and carrot pomace has also being reported by Adeola *et al.* (2017). This finding is also in accordance with the report of Okorie *et al.* (2016) for decreasing trend in crude protein content of composite flours produced from water yam and cowpea (18.56 to 1.85 %) as proportion of water yam flour increases. Compared to the recommended daily allowance of protein for males and females (9.1 to 56 g) (Boyle and Holben, 2006), values of protein obtained in flours produced in this study was substantial. This suggests that the flours may be useful in food formulation in societies with high protein deficiency and could also compensate for the large proportion of carbohydrates often ingested in Africa diets (Oyeyinka *et al.*, 2013).

Ash content of the flours ranged from 1.21 to 2.74 %. It was observed that decrease in African breadfruit flour caused significant increase ($p < 0.05$) in ash content of the flours. Sample 106 (Flour from 40% African breadfruit flour, 50% Water yam flour and 10% Coconut grits) recorded the highest ash content (2.74%) while sample 101 (Flour from 100% Wheat grain) recorded the least ash content (1.21%). Higher value of ash content recorded in sample 106 (Flour from 40% African breadfruit seed, 50 Water yam, 10% Defatted coconut grits) could be



attributed to higher quantity of water yam flour in the sample. This is in agreement with the report of Udensi *et al.* (2008) that water yam is a good source of ash with values ranging from 2.25 to 3.15 %. The ash content of flours produced in this study was lower than 2.04 to 4.01 % reported for flour blends of water yam and cowpea (Okorie *et al.*, 2016). Furthermore, 0.46 to 0.98 % of ash content reported by Adegunwa *et al.* (2014) for plantain-breadfruit composite flours was lower than the values obtained in this study. These variations could be ascribed to differences in raw materials used in composite flour formulation. Percentage ash of foods gives an idea about the inorganic content of the foods from where the mineral content could be obtained (Bello, 2008). It also aid in the metabolism of other organic compounds such as carbohydrate and fat (Sowoola *et al.*, 2002). Das *et al.* (2009) demonstrated foods possessing ash content of 3 % and above are ideal and recommended for food for humans. This implies that flours produced in this study might not aid in the metabolism of other organic compounds such as carbohydrate and fat (Sowoola *et al.*, 2002). But this is not of concern considering that most products from this flour are eaten between meals.

Crude fibre content of the flours ranged from 0.68 to 11.98 %. It was observed that increase in African breadfruit flour caused a significant increase ($p < 0.05$) in crude fibre content of the flours. Sample 102 (Flour from 70% African breadfruit flour, 20% Water yam flour and 10% Defatted coconut grits) recorded the highest crude fibre content (11.98 %) while sample 101 (Flour from 100% Wheat grains) had the least crude fibre content (0.68 %). Highest value of crude fibre content recorded in sample 102 (Flour from 70% African breadfruit flour, 20% Water yam flour and 10% Defatted coconut grits) could be attributed to higher quantity of African breadfruit flour in the blend. Earlier publication showed that African breadfruit contains 1.5 % of crude fibre (Wang *et al.*, 2011). More so, higher fiber content generally recorded in composite flours might be due to addition of defatted coconut grits to the products as coconut is reported to be high in fiber (Okafor and Ugwu, 2014). Trinidad *et al.* (2006) reported that coconut contains 60.9 % total dietary fiber (consisting of 56.8 % insoluble and 3.8% soluble). Such increase in crude fibre content with substitution of coconut grits is well documented (Obasi and Ifediba, 2018). Nutritional claims for dietary fibre foods recommended that for a product to be labeled as “source of fibre” it must contain > 3 g of dietary fibre/100 g (OJEC, 2012). This implies that



flours produced from blends of African breadfruit, water yam and coconut grits are source of dietary fibre, thus, consumption of products from the composite flour have the potential to lower serum cholesterol, obesity, healthy condition of the intestines (Odom *et al.*, 2013), and also aid the digestive system of human (Amusa *et al.*, 2002).

Fat content of the flours ranged from 1.31 to 7.35 %. It was observed that increase in African breadfruit flour caused a significant decrease ($p < 0.05$) in fat content of the flours. Sample 102 (Flour from 70% African breadfruit flour, 30% Water yam and 10% Defatted coconut grits) recorded the highest fat content (7.35 %) while sample 101 (Flour from 100% Wheat grain) had the least fat content (1.31 %). Highest fat content recorded in sample 102 (Flour from 70% African breadfruit flour, 30% Water yam and 10% Defatted coconut grits) could be attributed to higher quantity of African breadfruit flour in the sample. This is in agreement with findings of earlier publication that African breadfruit flour contains 11 % of fat (Akubor *et al.*, 2000). More so, Giami *et al.* (2004) affirmed that African bread fruit seed has high oil content. Fat content of flours produced in this study was higher than 1.01 to 4.86 % obtained from water yam-pigeon pea-carrot pomace flour blends (Adeola *et al.*, 2017), 0.42 to 0.63 % obtained from water yam-cowpea composite flour (Okorie *et al.*, 2016) but lower than 11.67 to 12.17 % reported for composite flours of plantain and breadfruit (Adegunwa *et al.*, 2014). Variations in fat content of the flours could be attributed to difference in raw materials used in their formulation. Diet providing 1 to 2 % of its caloric of energy as fat is said to be sufficient to human beings (Antia *et al.*, 2006). This implies that the developed flours could provide the body with maximum energy and facilitate intestinal absorption and transportation of fat-soluble vitamins A, D, E and K (Dreon *et al.*, 1990). More so, use of the composite flours in food formulation systems is imperative considering that fats in food products retains flavour and as well increases mouth feel of the products (Etudaiye *et al.*, 2008).

Moisture content of the flours ranged from 6.85 to 9.01 %. It was observed that increase in African breadfruit flour caused a significant decrease ($p < 0.05$) in moisture content of the flours. Sample 106 (Flour from 40% African breadfruit seed, 50% Water yam flour and 10% Defatted coconut grits) recorded the least moisture content (6.85 %) while sample 101 (Flour from 100% Wheat grain) had the highest moisture content (12.83 %). Moisture content of any food is an



index of its water activity and is used as a measure of stability and susceptibility to microbial contamination (Uyoh *et al.*, 2013). Higher moisture content recorded in sample 101 (Flour from 100% Wheat grain) could probably be that wheat flour used in this study possess higher moisture content than African breadfruit flour, water yam flour and coconut grits. This might be one of the reasons Uyoh *et al.* (2013) stated that moisture content of foods is influenced by factors such as storage condition. This implies that it possess higher tendency to help the body as the body does not need to use some of its own water to digest the food. This means that the body uses lesser energy and resources to digest and can then assimilate all the nutrients much faster. Lesser pressure is therefore put on the digestive system (Kwenin *et al.*, 2011). Values obtained for moisture content of flours produced in this study was lower than 9.14 to 10.97 % reported for water yam, pigeon pea and carrot pomace flour blends (Adeola *et al.*, 2017), and 9.43 to 10.44 % reported for water yam-cowpea composite flours (Okorie *et al.*, 2016). More so, the moisture contents of the flour blends formulated in this study were less than 10 %. This signifies its stability from moisture-dependent deterioration (Ayo-Omogie and Ogunsakin, 2013).

Carbohydrate content of the flours ranged from 57.76 to 76.21 %. Increase in water yam flour caused a significant increase ($p < 0.05$) in carbohydrate content of the flours. Sample 102 (Flour from 70% African breadfruit seed, 20% Water yam and 10% Defatted coconut grits) recorded the least carbohydrate content (57.76 %) while sample 101 (Flour 100% Wheat grain) had the highest carbohydrate content (76.21 %). Similarly, recent publication has it that carbohydrate content decreased with increase in African breadfruit flour (Obasi and Ifediba, 2018). This could be attributed to dilution effect of carbohydrate by African breadfruit which is well known to be a legume. This is not of concern since the lower the carbohydrate content of a food the more it is of immense benefit for diabetic and hypertensive patients requiring low sugar diets (Adewusi *et al.*, 1995). Highest carbohydrate content recorded in sample 101 (Flour from 100% Wheat grain) is an expected phenomenon considering that Adams *et al.* (2002) reported that nutritionally wheat contains 78.10 % carbohydrate. The range of carbohydrate content obtained in this study was lower than 83.60 % reported for soft wheat flour (David *et al.*, 2015) but higher than 55.5 to 59.1 % obtained from African breadfruit kernel flours processed using different methods (Akubor and Obiegbum, 2014). According to Butt and Batool (2010), higher carbohydrate



content recorded in flour produced from 100 % wheat than those of composite flours suggests that it has higher potential to be used in managing protein-energy malnutrition since there is enough quantity of carbohydrate to derive energy from in order to spare protein so that protein can be used for its primary function of building the body and repairing worn out tissues rather than as a source of energy. Carbohydrates are good sources of energy and at that; its high concentration it is desirable in breakfast meals and weaning formulas. In this regard therefore, higher carbohydrates content of the wheat flour would make it a better source of energy in breakfast meals formulations (Butt and Batool, 2010).

Conclusion

The study has not only clearly revealed that composite flour of good quality properties can be produced from local staples but also demonstrated the applicability of blends of flours from unhulled African breadfruit seed, water yam and coconut grit. Results of proximate composition showed that flour from blends of unhulled African breadfruit seed, water yam and defatted coconut grits possess higher crude protein, fat, crude fibre, and ash, with lower moisture content, and carbohydrate. It is therefore recommended that production of composite flour from blends of 40% unhulled African breadfruit seed, 50% water yam and 10% defatted coconut grits be encouraged as this could save a good deal of foreign exchange as well as encourage the use of indigenous local staples and in turn reduce the importation cost of wheat flour in Nigeria.

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EFFECTS OF DIFFERENT PRE-TREATMENT METHODS ON OIL YIELD AND QUALITY PROPERTIES OF AFRICAN OIL BEAN SEED OIL

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Abstract

Oil yield and quality are significant index factors for profitability in oilseed processing. African oil bean seed is rich in high level unsaturated lipids desired for culinary and some industrial applications. Conventional methods for oil extraction are time, solvent and high energy consuming as well as varying oil yields, poor quality and costly. Hence, this study to evaluate the effects of different pre-treatment methods on the yield and quality properties of African oil bean seed oils. African oil bean seed were subjected to cooking and toasting pre-treatment methods; while the raw served as control. Thereafter, each sample was milled into powder separately using locally fabricated attrition mill and oil was extracted from each pre-treated powder via Soxhlet extraction using n-hexane. Oil yield of each sample was calculated and their quality properties evaluated. Oil yield results were respectively 42.38% and 58.19% for cooked and roasted while the control was 46.88%. Quality properties ranged from 2.51 to 6.84 meq O₂/kg fat, 0.25 to 7.37% and 0.03 to 1.84 mg/g for peroxide, free fatty acid and thiobarbituric acid values respectively. Toasting African oil bean seeds before oil extraction has the highest oil yield but poor in quality while oil samples obtained from raw African oil bean seeds had the best quality parameters. Therefore, types of pretreatment decide the oil yield and quality.

Key words: Roasting, cooking, quality, oil yield, African oil bean seed oil.

Introduction

Vegetable oils are source of calorie, fatty acids and fat-soluble vitamins like vitamin A, D, E, and K. They encompass linoleic and alpha-linolenic acids, together with protective micronutrients like tocopherols (Vergallo, 2020). Vegetable oils are source of edible fatty acids, which play an important role in cellular metabolism as a way to store energy and also by providing energy when required (Kumar *et al.*, 2016). Vegetable oils being mainly used in frying, cooking or in manufacturing of food products like margarines, spreads and confectionaries are basically



extracted from crops like soybean, canola, sunflower and peanut (Kumar *et al.*, 2016) with limited attention to lesser known crops like African oil bean seed.

African oil bean seed (*Pentaclethra macrophylla*) is one of such seeds from which vegetable oil can be obtained. It is a native of tropical Africa and belongs to the family *leguminosea* and subfamily of *Mimosoideae* (Nwanagba *et al.*, 2020). It is known as 'Ugba' in Igbo, 'Ukana' by the Efiks in southern Nigeria, 'Ebaye' in Cameroon, and it is a popular condiment and meat analogue among consuming populations (Kar and Okechukwu, 2018). The oil-bean seeds contain 4-17% carbohydrate, 44-47% oil which has been found to be rich in oleic acid and linoleic acid. Ifeoluwa *et al.* (2014) also found out that the saturated fatty acid, lignoceric acid, occurred in high amounts constituting about 10% of the total fatty acid concentration. The oil of African oil bean seed is brownish-yellow in colour with the oil yield ranging from 34.00 to 51.70% (Ordu and Yingobo, 2021). African oil bean seeds oil has valuable fatty acid ester essential for human growth and development. Some of the chemical attributes of African oil bean seeds oil includes acid value (1.40 mg/KOH/g), peroxide (18.0 meq O₂/kg), iodine value (84.84 g/100 g) and saponification value (193.12 mg KOH/g) (Ordu and Yingobo, 2021). African oil bean seeds oil contains bioactive contents like sitosterol (457.58 mg/100 g), campesterol (34.54 mg/100 g) and stigma-sterol (18.52 mg/100 g) (Oyedeji *et al.*, 2019).

Conventional methods for oil extraction are time and solvent consuming, in addition to high energy cost which reflect on the final product cost. Aremu and Ogunlade (2017) opined that oil yield of vegetable oils is dependent on several factors like moisture content, seeds dimension, heating time and temperature. Therefore, altering African oil bean seed structure through cooking, roasting, among others, to improve mass transfer of lipids from the seed matrix is critical for maximizing oil yield and quality as well as save energy. This study therefore aimed at studying the effects of different pre-treatment methods on oil yield and quality properties of African oil bean seed oil.

Materials and Methods

Source of raw material

African oil bean seeds were purchased from Garki market in Enugu North Local Government Area, Enugu State.



Preparation of raw, roasted and cooked African oil bean seed powder

The method described by Okolo *et al.* (2016) was used in processing raw African oil bean seeds into powder. Roasted African oil bean seeds powder was obtained according to the method described by Onwuzuruike *et al.* (2022). For cooked African oil bean seed powder, African oil bean seeds (1 kg) were sorted, washed with clean water and cooked for 4 h. After boiling, the seeds were drained for 5 min, allowed to cool to 35°C for about 40 min and dehulled using a knife. Dehulled seeds were washed with portable water, sliced into smaller sizes of about 1.5 cm, oven drying (60°C for 48 h), milled with attrition mill to obtain cooked African oil bean seed mesocarp powder and was packaged in airtight plastic container until extraction.

Extraction of African Oil Bean Seed Oil

Oil from each powdered sample was obtained using Soxhlet extraction method as described by Onwuzuruike *et al.* (2022) with slight modification in quantity of African oil bean seed powders used.

Oil Yield Determination

The percent oil yields from pretreated African oil bean seeds were calculated using the equation described by Adepoju *et al.* (2019)

$$\text{oil yield (\%)} = \frac{W_o}{W_s} \times 100 \quad (\text{Eq. 1})$$

Where W_o = mass of oil extracted (g). W_s = mass of the seeds used (g).

Quality parameters determination

Peroxide value and free fatty acid values were determined according to the method described by AOCS (1993) while thiobarbituric acid number was determined according to the method described by Ankapong (2010).

Statistical Analysis

All experimental data were expressed as mean \pm SD (standard deviation) of duplicate determinations. The data were subjected to a one-way analysis of variance (ANOVA) using the SPSS software (version 21, IBM, USA) to determine the significant difference among the



experimental data, while Duncan Multiple Range Test (DMRT) method was used to separate the means of experimental data at 95% confidence interval.

Results and Discussion

Oil Yield as a Function of Different Processing Methods

The oil yield results of raw, cooked and roasted African oil bean seed oils were presented in Table 1. They are 46.88%, 42.38% and 58.19% respectively for raw, cooked and roasted samples. Oil yield is the amount of oil extracted per specific quantity of oil seed (Tenyang *et al.*, 2017). The results of oil yield showed that roasted African oil bean seeds had the highest oil yield than raw and cooked counterparts and might be utilized as a pre-treatment approach to enhance oil extraction. The current results are in agreement with Hojjati *et al.* (2016) and El-Beltagi *et al.* (2022), who reported that the oil content of wild almonds and sesame seed respectively, increased with roasting. This is because dry heating evaporate water from the interior of seeds microstructure, which increased the pressure inside the seed thereby causing material disintegration by rupturing cell membranes and increasing porosity. The increased porosity improves oil recovery efficiency by enabling oil passage. The lesser oil yield of unroasted oil seeds was attributable to the intactness of cell wall breakage through pressing, but after roasting, the porosity of the cell walls will increase, allowing the liberation of oil which in turn, increases the effectiveness of the oil recovery (Moghimi *et al.*, 2018). More so, cooking reduced the oil recovery effectiveness due to the increase moisture intake that mitigate the release of fat droplets for extraction, hence, the low oil yield of cooked African oil bean seed (Tenyang *et al.*, 2017). In general, African oil bean seed was shown to have appreciable oil content which classifies the oil seed as a rich source of vegetable oil. Oil seeds with oil content above 25% are considered to be good sources of edible oils (Akindele and Nsuhoridem, 2018). The oil yields of the present study exceeded 25% and may therefore be classified as good sources of edible oils for commercial exploitation. Raw and cooked African oil bean seed oils of this study was in agreement with the content reported by Esther *et al.* (2008) (47.90%) except roasted African oil bean seed oil which was higher. Ordu and Yingobo (2021) and Osabor *et al.* (2017) reported respective lower oil yield of 38.09% and 25.54%. The variation in the oil yields may be attributed to factors such as



pre-treatment methods prior to oil extraction, variety used, growing environment, soil influence as well as the method of extraction.

Table 1: Percentage oil yield from raw, cooked and roasted African oil bean seed

Pre-treatment methods	Percentage oil yield (%)
Raw(control)	46.88 ^b ±0.64
Cooked	42.38 ^c ±0.03
Roasted	58.19 ^a ±0.01

Values are means ± standard deviation of duplicate determination. Means with different superscripts (a-c) within each column are significantly different (p<0.05).

Quality Parameters of Raw, Cooked and Roasted African Oil Bean Seed Oils

The results are presented in Table 2.

Table 2: Quality parameters of raw, cooked and roasted African oil bean seed oils.

Oil samples	PV (meq O ₂ /kg fat)	FFA (% Oleic acid)	TBA (mg/g)
Control (soybean oil)	2.51 ^d ±0.02	0.25 ^d ±0.02	0.03 ^d ±0.01
Raw African oil bean seed oil	3.16 ^c ±0.02	4.04 ^c ±0.02	0.59 ^c ±0.01
Cooked African oil bean seed oil	4.47 ^b ±0.03	4.96 ^b ±0.02	0.61 ^b ±0.04
Roasted African oil bean seed oil	6.84 ^a ±0.18	7.37 ^a ±0.08	1.84 ^a ±0.01

Values are means of duplicate samples ± standard deviation. Means with different superscripts (a-d) within each column are significantly different (p<0.05). PV=Peroxide value. FFA= Free fatty acid value. TBA= Thiobarbituric acid value.

Peroxide value (PV)

Peroxide value (PV) is a measure of the level of lipid oxidation which decides the level of edible oils freshness (Potocnik *et al.*, 2018). Oils with high amounts of peroxides oxidize faster (Suri *et*



al., 2019). The peroxide results in Table 2, revealed that there were significant differences ($p < 0.05$) among the entire oil samples which ranged from 2.51 to 6.84 meq O₂/kg fat. Among the entire oil samples, the control had the least PV value compared to thermally processed counterparts (cooking and roasting). This could be aligned with its refined nature. Conversely, higher peroxide value in roasted African oil bean seed oil compared to other oil samples might be attributable to the acceleration of dry heat in the presence of air on the breakdown and decomposition of fatty acids to form peroxide compounds (Aditya *et al.*, 2015). Similar result had been reported by Potočnik *et al.* (2018). Higher PV results obtained in this study could be due to the attack of free radicals on unsaturated fatty acids, resulting in the build-up of hydroperoxides, which will likely increase the peroxide value in early phases or reduce peroxide value at high roasting temperature (Suri *et al.*, 2019). Peroxide value of the present study was lower than 18.00 meq O₂/kg reported by Ordu and Yingobo (2021) and 20.06 meq O₂/kg by Akinlabu *et al.* (2019). According to the CODEX Alimentarius standard for vegetal oil, the maximum allowable limit of PV is 10 meq O₂/kg fat (CODEX, 1999). The PV values of the present study are below the recommended maximum limit indicating slow oxidation rate and therefore are acceptable as fresh oils.

Free fatty acids (FFA)

The suitability of a vegetable oil for any culinary or industrial application depends on its free fatty acid values (FFAs) (Visioli *et al.*, 2018). Oils with high FFA values are highly associated with large losses of the natural oil during refining and therefore not undesirable and unacceptable during extraction. Ingestion of such oils implies increase blood cholesterol (Bazina and He, 2018). Hence, the overall quality of edible oil can be ascertained by the quantity of FFA present. Causes of high concentration of FFA value may be attributed to high extraction temperature, moisture in oil and supremely, lipases coming from the source or contaminating microorganisms (Atinafu and Bedemo, 2014). High free fatty acids accelerate oxidation of oils by decreasing the surface tension of the oil for increased diffusion rate of singlet oxygen from the headspace into the oil (Lozano-Castellon *et al.*, 2022). Free fatty acid (FFA) of the entire oil samples ranged from 0.25 to 7.37% with the control having the lowest FFA value because it is a refined oil where the FFA have been removed while roasted African oil bean seed oil had the highest, then



followed by cooked African oil bean seed oil. Higher values of the thermally processed samples could be attributed to the oil's thermal degradation as well as oxidation which may have generated many volatile substances like alcohols, aldehydes, alkanes, carboxylic acids. Additionally, many of these volatile chemicals may have also participated in Maillard reaction or generated fragrance compounds (Ji *et al.*, 2019). High number of volatile chemicals suggests that African oil bean seeds were enzymatically hydrolyzed through harvesting, handling, or oil extraction (Gharby *et al.*, 2015). High temperatures have been reported to cause increased FFA formation (Atinafu and Bedemo, 2014) which may be attributed to the higher FFA obtained in cooked and roasted African oil bean seed oils. Results of this study were higher than 0.70% reported by Ordu and Yingobo (2021) and 2.92% from Okpo and Evbuomwan (2014) who both worked on Ugba seeds. Only the control (0.25%) met the <0.05-0.5% maximum stipulated FFA level recommended by CODEX (1999) for edible oils compared to the rest and therefore a better quality, may be due to none thermal pre-treatment.-

Thiobarbituric acid value (TBA)

This is value index of the extent of secondary oil oxidation which occurs when the hydroperoxides formed during the primary oil oxidation (Aditya *et al.*, 2015) decomposes to form carbonyls and other compounds, particularly, aldehydes to give rancid odour. Therefore, the lower the TBA, the better the quality of the oil. The test is particularly useful for oils of low peroxide value (PV) and for assessing the quality of highly unsaturated oils (Orthoefer, 2006). Thiobarbituric acid values of this study ranged from 0.03 to 1.84 mg/g with significant differences ($p < 0.05$) among the oil samples. The roasted oil sample had the highest value (1.84 mg/g), followed by cooked sample (1.61 mg/g) while the control had the least (0.03 mg/g). These results reflect the levels of secondary oxidation products such as aldehydes and ketones likely to be present in the oil. The TBA values of the entire oil samples were considerably low compared to standard. permissible value of 4 mg/g allowable for edible oil (Agnieszka and Joanna, 2013), Though roasted and cooked samples had higher TBA values compared to the control, the entire TBA values were below the permissible level suggesting low concentration of secondary oxidation products and therefore may remain fresh for longer period before giving out rancid flavour.



Conclusion

The effects of different pre-treatment methods on the yield and quality properties of African oil bean seed oils evaluated in this study revealed that, roasting pre-treatment increased the oil yield of African oil bean seed but had poor quality while that from raw sample had better quality profile. Cooking pre-treatment method resulted to the lowest oil yield. This study has clearly demonstrated that the type of pretreatment an oil seed is subjected to prior to oil extraction affect significantly the yield and oil properties of the extracted oil.

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STRENGTH PROPERTIES OF KRAFT PAPERBOARD FOR FRESH TOMATO PACKAGING

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Abstract

Tomato is one of the most widely cultivated and extensively consumed fruit in Nigeria but perishable and changes continuously after harvest. The strength and type of package used to package tomato can extend its shelf life. This research was conducted with the overall objective to determine the strength properties of the packaging material and shelf life of tomato with the package. This study used Kraft paperboard to package 25 pieces of average sized tomatoes which was used to design the volume of the package as its weight first initiated noticeable deflection of the Kraft paperboard under three point bend fixture. The test pieces for flexural strength and stiffness test were 14mm wide and 120mm long. The result of the study showed that the minimum/maximum temperature and relative humidity were 28.1⁰C / 34.5⁰C and 71.7% / 85.9% respectively. Similarly, the maximum/minimum flexural strength and stiffness were 2.4339N/mm²/ 7.9894N/mm² and 0.6388N/mm / 2.1698N/mm over 16 days shelf life of tomato in the package. There was significant difference between flexural strength (0.0002) and stiffness (0.0011). The study showed that relative humidity is the most influential parameter affecting the strength properties of Kraft paperboard with correlation coefficient of -0.7467 with flexural strength.

Keywords: Tomato, Package, Kraft paperboard, Strength properties.

Introduction

The strength of any packaging material greatly affects the usefulness of it in packaging fresh tomato. Fresh tomatoes are fruits widely grown in Nigeria. It can be canned, eaten fresh with abundance of vitamin C and other minerals such as calcium, phosphorus, iron, sodium, potassium and zinc. (Produce for better wealth foundation, 1999).

Fresh tomato packaging can be defined simply as the packing of fresh tomatoes in an enclosure as required which include protection against brushing and physical injury, protection against microbial contamination and deterioration, ventilation provision for respiration and exchange of gases, protection against moisture and weight loss, slowing down respiration rate, delaying



ripening, increasing storage life and controlling ethylene concentration in the package (Gulzar, 2014).

Many materials has been used to package tomatoes such as polymeric films, plastic pun net, plastic tubular net, bamboo basket, kilt plastic basket and wooden boxes with their various limitations. In a study by Ashenafi, (2018), to determine the shelf life and quality of tomato fruit with low density perforated polyethylene, non-perforated low density polyethylene, carton and without packaging as control. The result of the study showed that perforated polyethylene had the highest shelf life of nine days. Similarly, Anyasi *et al.* (2016), used four low density polyethylene packages to package tomatoes treated each with potassium permanganate solution, boric acid, calcium chloride and a mixture of boric acid and calcium chloride. They also had non packaging as a control. The result showed that the maximum shelf life of 21 days was observed without testing the effects of the chemicals. Therefore, there is the need to package tomatoes naturally without chemicals and prevailing environmental conditions and also determine the strength properties of such material.

Kraft paperboard is made from wood pulp. It is known for high strength capable of being used for packaging. (Scott and Trosset, 1989). The Kraft paperboard has a smooth surface that will not easily scratch the surfaces of tomatoes. It can be easily folded into shape. The Kraft paperboard is easily recycled to produce another paperboard to reduce environmental pollution.

Despite its suitability and strength, Kraft paperboard effectiveness in packaging tomatoes under varying humidity conditions is not well understood. The influence of varying temperature and its effects to extending tomatoes shelf life in Kraft paperboard needs to be studied. Similarly, the flexural strength and stiffness of Kraft paper board under weight of packaged tomatoes with time needs to be understood. Hence, the need to study the strength properties of Kraft paperboard for fresh tomatoes packaging in portable packages that can be packed in crates for retail selling.

Materials and methods

The materials and method of the research adopted are stated in this section.

Description of study area

The study was conducted at the Chemical Engineering Laboratory of Federal Polytechnic Nekede, Imo State, Nigeria. Nekede is located 5.41870N, 7.07530E in Owerri West local



government area of the state. It is about two (2) Km from Owerri capital city of Imo state. The study was conducted in April, 2022. The average temperature and humidity of Nekede at that period is 30°C and 73.5% respectively during the experimentation time.

Experimental materials and equipment used:

The Kraft paper of single wall (also known as double face corrugated) was used as the packaging material. Other materials are shown in Table 1

Table 1: Equipment used for the study

S/N	DESCRIPTION	FUCTIONS
1	Axion Fast X – ray fluorescence (XFR)	Used to determine the chemical content of tomato and paper board
2	Chemical Weighing Balance	Used for weight determination
3	Digital Hygrometer	Used to determine maximum and minimum temperature and humidity
4	Flexural Testing Machine	Used to test the Flexural Strength and Stiffness of paper board
5	Gas Chromatography – Mass Spectroscopy (GC – MS) Machine	Used to determine chemical state of tomato and paper board when shelf life has been exceeded
6	Software Packages: Autocad, and Matlab	Autocad – Used for drawing design Matlab – Used for Graphing

Sample preparation and sampling criteria

The criteria for selecting a tomato were averaged sized tomato with about 5.5cm height and 6.5cm diameter, well ripped tomato without green spots and tomato without surface scratch or decay. The selected tomatoes were washed with clean water. They were kept to dry before packaging. The packages were designed to be portable for retail selling. The weight of an averaged sized tomato was taken. The weight of 25 pieces of averaged sizes tomatoes gave initial deflection when packed on top of Kraft paperboard with three point bend fixture. The package was design by volume calculation of 25 average sized tomatoes. The standard used for flexural



strength is ASTM D790 while DIN 53121 was used for stiffness. ASTM D790 uses three point bend fixtures while DIN 53121 uses force to bend a test stripe to a specified angle. The two standards were used to design the test pieces for flexural strength and stiffness as follows: 14mm wide and 120mm long.

Method of analysis

The analysis was done with tomatoes packaged in Kraft paperboard and literatures from other fresh tomato packaging. The temperature, humidity, chemical content of tomato and flexural/stiffness stripe from the package were collected during the experimental period on the packages. The collected data were used to determine the shelf life of the tomatoes in the packages. The data were taken from the packages during the packaging period before the shelf life was exceeded.

Chemical effect

The chemical contents of tomatoes, Kraft paper and decayed tomatoes on the Kraft paper were determined and analyzed. According to Ali *et al.* (2020), all mineral contents are grouped into major elements, trace elements and ultra-trace elements. In their findings, major elements are needed daily above 50 milligrams, trace elements are needed below 50 milligrams while ultra – trace elements are needed about 1 micrograms daily.

Shelf life

The shelf life of tomato is a period of time which starts from harvest and extends to the beginning of the decay of tomato.

Strength Properties

The two strength properties that were considered in this research were that of flexural strength and stiffness. To do this, the following standard formulas were used:

Flexural Strength:

$$\sigma_f = \frac{3Fl}{2bd^2} \quad (1)$$

Where σ_f is flexural strength, F is force, L is support span, b is breath of test piece, d is thickness of testpiece while 3 and 2 are constants.

Stiffness:



$$S_b = \frac{f}{\Delta L} \quad (2)$$

Where S_b is stiffness, f is force and ΔL is change in length of test piece.

Environmental influences

Tomatoes are living organisms even after harvesting. Their shelf life is dependent on the prevailing environmental conditions. The freshness of tomato can only be sustained if the normal metabolism activities continue. The metabolism involves the absorption of oxygen by tomatoes to break down available carbohydrates to produce water, carbon iv oxide and heat. In this process, some heat is lost reducing the Gibbs energy. Whenever oxygen needed is restricted, it will lead to the production of small quantity of alcohol which initiates its spoilage. The environmental factors that can easily affect the shelf life of tomatoes include: - temperature, relative humidity, concentration of oxygen, carbon iv oxide and ethylene. The environmental conditions also influence the respiration rate as well as the transpiration rate. Consequently, transpiration and respiration are two major outcomes of the environmental effects that greatly influence the shelf life of tomato.

Results and Discussion

The results and discussion of the research are stated in this section.

Table 2: Stiffness, flexural strength, maximum temperature and maximum humidity results.

No. Of days	No of Toma toes	Stiffness packag ing (N/mm)	of materials	Flexural strength of Packaging material (N/mm ²)	Maximum Temperature (°C)	Maximum Relative Humidity (%)
1	25	1.1303		6.0141	34.5	71.6
2	25	0.9900		4.9383	30.3	75.8
3	25	0.9741		3.8624	29.5	79.8
4	25	0.9487		3.8095	28.2	81.1
5	25	0.8803		3.5450	27.3	84.6
6	25	2.1698		7.9894	30.6	68.6
7	25	0.7302		3.4744	30.2	76.7
8	25	0.7218		3.3157	28.6	85.2
9	25	0.7197		3.2628	29.5	82.9
10	25	0.7148		3.1041	28.1	85.9
11	25	0.7073		2.9630	29.2	84.7
12	25	0.7061		2.9630	32.0	79.2

13	25	0.6875	2.7866	30.3	76.9
14	25	0.6639	2.6808	29.0	83.8
15	25	0.6521	2.5397	29.5	84.7
16	25	0.6388	2.4339	28.9	82.7

Flexural strength of Kraft paperboard over time

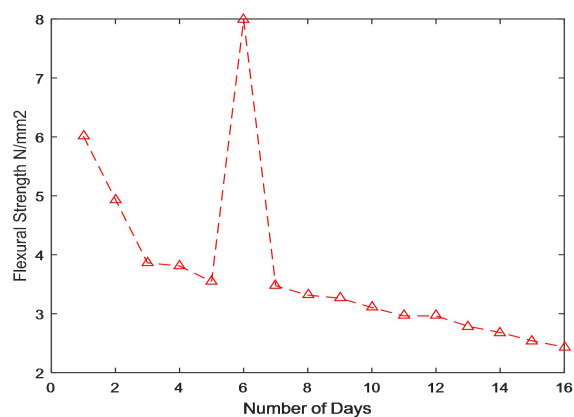


Fig.1 Flexural strength variation of Kraft paperboard over time

Stiffness of Kraft paperboard over time

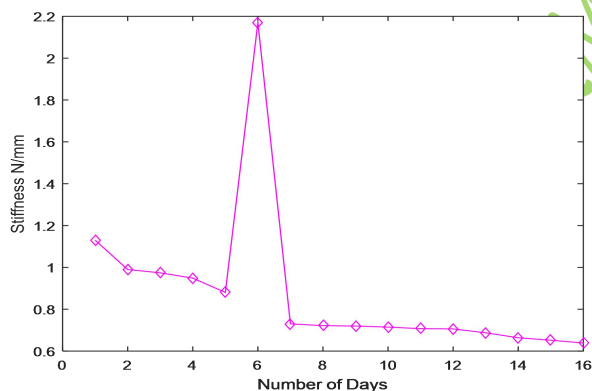


Fig.2 Stiffness variation of Kraft paperboard over time

Statistical Analysis

	Mean	Standard deviation
Flexural strength	3.7302	1.4603
Stiffness	0.8772	0.3747
Relative Humidity	80.2625	5.1431
Temperature	29.7313	1.7005

**Correlation coefficient (r)**

Stiffness / Flexural strength = 0.9450, Flexural strength / Relative Humidity = -0.7467

Flexural strength / Temperature = 0.2786

Coefficient of Determination (R²)

Between Stiffness and Flexural strength = 0.8930

Between Flexural strength and Relative humidity = 0.5576

Between Flexural strength and Temperature = 0.0776

P – Value

Flexural strength = 0.0002, Stiffness = 0.0011

Discussion

Fig.1 and Fig. 2 show the flexural strength and stiffness over time respectively of the Kraft paperboard. Material under load yields over time. Similarly the strength properties of Kraft paperboard under the weight of tomatoes reduce with time. However, the strength properties increase at the point when the layers of the Kraft paperboard were compressed together giving rise to resistance to yielding instantaneously before degradation continues. According to Aljandra *et al.* (2009), water is one of the byproduct of respiration in the tomato. Similarly, Levlin and Soderhjelin, (1999), show that increase in moisture content of a material will decrease flexural strength and stiffness, therefore, increase in relative humidity resulted in the reduction of strength properties over time.

The mean flexural strength and stiffness are 3.7302 and 0.8772 with 1.4603 and 0.3747 standard deviations respectively. The correlation coefficient reveals that as stiffness reduces, flexural strength reduces; as relative humidity increases, flexural strength reduces while temperature had minimal effects on strength properties. The coefficient of determination shows that approximately 89.30% of variation in stiffness can be explained by the variation in flexural strength; 55.76% of variation in flexural strength can be explained in variation in relative humidity while 7.76% of variation in flexural strength can be explained in variation in temperature. The ANOVA results indicated that there is significant difference in both flexural strength (0.0002) and stiffness (0.0011) over the 16 – day period. Therefore, it can be concluded



that Kraft paperboard strength properties are suitable for fresh tomato packaging but its degradation over time should be considered. In comparing with the result obtained by Dandago *et al.* (2017), they packaged tomatoes with Kraft paper bag, perforated polyethylene with six holes and sealed perforated bag. At the end of their study, Kraft paper bag had the highest shelf life of 21 days because of its ability to maintain low temperature and its strength. Similarly, Abdullah *et al.* (2010) in their study packaged tomatoes in wooden crates, mesh polyethylene and corrugated cardboard box to check the rate of weight loss, the result showed that corrugated cardboard box had the highest retained weight of 11.05g.

Harmful effects on decayed tomato on Kraft paperboard

The result of the chemical contents before and after exceeding shelf life of tomatoes in the package shows that only ultra-trace elements (aluminum, arsenic, lead, cadmium, silicon and tin) were poisonous to human beings. The implication is that decayed tomatoes have health challenges from ultra-trace elements, for example the poisonous effect from aluminum will cause bone fracture, dementia, seizures, impaired conditions etc. This will equally breed bacteria leading to multiple health challenges.

Recommendations

- 1) Modified atmospheric packaging material can be coated inside the Kraft paperboard to reduce the effect of humidity.
- 2) Crates should be produced for packaging the Kraft paperboard packages to reduce the effects of vibration on the Kraft paperboard while transporting tomatoes.
- 3) Further study should monitor or measure the concentration of gases in the packages.

Conclusion

The result of this research showed that relative humidity is the most influential parameter affecting the strength properties of Kraft paperboard with correlation coefficient of -0.7467 with flexural strength. There is significant difference in both flexural strength (0.0002) and stiffness (0.0011). The strength properties of the packaging material decrease with time yielding under the weight of tomatoes with fluctuation. Although the study was conducted with one packaging material and lack of monitoring for oxygen, carbon iv oxide together with ethylene; the strength



properties of Kraft paperboard can be improved by incorporating the mentioned limitations and using water resistant coating to reduce the impact of humidity. The decayed tomatoes on the Kraft paperboard were discovered to be toxic to human health. The strength properties of Kraft paperboard was sufficient enough to be used to package fresh tomatoes for 16 days.

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DEVELOPMENT OF RAINFALL-INTENSITY – DURATION MODELS FOR LAGOS CITY IN SOUTH –WEST NIGERIA

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Abstract

Inadequate meteorological data for accurate designing, operation and planning of water resources against extreme rainfall event is a major challenge confronting engineers. Thirty (30) years (1993-2022) daily rainfall data were collected for Lagos city from Nigeria Meteorological Agency (NIMET), Oshodi, Lagos State for the study. The method of annual maximum series was used to select data sets for rainfall analysis. Gumbel and Log Pearson Type 111 distributions were used to compute the observed rainfall intensity values at durations of 10, 15, 20, 30, 60, 120, 180, 240, 300 and 360 minutes for return periods of 2, 5, 10, 20, 50 and 100 years. The difference in periodic intervals between minutes (for duration) and years (for return periods) in Rainfall Intensity-duration-Frequency (IDF) models is due to their distinct purposes in hydrologic analysis. Minutes measure the temporal spread of rainfall, while years measure the probability of occurrence over time. Infrastructure must be designed to handle both short-duration storms (these storms help capture extreme storm events) and long-term recurrence probabilities (these return periods help assess flood risks over decades), requiring data at different scales. To obtain parameters for the IDF models for each location, the computed rainfall intensities were subjected to non-linear regression analysis using Microsoft Excel Optimization Technique Solver wizard for the respective durations and return periods. The IDF Models developed are for Lagos

$I = \frac{1937r^{1.28}}{(t+30.64)^{0.75}}$ (Gumbel) and $I = \frac{1517r^{1.66}}{(t+40.06)^{0.83}}$ (Log Pearson Type 111). The performance of the models were analyzed by determining the chi-square(χ^2), coefficient of determination(R^2) and Root Mean Square Error(RMSE) of the fitted distributions. The correlation coefficient (R) and coefficient of determination values (R^2) obtained from the fitted IDF Models adopting both Gumbel and Log Pearson Type 111 distribution have perfect value of 1 and lower root mean square errors (RMSE) values ranging from 0.48 to 15.86. This shows that both Gumbel and Log Pearson 111 methods fit the models well. The Intensity Duration Frequency (IDF) Models (results) developed will serve as tools for the Engineers and Hydrologists in estimating storm water runoff from a watershed for the design of drainage systems, reservoir management and planning of water resources development. This will mitigate flooding and its consequences.

Keywords: Development, Rainfall, Intensity, Duration, Frequency, Model



Introduction

Lagos City, situated on the coast of Nigeria, has experienced rapid urbanization and significant climate variability over recent decades. This megacity is home to over 20 million people and faces complex challenges related to urban flooding exacerbated by its geographical location, low-lying topography, and inadequate infrastructure (Adelekan, 2010;). The city's susceptibility to flooding is heightened by factors such as heavy rainfall, sea-level rise, land subsidence, and poor drainage systems (Daramola *et al.*, 2016).

Historically, Lagos has experienced recurrent flooding events that have caused extensive damage to property, infrastructure, and public health (Awosika & Olagunju, 2019). These floods often result from intense rainfall events, exacerbated by urbanization processes that alter natural drainage patterns and increase surface runoff (Adelekan, 2010; Daramola *et al.*, 2016).

The concept of Rainfall Intensity-Duration-Frequency (IDF) analysis is pivotal in understanding and quantifying rainfall characteristics essential for flood risk management (Koutsoyiannis, 2004; Oguntoyinbo *et al.*, 2018). Precipitation is an important component in the hydrologic cycle. Brian *et al.* (2006) posited that rainfall frequency analyses are desirable in the development plus designing of different water resources schemes, this includes storm sewers, culverts, and other hydraulic structures. A life threatening precipitation happening endangers the quality of water, annihilation of assets, loss of lives due to flooding and pollution (Brian *et al.*, 2006). The valuation of dangerous precipitation is a vital issue in hydrologic risk investigation and design. Additionally, they noted that the assessment of rainfall excesses as embodied in the intensity duration-frequency (IDF) relationship has been the main objective of applied and theoretical hydrology. Similarly, Elsebaie (2012) noted that rainfall intensity-duration-frequency curves are graphical demonstrations of the quantity of rainwater that falls within a specified period of time in catchment areas. Prodanovic and Simonovic, (2007) suggested, that to design flood protection structures involving hydrologic flows, rainfall events statistics (that is, in relations to intensity, duration, and period of return) are required. Additionally, Elsebaie (2012) noted that, graphically the measure of precipitation that falls within a catchment range in a specified period of time are denoted by Rainfall – Intensity - Duration-Frequency (IDF) curves. He added that, IDF curves are an important tool for the engineers when designing urban drainage works. According to



(Koutsoyiannis, 2003) the IDF relationship is a mathematical connection between the precipitation intensity I , the duration d , and the return period T .

Akpan and Okoro (2013), Nwaogazie and Duru (2002) and Nwoke and Okoro (2012) developed Rainfall Intensity Frequency Models based on statistical method of least squares. In Nigeria, current studies on rainfall IDF development have been done in Southern Nigeria, with little information made available about rainfall intensities in particular for short durations. The insufficient accessible IDF curves for selected parts of the country are very costly and plotting of the curves was done manually. Hence, this method of developing IDF curves manually is prone to error. The main objective of this research was to develop Intensity Duration – Frequency (IDF) curves and models for estimating the precipitation intensities for Lagos city, using two statistical methods, that is Gumbel distribution and Log Pearson Type 111 distribution.

Materials and Method

Description of Study Area

Lagos (figure 1), Nigeria is situated in western Africa and in the southwestern region of Nigeria. Its capital is Ikeja. It is the sixth largest city in the world and the largest city in sub-Saharan Africa. Lagos lies at latitude $6^{\circ}27' N$ and longitude $3^{\circ}23' E$ (table 1). The state is bound from the north by Ogun state, in the west by the Republic of Benin and the south by the Atlantic Ocean/Gulf of Guinea (Ojeh et al., 2016). The total landmass of the state is about $3,345 \text{ km}^2$ – $3,577.28 \text{ km}^2$, which is just about 0.4 per cent of the total land area of Nigeria. Water body accounts for 29.8 per cent of this while 60 per cent of the remaining areas are wetlands and remotely detached by creeks and lagoons. Lagos is along the tropical rain forest belt with wetlands and rain forest being the predominant eco-zones (Ojeh et al., 2016). Based on the UN-Habitat and international development agencies' estimates, Lagos State is said to have about 24.6 million inhabitants in 2015.

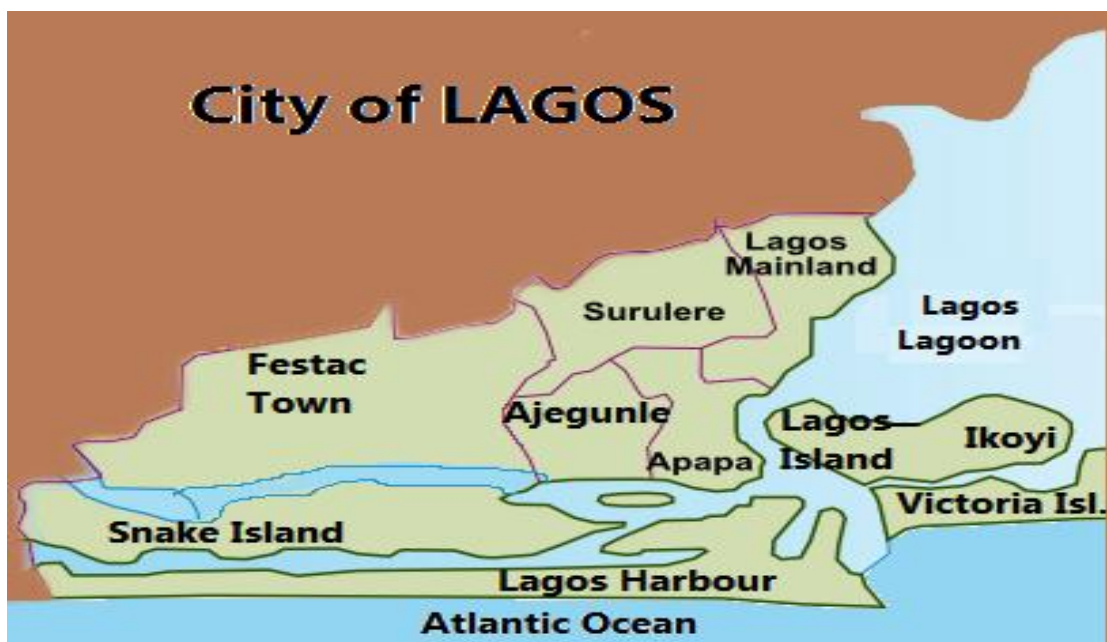


Figure 1: Map of Lagos City

Climate of study area

The warm, humid maritime tropical air mass interacting with the hot and dry continental airmass from the interior creates the seasons in the country; a rainy season from April to October and a Harmattan season from November to March with mean annual rainfall of 1,657 mm. The air is quite humid throughout the year, with monthly average maximum temperatures ranging from 27°C in July/August to 34°C in January/February. There are 1,885 hours of sunshine per year with the sun mostly overhead. The average annual relative humidity in Lagos state is 84.7 per cent and average monthly relative humidity ranges from 80 per cent in March to 88 per cent in June. Solar radiations are quite high and readily available for most hours during the day and for Lagos, it is about 1,750kW/m² annually.

Table 1: Characteristics of the meteorological stations of the study cities

Location	Capital	Coordinate	Agro-ecological zones	AvailableData Range
Lagos	Ikeja	6°27'N, 3°23'E	Western Moist Forest	1983- 2014



Data Collection

The required data in this research are the precipitation depths for smaller durations namely, 5, 10, 15, 20, 30, 60, 120, 180, 240, 300 and 360 minutes. The difference in periodic intervals between minutes (for duration) and years (for return periods) in Rainfall Intensity-duration-Frequency (IDF) models is due to their distinct purposes in hydrologic analysis. Minutes measure the temporal spread of rainfall, while years measure the probability of occurrence over time. Infrastructure must be designed to handle both short- duration storms (these storms help capture extreme storm events) and long-term recurrence probabilities (these return periods help assess flood risks over decades), requiring data at different scales. Precipitation data were collected from Nigeria Meteorological Agency Lagos, Nigeria. Thirty-two years span of records was used for the studied location between 1993-2022.

Development of IDF curves

Two common frequency analysis techniques were used in the development of the relationship between rainfall intensity, storm duration, and return periods from rainfall data for the region under study. These techniques are the Gumbel distribution and the LPT III distribution.

Gumbel theory of distribution

Gumbel assumption methodology was adopted to perform the flood probability studies. In addition, Elsebaie (2012) noted that this is because the method of the analysis is widely accepted for IDF analysis owing to its appropriateness for modeling maxima. The Gumbel methodology determines the 2, 5, 10, 25, 50 and 100 year return intervals for each duration period and hence requires several calculations. The frequency precipitation for duration with a definite return period is expressed by the following formula:

$$P_T = P_{ave} + KS \quad (1)$$

Where K is Gumbel frequency factor given by equation 2



$$K = \frac{\sqrt{6}}{\pi} \left[0.5772 + \ln \left[\ln \left[\frac{T}{T-1} \right] \right] \right] \quad (2)$$

Where P_{ave} is the average of the maximum precipitation corresponding to a specific duration.

In utilizing Gumbel's distribution, the arithmetic average in Eq. (3) was used:

$$P_{ave} = \frac{1}{n} \sum_{i=1}^n P_i \quad (3)$$

Where P_i is the individual extreme value of rainfall and n is the number of events or years of record. The standard deviation, S of P data was calculated using Eq. (4)

$$S = \left[\frac{1}{n-1} \sum_{i=1}^n (P_i - P_{ave})^2 \right]^{1/2} \quad (4)$$

The frequency factor (K), which is a function of the return period and sample size, was multiplied by the standard deviation to give the departure of a desired return period rainfall from the average.

Then the rainfall intensities, I (in mm/h) for return period T were obtained as shown in equation 5.

$$I_T = \frac{P_T}{T_d} \quad (5)$$

Where, T_d is duration in hours, P_T is frequency precipitation values and I_T is intensities for different durations. From the raw data, the maximum precipitation (P) and the statistical variables (average and standard deviation) for each of the duration 5, 10, 15, 20, 30, 60, 120, 180, 240, 300 and 360 minutes were computed.

Log pearson type III

The LPT III probability model was used to calculate the rainfall intensity at different rainfall durations and return periods to form the historical IDF curves for the selected locations. LPT III distribution involves logarithms of the measured values. The mean and the standard deviation

were determined using the logarithmically transformed data. The simplified expression for this latter distribution is given as follows:

$$P^* = \log (P_i) \quad (6)$$

$$P^*_T = P^*_{ave} + K_T S \quad (7)$$

$$P^*_{ave} = \frac{1}{n} \sum_{i=1}^n P^* \quad (8)$$

$$S^* = \left[\frac{1}{n-1} \sum_{i=1}^n (P^* - P^*_{ave})^2 \right]^{1/2} \quad (9)$$

Where, P^*_T is frequency precipitation and P^*_{ave} is the average of the maximum precipitation corresponding to a specific duration based on the logarithmically transformed P_i values; i.e. P^* of Equation (6). K_T is the Pearson frequency factor which depends on return period (T) and skewness coefficient (C_s). The skewness coefficient (C_s) is required to compute the frequency factor for this distribution.

The skewness coefficients were computed using Equation (10) as suggested by (Burke and Burke, 2008).

$$C_s = \frac{n \sum_{i=1}^n (P^*_i - P^*_{ave})^3}{(n-1)(n-2)(S^*)^3} \quad (10)$$

K_T values can be obtained from tables in many hydrology references; for example (Chow, 1988)).

By knowing the skewness coefficient and the recurrence interval, the frequency factor, K_T values for the LPT III distribution were extracted from hydrology text books. The frequency precipitation P^*_T values and intensities (I_T) for six different durations and six return periods using LPT III methodology were computed.

Intensity-Duration –Frequency (IDF) Model Development

The Intensity-Duration-Frequency (IDF) formulae are the empirical equations representing a relationship between the variables. The variables used for the development of the appropriate mathematical models are the maximum rainfall intensity, the rainfall duration and frequency. The maximum rainfall intensity is the dependent variable, while the independent variables are the rainfall duration and frequency.

Several commonly used IDF equations relating the rainfall intensities, the frequencies and durations are available in literature (Chow, 1988; Burke and Burke, 2008; Nhat *et al.*, 2006 and Mohammad, 2016). The commonly used IDF equation is Sherman.

$$\text{Sherman equation} \quad i = \frac{aT^b}{(t+d)^c} \quad (11)$$

Where,

i is intensity of rainfall in mm/hr; t is duration of rainfall in minutes; T is return period of rainfall in years; a , b , c and d are the regional IDF parameters to be determined.

Equation (11) which is the most general form of IDF equation has been used to develop the IDF equations by optimization method.

Application of excel solver optimization technique to estimate IDF parameters

Excel solver is an optimization Technique in Microsoft excel mainly used to get the optimum values of parameters of nonlinear and linear equations. The excel solver methods are mainly the Generalized Reduced Gradient (GRG Solver) for optimization of nonlinear equations and the linear programming Solver (LP Solver) for linear equations. Due to the fact that IDF equations are nonlinear, the GRG Solver was used in this work to get the optimum of the parameters for the models.

Calibration of the sherman (1932) model

Sherman (1932) model as given in equation (11) was calibrated using GRG Solver optimization method to obtain optimum values for the regional parameters namely a, b, c and d for the models.

Thus the objective function becomes:

$$\text{Min SSE} = \sum_{i=1}^n (i_{\text{obs}} - i_{\text{est}})^2 \quad (12)$$

Where i_{obs} is observed intensity corresponding to any duration and i_{est} is estimated intensity corresponding to any duration. Solving equation (12) produces the optimum values for the parameters a, b, c and d achieved through iterative process that produces the least squared error.

Model Performance Analysis

The performance of the Intensity Duration Frequency (IDF) models given by Gumbel distribution and Log Pearson Type 111 Distribution (LPT 111) were evaluated by obtaining empirical data from the models and then goodness of Fit test, Correlation Coefficient, and Root Mean Square Error (RMSE) analysis were carried out. To determine the best-fit distribution, the observed distributions were fitted to the theoretical distribution by comparing the frequencies observed in the data to the expected frequencies of the theoretical distribution. The aim of the test is to decide how good is a fit between the observed frequency of occurrence in a sample and the expected frequencies obtained from the hypothesized distributions. A Goodness-of-fit test between observed and expected frequencies is based on the chi-square quantity, which is expressed in equation 13.

$$\chi^2 = \sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i} \quad (13)$$

Where,

χ^2 is a random variable whose sampling distribution is approximated very closely by the chi-square distribution. The symbols O_i and E_i represent the observed and expected frequencies,

respectively, for the i -th class interval in the histogram. The symbol k represents the number of class intervals.

Mohammad (2016) provided programmable formulae to obtain coefficient of determination (R^2) and Root Mean Square Error (RMSE) as follows:

$$R^2 = \frac{\sum_{i=1}^n (I_{obs} - I_{avg})^2 - \sum_{i=1}^n (I_{obs} - I_{pred})^2}{\sum_{i=1}^n (I_{obs} - I_{avg})^2} \quad (14)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (I_i - \hat{I}_i)^2} \quad (15)$$

The theoretical description of Correlation Coefficient (CC) is as given in equation (28)

$$CC = \sum_{i=1}^N \left(\frac{(I_i - \bar{I})(\hat{I}_i - \bar{\hat{I}})}{\sqrt{\sum_{i=1}^N (I_i - \bar{I})^2 + \sum_{i=1}^N (\hat{I}_i - \bar{\hat{I}})^2}} \right) \quad (16)$$

Where I_i is the recorded rainfall intensity of i th event, \hat{I}_i is the estimated rainfall intensity of the i th event. \bar{I} is the average recorded rainfall intensity and $\bar{\hat{I}}$ is the average of estimated rainfall intensity.

Results and Discussion

Intensity Duration Frequency (IDF) Curves by Gumbel and Log Pearson Type (LPT) III Methods for Lagos city.

The results of the Intensity Duration- Frequency curves by Gumbel and Log Pearson Type methods for Lagos city are shown in Figures 2 and 3, respectively.

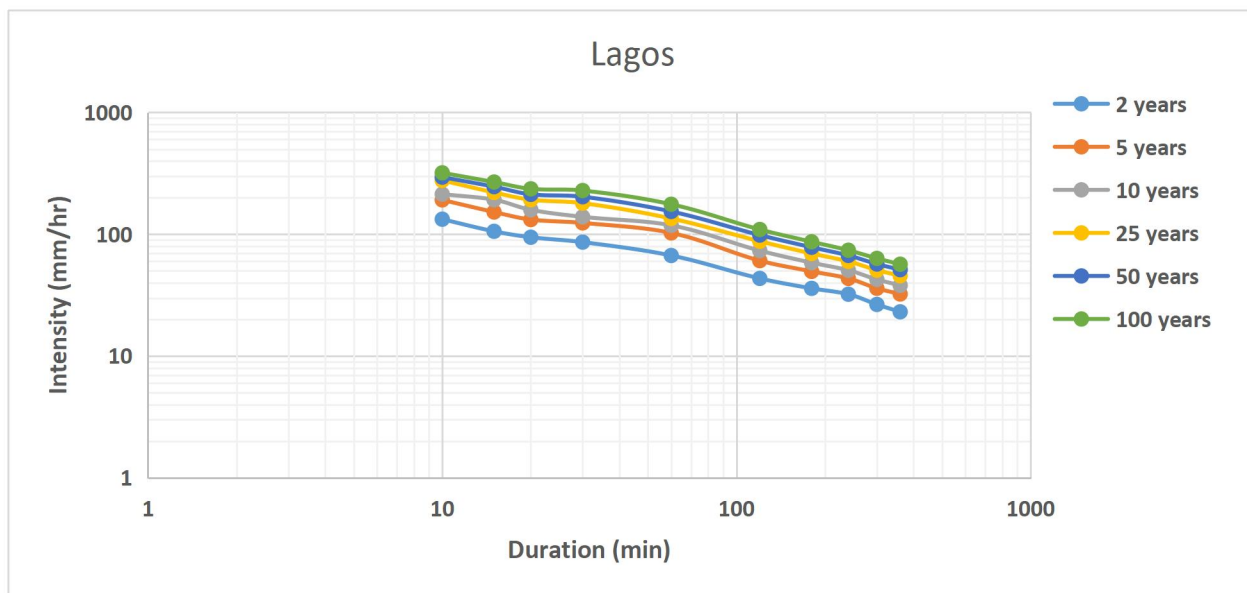


Figure 2: IDF curves by Gumbel method at Lagos city (South-West Nigeria)

How many stations were established in Lagos to ensure evenly distribution of data that represented weather functions in Lagos.

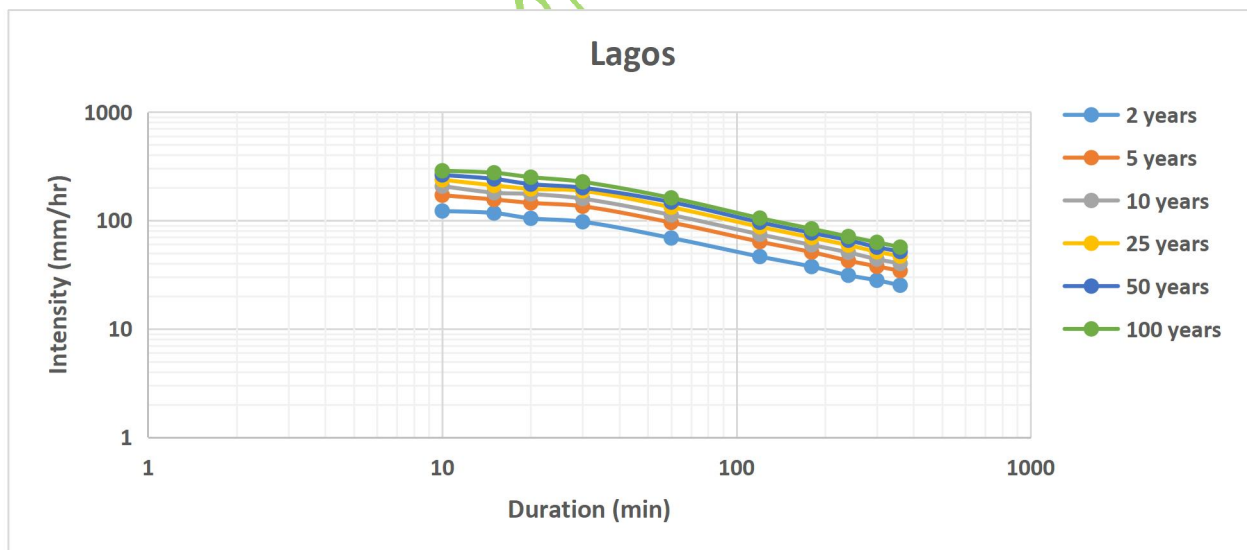


Figure 3: IDF curves by LPT III method For Lagos City (South-West Nigeria)

Figures 2 and 3 represents the IDF curves obtained by Gumbel and LPT 111 methods for Lagos region. The trends of the curves from the two methods show good consistency. The curves revealed that rainfall intensity decreases with increasing duration and for a given duration, the higher the return period, the higher the rainfall intensity. This result is supported by similar work of David and Nwaogazie (2020). However, the rainfall intensities are increasing more with return periods and durations in the IDF curves obtained using Log Pearson Type 111 distributions than in IDF curves obtained using Gumbel distributions. This shows that LPT 111 method gave higher results in rainfall intensities than Gumbel method.

Rainfall Intensity Duration Frequency Models and their Parameter Values

The parameter values used in deriving the Gumbel and Log Pearson Type III models, including the models for the region are shown in Table 2.

Table 2: Parameters values used in deriving models for rainfall intensity at Lagos region

S/No.	Location	Distribution	Parameters				Models
			a	b	c	d	
1.	Lagos	Gumbel	193	1.28	0.75	30.64	$I = \frac{193T_r^{1.28}}{(t + 30.64)^{0.75}}$
		Log Pearson Type III	151	1.66	0.83	40.06	$I = \frac{151T_r^{1.66}}{(t + 40.06)^{0.83}}$

The Gumbel and Log Pearson Type 111 models, including the parameter values used in deriving the models for the region studied are shown in table 2. The parameter values used in deriving the models are a, b, c and d. For Lagos region, the values of parameters b(1.66), c(0.83) and

d(40.06) are higher for Log Pearson Type 111 method, except for a(151) that is lower than Gumbel's a value which is 193. The interpretation is that Log Pearson 111 predicts higher rainfall Intensity values than Gumbel at same durations and return period.

Model Performance/Validation for Lagos IDF models

The results of the computed indicators of goodness of fit between Gumbel and Log Pearson Type III Models, namely Chi Square (χ^2), Root Mean Square Error (RMSE), Correlation Coefficient (R) and Coefficient of Determination (R^2) are given in table 3 to 4.

Table 3: Model Performance/Validation for Lagos IDF Model Obtained by Gumbel Method

Location	Distribution	Model validation	Duration (min)									
			10	15	20	30	60	120	180	240	300	360
Lagos	Gumbel	χ^2	3.62	7.40	2.78	8.50	0.46	1.03	1.46	0.27	0.20	5.64
		RMSE	11.48	15.86	9.40	15.00	3.04	3.74	3.76	1.58	1.26	6.05
		R	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		R^2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		P-value	0.58	0.17	0.70	0.12	0.99	0.96	0.99	0.99	0.99	0.98

Table 4: Model Performance/Validation for Lagos IDF Model Obtained by Log Pearson Type III Method

Location	Distribution	Model validation	Duration (min)									
			10	15	20	30	60	120	180	240	300	360
Lagos	Log Pearson Type III	χ^2	3.90	7.36	2.4	6.68	0.2	0.8	0.3	0.0	0.0	0.4
					0		9	0	5	4	2	8
		RMSE	11.8	15.6	8.4	13.4	2.3	3.3	2.0	0.6	0.4	2.0
			6	0	2	4	6	0	0	3	8	0
		R	1.00	1.00	1.0	1.00	1.0	1.0	1.0	1.0	1.0	1.0
					0		0	0	0	0	0	0
		R^2	1.00	1.00	1.0	1.00	1.0	1.0	1.0	1.0	1.0	1.0
					0		0	0	0	0	0	0
		P-value	0.54	0.16	0.6	0.22	0.9	0.9	0.9	0.9	0.9	0.9
					8		9	7	9	9	9	8

Tables 3 and showed the model performance / validation of IDF Model obtained for Lagos region using Gumbel and Log Pearson Type III distributions respectively.

The results obtained revealed that in all cases the correlation coefficient (R) and coefficient of determination (R^2) obtained from the fitted IDF Models adopting both Gumbel and Log Pearson Type 111 distributions have perfect value of 1. This indicates the goodness of the formulae to estimate IDF models in Lagos region. This result is in agreement with similar work done by David and Nwaogazie(2020) indicating that the two probability distribution models are fit for prediction of rainfall intensities for Lagos metropolis.

Results of chi square goodness of fit test between the observed and predicted intensities for both Gumbel and LPT 111 method revealed that most of the data fit the distributions at level of significance of 5%, except the data for 10 minutes, 15 minutes and 30 minutes duration that do not give good fit using both distributions.

The values of Root Mean Square errors (RMSE) obtained using Gumbel and Log Pearson Type 111 distributions for Lagos region are lower at higher durations from 60 minutes to 360 minutes,



but higher for lower durations from 10 minutes to 30 minutes for both. This shows that the derived formulae can be used to estimate any frequency rainfall data for Lagos region, especially at higher durations using both methods.

Comparison of Observed and Predicted Rainfall Intensities

The results of the predicted rainfall intensities for different durations and return Periods are shown in tables 5 and 6. Also some selected index values of predicted intensities for comparison of short, medium and higher durations are shown in table 7.

Table 5: Predicted Intensity-Duration frequencies for different return periods by Gumbel method at Lagos (South-West (Nigeria))

Return Period (Years)	2		5		10		25		50		100	
Duration (min)	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
10	132.837	126.932	191.348	182.834	213.152	202.859	276.480	264.036	294.03	279.903	319.206	303.424
15	105.68	114.230	152.192	164.140	192.024	206.215	220.260	237.291	245.680	264.775	268.192	289.336
20	94.471	99.258	131.959	138.876	158.591	1166.932	192.005	202.110	212.522	223.922	235.874	248.556
30	86.16	77.612	123.920	112.257	138.906	125.215	180.010	163.678	203.208	184.938	228.424	215.742
60	66.92	64.983	102.512	99.998	118.304	115.453	134.613	131.249	153.724	150.020	176.160	172.111
120	43.406	45.631	60.714	63.682	73.357	83.980	87.531	91.622	98.422	102.992	109.382	114.411
180	35.943	39.163	49.547	53.075	58.407	62.146	69.503	73.496	78.163	82.359	86.727	88.418
240	32.186	33.553	43.396	44.854	50.612	52.115	59.821	61.414	66.981	68.638	73.907	75.598
300	26.528	27.823	35.984	37.275	42.546	43.809	50.726	52.006	56.964	58.245	63.341	64.592
360	23.069	17.706	32.310	26.604	38.046	32.084	45.678	39.453	51.207	44.772	56.737	50.057

**Table 6: Predicted Intensity-Duration frequencies for different return periods by Log Pearson Type 111 method at Lagos (South-West Nigeria)**

Return Period (Years)												
Duration (min)												
2												
5												
10												
25												
50												
100												
Observed Predicted Observed Predicted Observed Predicted Observed Predicted Observed Predicted Observed Predicted												
10	122.160	115.637	170.560	161.369	206.780	198.941	237.00	224.207	262.540	248.414	286.930	271.645
15	116.96	125.579	155.840	167.939	180.110	194.347	210.19	227.122	241.310	260.110	274.820	295.162
20	104.470	109.162	145.060	151.663	175.180	183.249	195.090	215.503	215.940	226.539	250.39	261.472
30	97.123	89.731	135.020	124.634	158.680	146.316	187.040	172.550	200.040	183.940	226.650	208.983
60	68.827	67.459	95.593	93.682	112.31	109.946	132.33	129.655	147.460	144.461	147.46	158.118
120	46.395	48.250	63.636	66.250	74.401	77.445	87.299	90.922	96.133	100.165	96.133	109.526
180	37.504	38.608	51.007	52.561	59.439	61.273	69.542	71.665	76.67	79.079	76.67	86.291
240	31.186	31.545	42.55	43.052	50.645	51.263	39.146	59.806	65.67	66.463	65.67	71.876
300	28.032	27.761	37.70	37.314	43.924	43.510	31.381	30.800	56.634	56.061	56.634	62.099
360	25.242	23.811	34.35	32.792	40.037	38.25	46.851	44.632	51.659	49.275	51.659	54.030

The rainfall intensity of any duration and return period is predicted by the aid of the developed IDF models. The factors that enhance the distribution of the observed and predicted rainfall intensities are duration and return period. Observed and predicted rainfall intensities were compared as way of verification of the developed models. For the studied location in Tables 5 and 6, it was noted that rainfall intensity decreases with increasing durations and for a given duration the higher return period yielded corresponding higher intensity values. From Table 6, the highest predicted intensity values were given by Log Pearson Type 111.

**Table 7: Comparison of selected index values of predicted intensities (mm/hr) for short, medium and higher durations**

Method	Station	10 min duration	60 min duration	300 min duration
100 year return period	100 year return period	100 year Return period		
Gumbel	Lagos	303.42	172.11	63.42
Log Pearson	Lagos	271.65	158.12	62.10

Type 111

Table 7 shows the comparative predicted intensities by Gumbel and Log Pearson Type111 Models for short, medium and higher durations. For example in table 7 at 10 minutes duration and 100 year return period, the predicted intensities by Gumbel model was 303.42mm/hr.. The predicted intensities at the same 10minutes duration and 100 year return period by Log Pearson Type 111 was 271.65mm/hr,. Also for 60minutes duration and 100 year return period, the predicted intensities by Gumbel was 172.11mm/hr. While at the same 60minutes duration and 100 year return period, the predicted intensities by Log Pearson Type 111 was 158.12mm/hr. Finally, at 300minutes duration and 100 years return period, the predicted intensities by Gumbel was 63.42mm/hr. While at the same 300minutes duration and 100 year return period, the predicted intensities by Log Pearson Type 111 was 62.10mm/hr. The predicted intensities values given in tables 7 establishes the consistent superiority of Gumbel model over Log Pearson Type 111 model in predicting higher intensity values at short, medium and higher durations in the studied location. This observation was also established in the works for Ikeja and Lahore city IDF models by David and Nwaogazie (2020) and Ahmed and Ali (2016) respectively.

Conclusion

This work shows the procedure for the development of rainfall intensity duration frequency models for Lagos in South - West Nigeria. In this study, IDF models were developed for studied location. These models are guides for estimating the rainfall intensities for any specific return period at different durations. The highest intensity occurs at return periods of 100 years with



durations of 10minutes (0.15hr), while the lowest intensity occurs at return period of 2 years with durations of 360minutes (6.0hr).

Engineering implications of Findings

The IDF Models developed will serve as tools for the Engineers and Hydrologists in estimating storm water runoff from a watershed for the design of drainage systems, reservoir management and planning of water resources development. This will mitigate flooding and its consequences. Also, the findings when applied as demonstration tools in teaching land drainage courses to Engineering students, will enhance their understanding and appreciation of the course duration and lower intensity at longer duration. The prediction of rainfall intensity with the

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COVID-19 RESTRICTIONS AND THEIR IMPACT ON RURAL CASSAVA PRODUCTION AND HOUSEHOLD LIVELIHOODS IN IKWUANO LGA, NIGERIA.

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Abstract

This study analyzed Covid-19 Restrictions and their Impact on rural Cassava Production and Household Livelihoods in Ikwuano LGA, Nigeria. Cassava, a staple crop and major sources of income encountered serious challenges during the lockdown, including movement restrictions, labor shortages, and disruptions in market access. A multi-stage sampling technique was used to select 120 cassava farmers across the four clans in Ikwuano LGA. Data were collected using structured questionnaires and interviews, analyzed using descriptive and inferential statistics. Findings reveal that most cassava farmers were male (53%), with a mean age of 26 years, and 75% participate full-time farming activities. Major constraints during the pandemic included unavailability of agrochemicals (mean score 3.47), market disruptions (mean score 3.37), and high labor cost due to farmer shortages. The findings revealed unavailability of agrochemicals and insecticides was a major challenge, with 83.4% of respondents agreeing or strongly agreeing, result in a high mean score of 3.47, respectively. The study concluded that Covid-19 restrictions exacerbated pre-existing challenges in cassava production, threatening food security and rural Cassava Production. The study therefore recommends enhanced input supply, improved market access, and better financial support can help strengthen cassava farming in region like Ikwuano. By implementing these recommendations, stakeholders can build a more resilient, productive cassava sector that benefits rural households and contributes to broader economic growth.

Keywords: *Agriculture, Cassava production, rural, Covid-19 Restrictions.*

Introduction

Nigeria produces 45 million metric tons of cassava annually, making it one of the main food crops grown (FAO, 2020) and during the climate change phase, production has increased even more. Promotion of cassava as an industrial crop has received increased attention from various actors in many West African countries, with the aim of increasing employment opportunities, improving foreign exchange earnings, and diversifying farmers' incomes (Sanni *et al.*, 2009). in Ukonu *et al.* (2022), states that cassava has been shown to have high income generation potential over the years and can help resource-poor smallholder producers improve their standard of living



once they adopt and use suitable production and processing technologies and marketing opportunities.

Cassava chips and pellets are used in animal feed and alcohol production and different types of food preparations: Gari, Fufu, Lafun, Kpokpogari, Tapioca, Abacha. The solution to poverty and low returns to the men and women engaged in cassava production and processing is to concentrate on introducing improved varieties, agronomic practices, labour-saving harvesting and processing technologies and finding new industrial uses for cassava (Nwakor, *et al.*, 2016). Cassava enterprise has the capacity of caring over ₦720, 000.00 in a year for a farmer (Onumadu, *et al.*, 2012).

An extremely significant crop to Nigeria's economy is cassava, with average yields of roughly 11 metric tons per hectare and an annual output of over 33.8 million metric tons, it is estimated that 30 million farmers cultivate cassava. Over 52 million metric tons were produced in 2011 (FAO, 2013). According to Ogunleye and Ojedokun (2014), cassava can help create jobs, increase income, and improve food security for many Nigerian households in addition to providing food for the 200 million people who live in sub-Saharan Africa.

The rural populace engages in a variety of agricultural pursuits in an effort to find ways to boost and stabilize their income or to augment farming in order to raise the standard of living or welfare of their households. One significant national subsector is the rural community. To improve the country's economic survival, the vast potential of rural communities and the impoverished in these areas can be harnessed. Cassava, yam, cocoyam, oil palm, coca, citrus, cowpea, vegetables, and a variety of other crops are grown by smallholder farmers, who make up the majority of rural residents (Onumadu, *et al.*, 2012). The most common crop farmed by smallholder farmers of all genders and ages is cassava. Because it can adapt to a wide range of climatic and edaphic conditions and is more resilient to drought, pests, weeds, and diseases than other crops, cassava is popular among Nigerian farmers. In addition, the crops provide food security for the community and generate cash income for farming households (Odii et al. (2000). Nigeria faces a lot of challenges including that of attaining food security, which is one of the millennium development goals (FAO, 2003). Some of These challenges are caused by depleting natural resources (soil, water and climate), poorly performing micro economies, and agricultural



policies, bad economy. Due to these challenges, smallholder farmers in Nigeria are poverty stricken. These challenges affect individual farmers and put the household welfare at risk. Consequently, this risk encourages farmers to diversify into other non-farm activities which are expected to supplement their income (Adagbo, *et al.*, 2023).

The impact of Covid-19 on agriculture is devastating, complex and varied across diverse segments that form the agricultural value chain. This impact will reverberate across the larger economy and will linger unabatedly than few months. Commercial crops like cassava are drastically hit as they tend to be more dependent on farmers who are faced with social distancing, quarantine and lockdown. The Shortage of farmers due to COVID-19 pandemic has resulted in a sharp increase in daily wages for harvesting crops (World Bank, 2020). In several areas, the rise is as high as 50%, making it un-remunerative for the produce since prices have collapsed due to either lack of market access including the stoppage of transportation and closure of borders. COVID-19 pandemic seems to escalate the already existing food security giving the additional impact it has on both production and marketing segment of cassava value chain.

The entry of COVID-19 in Nigeria and the subsequent implications and impact have adversely crushed businesses, households and the economy. The slowdown of retail and trade activities, as most finished goods flow through the sector to final consumers, has also affected the manufacturing sector, especially for nonessential goods. The International Monetary Fund (IMF) estimated that the Nigerian economy would shrink by 5.4% by the end of 2020, a loss of about N6 trillion to the economy.

Problem Statement

Ikwuano LGA in Abia State, Nigeria, is one of the developing regions that suffered greatly from the COVID-19 pandemic's unprecedented restrictions that disrupted rural agricultural practices worldwide. A number of issues affected cassava, a staple crop and the main source of income for many rural households in this region, including limited market access, labor shortages, input scarcity, and restricted mobility. Cassava yield, household income, and food security were all impacted by these disruptions, making rural farming communities even more vulnerable. In order to better understand how COVID-19 restrictions affected cassava production in Ikwuano LGA, this study will examine constraints faced by cassava farmers (labor availability, input



accessibility, market disruptions), and the extent of engagement of rural households in production of selected cassava (the financial effects on rural households).

There is little data on how the COVID-19 pandemic has affected rural households' ability to grow cassava in Ikwuano LGA of Abia State in the study area. Similarly, rural households in Abia State, Nigeria, engage in a wide range of income-generating activities to make a living, meet their needs, and fulfill their social responsibilities. One of the main sources of income for rural households in the area is root and tuber farming. However, it is currently unknown how many people in Abia state are involved in the production of cassava (a root and tuber crop) and how much these businesses contribute to rural households. Therefore, the purpose of this study is to examine how the COVID-19 pandemic restrictions have affected the production of cassava among rural households in Ikwuano LGA, Abia State, Nigeria.

The specific objectives were to:

- i. describe the socio-economic characteristics of the cassava farmers;
- ii. identify the constraints faced by cassava farmers during COVID-19 Pandemic in the study area;
- iii. assess the extent of engagement of rural farmers in production of selected cassava

Hypothesis of the Study

H_1 = there is no significant relationship between major cassava grown and extent of engagement of rural households in production of selected cassava.

Methodology

Study Area

Abia State is a state in the South-East geopolitical zone of Nigeria. It is bordered to the Northwest by Anambra State and Northeast by the states of Enugu, and Ebonyi, Imo State to the west, Cross River State to the East, Akwa Ibom State to the Southeast, and Rivers State to the South. Ikwuano is a Local Government Area of Abia State, Nigeria. Its headquarters is in Isiala Oboro. The name Ikwuano etymologically indicates that there are four different ancient kingdoms that make up the community called Ikwuano. These include Oboro, Ibere, Ariam/Usaka and Oloko (Nwosu, 2022).



The population of Ikwuano during the 2006 census was 137,993. As at 2015, it increased to 175,078. The area is inhabited primarily by the Igbo people. It experiences an average weather temperature of 28 °C. The area witnesses two distinct seasons which are the rainy and dry seasons. The average humidity level is put at 62%. The vegetation of the area is predominantly lowland rainforest, which makes it suitable for growing yam, cassava, maize, cashew and ginger (Ikwuano, Abia, Nigeria - City, 2023). This has led to the area becoming the food basket of Abia State. Farming is one of the key economic activities of the Ikwuano people.

Ikwuano is situated in the palm belt of Eastern Nigeria. Other important economic engagements of the Ikwuano people are hunting, craftsmanship and wood carving (Ikwuano, Abia, Nigeria - City, 2023).

Data Collection

Data for this study were generated from primary source through the administration of questionnaire, and use of oral interview schedule. Furthermore, likert type measuring scale was developed to elicit information from the respondents, especially for realizing objective 2 of the study.

Sampling Technique

A multi-stage sampling procedure was used to select cassava farmers used in this study. The first stage was the purposive selection of four (4) clan, that make-up Ikwuano LGA which includes: Ariam/Usaka, Ibere, Oboro, Oloko. Purposive selection of Ten (10) major villages, with total of forty (40) respondents which forms the second stage. In the third stage a random selection of twenty cassava farmer's production in Ariam/Usaka. Purposive selection of fifteen (15) rural household cassava famers in the fourth stage from Ibere clan also in the fifth stage random selection of twenty five (25) rural cassava famers production in Oboro Clan. The sixth stage, selection of twenty (20) rural cassava farmers in the last stage in Oloko village, with respondent of 120.

Model specification

H_1 = there is no significant relationship between major cassava grown and extent of engagement of rural households in production of selected cassava.



Results and discussion

Socio-Economic Characteristics of Cassava Producing Farmers in Ikwuano LGA, Abia State.

Table 1: Socio-Economic Distribution of Cassava Producing Farmers in the study area

Variables	Frequency	Percentage	Mean
Age			
≤ 20	14	11.7	26
21 – 25	14	11.7	
26 – 30	44	36.6	
40 ≥	48	40.0	
Marital Status			
Married	69	57.5	
Single	51	42.5	
Level of education			
No schooling	13	10.8	
Primary	24	20.0	
Secondary	47	39.2	
Tertiary	36	30.0	
Sex			
Female	57	47.5	
Male	63	52.5	
Occupation			
Farming	46	38.3	
Trading	30	25.0	
Civil servant	18	15.0	
Farming and trading	26	21.7	
Unemployed			
1 – 2 years	16	13.3	4.18
3 – 4	29	24.2	
5 ≥	75	62.5	
Years of farming			
6 – 10 years	25	20.8	
11 – 20 years	15	12.5	
21 – 25 years	46	38.3	
35 – 40years	34	28.3	
Hours spent on farming			
≤ 4 hours	76	63.3	5.47
≥ 8 hours	44	36.7	
Hectares of land			
1 – 2 ha	72	60	
3 – 4 ha	36	30	
≥ 5 ha	12	10	
Nature of Engagement			
Part-time	30	25.0	



Full-time	90	75.0
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Source; field survey, 2022.

The socioeconomic Characteristics of cassava farmers in Ikwuano LGA, Abia State during the COVID-19 pandemic, is shown in Table 1. **Older adults (40 percent) make up the largest age group.** Given that the mean aged of cassava farmers was 26, this suggested that a sizable portion of them are older, which may have an impact on the physical demands and productivity levels of cassava production in Ikwuano LGA Abia State. The majority of cassava farmers are probably responsible for their families, which may affect their desire to keep steady sources of income. The majority of participants (57.5%) are married, whereas 42.5% are single. 30% has tertiary education, while only ten percent (10%) have no formal education. The majority of respondents (39 %) have only completed secondary school. The farmers may find it easier to comprehend and adjust to new farming methods due to their comparatively high educational attainment. With 52.5% of the population being male and 47.5% being female, the gender distribution reveals a slight male predominance, suggesting that regional cassava farming is fairly balanced in terms of gender participation. Farming is the primary occupation for 38.3%, while 21.7% are involved in both farming and trading. This shows a strong commitment to agriculture as a primary or complementary income source. A majority (62.5%) has been unemployed for five years or more which may indicate limited alternation employment opportunities and reliance on cassava farming for livelihood. The largest group, 38.3%, has between 21 – 25 years of farming experience; suggest a highly experienced farming population. About 63.3% spent four (4) hours or less daily, while 36.7% participate for (8) hours or more, this could reflect part-time or other engagements besides farming. Most respondents (60%) farm on 1-2 hectares, with only 10% managing five or more hectares. This indicates a predominance of small-scale farming. A majority (75%) are full-time participants in cassava farming, highlighting the importance of this crop as a major source of income and sustenance. This table highlights the demographics and farming practices of cassava producers in Ikwuano, illustrating their education background, experience, and level of engagement in cassava farming etc, which could impact their resilience to challenges such as those brought by COVID-19.

**Table 2: Constraints faced by cassava farmers in the study area.**

Constraints faced by cassava farmers	Strongly agree	Agree	Disagree	Strongly disagree	Sum of scores	Mean score
High incidence of pests and diseases	31(25.8)	26(21.7)	32(26.7)	31(25.8)	297	2.48
Unavailability of agrochemicals	80(66.7)	20(16.7)	16(13.3)	4(3.3)	416	3.47
Unavailability of insecticides	80(66.7)	20(16.7)	16(13.3)	4(3.3)	416	3.47
Degradation of soil fertility as a result of erosion	16(13.3)	12(10.0)	30(25.0)	62(51.7)	222	1.85
Urbanization	16(13.3)	12(10.0)	30(25)	62(51.7)	222	1.85

Source; field survey, 2022.

Table 2 represents constraints faced by cassava farmers in Ikwuano LGA Abia State, during the COVID-19 pandemic. Farmers ranked challenges affecting cassava production, with a focus on factors like pests, disease, agrochemical access, and soil fertility.

Approximately 47.5% of respondents either agreed or strongly agreed that pest and disease significantly constrained their cassava production, with a mean score of 2.48. The prevalence of pests and diseases during the pandemic aligns with findings by Arouna *et al.* (2020), who noted that limited access to agricultural inputs, including pesticides, during covid-19 heightened pest pressures on crops West Africa.

The unavailability of agrochemicals and insecticides was a major challenge, with 83.4% of respondents agreeing or strongly agreeing, result in a high mean score of 3.47. COVID-19-related restrictions disrupted supply chains, making agrochemicals scarce or unaffordable for smallholders, as reported by the FAO (2020), which documented similar challenges in input supply during the pandemic across developing nations.

Responses were mixed regarding soil fertility, with only 23.3% of respondents agreeing on this as a significant issue, reflected in a lower mean score of 1.85. Though soil fertility is crucial for productivity, it was less impacted by immediate pandemic-impacted restrictions. However, the degradation still highlights a broader environmental challenge for sustainable cassava farming in region like Nigeria, as suggested by Nwakor *et al.*, (2016), who emphasize soil health's importance in cassava resilience.



Similar to soil fertility concerns, 23.3% of farmers viewed urbanization as a constraint, yielding a mean score of 1.85. Although urbanization was less directly tied to COVID-19, its effects may have been amplified during the pandemic, as urban demand shifts impacted rural resources. Ogunleye and Ojedokun (2014) also cite urban encroachment as a long-term threat to agricultural land availability in Nigeria.

Table 3 indicates that the most critical constraints faced by cassava farmers during the pandemic were the scarcity of agrochemicals and insecticides, drive by COVID-19 restrictions that disrupted input supply chains. Pests and disease also posed notable challenges, impacting crop health and yield. These finding align with reports on how pandemic restrictions adversely affected smallholder access to essential farming inputs, underscoring the need for resilient agricultural supply chains to safeguard food security in crises.

Table 3 the extent of engagement of rural farmers in the production of selected cassava in the study area.

Extent of engagement	Sometimes	Occasions	Often	Never	Rarely	Not Often	None	Sum of Scores	Mean Score
Game-Changer	21(17.5)	36(30.0)	6(5.0)	17(14.2)	13(10.8)	16(13.3)	11(9.2)	543	4.53
Hope	20(16.7)	36(30.0)	6(5.0)	19(15.8)	12(10.0)	16(13.3)	11(9.2)	541	4.51
Obasanjo-2	20(16.7)	35(29.2)	6(5.0)	17(14.2)	13(10.8)	17(14.2)	12(10.0)	533	4.44
Baba-70	19(15.8)	35(29.2)	7(5.8)	20(16.7)	12(10.0)	16(13.3)	11(9.2)	537	4.48
Poundable	20(16.7)	36(30.0)	6(5.0)	18(15.0)	13(10.8)	16(13.3)	11(9.2)	540	4.50
TME 419	19(15.8)	35(29.2)	6(5.0)	19(15.8)	13(10.8)	16(13.3)	12(10.0)	532	4.43
Dixon, (TMS-9800581)	20(16.7)	35(29.2)	6(5.0)	18(15.0)	14(11.7)	16(13.3)	11(9.2)	537	4.48
Farmer's Pride, (TMS-981632)	19(15.8)	35(29.2)	6(5.0)	20(16.7)	12(10.0)	16(13.3)	12(10.0)	533	4.44
Fine Face, (TMS-980505)	21(17.5)	35(29.2)	6(5.0)	17(14.2)	13(10.8)	16(13.3)	12(10.0)	538	4.48
Sunshine, (TMS-070593)	19(15.8)	35(29.2)	7(5.8)	19(15.8)	13(10.8)	16(13.3)	11(9.2)	536	4.47
Ayaya (CR36-5)	20(16.7)	36(30.0)	6(5.0)	19(15.8)	12(10.0)	16(13.3)	11(9.2)	541	4.51

Source; field survey, 2022.

The Table assesses how frequently different varieties of cassava are cultivated by farmers, which reflects their preferences and the economic importance of each variety.



High engagement varieties; varieties such as Game-Changer, Hope, Ayaya scored the highest in terms of engagement, with mean scores of 4.53, 4.51 and 4.51, respectively. This high level of engagement indicated that these varieties are regularly and frequently cultivated by farmers, likely due to their high yield potential, resilience, and market demand. Studies by Ogunleye and Ojedokun (2014) suggest that cassava varieties with strong market appeal and adaptability to local growing conditions tend to see higher engagement among smallholder farmers.

Moderate engagement varieties; other varieties, including Baba-70, Farmer's Pride, and Fine Face, have slightly lower engagement scores but are still frequently cultivated. The steady use of these varieties points to their role in diversifying production, which helps farmers manage risks associated with pests, diseases, and changing market preferences. Nwakor *et al.*, (2016) emphasized that variety diversification is a common strategy in West African agriculture, as it reduces dependency on a single crop and enhances resilience against environment challenges.

Lower engagement varieties: Obasanjo-2 and TME 419 had relatively lower engagement scores, indicating less frequent cultivation by farmers. These varieties may be less suited to local conditions or have lower market demand, leading farmers to prioritize varieties that offer greater productivity or profitability. Ukonu *et al.*, (2022) noted that smallholder farmers tend to favor varieties that perform well both in terms of yield and market value, thus avoiding varieties that may not provide optimal returns in their specific contexts.

Engagement as a Resilience Strategy: the pattern of engagement across various cassava varieties highlights the importance of crop diversity in supporting rural livelihoods. By cultivating multiple varieties with varying levels of engagement, farmers in Ikwuano are likely better positioned to cope with fluctuating environmental conditions and market demands. This aligns with findings by Arouna *et al.*, (2020), who observed that maintaining a diverse crop portfolio is essential for rural households to manage agricultural risks effectively and maintain food security. Cassava varieties like Game-Changer, Hope, and Ayaya are the most consistently engaged by farmers, likely due to their favorable traits and market demand. The varied engagement levels across different varieties suggest that farmers employ a diversification strategy to reduce risk and adapt to both environmental conditions and economic factors. This approach is consistent with



research on resilience strategies among smallholder farmers in Nigeria and across West Africa, highlighting how crop diversity supports sustainable agricultural livelihoods.

H_1 = there is no significant relationship between major cassava grown and extent of engagement of rural households in production of selected cassava.

Table 4a model summary

Model	R	R Square	Adjusted Square	Std. Error Estimate	F Change
	.871	.759	.741	3.509	43.972

Source; field survey, 2022.

Table 4b explores the relationship between the choice of major cassava varieties and the extent of engagement in cassava production among rural households in Ikwuano LGA, Abia State. This regression analysis provides insight into how the frequency of cultivating specific cassava varieties correlates with farmers' production engagement levels.

Model summary (R-Squared): with an R-squared value of 0.759, of the variation in the extent of engagement in cassava production can be explained by the choice of cassava varieties grown. This high R-squared value indicates a strong relationship between variety selection and farmers' level of engagement, highlighting that certain varieties may encourage higher production activity. Ukonu *et al.*, (2022) observed that farmers often dedicate more time and resources to high-demand, resilient cassava varieties that yield greater economic benefits.

Table 4b ANOVA

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	4331.049	8	541.381	43972	.000
Residual	1378.951	112	12.312		
Total	5710.000	120			

Source; field survey, 2022.

Significance of the model (ANOVA Test): the ANOVA test shows an F-value of 43.972 with a p-value of 0.000, indicating that the model is statistically significant at the 1% level. This significance implies that the variety of cassava grown is a key determinant of the extent of production engagement, supporting the idea that farmers' choice of variety is closely tied to their



commitment levels in cassava farming. Research by Sanni *et al.*, (2009) similarly found that farmers tend to be more engaged in cultivating varieties with higher yield potential and market value, as these varieties offer a better return on investment.

Implication of variety selection on engagement: the high level of significance suggests that varieties like game-changer or farmer's prides, which are more frequently grown, likely require or encourage greater production efforts from farmers. These varieties may demand more intensive farming techniques or offer better economic incentives, motivating farmers to engage more deeply in their cultivation.

The stronger correlation between variety choice and engagement level indicates that promoting high-yield, disease-resistant cassava varieties could enhance production engagement across rural areas.

Conclusion and Recommendation

The majority of the respondents in the study area were married, with a mean age of 26 years. The respondents' households were larger than usual, this suggested that a sizable portion of them are older, which may have an impact on the physical demands and productivity levels of cassava production in Ikwuano LGA Abia State. The majority of cassava farmers are probably responsible for their families, which may affect their desire to keep steady sources of income. The majority of respondents has completed secondary education, the farmers may find it easier to comprehend and adjust to new farming methods due to their comparatively educational attainment. Farmers may therefore be regarded as literate, the findings revealed gender distribution a slight male predominance, suggested that cassava farming is fairly balanced in terms of gender participation. Farming were the primary Occupation, this shows a strong commitment to agriculture as a primary or complementary income source. Most respondents owned farms with five or more hectares, this indicates a predominance of small-scale farming. Majority are full-time participants in cassava farming, highlighting the importance of this crop as a major source of income and sustenance.

The findings revealed prevalence of pests and diseases during the pandemic aligns with findings by Arouna *et al.* (2020), who noted that limited access to agricultural inputs, including pesticides, during covid-19 heightened pest pressures on crops. The unavailability of agrochemicals and



insecticides was a major challenge, restrictions disrupted supply chains, making agrochemicals scarce or unaffordable for smallholder farmers, as reported by the FAO (2020), which documented similar challenges in input supply during the pandemic across developing nations. Varieties such as Game-Changer, Hope, Ayaya scored the highest in terms of engagement, respectively, this high level of engagement indicated that these varieties are regularly and frequently cultivated by farmers, likely due to their high yield potential, resilience, and market demand. Studies by Ogunleye and Ojedokun (2014) suggest that cassava varieties with strong market appeal and adaptability to local growing conditions tend to see higher engagement among smallholder farmers.

The challenges faced during the COVID-19 pandemic, such as limited input access and market constraints, also revealed the vulnerabilities with the cassava production system. Addressing these issues through enhanced input supply, improved market access, and better financial support can help strengthen cassava farming in region like Ikwuano. By implementing these recommendations, stakeholders can build a more resilient, productive cassava sector that benefits rural households and contributes to broader economic growth.

The following recommendations were proffered;

- ✓ Government and local agencies should work to stabilize input supply chains, making these resources more affordable and accessible. Subsidized input programs could be effective in reducing costs for smallholder farmers.
- ✓ Encourage diversification can help mitigate risks associated with pest infestations or market fluctuations. Government programs should support the cultivation of a range of crops and cassava varieties to promote resilience among smallholder farmers.
- ✓ Agricultural extension programs should prioritize the dissemination of high-yield, disease-resistant varieties like game-changer and farmer's pride. These varieties not only improve yields but also enhance farmer commitment to production, support income generation and food security.



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EFFECTS OF METHANOLIC EXTRACT OF *AZADIRACHTA INDICA* (NEEM LEAVES) ON BOVINE EPIDIDYMAL SPERMATOZOA *IN VITRO*

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Abstract

Azadirachta indica (Neem) is a member of the Meliaceae (mahogany) family and is used for several medicinal purposes. *A. Indica* has been reported to be used traditionally to prevent pregnancies in some parts of Africa. The effects of *A. Indica* leaves on bovine epididymal spermatozoa *in vitro* were evaluated in this study. A 1000 µg/ml dose of the extract dissolved in 2.9 % sodium citrate buffer was prepared after which serial dilutions were done to obtain 500 µg/ml, 250 µg/ml, 125 µg/ml, 62.5 µg/ml doses of the extract. 20 epididymal Samples were divided into 5 groups of 4 samples (A, B, C, D and E). Group A served as the control group and contained epididymal spermatozoa suspended in sodium citrate buffer, while groups B, C, D and E contained epididymal spermatozoa suspended in 500, 250, 125 and 62.5 µg/ml of the extract respectively. The samples were evaluated for motility, viability/survivability, acrosome integrity and morphology. There was a significant decrease ($P<0.05$) in the motility and viability of the control group (A) compared with those of groups B, C and D. Acrosome integrity differed significantly ($P<0.05$) between groups A and B, while no significant difference ($P>0.05$) was detected when group A was compared with C, D and E. There was a significant increase ($P<0.05$) in sperm morphological abnormality between group A and groups B, C and D. The findings of this study showed that the methanol extract of *A. indica* had a spermicidal effect at 250 µg/ml dose and above on bovine epididymal spermatozoa and lends validity to its folkloric use for pregnancy prevention.

Introduction

The search for effective and accessible contraceptive methods has led researchers to explore the potential of natural products, including plants, as spermicides (Kumar *et al.*, 2018). The necessity to develop a safe and effective pre-coital spermicidal contraceptive to control pregnancy and population growth still exists (Kumar *et al.*, 2018). Although many types of spermicidal contraceptives are available, they have side effects, may be toxic and are not easily accepted (United nations, 2020).

Neem (*Azadirachta indica*) is a member of the Meliaceae (mahogany) family belonging to the Indian subcontinent. The tree was introduced (adventive or exotic species) in Nigeria from



Ghana, and it was first grown from the seed in Maiduguri, the then Borno Province (now Borno State), Nigeria, in 1928 (Bello *et al.*, 2023). The Neem trees have been grown successfully in all parts of Nigeria. Neem has become a naturalized species in various parts of Nigeria in diverse ecological and climatic conditions.

It is known with different names by different ethnicity and region in Nigeria: “Akum-shut-up” (Igbo), “Dogoyaro” (Hausa), English: neem (Okigbo *et al.*, 2009). In East Africa it is known as Muarubaini (Swahili), which means the “tree of the 40”, as it is supposed to cure 40 different diseases. (Eureka and Kaushik, 2016). Neem leaves and bark have been the primary ingredients in ancient medicinal preparations for malaria because of their availability throughout the year (Akin-Osanaiya *et al.*, 2013). In West Africa and India, aqueous and alcohol extracts of bark and leaves of neem are effective anti-malaria agents, particularly on chloroquine resistant strains (Aa and Mo, 2018; Udeinya *et al.*, 2008; Udeinya *et al.*, 2004).

Family planning has been encouraged through numerous means of contraception, but these contraceptives have several unwanted side effects produced by their steroid content, such as obesity, dysmenorrhea, carcinoma of the breast and uterus (Chandra-Mouli *et al.*, 2014). These methods are also typically female-oriented. These side effects from the use of the pills make them unsafe for long term use and expensive. Countless measures have been taken to decrease the side effects of these pills but there is little success (Dash *et al.*, 2014). As a result of the serious adverse effects caused by synthetic steroidal contraceptives on female population, the focus has been shifted to local plants for possible contraceptive effects on male population. Also, understanding the anti-fertility effect of *A. indica* could contribute to the development of natural, non-invasive methods of controlling fertility and provide insight into developing new, natural spermicides. The aim of this study was to determine the effect of *A. indica* on epididymal sperm parameters of bulls *in vitro*.

Materials and Methods

Study location

The research was carried out at the physiology laboratory (block d) of the College of Veterinary Medicine, Michael Okpara University of Agriculture, Umudike. The University is situated in the Southeast geopolitical zone and located at latitude 5 28’ north and latitude 7 33’ east. The area



has warm temperature range of 23°C to 36°C. High temperatures are experienced between late January and April in this area. The level of rainfall is between 200mm and 600mm. All procedures were carried out in line with the institutional ethical instructions for research with animals, and adequate consultations were made with the committee on research ethics of the College of Veterinary Medicine, MOUAAU, concerning the number of samples to be used. The ethical number assigned to this work is MOUAAU/CVM/REC/202503.

Plant Identification and Collection

Fresh mature healthy neem (*Azadirachta indica*) leaves were collected from the premises of the college of Veterinary Medicine Umudike. The leaves had been identified and verified by a Professor of forestry management in the College of Natural Resources and Environment Management, Michael Okpara University of Agriculture, Umudike, Professor M.C. Dike and a sample stored in the department's herbarium. The herbarium number is MOUAAU/VPP/15/010. The leaves were collected and washed properly, air dried at room temperature and made into powder with a mechanical grinder to obtain a fine powdered material.

Preparations of Neem Leaf Extract

100g of the grinded neem leaves was weighed and extracted using the maceration method with 80% methanol solvent, then immersed in methanol for 48 hours with intermittent shaking every 3 hours. Methanol was used for extraction because of its polarity i.e. it's ability to extract both lipophilic and hydrophilic molecules and its ease of evaporation due to its high volatility compared to ethanol (Lee et al., 2024). The solvent was allowed to evaporated totally so that there wasn't any remnant that would affect our results. The extracted mixture was filtered using filter paper to separate the residue and the filtrate. The filtrate which consists of the solvent and the active ingredient of neem leaves was heated with a hot air oven at 50°C to evaporate and dry up the solvent. The extract obtained was then put in a beaker. The percentage yield of the extract was calculated using the formular; % yield = weight of the extract/weight of plant material used x 100.

Sample Collection

10 scrotal sacs were excised from mature White Fulani bulls immediately after slaughter at the Ubakala Abattoir in Umuahia South Local Government Area of Abia State, Nigeria. Samples



were placed in a thermos flask containing ice packs and transported immediately to the laboratory for processing. Age of the Bulls were determined using their dentition. Samples were collected only from apparently healthy and sexually mature bulls.

Experimental Procedure

A 1000 µg/ml dose of the extract dissolved in 2.9% sodium citrate was prepared after which serial dilutions were done to obtain 500 µg/ml, 250 µg/ml, 125 µg/ml, 62.5 µg/ml doses of the extract. Testicles were dissected away from the tunica vaginalis and other extraneous tissues. The excised testes and epididymides were separated. Sperm cells were collected from the cauda epididymides at room temperature by incision method. Incisions were made on the lower end of the epididymides to enable sperm cells swim out into prewarmed (37 °C) 5 ml of 2.9% sodium citrate buffer in a petri dish or 5ml of different doses of the extract. The sample was kept in a hot water bath at 37 °C for 30 minutes after which sperm cells were evaluated.

Experimental Design

Samples were divided into 5 groups of 4 epididymides. Group A (control group): contained epididymal spermatozoa that were suspended in 2.9 % sodium citrate buffer solution (5 ml). Group B: contained epididymal spermatozoa suspended in 500 µg/ml of the extract dissolved in 2.9 % sodium citrate buffer solution (5 ml). Group C: contained epididymal spermatozoa suspended in 250 µg/ml of the extract dissolved in 2.9 % sodium citrate buffer solution (5 ml). Group D: contained epididymal spermatozoa suspended in 125 µg/ml of the extract dissolved in 2.9 % sodium citrate buffer solution (5 ml). Group E: contained epididymal spermatozoa suspended in 62.5 µg/ml of the extract dissolved in 2.9 % sodium citrate buffer solution (5 ml).

Determination of Spermatozoa Progressive Motility

Spermatozoan progressive motility of the various storage groups including control (0-3 hours) were evaluated by placing a drop (5 µl) of sperm sample on a pre-warmed, grease-free slide (Abu *et al.*, 2016; Rekwot *et al.*, 1970)). A cover slip was put over the drop and examined under the high-power (40x magnification) of a microscope, and the percentage of progressive motility was determined.



Determination of Spermatozoan Viability

Viability of sperm cells was determined by placing a drop (5 μ l) of sperm samples on a clean, grease-free slide and mixed with a single drop of eosin-nigrosine stain (Hoseinzadh-sani *et al.*, 2013; Blom, 1973). The spermatozoa were allowed to interact with the stain for at least 2 minutes and then a smear was made. The smear was air-dried and examined under oil immersion objective (100x magnification). Spermatozoa that stained either partially or completely were considered as dead and the spermatozoa that appeared colorless were considered as live.

Determination of Acrosome Integrity

Acrosome status was determined by briefly adding a small (10 μ L) drop of the sample on a clean slide and then making a smear (Abu *et al.*, 2016; Watson, 1975). The smear was air-dried and kept in Hancock's fixative for 15–20 minutes in a coupling jar. After the prescribed time interval, the slides were washed under slow running tap water for another 15–20 minutes and finally rinsed with distilled water. The slides were kept in a coupling jar containing Giemsa working solution overnight. The next day, the stained slides were rinsed with slow running tap water, air-dried, and observed under oil immersion objective (100 \times magnification). Two hundred spermatozoa were examined across different fields and the percentage of spermatozoa with intact acrosomes were determined. The mean results were expressed as percent acrosome integrity.

Determination of Sperm Morphological Abnormality

Sperm morphological abnormality was determined by viewing the Giemsa-stained slides. Two hundred spermatozoa were examined across different fields and the percentage of spermatozoa with morphological abnormalities was determined. The mean results were expressed as percent morphological abnormality.

Data Analysis

Data collected were analyzed by one way analysis of variance (ANOVA) and expressed as mean \pm SEM (standard error of the mean). The differences between means were analyzed by Tukey multiple comparisons test. The level of significance was set at 5%

Results

Effect of *A. indica* on Mean Progressive Sperm Motility (%)

Mean progressive sperm motility was 71.67 ± 4.4 %, 00.00 ± 00 %, 00.00 ± 00 %, 55.00 ± 2.9 % and 66.67 ± 3.3 % for Groups A, B, C, D and E respectively. (Figure 1).

There was no significant difference ($P > 0.05$) in the mean sperm motility between the control group (A) and E. However, there was significant difference ($P < 0.05$) when the mean sperm motility of Group A was compared with that of groups B, C, and D. Furthermore, no significant difference ($P > 0.05$) was observed in the mean sperm motility between groups B and C, and groups D and E.

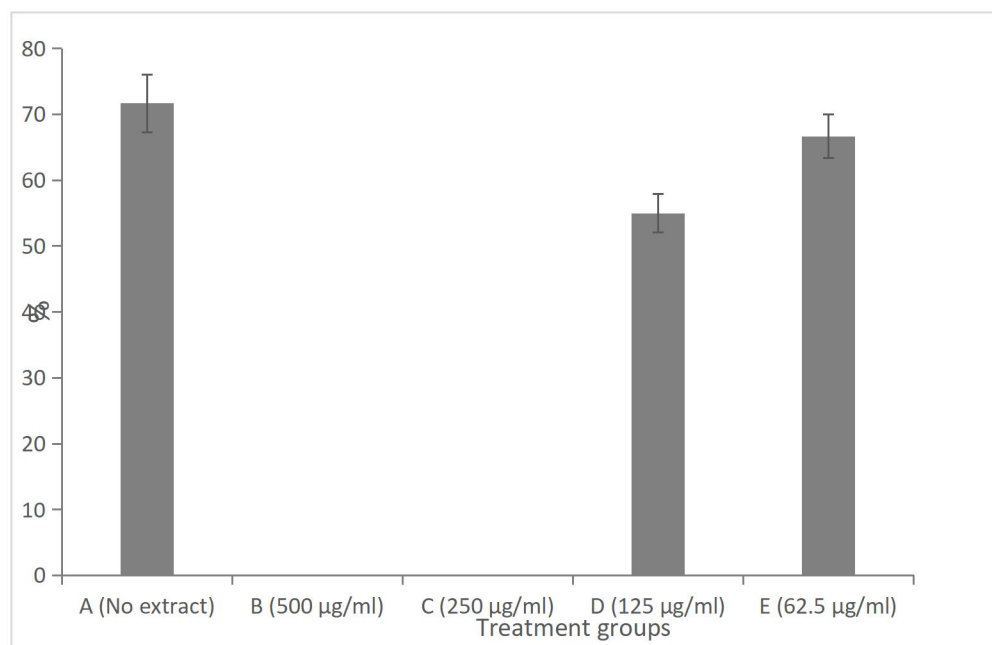


Figure 1 Effect of *A. indica* on Mean % Sperm Motility

Effect of *A. indica* on Mean Sperm Viability (%)

The mean sperm viability recorded was 69.23 ± 3.6 %, 11.00 ± 2.1 %, 26.67 ± 4.4 %, 49.73 ± 4.8 % and 66.67 ± 4.4 % for Groups A, B, C, D and E respectively (Figure 2).

There was no significant difference ($P > 0.05$) in the mean sperm viability between the control group (A) and E. However, there was significant difference ($P < 0.05$) between the control group

(A) and groups B, C, D, Furthermore, there was no significant difference ($P > 0.05$) in the mean sperm viability between groups B and C, and groups C and D.

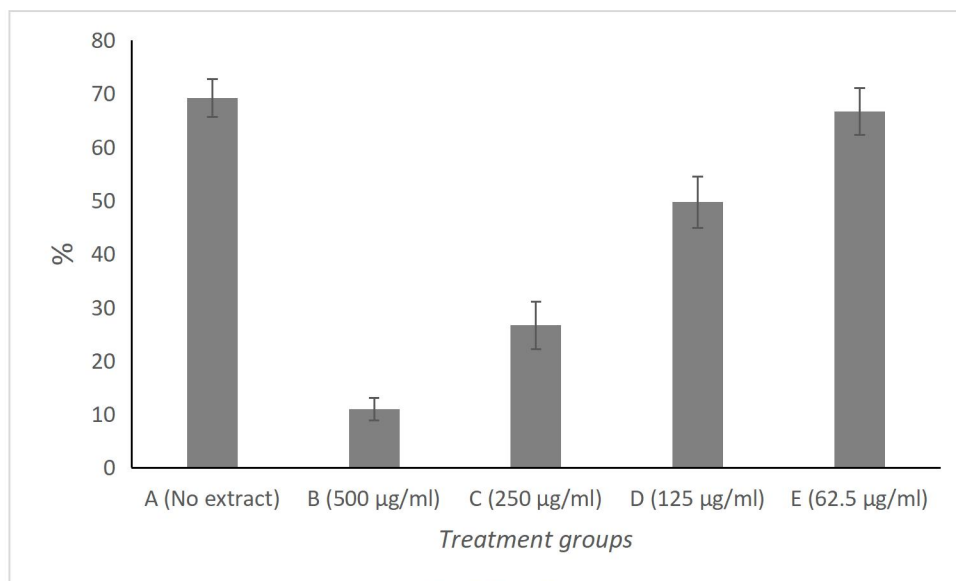


Figure 2 Effect of *A. indica* on Mean % Sperm Viability

Effect of *A. indica* on Mean Acrosomal Integrity (%)

The mean Acrosomal integrity recorded was 79.67 ± 4.9 %, 47.60 ± 2.4 %, 59.00 ± 8.2 %, 65.00 ± 5.0 % and 74.67 ± 2.0 % for Groups A, B, C, D and E respectively (Figure 3).

There was no significant difference ($P > 0.05$) in the mean acrosomal integrity between the control group (A) and groups C, D and E. However, there was significant difference ($P < 0.05$) between group A and B. Furthermore, there was no significant difference ($P > 0.05$) observed between groups C, D and E while there was significant difference ($P < 0.05$) between group B and E.

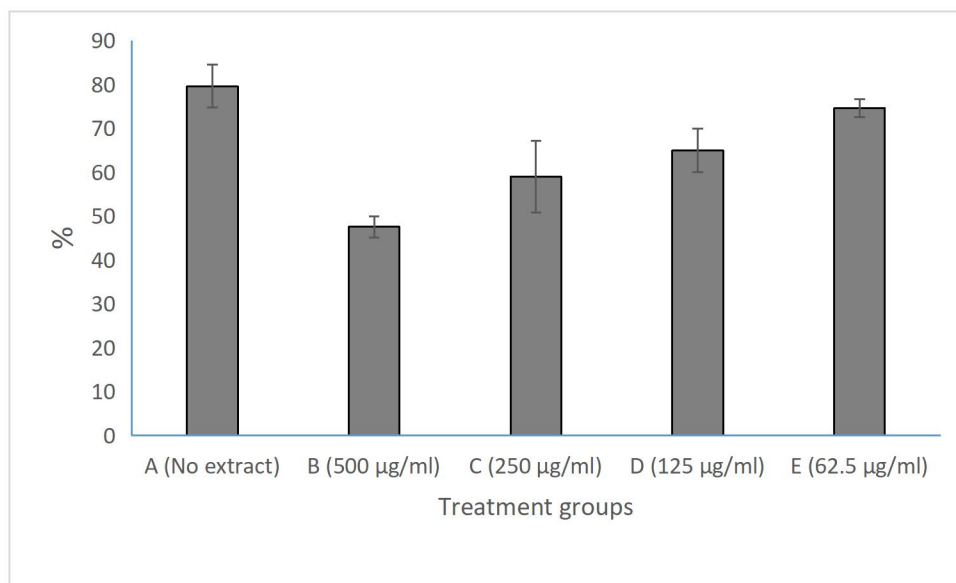


Figure 3 Effect of *A. indica* on Mean % Acrosomal Integrity

Effect of *A. indica* on Mean Morphological Anomaly (%)

The Mean Morphological anomaly for Groups A, B, C, D and E was 41.00 ± 2.1 %, 70.00 ± 1.2 %, 77.67 ± 4.3 %, 59.33 ± 5.2 % and 46.67 ± 1.7 % respectively (Figure 4).

There was no significant difference ($P > 0.05$) in the mean of morphologically abnormal sperm between the control group (A) and E. However, there was significant difference ($P < 0.05$) when the control group (A) was compared with groups B, C, and D. Furthermore, there was no significant difference ($P > 0.05$) between groups B, C, D and also between group D and E.

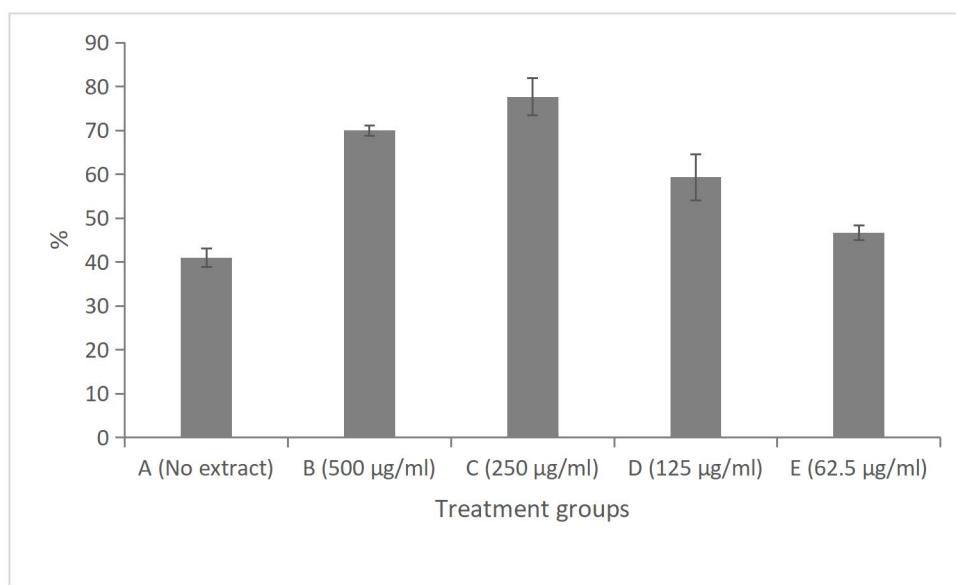


Figure 4 Effect of *A. indica* on % Morphologically abnormal sperm

Discussion

In the current study, it was observed that *A. indica* at 250 µg/ml and 500 µg/ml caused absolute immobility in the spermatozoa samples. However, at 62.5 µg/ml, no significant difference ($P > 0.05$) was observed in sperm motility compared to the control group. The decrease in spermatozoa motility may be caused by the presence of saponins in the methanol crude extract of *A. indica*. Saponin may decrease spermatozoa motility and viability gradually to absolute zero (Joshi *et al.*, 2011). This concurs with the findings of Al-jadidi and Hossaini (2015). They linked azadirachtin, which is the major alkaloid found in ethylacetate, chloroform and hexane fractions of the methanolic crude extract to be associated with decreasing sperm motility and concentration.

For live and dead ratio (sperm viability), a significantly ($p < 0.05$) high percentage of dead spermatozoa was recorded in groups with higher doses of the extract (500 and 250 µg/ml), compared to the control and the lower dose groups (125 and 62.5 µg/ml). *In vitro* screening of most plant extracts (plants like *Carica papaya*, *Allium sativum*, *Cestrum parqui*, *Ruta graveolens*, *Achyranthes aspera* and *Stephania hemandofolia*) for their spermicidal properties also indicated that it involves either loss of functionality or motility as an end point (Abu *et al.*, 2011).



Groups with higher doses of the extract (B and C) showed low acrosome integrity while groups with lower dose (E) showed normal acrosome integrity.

There was significant difference in sperm morphological abnormality between the control group and groups B and C (higher doses of the extract). Increased free head and bent tail sperm morphological abnormalities were observed. The control group had morphological anomaly which could be attributed to poor collection process.

Various active compounds contained in the neem leaf have an antifertility and spermicidal effect (Hashmat *et al.*, 2012). The active components of neem oil have been found to be absorbed through the vaginal mucosa into circulation and exerted 9 antifertility effects in addition to direct spermicidal effect. Majority of plant-derived spermicides were attributed to triterpens obtained from saponins of several structural types, and phenol compounds (Aladakatti and Jadaramkunti, 2015). Studies have been reported that on reproductive indices, neem seed oil and leaf extracts have been shown to act as a powerful spermicide with significant inhibition of spermatogenesis, decreased sperm motility, count and cessation of fertility (Subapriya *et al.*, 2005). According to Ekasari (2011), from the results of research conducted by scientists on experimental animals and in humans, it was found that spermatozoa from animals and humans became inactive after 30 seconds of contact with neem oil. Aqueous extract of old and tender leaves of *Azadirachta indica* (neem) are reported to immobilize and cause 100 % mortality of human spermatozoa with no morphological changes in sperm head, mid- piece and tail (Khillare and Shrivastav, 2003). The results obtained indicate that the oil used intravaginally before sex can prevent pregnancy. A study conducted by Arief (2014) proved that the administration of neem extract to white mice could reduce spermatozoa's quantity and quality at different doses (Arief *et al.*, 2014).

The findings of this work have shown that methanol extract of *A. indica* have spermicidal effect *in vitro* at 250 µg/ml dose and above on bovine epididymal spermatozoa which corroborates the findings from *in vivo* studies and also lends validity to the folkloric use of this plant for pregnancy control.

A limitation of this study was the fact that a standard spermicidal drug was not used as a positive control so as to measure how the extract compares with already existing spermicidal drugs.



We recommend that further studies be carried out to compare how this plant extract fares with standard spermicides so as to determine its suitability for development as a natural spermicide and a viable alternative to the already existing spermicides.

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PREVALENCE OF DYSLIPIDEMIA AND OBESITY AMONG YOUNG NIGERIAN ADULTS: A CASE STUDY OF ABIA STATE

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Abstract

Dyslipidemia and obesity are significant risk factors for cardiovascular diseases, yet their prevalence among young adults in Nigeria remains underexplored. This study aimed to assess the prevalence of dyslipidemia and obesity among young Nigerian adults in Abia State. A total of 154 young adults were selected using purposive and simple random sampling techniques from seven locations (three urban and four rural areas) in Abia State between August and September 2024. Participants were categorized into three age groups: 17–20, 21–30, and 31–40 years. Data collection involved a predesigned interviewing schedule, including personal information, weight, height, waist circumference, and blood lipid profile. Body mass index (BMI) and waist circumference were used to assess obesity, while dyslipidemia was determined based on lipid profile analysis. The overall prevalence of dyslipidemia, overweight, and BMI-based obesity among the studied population was 6.5%, 11.0%, and 6.5%, respectively. Waist circumference-based obesity was observed in 15.6% of participants. Females had a higher prevalence of BMI-based obesity (90%) compared to males (10%). Similarly, waist circumference-based obesity was more prevalent in females (59.2%) than in males (40.8%). Dyslipidemia was also more common in females (70%) than in males (30%). The findings indicate a high prevalence of obesity among young adults in Abia State, with a greater burden observed in females. The results highlight the need for targeted public health interventions to address obesity and dyslipidemia in this population to mitigate future cardiovascular risks.

Keywords: Dyslipidemia, obesity, young adults, Nigeria, body mass index, waist circumference, cardiovascular risk.

1. Introduction

Dyslipidemia and obesity are major public health concerns that contribute significantly to the global burden of non-communicable diseases (NCDs), particularly cardiovascular diseases (CVDs), type 2 diabetes, and metabolic syndrome (Chukwuonye *et al.* 2022; Nnamudi *et al.* 2020b). Dyslipidemia is characterized by abnormal lipid levels, including elevated total cholesterol, low-density lipoprotein cholesterol (LDL-C), triglycerides, and reduced high-density lipoprotein cholesterol (HDL-C), all of which are critical risk factors for atherosclerosis and



cardiovascular complications (Tietge 2014). Similarly, obesity, defined as excessive body fat accumulation with adverse health effects, is a growing concern, particularly in developing countries undergoing rapid urbanization and dietary transitions (Phelps *et al.* 2024).

The prevalence of obesity and dyslipidemia has been increasing in many low- and middle-income countries, including Nigeria, where lifestyle changes, reduced physical activity, and increased consumption of processed foods have contributed to the rising burden of metabolic disorders (Nnamudi *et al.* 2020a; Obsa *et al.* 2021). While obesity was once considered primarily an issue in high-income nations, it is now recognized as a major threat in Africa, where changes in dietary patterns, urbanization, and socio-economic factors are fueling an obesity epidemic (Vekic *et al.* 2019). The interplay between obesity and dyslipidemia is particularly concerning, as excess body fat is strongly linked to lipid abnormalities, insulin resistance, and systemic inflammation, which increase the risk of chronic diseases at younger ages (Bamba & Rader 2007; Jung & Choi 2014).

In Nigeria, the prevalence of obesity and dyslipidemia have been associated with risk of cardiovascular disease (Ogah *et al.* 2023). Also, studies on obesity and dyslipidemia have predominantly focused on older adults and specific high-risk populations, such as individuals with hypertension or diabetes (Ekpenyong *et al.* 2012). However, there is a growing concern regarding the prevalence of these conditions among young adults, who represent a critical demographic group for early prevention and intervention. Young adulthood is a formative period in which lifestyle behaviors, including dietary habits, physical activity levels, and metabolic health, are established and can influence long-term health outcomes (Spring *et al.* 2014).

Abia State, located in southeastern Nigeria, presents a unique case for studying these conditions due to its socio-economic diversity and mix of urban and rural populations. Rapid urbanization in cities such as Umuahia and Aba has led to shifts in dietary habits and physical activity patterns, mirroring global trends associated with increasing obesity and metabolic disorders (Ekpenyong & Akpan 2013).



Furthermore, gender differences in obesity and dyslipidemia patterns have been reported in various studies, with females often showing a higher prevalence of obesity due to biological, hormonal, and socio-cultural factors (Kang & Park 2022; Oda & Kawa 2009). Given that previous research has documented an increasing burden of overweight and obesity among Nigerian women, this study aims to explore whether similar trends exist among young adults in Abia State. Identifying these patterns early is essential for designing effective interventions that can curb the rise of metabolic disorders before they manifest into severe health complications.

This study aimed to assess the prevalence of dyslipidemia and obesity among young Nigerian adults in Abia State and to examine the potential gender, age, and urban-rural disparities in these conditions.

2. Methods

This study employed a population-based, purposive cross-sectional design to assess the prevalence of dyslipidemia and obesity among young Nigerian adults in Abia State. A total of 154 male and female participants, aged between 17 and 40 years, were selected from **seven** locations in Abia State, including Christ the King Church World Bank, Winners Chapel Agbama, Federal Medical Centre – Medical Students' Hostel, Okpuala Ngwa, Ntigha, Urata, and Umuosu. The study was conducted between August and September 2024. The study included young Nigerian adults (male or female) aged 17–40 year and individuals who had resided in the selected areas of Abia State for at least one year before the study period. Also, this study included participants who provided informed consent to participate in the study.

Each participant was administered a structured questionnaire to collect demographic and lifestyle data, including age, sex, smoking habits, dietary patterns, and physical activity levels. Anthropometric measurements were taken following standard protocols. Weight was measured using a Detecto scale (MO, USA) with participants wearing light clothing and no shoes. Measurements were recorded to the nearest 0.1 kg. Similarly, height was measured using a wall-



mounted stadiometer with participants standing upright, and values were recorded to the nearest 1 cm.

Body mass index (BMI) was used as an indicator for overweight and obesity, calculated as weight in kilograms divided by height in meters squared. Classification followed the World Health Organization (WHO) guidelines, categorizing individuals as underweight (BMI <18.5 kg/m²), normal weight (BMI 18.5–24.9 kg/m²), overweight (BMI 25.0–29.9 kg/m²), and obese (BMI ≥30.0 kg/m²). Waist circumference was used to assess abdominal obesity, with cut-off values of >102 cm for males and >88 cm for females. It was measured using a non-stretchable measuring tape at the midpoint between the lower margin of the last rib and the top of the iliac crest with values recorded to the nearest 0.1 cm.

Blood pressure measurements were obtained using a standardized sphygmomanometer, with hypertension defined as systolic blood pressure (SBP) ≥140 mmHg and/or diastolic blood pressure (DBP) ≥90 mmHg, or current use of antihypertensive medication.

Lipid profile assessments included total cholesterol, high-density lipoprotein (HDL-C), low-density lipoprotein (LDL-C), and triglycerides (TG), measured using the Reflotron Plus (Roche Diagnostics GmbH, Germany). Hypercholesterolemia was defined as total cholesterol ≥5.2 mmol/L, low HDL-C as <0.9 mmol/L, high LDL-C as >4.1 mmol/L, and high triglycerides as >4.5 mmol/L, following WHO and American Heart Association (AHA) guidelines. Measurements were taken under standardized conditions to ensure reliability and accuracy.

2.1 Statistical analysis

Data were collected, coded, and entered into an IBM-compatible computer using SPSS version 25 for Windows. Qualitative variables were presented as frequencies and percentages. The chi-square test was used to assess the association between age, gender, overweight, obesity, and dyslipidemia. A significance level of $p < 0.05$ was considered statistically significant for all tests.



3. Results

A total of 154 young adults were recruited from seven different areas of Abia State, Nigeria, including Christ the King Church World Bank, Winners Chapel Agbama, Federal Medical Centre, Medical Students Hostel, Okpuala Ngwa, Ntigha, Urata, and Umuosu. The participants' ages ranged from 17 to 40 years, with a mean age of 28.9 ± 7.5 years. Of the total participants, 99 (64.3%) were males, while 55 (35.7%) were females. The distribution of age groups showed that 47.4% of participants were aged 17–20 years, 11.7% were aged 21–30 years, and 40.9% were within the 31–40-year range. Additionally, 10.4% of the participants reported being smokers. Table 1 summarizes the study participants' characteristics.

Table 1: Baseline characteristics of study subjects

Variable	Category	Frequency (%) N=154
Age group	17-20	22 (14.3)
	21-30	67 (43.5)
	31-40	65 (42.2)
Gender	Male	99 (64.3)
	Female	55 (35.7)
Smoking	No	138 (89.6)
	Yes	16 (10.4)
Hypertension	No	120 (77.9)
	Yes	34 (22.1)

Based on BMI classification, 20.1% of the participants were overweight, while 6.5% were obese. Waist circumference-based obesity was observed in 15.6% of participants. Hypertension was diagnosed in 22.1% of the study population. The overall prevalence of dyslipidemia was 6.5% (Table 2).

**Table 2: Mean Value of Participants Anthropometrics**

Participants	Age	Height	Weight	BMI	WC	WHR
Male	29.4±7.4 ^a	172.2±5.9 ^b	64.7±11.6 ^a	21.8±3.2 ^a	77.7±9.6 ^a	0.9±0.2 ^b
Female	28.7±7.5 ^a	161.9±7.9 ^b	61.8±13.3 ^b	23.6±5.2 ^b	79±11.3 ^a	0.8±0.1 ^b

WC= Waist Circumference; TAG= Triacylglycerol; WHR= Waist Hip Ratio
Values with different superscripts across the column show significant differences

The result of lipid profile is presented on Table 3.

Table 3: Mean Value of Participants Lipid Profile

Participant	Total Cholesterol	HDL	LDL	TAG
Male	183.3±79.7 ^a	49.1±24.1 ^a	56.3±53.8 ^a	117.9±80.3 ^a
Female	186.6±97.6 ^b	58.5±31.3 ^a	55.9±59 ^a	119.9±81.5 ^a

TAG= Triacylglycerol; HDL: High Density Lipoprotein; LDL= Low Density Lipoprotein
Values with different superscripts across the column show significant differences

Table 4 presents the prevalence of obesity and dyslipidemia stratified by gender and age. Regarding BMI-based obesity, females had a higher proportion of normal BMI than males in the 17–20 and 31–40-year age groups. However, in the 21–30-year age group, a greater proportion of males had a normal BMI compared to females. Overweight was more common in males aged 31–40 years, whereas females in the 21–30-year age group had a higher prevalence of overweight. Notably, obesity was more prevalent among males, although within the female group, obesity was more prominent in those aged 31–40 years.

For waist circumference-based obesity, females had a significantly higher prevalence than males in the 31–40-year age group, while the prevalence was equal among the 21–30 and 31–40-year age groups. Among females, the highest proportion of waist circumference-based obesity was found in those aged 31–40 years ($p = 0.001$).



Table 4: Prevalence of obesity and dyslipidemia among participants by age and gender.

Female							Male						No	%	$\chi^2 = 12.61,$ $P = 0.46$
17-20		21-30		31-40		17-20		21-30	31-40						
No	%	No	%	No	%	No	%	No	%	No	%	No	%		
BMI															
Normal	7	14	20	40	23	46	5	14	17	46	15	41	87	56.49	
Obese	0	0	4	44	5	56	0	0	0	0	1	100	10	6.49	
Overweight	2	8	13	52	10	40	0	0	4	44	5	56	34	22.08	
Underweight	6	40	6	40	3	20	2	25	3	38	3	38	23	14.94	
Waist circumference														$\chi^2 = 5.84,$ $p = 0.50$	
Normal	15	19	34	44	28	36	7	13	23	43	23	43	130		84.42
Obese	0	0	9	41	13	59	0	0	1	50	1	50	24		15.58
Hypercholesterolemia														$\chi^2 = 2.31,$ $p = 0.33$	
No	12	13	40	43	40	43	7	13	24	46	21	40	144		93.51
Yes	3	43	3	43	1	14	0	0	0	0	3	100	10		6.49
Hypertriglycemia														$\chi^2 = 8.13,$ $p = 0.015$	
No	10	13	41	51	29	36	5	11	20	44	20	44	125		81.17
Yes	5	26	2	11	12	63	2	20	4	40	4	40	29		18.83



Dyslipidemia, as assessed by hypercholesterolemia, was significantly higher among males aged 31–40 years compared to their female counterparts ($p = 0.005$). These findings highlight a gender- and age-related pattern in obesity and dyslipidemia prevalence among young adults in Abia State.

4. Discussion

The aim of this study was to determine the prevalence of dyslipidemia among young adults in selected areas of Abia State, Nigeria. The findings revealed that the overall prevalence of dyslipidemia, overweight, and obesity among the study participants was 6.49%, 22.08%, and 6.49%, respectively. Waist circumference-based obesity was detected in 41.5% of participants. These results are consistent with global trends, as the prevalence of dyslipidemia has been increasing worldwide (AlMajed *et al.* 2011; Rühli *et al.* 2008).

A previous study conducted in Imo State, Nigeria, using standard WHO diagnostic criteria, reported a dyslipidemia prevalence of 34.1%, along with 38.5% overweight and 20.7% obesity among women attending a local community meeting (Osuji *et al.* 2010). Another study evaluating dyslipidemia among hypertensive Nigerians found that 60.0% of hypertensive patients had dyslipidemia, with 43.4% presenting high total cholesterol (TC), 30.3% high low-density lipoprotein cholesterol (LDL-C), 20.8% elevated triglycerides (TG), and 12.9% low high-density lipoprotein cholesterol (HDL-C) (Ayoade *et al.* 2020). These findings highlight the growing

burden of dyslipidemia in Nigeria. Nnamudi *et al.* (2020a) also investigated the prevalence of obesity, metabolic syndrome and the different BMI-metabolic risk sub-phenotypes in a young adult Nigerian population. Their findings found that obesity was 10.88% (5.40% males; 15.80% females) of the study population (Nnamudi *et al.* 2020a). Our study also found that the prevalence of dyslipidemia based on hypercholesterolemia was significantly higher among males aged 31–40 years compared to their female counterparts. Similarly, a study conducted in Turkey reported that dyslipidemia was more prevalent in men than women and increased with age (Bayram *et al.* 2014). However, we observed a reverse trend for hypertriglyceridemia, with a higher prevalence among females in the 31–40 age group. This suggests an increasing cardiovascular risk with age and gender-related variations in lipid profiles. A



study conducted among Indians aged 20-29 years similarly found that high TG and low HDL cholesterol levels were more common in males and increased with age (Ezhilan *et al.* 2009).

Several studies in Nigeria have also documented a high prevalence of dyslipidemia. Odenigbo and Oguejiofor (2008) reported a 51% prevalence among professionals in South-South Nigeria, with high LDL-C being a common pattern. Agboola-Abu and Onabolu (2000) noted that individuals from the upper social class attending a medical research center had a high prevalence of hypercholesterolemia (60.4%) and hypertriglyceridemia (22.6%). Similarly, a cross-sectional study in Northern Nigeria by Sani *et al.* (2010) found elevated TG and LDL-C levels in 15.0% and 25.7% of participants, respectively.

In studies focusing on hypertensive populations, Akintunde *et al.* (2010) reported a dyslipidemia prevalence of 58.9%, while Ojji *et al.* (2009) found that newly diagnosed hypertensive individuals had high LDL-C (17%), TC (11.1%), and TG (7.6%) based on ATP III criteria. These findings align with our study, which also indicates a high prevalence of dyslipidemia among older individuals.

Regarding obesity and overweight, our study found that these conditions were more frequent in males aged 31-40 years, whereas waist circumference-based obesity was more prevalent in females. This is consistent with previous studies, which have shown that men tend to have higher BMI-based obesity, while women have higher central obesity (Hajian-Tilaki & Heidari 2007) (Yahia *et al.* 2008). A Nigerian study estimated the prevalence of overweight and obesity as 27.6% and 14.5%, respectively, with overweight being slightly more common in women (28.3%) than men (26.3%), while obesity was significantly higher in women (23.0%) than men (10.9%) (Chukwuonye *et al.* 2022)..

The present study also observed an age-related increase in dyslipidemia. Hypertriglyceridemia was more prevalent in females aged 31-40 years (68.4%) and in males aged 21-30 years (50.0%), with an overall prevalence of 29.0% ($p=0.004$). This aligns with a study by Liu *et al.* (2018) which reported a 29.09% prevalence of dyslipidemia in individuals aged 18-40 years. Furthermore, evidence suggests that childhood obesity increases the risk of elevated lipid levels and hypertension in adulthood, contributing to coronary heart disease (Guo *et al.* 2002; Steinberger *et al.* 2001).



Interestingly, while hypercholesterolemia was significantly higher in males aged 31-40 years, younger females exhibited higher total cholesterol and LDL-C levels compared to older females. The higher dyslipidemia prevalence in males may be linked to risk factors such as smoking, alcohol consumption, and hypertension. Additionally, hormonal differences may play a role, as estrogen has been shown to inhibit LDL transport by downregulating endothelial scavenger receptor B1 (SR-B1), offering some protective effects against dyslipidemia in premenopausal women (Sessa 2018; Zhang *et al.* 2022).

5. Conclusion

Overall, this present study provides critical insights into the prevalence of dyslipidemia among young adults in Abia State, Nigeria, highlighting its association with age, gender, and obesity patterns. The findings reveal a significant burden of dyslipidemia, particularly among males aged 31-40 years and females with central obesity, emphasizing the need for early detection and intervention. Given the rising global and national trends in cardiovascular diseases, these results underscore the importance of targeted public health initiatives, including lifestyle modifications, routine lipid screening, and community-based awareness programs to mitigate long-term cardiovascular risks. Future research should focus on the interplay of genetic predispositions and environmental factors contributing to dyslipidemia, enabling the development of more effective prevention strategies tailored to the Nigerian population.

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EFFECTS OF *JUSTICIA SECUNDA* (VAHL) LEAF ON OXIDATIVE STRESS AND SERUM BIOCHEMICAL PARAMETERS IN *TRYPANOSOMA BRUCEI* INFECTED RATS

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Abstract

This study investigated the effects of *Justicia secunda* leaf extracts on oxidative stress and serum biochemical parameters in *Trypanosoma brucei* infected rats. Twenty five albino rats were randomly assigned into five groups (I-V) of five rats each. Group I served as uninfected untreated (control), group II infected untreated, group III infected and treated with diminazene aceturate (DA), group IV infected and treated with *J. secunda* and group V was treated with both DA and *J. secunda*. The mean malondialdehyde (MDA) was significantly ($P>0.05$) higher in the infected untreated group compared to the infected treated groups. The mean superoxide dismutase (SOD) and glutathione (GSH) of the groups treated with *J. secunda* and both *J. secunda* and DA did not show any significant ($P<0.05$) difference. The mean catalase (CAT) of the groups treated with DA and both DA and *J. secunda* did not show any significant ($P<0.05$) difference. The mean total protein and albumin of the infected groups were significantly ($P>0.05$) lower than the control on day 7 post infection (PI). On day 14 PI (7 Post treatment PT) the infected untreated group was significantly lower ($P>0.05$) than the infected treated groups. The mean aspartate aminotransferase (AST), alanine aminotransferase (ALT) and alkaline phosphatase (ALP) of infected untreated group was significantly ($P>0.05$) higher on day 14 PI (day 7 PT) compared to the infected treated groups. The mean blood urea nitrogen BUN and creatinine levels of the infected groups did not show any significant ($P<0.05$) difference on day 7 PI. On day 14 PI (7 PT) the BUN of the infected untreated group was significantly ($P>0.05$) higher than the infected treated groups, whereas the creatinine did not show any significant ($P<0.05$) difference. In conclusion *J. secunda* leaf extract exhibited improved oxidative stress markers and hepatoprotective effects in *T. brucei* infected rats.

Key words: *Justicia secunda*; *Trypanosoma brucei*; Oxidative stress; Serum biochemistry; Rat.

Introduction

Traditional and complementary medicines (TCM) are currently among the vital part of global health care system (Burton *et al.*, 2015; Kitadi *et al.*, 2019). In Africa, it is estimated that over 80% of the population rely on medicinal plant species to meet their basic health care needs, despite the tremendous improvement in the health care system (Ngbolua *et al.*, 2011). The reason for this may be attributed to high cost and unavailability of orthodox drugs, and the perceived side effects especially for the people living in remote areas. Poverty and cultural inclination is also a major factor contributing to this current



trend (Akah *et al.*, 2009; Miri *et al.*, 2015). Among the ailments usually treated with traditional medicines are inflammatory conditions, anaemia, diarrhoea, convulsions and mental disorders (Hajhashemi *et al.*, 2009; Kitadi *et al.*, 2019).

Justicia secunda Vahl commonly known as Blood root and Sanguinaria is an evergreen, perennial plant, which grows up to 90-200 cm with purplish green stem and pink flower. It is a well-known medicinal plant belonging to the family Acanthaceae and native to the north of South America and Venezuela (Carrington *et al.*, 2012; Onochie *et al.*, 2020). Some of the traditional uses of *J. secunda* includes in management of anaemia, hypertension, diabetes, respiratory and gastrointestinal disorders as well as inflammation (Theiler *et al.*, 2017; Kitadi *et al.*, 2019). Phytochemical screening of the plant has shown the presences of tannins, flavonoids, alkaloids, quinines and anthocyanins (Theiler *et al.*, 2010) Luteolin, aurantamide acetate, auranamide, quindoline and pyrrolidone derivatives, secundarellone A, B and C have been isolated from *J. secunda* (Koffi *et al.*, 2013; Calderon *et al.*, 2013).

African animal trypanosomosis (AAT) is a haemoparasitic disease of animals in sub-Saharan Africa associated with huge economic losses (WHO 2007; Yohannes *et al.*, 2013). The major clinical manifestations of the AAT includes anaemia, weight loss, weakness, anorexia, unthriftiness, abortion, low milk production, and decrease in reproductive efficiency (Radostis *et al.*, 2003). Another striking feature of African trypanosomes is their capacity to cause immunosuppression in the affected hosts and consequent tissue oxidation (Stijiemans *et al.*, 2016; Akpa *et al.*, 2021). The infection with trypanosomes results in the production of reactive oxygen species (ROS) and free radicals which are cytotoxic agents (Gutteridge, 1995), damaging vital components of the cell, including proteins and lipids (Murray *et al.*, 2003). Alterations in various biochemical changes in trypanosmosis have been observed in various animal species due to the effects of the parasite on different organs and systems (Omeje and Anene, 2012). Recent studies have shown that oxidative stress markers and serum biochemical changes are important indices for disease diagnosis and prognosis (Onasanya *et al.*, 2015). Previous studies have also demonstrated the beneficial effects of *J. secunda* especially its haematinic property (Ofeimun *et al.*, 2020; Ukwueze *et al.*, 2024). However, there is paucity of information on the effects of *J. secunda* on the oxidative stress makers and serum biochemical changes in *T. brucei* infected rats. Hence the need for this research work, which was designed to assess the effects *J. secunda* on the oxidative stress and serum biochemical changes in *T. brucei* infected rats,



Materials and Methods

Plant collection, identification and extraction

Fresh leaf of *Justicia secunda* Vahl were collected from the National Corps Research Institute, Umudike (NCRI). The leaf were identified and authenticated at the Department of Plant Science and Biotechnology, Michael Okpara University of Agriculture, Umudike. The fresh leaf were washed with water and dried under a shade at room temperature for one week. The dried plant materials were coarsely powdered using a milling machine. Four hundred and ninety-nine grams (499g) of the fine powder of *J. secunda* was weighed, using a weighing balance. The plant material was soaked with 90% of methanol in a Winchester bottle. This was shaken every 3 hours intervals during the day time and allowed to stand for 72 hours at room temperature and thereafter sieved and filtered through a Whatman number one filter paper. The filtrate was later concentrated at a temperature of 60 °C with the use of an electric oven and the extract was stored in a refrigerator at 4°C for future use. The percentage yield was calculated using the formula below: % yield = (weight of extracted material/weight of plant material) x 100/1

Acute toxicity test

This study was carried out using the up-and-down method of acute toxicity test as described by Rispin *et al.* (2002). Six albino rats were selected for the acute toxicity test and they were randomly divided into two groups of three rats each. One group was treated with the plant extract at 200mg/kg while the second group was given an equal volume of distilled water, orally by gastric gavage. Thereafter, the rats were observed for 48 hours for signs of toxicity and mortality.

Experimental animals

Twenty five apparently healthy female adult albino rats weighing between 100-110 grams were used for this study. They were sourced from the Department of Veterinary Physiology and Pharmacology, Michael Okpara University of Agriculture, Umudike. The animals were housed in a well-ventilated fly proof animal house and allowed to acclimatize for two weeks before the commencement of the study. The animals were humanely cared for in compliance with the principles of Laboratory Animal Care. They were fed commercial pelleted grower feed (Chikun®) and water was given *ad libitum*.



Parasites inoculation

The *Trypanosoma brucei* parasite used in this study was obtained from the Department of Veterinary Parasitology and Entomology, University of Nigeria, Nsukka. The trypanosomes were passaged in donor rats before infection of the experimental animals. The rats were infected intraperitoneally (IP) with 0.1 ml of saline diluted blood containing 1.5×10^6 trypanosomes. The number of infective trypanosomes was determined using the rapid matching method of Herbert and Lumsden (1976).

Experimental procedure

The albino rats were divided into five groups of five rats each. Group I uninfected untreated (control), group II infected untreated, group III infected and treated with diminazene aceturate (DA), group IV infected treated with *J. secunda* and V was treated with both DA and *J. secunda*. At the peak of parasitemia (day 7 post-infection), group III and V were treated with a single dose of diminazene aceturate (Babazine ®) intramuscularly at the dose of 7 mg/kg body weight, while the groups IV and V were treated with *J. secunda* for seven days orally at dose of 200mg/kg body weight.

Parasitaemia

The parasitaemia was determined using the wet mount method and micro haematocrit buffy coat microscopy (MBC) as described by Murry *et al.* (1977). The parasitaemia was monitored daily from day two post infection till patency

Blood collection and determination of parameters

Two ml of blood was collected from the medial cantus of the eye into vacutainer tubes without anticoagulant and the tubes were left undisturbed for 30 minutes to enhance serum production. The tubes were then centrifuged for 2 minutes at 30,000 revolutions per minute using a microhematocrit centrifuge. The serum supernatant was immediately aspirated into labelled sample bottles and stored in the refrigerator until use.

Malondialdehyde (MDA) was determined according to Fauziah *et al.* (2018). Catalase (CAT) activity was determined according to Iwase *et al.* (2013). Reduced glutathione (GSH) was estimated as described by Hamid *et al.* (2019). Serum superoxide dismutase (SOD) activity was measured according



to Gaeta *et al.* (2002). While, total serum protein, albumin, blood urea nitrogen, creatinine, alanine aminotransaminase (ALT), aspartate aminotransferase (AST) and alkaline phosphatase (ALP) were determined using commercial kits (Randox) according to the manufacturer's instruction.

Statistical analysis

Data obtained from the study were expressed as means \pm standard error. Statistical significance was analyzed using one-way analysis of variance (ANOVA) and Duncan's multiple range test with SPSS version 20 software package. The level of significance was accepted at $p < 0.05$

Results

The mean MDA was significantly ($P > 0.05$) higher in the infected untreated group compared to the infected treated groups. The infected treated groups did not show any significant ($P > 0.05$) difference and comparable with the control. The mean SOD and GSH of the infected treated with *J. secunda* and both *J. secunda* and DA did not show any significant ($P > 0.05$) difference. However, the mean SOD of infected treated with DA and infected untreated did not show any significant ($P > 0.05$) difference, while the mean GSH of infected treated with DA was significantly ($P < 0.05$) higher than the infected untreated. The mean CAT of the groups infected treated with DA and both DA and *J. secunda* did not show any significant ($P > 0.05$) difference, but they were significantly ($P < 0.05$) higher than the infected treated with *J. secunda*, which did not differ significantly ($P > 0.05$) from the infected untreated (Figure 1).

Then mean total protein of the infected groups were significantly ($P < 0.05$) lower compared to the control on day 7 post infection (PI). On day 14 PI (day 7 post treatment) (PT) the infected treated groups did not show any significant ($P < 0.05$) difference within the groups and when compared with control, but were significantly ($P > 0.05$) higher than the infected untreated. From day 21 PI (14 PT) the infected treated groups and the control did any significant ($P > 0.05$) difference till the end of the experiment (Figure 2). The mean albumin of the infected groups did not show ($P > 0.05$) did not show any significant difference on day 7 PI. On day 14 PI (day 7 PT) the infected untreated group was significantly lower ($P < 0.05$) than the infected treated groups and control. From day 21 PI (14 PT) the infected treated groups and the control did any significant ($P > 0.05$) difference till the end of the

experiment (Figure 3). The mean AST, ALT and ALP of infected untreated group was significantly ($P < 0.05$) higher on day 14 PI (day 7 PT) when compared to the infected untreated groups and the control. From day 21 PI (day 14 PT) the infected untreated groups did not show any significant ($P > 0.05$) difference and comparable with the control (Figures 4, 5 and 6).

The mean BUN of the infected groups did not show any significant ($P > 0.05$) difference on day 7 PI, but were significantly ($P < 0.05$) higher than the control. On day 14 PI (day 7 PT) the infected untreated was significantly ($P < 0.05$) higher than the infected treated groups and the control, while the infected treated groups and the control did not ($P > 0.05$) show any significant difference till the end of the experiment (Figure 7). The mean creatinine of the infected groups did not show any significant ($P > 0.05$) difference on days 7 and 14 PI (days 0 and 7 PT), though the infected untreated group was higher than other infected treated group on day 14 PI. From day 21 PI (14 PT) the infected treated groups and the control did any significant ($P > 0.05$) difference till the end of the experiment (Figure 8).

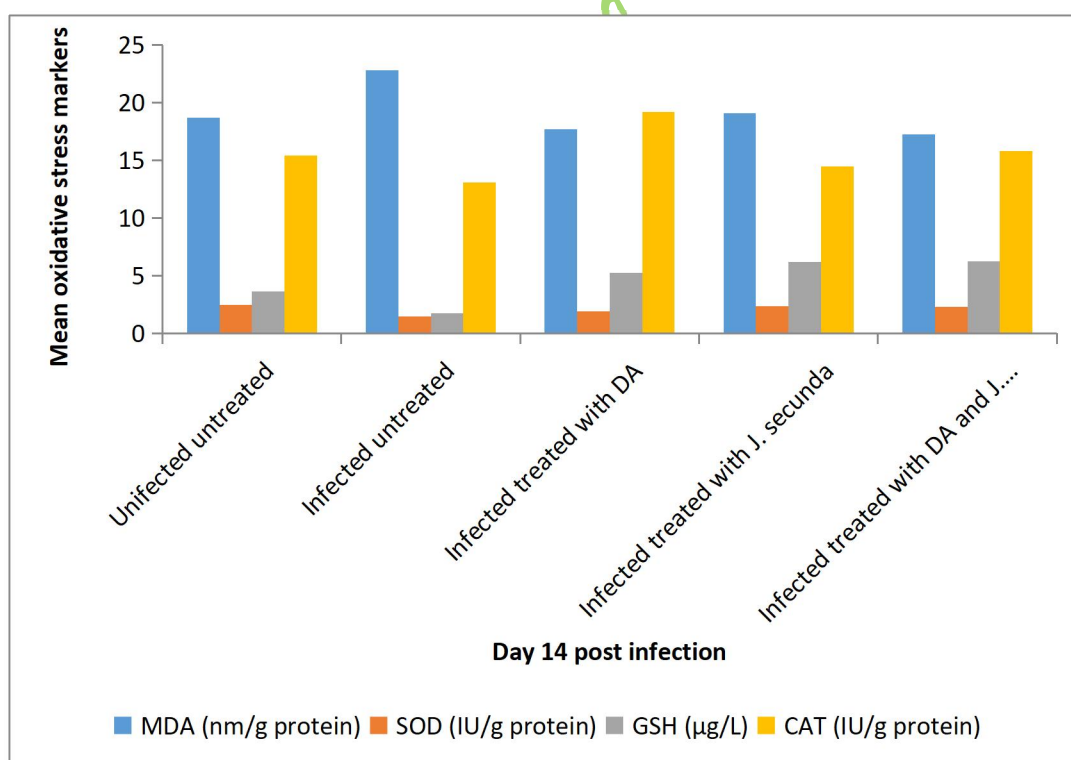


Figure 1: The mean oxidative stress makers of *T. brucei* infected rats treated with either diminazene aceturate or *J. secunda* leaf extract..

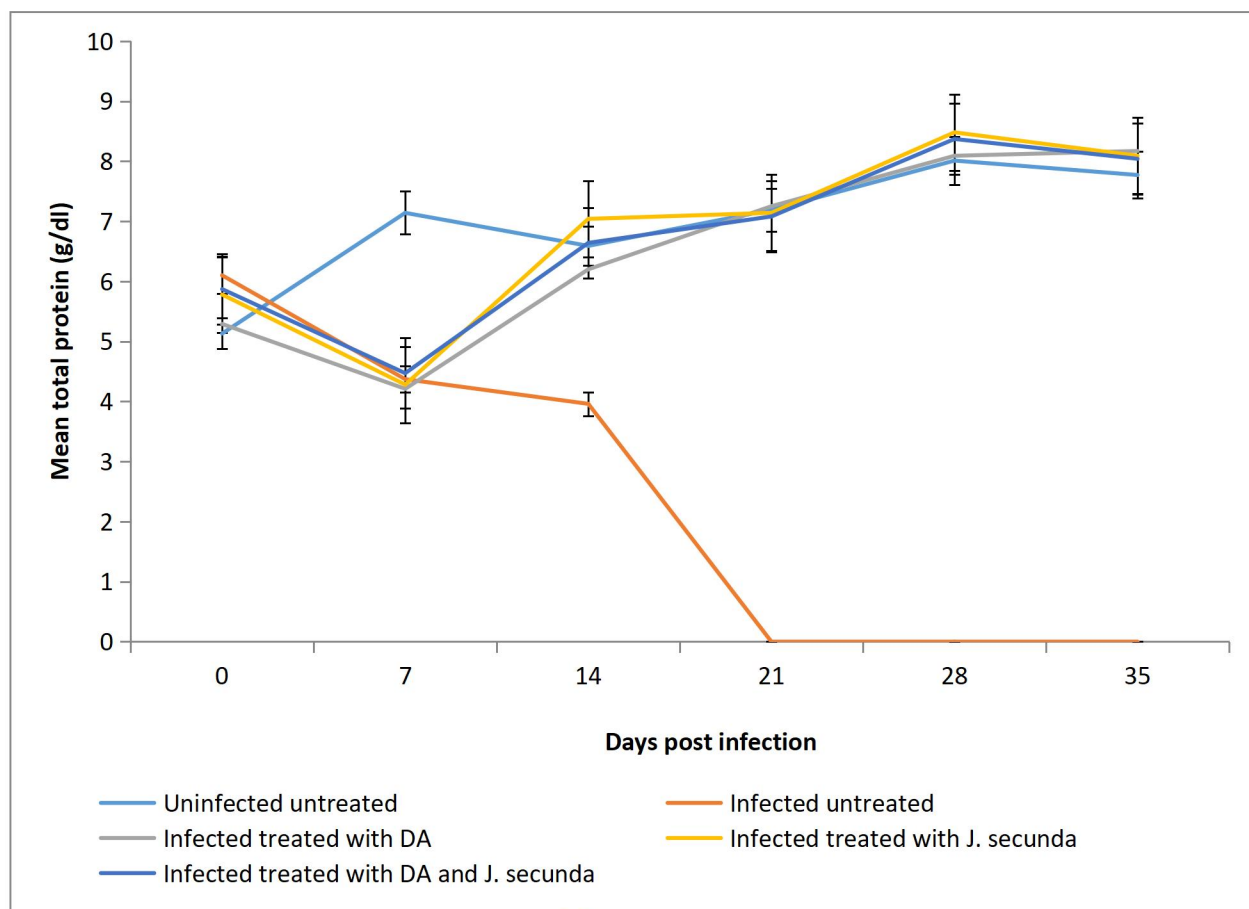


Figure 2: The mean total protein (g/dl) of *T. brucei* infected rats treated with either diminazene aceturate or *J. secunda* leaf extract

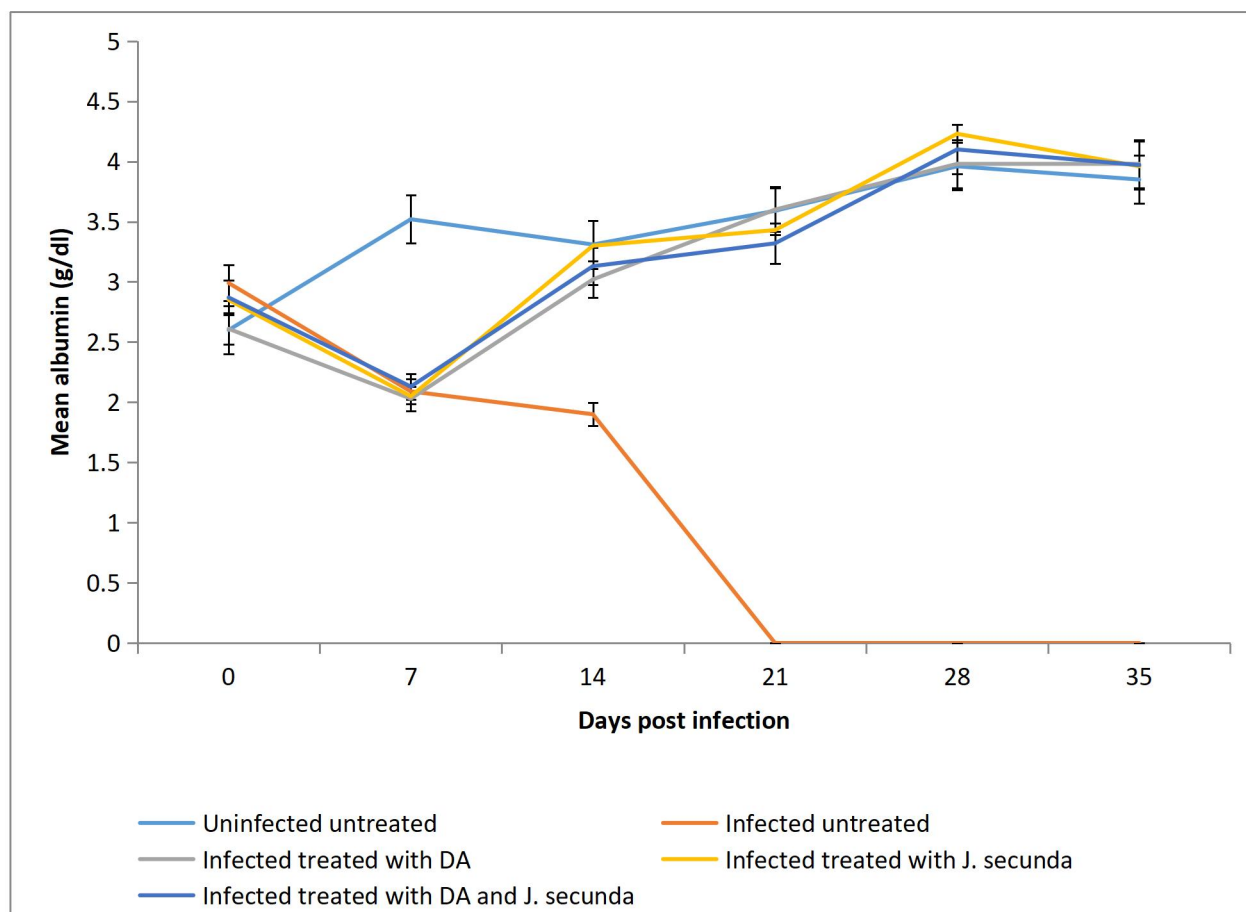


Figure 3: The mean albumin (g/dl) of *T. brucei* infected rats treated with either diminazene aceturate or *J. secunda* leaf extract.

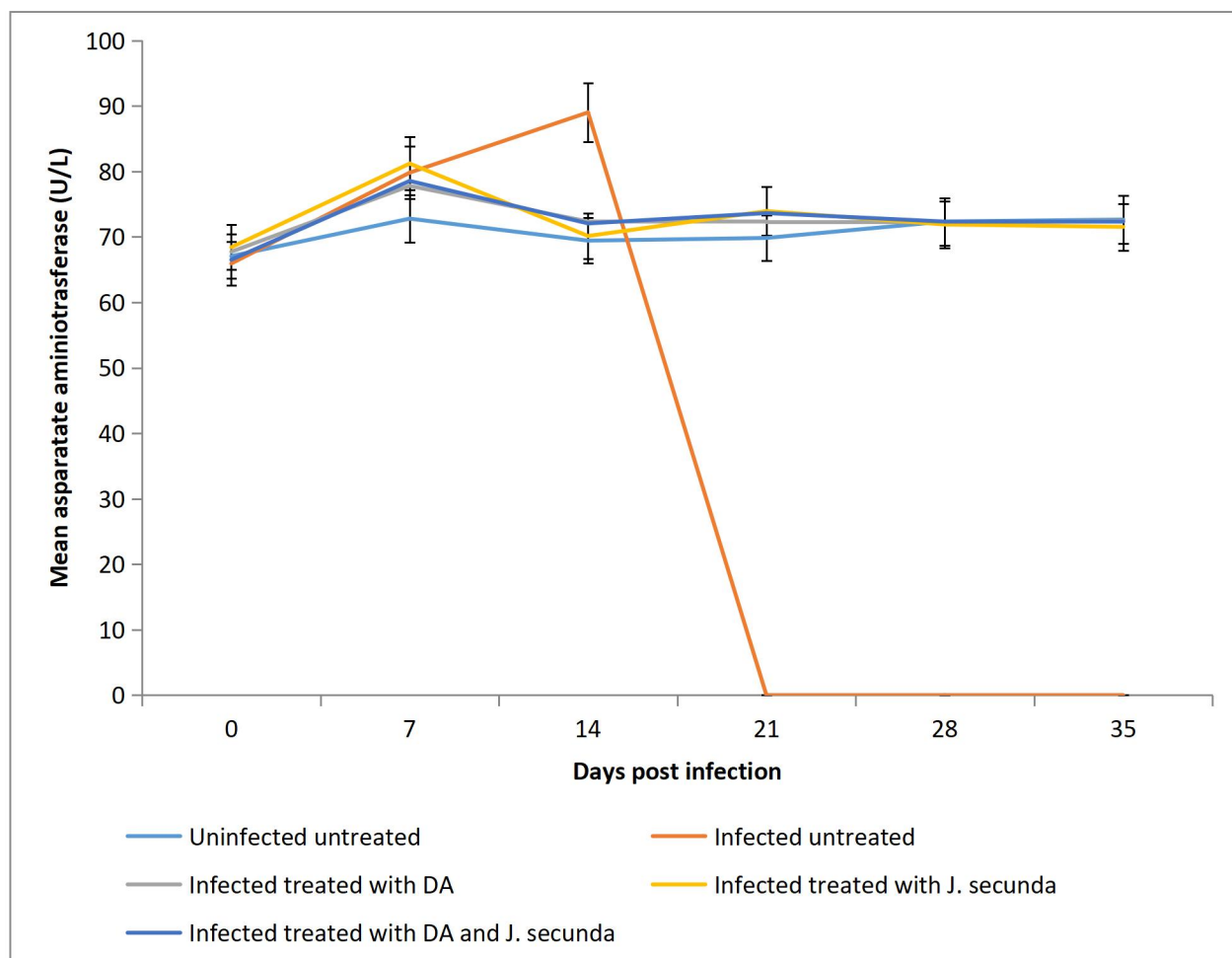


Figure 4: The mean aspartate aminotransferase (u/l) of *T. brucei* infected rats treated with either diminazene aceturate or *J. secunda* leaf extract.

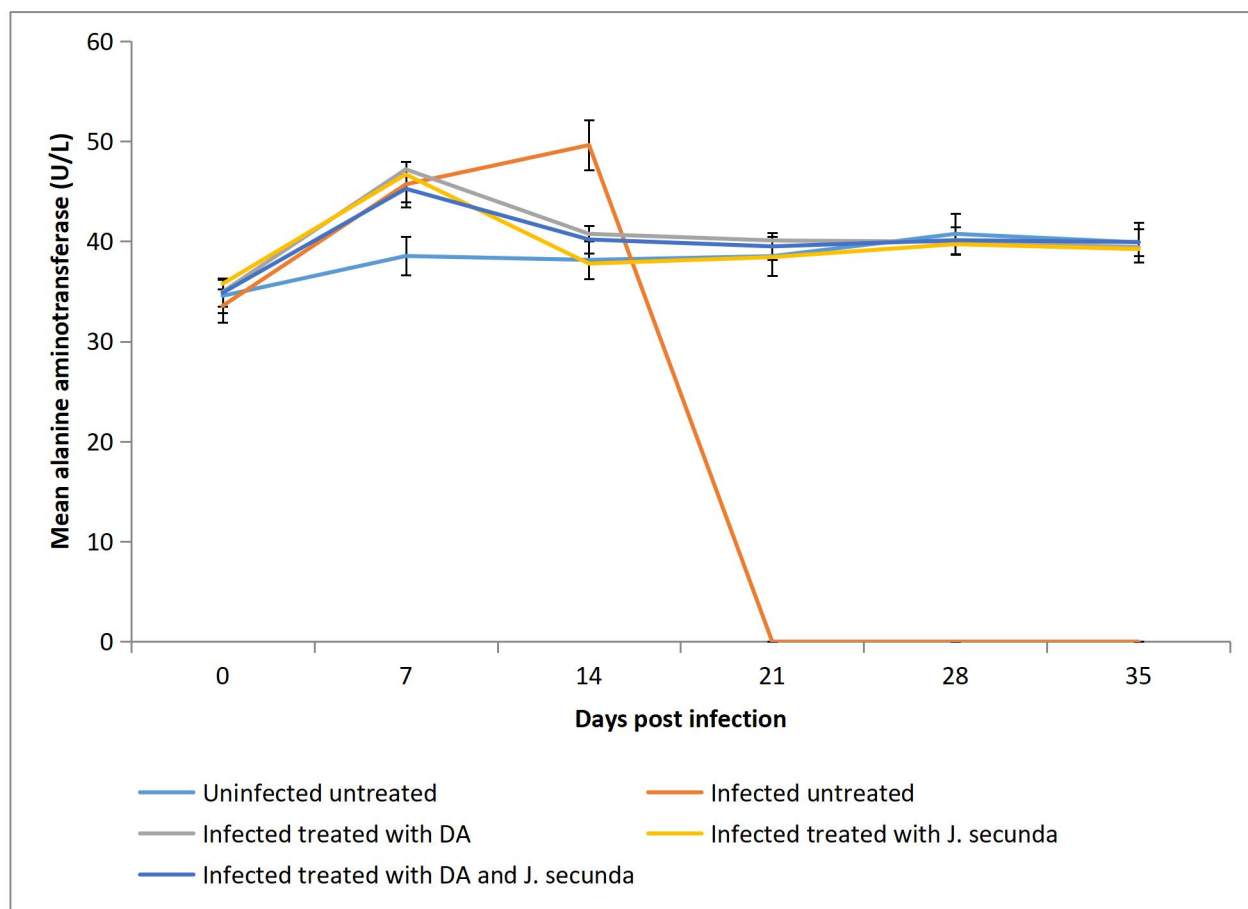


Figure 5: The mean alanine aminotransferase (u/l) of *T. brucei* infected rats treated with either diminazene aceturate or *J. secunda* leaf extract.

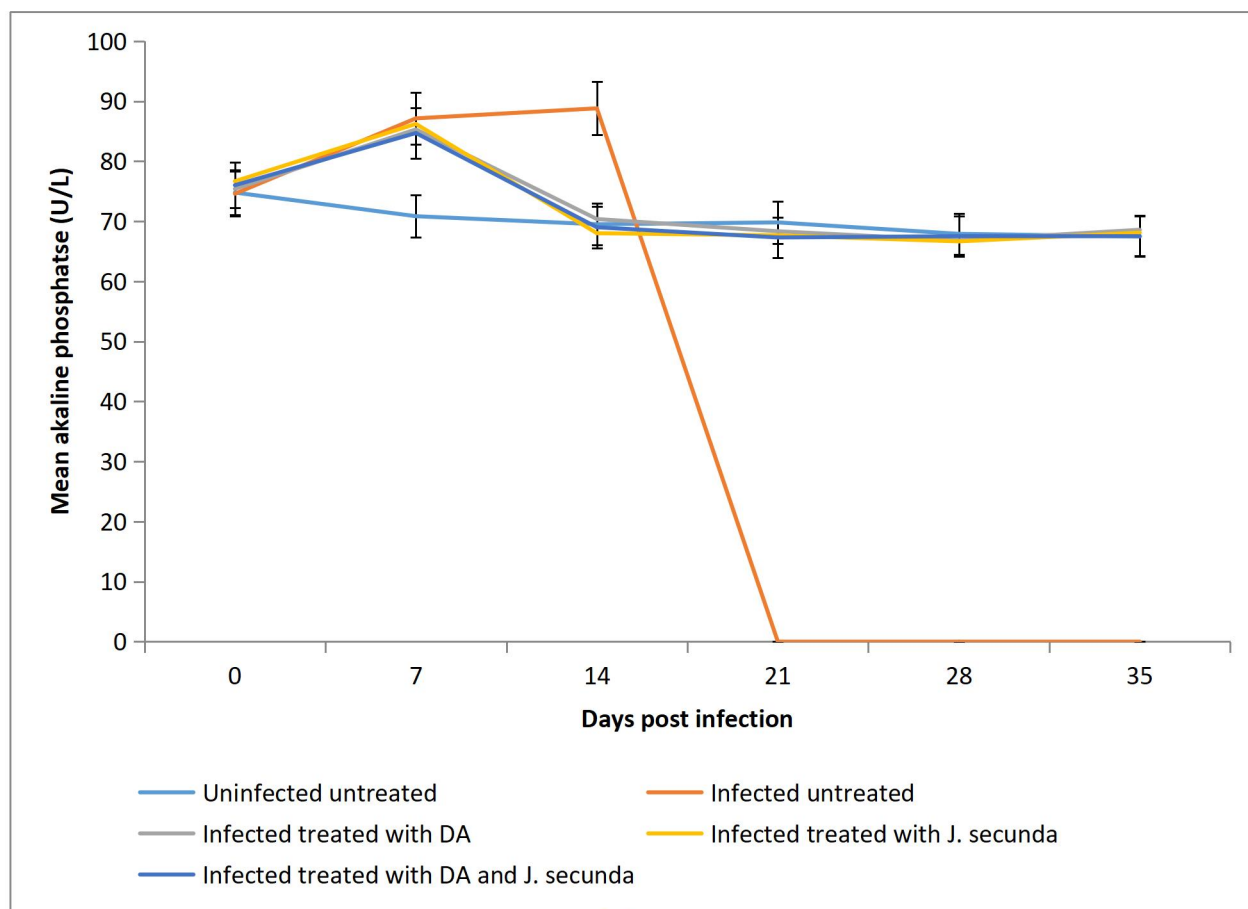


Figure 6: The mean alkaline phosphatase (u/l) of *Trypanosoma brucei* infected rats treated with either diminazene aceturate or *J. secunda* leaf extract.

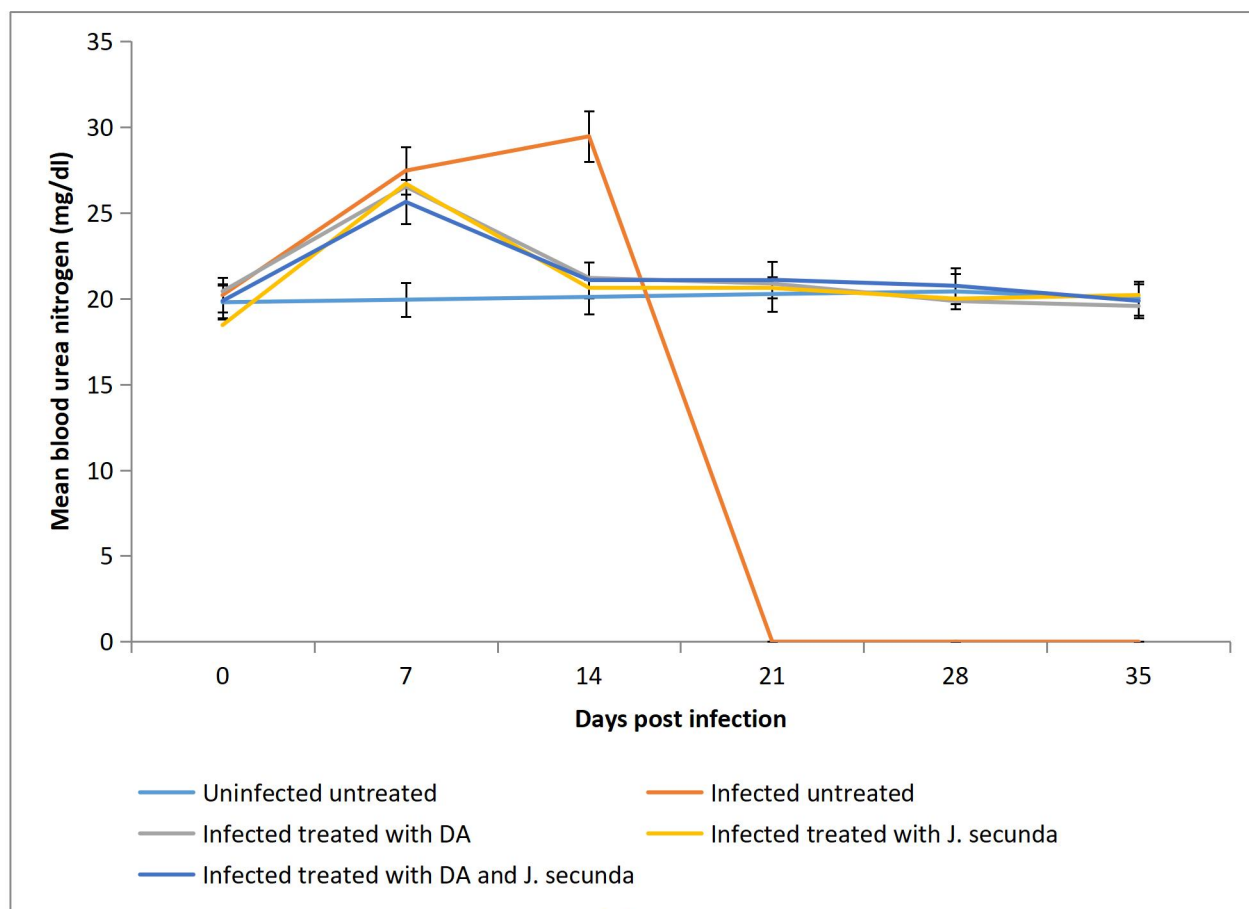


Figure 7: The mean blood urea nitrogen (mg/dl) of *T. brucei* infected rats treated with either diminazene aceturate or *J. secunda* leaf extract.

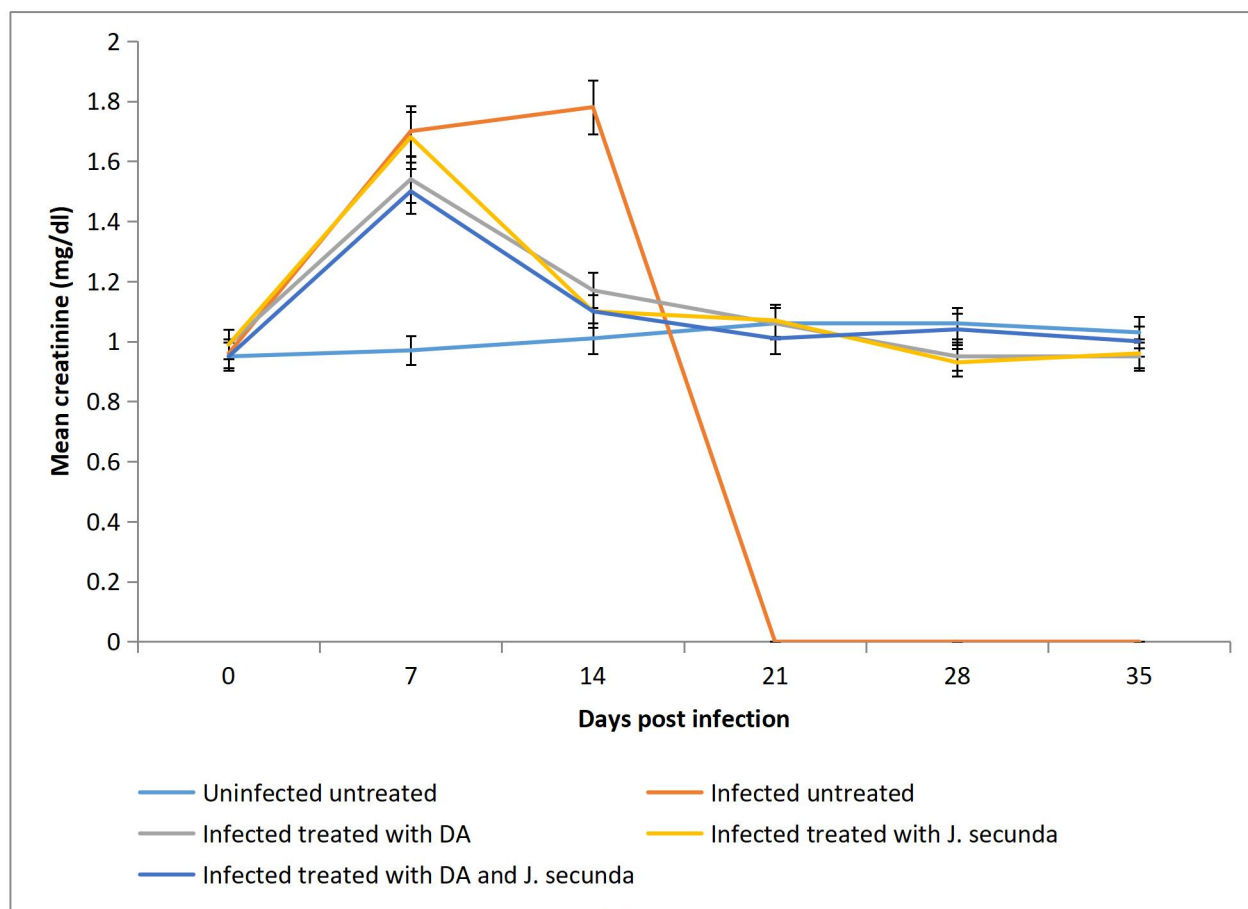


Figure 8: The mean creatinine (mg/dl) of *T. brucei* infected rats treated with either diminazene aceturate or *J. secunda* leaf extract.

Discussion

African animal trypanosomosis is a well-known immune suppressive disease associated with oxidative stress and organ dysfunction (Awekew *et al.*, 2017; Erin *et al.*, 2020). Research in oxidative stress is currently gaining ground and has been a leading topic in both fields of human and veterinary medicine with many possibilities because of their correlation to diseases (Erin *et al.*, 2020). In this study, infection with *T. brucei* caused a significant ($P < 0.05$) increase in the mean MDA of the infected untreated groups, which suggests trypanosome induced oxidative stress. This result corroborates with the previous reports of Ogunsanmi and Taiwo (2007), Umar *et al.* (2007) and Akanji *et al.* (2009), who demonstrated the important role of free radical induced oxidative stress in the pathogenesis of trypanosomosis. Kobo *et al.* (2014) and Eze *et al.* (2008) in a similar study observed increased MDA in



Wistar rats infected with *T. brucei*, while Akpa *et al.* (2021) reported increased MDA in *T. brucei* infected dogs due to oxidative stress and lipid peroxidation. The enhanced antioxidants status (increased GSH, SOD and CAT) observed in *J. secunda* treated group may be attributed to the antioxidant properties of the plant bioactive compounds which suppressed the effects of oxygen radicals and played a critical role in the prevention and reversal of oxidative stress-induced disorders (Tan *et al.*, 2018). The findings of this work, further corroborates the works of Aimofumeh *et al.* (2020), who reported the protective effects of *J. secunda* leaf extracts against acetaminophen induced liver damage in rats by alleviating the oxidative stress and enhancing the antioxidant status of the animals. Phytochemical evaluation of *J. secunda* has been shown to contain considerable amounts of phenols, flavonoids, tannins, saponins, and alkaloids. It has been widely reported that these bioactive compounds possess antioxidant properties and are capable of inhibiting harmful metabolites including hydroxyl, peroxy, superoxide anion radicals, and oxidative reactions triggered by ROS in biological systems (Tan *et al.*, 2018).

Infections with the *T. brucei* caused a decrease in total protein and albumin, which improved following treatment with DA and *J. secunda*. The decreased total protein level may also be due to reduced protein synthesis arising from damaged liver or as a result of excessive protein breakdown arising from reduced feed intake in trypanosome infected animals (Adewusi and Afolayan, 2010). The low level of albumin in trypanosome infections has been related to the level of parasitaemia and severity of the disease, caused by catabolism, and uptake of albumin by trypanosome parasites (Katunguka-Rwakishaya *et al.*, 1997). This result is also in agreement with Edeoga *et al.* (2012) who observed a similar result in *T. brucei* infected rats, but disagrees with Akpa *et al.* (2022), who observed hyperproteinaemia and hyperalbuminaemia in *T. brucei* infected dogs.

In this study, trypanosome infections increased the ALT, AST and ALP values in the infected untreated group, compared to the *J. secunda* treated group where the activities of the enzymes were reduced and comparable with the control. This result suggests that *J. secunda* is hepatoprotective in nature and possess antioxidant potential, which could protect the liver activity against ROS-induced hepatic injury (Adewusi and Afolayan, 2010). Phenols, tannins, and flavonoids which are bioactive constituents of *J. secunda* had been reported to exhibit hepatoprotective, nephroprotective, anti-inflammatory, and antioxidant activities (Mabozou *et al.*, 2019).



Marked elevations in these liver enzymes ALT, AST and ALP in *T. brucei* infected rabbits have been previously reported (Orhue and Nwanze, 2004). The elevations are suggestive of secondary hepatic damage, which may be due the leakage of these enzymes from their intracellular stores into plasma (Orhue *et al.*, 2005). The blood urea nitrogen and creatinine levels were elevated in this study and are consequent upon renal damage due to the effects trypanosome parasites on the kidney (Egbe-Nwiyi *et al.*, 2005).

In this study, *J. secunda* treated group and the group treated with combination of DA and *J. secunda* did not show any significant ($P>0.05$) difference in the values obtained. This result further buttress the dose dependent antitrypanosomal activities of *J. secunda* leaf extracts as previously reported (Ukwueze *et al.*, 2024). Additionally, the DA treated group had marginal oxidative stress as seen in the catalase activity. Akpa *et al.* (2021) in a similar study reported inability of diminazene aceturate and isometamidium to satisfactorily reverse oxidative stress in *T. brucei* infected dogs.

Conclusion

It can be concluded that the *J. secunda* leaf extract exhibited improved oxidative stress markers and hepatoprotective effects in *T. brucei* infected rats. The *J. secunda* leaf extract did not also show synergistic effects on the chemotherapeutic effectiveness of diminazene aceturate. It is therefore, recommended that *J. secunda* leaf extract be further explored as a source of antioxidant in the management of oxidative stress-related disorders especially in African animal trypanosomosis.

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SUB-THEME 10: Leveraging Internet of Things, Artificial Intelligence and Data Analytics for sustainable Agricultural, Educational and Industrial Systems



FACTORIAL MODEL PREDICTION FOR PERFORMANCE OF SAWDUST ASH-METAKOLIN BLENDED OIL WELL CEMENT

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Abstract

Factorial model exhibit good iteration and response information for analysis and mathematical prediction model; which may be manipulated using any design of experiment (DOE) software for accurate and high correlation analysis as well as correlated predictions. In this study, the viability of using Sawdust Ash (SDA) and Metakaolin (MK) as a blend to ordinary Portland cement (OPC) was carried out using a mathematical arrangement of a factorial model allowing percentages blend of the OPC with Metakaolin for 10%, 12.5% and, 15% whereas sawdust ash at 0%, 5% 10%. Materials for the study were characterized based on physical, chemical, and pozzolanic test properties. Slurry property testing was based on the mix formulation generated from the Design of the Experiment (DOE) using two domains three interactive factors (2x3) level. The slurry was tested for thickening time, free fluid, fluid loss, slurry density, and rheology parameters respectively at 45-65°C conditioning temperature following the specifications of the American Institute of Petroleum (API) SPEC 10A and 10B). Metakaolin blend with OPC alone at 15% were detrimental to rheology but the incorporation of Sawdust Ash up to 10% with Metakaolin at both 10% and 15% improved the performance; free water was within (0.032-1.435%) which was below the 5.9% maximum and fluid loss decrement with API RP-10B of 50 to 250ml for liner cementing, increment of thickening time as well as modulating the rheology making the formulation pumpable. Results showed optimal performance for blend (75%OPC, 10%MK, 10% SDA).

Keywords: Factorial model, Oil Well, Cementing, Metakaolin, Sawdust Ash

Introduction

Factorial design (FD) is a model method that monitors the interactions of multiple factors as well accommodate the outcome of both main and interaction effects of the experimental factors or variables (Cheong and Gupta, 2005). The number of experimental runs performed for the model development for full factorial design is governed by the Equation 1.0.

$$N = L^K \quad (1.0)$$



Where K denotes experimental variable referred to as factors

L is the number of domain levels of variables,

N is the total number of experimental runs,

While K can be represented as $X_n, X_{n+1}, X_{n+2}, \dots$, and X_K regarding various experimental factors. Experimental runs based on two (2) level is attributed to 2^K level domain ‘-’(-1) to indicate low level and ‘+’ (+1) for high level which can be percentage of additive of constituent in an experimental sample or percentage of replacement of constituent in an experimental sample. The response variable for any experimental design for two (2) level factorial parameters from full factorial design for either four factors (2^4) yields sixteen (16) experimental runs generated for four (4) factors whereas eight (8) experimental runs for three (3) factors interaction formulations (2^3) (Falode, Salam, Arinkoola, and Ajagbe, 2013). The quantity of each of the variables under low and high domain related to the response variable for the experiment is as well as the desired test outcome. Running the full complement of all possible factor combinations means that all the main and interaction effects can be estimated. This study focus on the pozzolanic interaction of the blending of ordinary portland cement (OPC) with Metakaolin for 10%, 12.5% and, 15% whereas sawdust ash at 0%, 5% 10% which made up for 10 to 25% combine replacement. The model allow underuse and addition in excess of pozzolan samples (Metakaolin and Sawdust Ash) from 5% - 10%; following factorial standard runs.

Theoretical Background

Oil well-cementing operation is a sensitive operation that needs prescient design information for onsite formulation. It makes use of a tested and viable model of higher accuracy of interaction and regression coefficient to predict the various desired required properties of cementing material for a successful well-cementing operation (Magarini, Lanzetta, and Galletta, 1999). One of the important requirements before introducing wells into operation is the strengthening of the casing columns and insulation of layers by injecting grouting (Magarini, Lanzetta, and Galletta, 1999). Furthermore, the criteria considered in choosing an oil-well cement slurry for individual wells is the physical and performance requirements of the slurry which include the thickening time, rate of fluid loss, slurry density, rheology of the slurry, and amount of free fluid; which must be kept to zero calling for reduction in the water separation of the slurry, with regards to requirements of the American Petroleum Institute (API) Specification (ASTM-C150, 2007). A consideration for complex behavioural requirement of oil well



cement slurry design demands for the use of factorial design model which has been successfully employed in various studies such as to develop a model to predict the compressive strength of oil well cement, predict the rheology of oil well cementing material containing chemical additives. The model allows effects of different factors which can be the constituent or additives to be usually considered individually as well as their interaction with each other during the development. The model has a high efficiency with correlation coefficient of 99.8%, standard error of 0.1325, and accuracy of 99.8% (Torbjorn, Elisabeth, Lisbeth, Bernt, Asa and Jarle, 1998). The mathematical model had r repetitions per cell in a completely randomized design according to Equation 2 yielding Equation 3.

$$Y_{ijk} = \mu + A_i + B_j + AB_{ij} + C_k + AC_{ik} + BC_{jk} + ABC_{ijk} + E_{ijkv} \quad (2)$$

Where $i, j, k = (0, 1)$ and $r = (1, 2, \dots, r)$ repetitions, μ = interactive intercept coefficient while E = experimental error coefficient (QMET 201, 2014).

Thus for X_1, X_2 , and X_3 factors the model becomes

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 - b_{123}X_1X_2X_3 + e \quad (3)$$

Where b_0 corresponds to μ and e corresponding the interactive errors for b_1, b_2 and b_3 factors.

The model pseudo effect for 2^3 level domain.

Materials and Methods

Experimental Material: Sawdust ash were obtained from sawdust in timber market Umuahia, whereas Metakaolin were obtained from kaolin deposit in Umuariaga Oboro Ikwuano, Abia state. It were prepared by employing the standard methods within the specified temperature of calcination and heating time of 90 min for Metakaolin before being employed to the experimental module. Ordinary Portland cement for the research of grade 42.5 OPC class B according to classifications of (ASTM-C150, 2007). and American Petroleum Institute (API, (2010), 10A,). The water for the study was clean tap water from the laboratory conforming to the standard spelt in (BS EN 196-3, 2016 and Schlumber, 2013)

Methods: For this study, two sets (2) of samples were prepared. One set made from factorial model experimental runs as generated in Minitab design of experiment (DOE) for slurry properties of Metakaolin –Sawdust Ash (MKSDA) blended OPC and the other set of control sample containing pure class B cement in accordance to (Torbjorn et al., 1998) mix specifications.



The design followed factorial 2^3 level domain; which have various combinations and percentages blend of the ordinary portland cement (OPC) with Metakaolin for 10%, 12.5% and, 15% and sawdust ash for 0%, 5% 10% which made up for 10 to 25% pozzolan incorporation in low and high level in the experimentation at absolute volume density of the individual pozzolan material. The model design allow for slight under use as well as excess dose of the combine percentage blending with Metakaolin and sawdust ash; aligning with the factorial design by Falode, et al. (2013) For the batching process, the water cement ratio W/C was maintained at 0.46 based on API standards API SPEC 10B for all the samples as reported by Qosai and Rad (2018) for Mk dosage below 30%. The pseudo mix were formulated factorial design of three factors-two replica ($2^3 \times 2$) factor level with two centre points randomized to take care of statistical fringes (Falode, et al. 2013) the resultant design is as shown in the Table 1. Where N1 to N18 represents the run order for the randomised blended cementing sample from the factorial design, while the C1 and C2 run orders represent the control sample with only class B ordinary Portland cement. The samples were tested for various led down simulated test by API 10A&B for slurry required to be used in well bore; which included thickening time, fluid loss, free water, rheology, and slurry density. The mechanical testing were mainly for cube density, water absorption and compressive strength at 8 hours, 24 hours, 7 and 28days curing periods respectively using 160 samples of 100mm^3 cubes.

Table 1 factorial Pseudo and Actual Mix Ratio for the Formulation Generated from Minitab DOE

StdOrder	RunOrder	Blocks	OPC	Metakaolin (MK)	Sawdust Ash (SDA)	Equivalent OPC (%)	Equivalent MK (%)	Equivalent SDA (%)
11	1	1	-1	1	-1	90	15	-
3	2	1	-1	1	-1	90	15	-
9	3	1	-1	-1	-1	90	10	-
12	4	1	1	1	-1	75	15	-
16	5	1	1	1	1	75	15	10
14	6	1	1	-1	1	75	10	10
10	7	1	1	-1	-1	75	10	-
2	8	1	1	-1	-1	75	10	-



15	9	1	-1	1	1	90	15	10
17	10	1	0	0	0	82.5	12.5	5
1	11	1	-1	-1	-1	90	10	-
13	12	1	-1	-1	1	90	10	10
18	13	1	0	0	0	82.5	12.5	5
7	14	1	-1	1	1	90	15	10
8	15	1	1	1	1	75	15	10
5	16	1	-1	-1	1	90	10	10
4	17	1	1	1	-1	75	15	-
6	18	1	1	-1	1	75	10	15
C ₁						100	-	-
C ₂						100	-	-

Results and Discussion

This research results were presented in phases of the experimental methodology regarding material characterization, formulated sample slurry test and mechanical test respectively.

Material Characterization: Sawdust ash was physically characterized as the most light of the three cementitious material. This potentially present it as a possible constituent of tail cementing; while metakaolin (MK) makes a positive blending material in both case of lead or tail cementing. On the other hand, results from the chemical and pozzolanic test yields a combine percentage composition of the major oxides including: [Silica (SiO₂), Aluminium Oxide (Al₂O₃), Iron oxide (Fe₂O₃) and Potassium Oxide (K₂O)] for metakaolin to be 84.26% and more than 70% of (SiO₂), (Al₂O₃), (Fe₂O₃) thus classifies it as Class N pozzolan according to ASTM C618-15. Sawdust ash for this study had slightly lower composition of about 51%, classifying it as Class C pozzolan in accordance to ASTM. The pozzolanic activity of metakaolin was paramount as compared to that of sawdust; attributed to the use up of detrimental Ca(OH)₂ by production of hydration in the cement matrix by metakaolin. Hence its potential positive blend in cementing for geothermal and deep well where Ca(OH)₂ by product is more.



Slurry Experimental Result: For the result obtain from slurry experimentation in accordance to American Petroleum Institute spec 10A&B for both the control samples as well as blended samples showed that thickening time; the time to reach 100 Bearden unit of consistency (Bc) were more than stipulated 90 minutes minimum. Nevertheless, higher values of time were recorded for run samples which had high level (15%) of metakaolin compared to control samples and those containing sawdust ash at high level (10%). Therefore, metakaolin (MK) retard the slurry more from thickening than when incorporated alongside sawdust ash (SDA). Thus the potential in creating more handling and pumping time of the slurry to its target depth. The following regression model with respect to Equation 3. Corresponding to the yielded coefficient of effect in Equation 4.

$$\text{Thickening time} = 107.913 + 2.15X_1 + 5.90X_2 - 2.588X_3 + 3.037X_1X_2 + 3.90X_1X_3 - 2.85X_2X_3 - 0.963X_1X_2X_3 + 0.3626 \quad (4)$$

Where: X_1 -Cement, X_2 -Metakaolin (MK), X_3 -Sawdust Ash (SDA)

The result of slurry density shows a yield density and specific gravity within the range of 1.71-1.785. for class A and B cement as stipulated and reported by API, (2010), 10A ; also were in agreement with the range reported by Broni-bediako, Joel, and Ofori-sarpong, (2016) as within (1.45g/cm³-1.84g/cm³). Metakaolin increased the density of the slurry from the mean value of 1.75 to 1.785g/cm³ accounting for 2% increase. Nevertheless, incorporating sawdust ash reduced the sample density accounting for 2.3% decrement as compared to that of control samples. The result of free water at conditioned temperature range of 65-45°C static for 2 hours shows that sawdust ash incorporated samples at (10%) and 5% blend reduced the free water within (0.120%, 0.032%); below the 5.9% maximum free water stipulated by API, (2013), 10B-2. Hence, SDA is potential in reducing excess free water during slurry pumping. The following regression model with respect to Equation 3 corresponding to the yielded coefficient of effect is given in Equation 6.

$$\text{Free water} = 0.3463 + 0.0831X_1 - 0.1126X_2 - 0.0623X_3 - 0.0170 X_1X_2 - 0.1264X_1X_3 - 0.0231X_2X_3 + 0.1325X_1X_2X_3 + 0.02072 \quad (6)$$

As regards fluid loss, samples blended with sawdust ash in combination with metakaolin kept the fluid loss within the maximum range of API RP-10B (50 to 250ml /30minutes) as compared to samples with only metakaolin blend as well as control samples C_1 and C_2 which had the highest mean fluid loss of (484.970 and 508.645 ml/30min) at 10 and 11minutes blow out. Thus presenting sawdust ash (SDA)

blend with metakaolin (MK) as a decent fluid loss and blowout control pozzolan reducing the slurry fluid loss by about 57%. The following regression model with respect to Equation 3. Corresponding to the yielded coefficient of effect in Equation 7.

$$\text{Fluid loss} = 298.90 + 10.83X_1 - 6.700X_2 - 18.54X_3 + 3.76 X_1X_2 - 6.89X_1X_3 + 64.55X_2X_3 + 11.93 X_1X_2X_3 + 5.273 \quad (7)$$

The rheology performance of the samples, which is a function of plastic viscosity, yield point of shear stress and corresponding gel strength at 10 seconds as well as 10 minutes gel strength after 20minutes conditioning at 60°C. The plastic viscosity where below 100 mPa.s (cp) which according to the report of report of Broni et al. (2016). regarded as the maximum limit for all cementing slurry to be kept pumpable; with exception of samples which contain only cement combination of Metakaolin at high level replacement yielding (129cp-132cp). The result from the gel strength at 10 seconds and 10 minutes as displayed in Figure 1 shows control samples to have lowest value of gel strength compared to other samples. Also, for yield point shear stress, samples with MK has higher yield point compared to the samples containing combinations of sawdust ash at 10% Hence, a clear indication of the detrimental effect of Metakaolin at high level blend (15%) on the cementing slurry in absence of Saw dust ash in the blend.

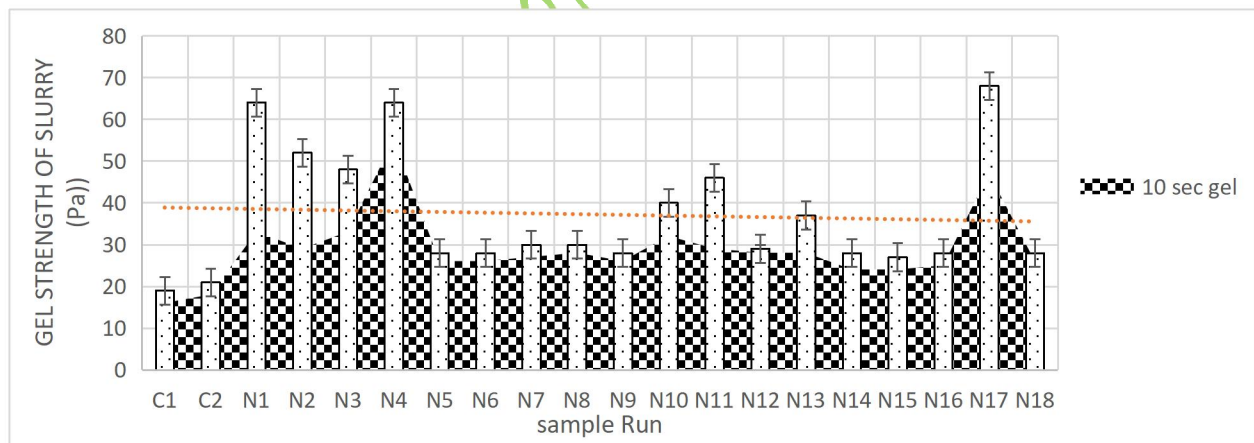


Figure 1. Plot of Gel Strength of Slurry at 10 Seconds and 10 Minutes

The following factorial regression model corresponding to the yielded coefficient of effect is given in Equation 8, 9, and 10;

$$\text{Plastic Viscosity} = 58.31 + 15.19X_1 + 13.50X_2 - 11.63X_3 + 5.25 X_1X_2 - 8.25X_1X_3 - 8.44X_2X_3 - 9.94 X_1X_2X_3 + 1.155 \quad (8)$$



$$\begin{aligned} \text{Yield Point} = & 59.19 + 1.58X_1 + 2.74X_2 - 3.82X_3 - 3.82X_1X_2 + 2.03X_1X_3 - 1.22X_2X_3 \\ & + 1.70 X_1X_2X_3 + 0.7813 \end{aligned} \quad (9)$$

$$\begin{aligned} 10 \text{ Sec Gel Strength} = & 30.375 + 2.00X_1 + 2.625X_2 - 4.75X_3 + 3.00X_1X_2 - 2.125 X_1X_3 - \\ & 3.250X_2X_3 - 2.875 X_1X_2X_3 + 0.6719 \end{aligned} \quad (10)$$

Mechanical Test Result: The cube density were influenced by the blend of SDA and MK at higher replacement levels (10% and 15%). The density of the samples where within the range of (1746.667 – 1906.667 kg/m³) while samples blended with MK alone had lower density of less than 5.7% as compared to the controlled samples, on the other hand, the samples water absorption after 28 days curing were within the range (1-3%) as stipulated by Schlumber (2013). The control sample had the highest value of early strength after 24 hours of curing (13.9 and 14.4 N/mm²). However, Sawdust ash shows more influence in improving the compressive strength at 28days when in high level blend with Metakaolin at all levels of OPC incorporation. This could be attributed to the pozzollan filler tendency of the two combine materials in the micro matrix of the cemented cake. More strength increment is expected following the report of Ettu et al.(2016), Pacheco, Arman and Said. (2011),and Hemant,(2011).The resultant factorial regression model following the coefficient for 24 hours and 28 days strength is given by Equation 11, and 12:

$$\begin{aligned} 24 \text{ hours strength} = & 11.7250 - 0.2563X_1 + 0.0063X_2 + 0.4562X_3 - 0.2500X_1X_2 - 0.1875 X_1X_3 - \\ & 0.4375X_2X_3 - 0.1563 X_1X_2X_3 + 0.08260 \end{aligned} \quad (4.11)$$

$$\begin{aligned} 28 \text{ days strength} = & 30.1864 - 0.2239X_1 - 0.498X_2 + 0.4828X_3 + 0.1698X_1X_2 + 0.0052 X_1X_3 - \\ & 0.1864X_2X_3 - 0.3636 X_1X_2X_3 + 0.1753 \end{aligned} \quad (4.12)$$

Where: X_1 -Cement, X_2 -Metakaolin (MK), X_3 -Sawdust Ash (SDA)

Conclusion

Factorial model have been successfully deployed in investigating and predicting the Engineering performance of Ordinary Portland cement when blended with Metakaolin and Sawdust Ash identifying and estimating significant interactive parameters. The results of the slurry and mechanical property parameters were an indication of the cementing requirement based on the factorial output showed that Sample formulations with (75%OPC, 10%MK, 10% SDA), (75%OPC, 15%MK, 10%SDA), and (90% OPC, 10%MK, 10%SDA)] had optimal performance with respect to both slurry and mechanical



properties necessary to maintain excellent cementing process of new well as well as the integrity of the well over a longer period of its service life.

Sawdust Ash serve as restrictive constituent in controlling the detrimental effect of Metakaolin which is a more active pozzolan when in excess or alone in the replacement blend.

Therefore Ordinary Portland Cement (OPC) blend of Metakolin and Sawdust Ash fine granule is recommended in addressing excessive fluid loss and water pocket formation in cementing slurry paramount in geothermal and gas filled oil well prone to catastrophic failures. As well as standing out as an environmentally friendly material in addressing the impact of imported oil well cement dependency, pollution and reducing global carbon foot print.

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APPLICATION OF TOP-MIDDLE-BOTTOM (TMB) ROW TECHNIQUES IN THE SOLUTION OF CAYLEY-SUDOKU PUZZLE

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Abstract

Cayley -Sudoku puzzles are a challenging variation of traditional Sudoku, introducing unique constraints and patterns that demand advanced solving strategies. This paper explores the use of horizontal block techniques as a systematic method to simplify and solve Cayley-Sudoku puzzles. Horizontal block steps involve analyzing groups of rows corresponding to the top (T), middle (M) and bottom (B) sections of the grid to deduce possible digit placements, systematically narrowing down options. These methods reduces complexity by dividing the grid into manageable sections and enhances logical reasoning through structured deductions. This approach is shown to be an effective and efficient techniques, making it a valuable tool for mastering Cayley-Sudoku puzzles.

Keywords: Cayley- Sudoku puzzle, Constraints, Horizontal block, Vertical block, Grid, cells

Introduction

Cayley -Sudoku puzzles are a variation of the classic Sudoku puzzle, requiring logical reasoning and strategy to solve .Henry (1968), Carmichael *et al.*, (2010),Gallian (2006). Unlike standard Sudoku, Carley-Sudoku incorporates additional constraints such as unique patterns or rules in specific regions of the grid. One effective method to solve these puzzles by focusing on horizontal block rows and vertical block columns respectively as a primary strategy. This paper explores the methodology of using both horizontal block rows and vertical block columns to solve Cayley- Sudoku puzzles and demonstrates how this approach simplifies the problem-solving process.

Overview of Cayley -Table

In this section, we explore the application of Cayley tables, a fundamental concept in in group theory, in the design and soling of Cayley Sudoku puzzles. Cayley tables, named after British mathematician Arthur Cayley , are used to represent the operation of a finite group, Wilson (2006). These tables are akin to multiplication tables, where the elements of a group are combined according to the group operation. Cayley. The key properties of Cayley tables include:

1. Closure: Every entry in the table is an element of the group.



2. Identity: There exists a row and column corresponding to the identity element, where the operation returns the other element.
3. Inverses: Each element has an inverse such that their operation results in the identity.
4. Associativity: Although not directly shown in the table, the group operation must be associative.

Cayley tables provide a compact representation of a group's structure, making them suitable for integration into puzzles like Cayley-Sudoku.

Overview of Cayley -Sudoku Puzzle

Cayley-Sudoku is an extension of the traditional Sudoku puzzle where the grid is filled using the elements of a finite group rather than numbers. The constraints of the puzzle combine the rules of Sudoku with the structure of a Cayley table:

1. Each row and column must contain all elements of the group exactly once.
2. Each sub-grid (in standard 9×9 Sudoku, each 3×3 box) must also contain all elements of the group.
3. The entries must satisfy the group operation as defined by the Cayley table.

For example, if the puzzle is based on the group $\mathbb{Z}_4 = \{0, 1, 2, 3\}$ under addition modulo 4, the Cayley table would dictate how the elements interact.

Roles of Cayley Table in Solving Cayley-Sudoku Puzzle

The Cayley tables serve as both a reference and a constraint generator for solving Cayley-Sudoku puzzles. The solver uses the following strategies:

1. Group Operation Verification: Check that every combination of row column elements satisfies the group operation defined by the Cayley table
2. Deduction: Leverage group properties such as the identity element and inverses to deduce missing entries.
3. Logical Placement: Apply traditional Sudoku rules (unique placement in rows, columns, and sub-grids) while adhering to group constraints.

An example puzzle with \mathbb{Z}_4 might start with some entries pre-filled, and the solver uses both sudoku logic and the Cayley table to complete the grid.



Solving Cayley-Sudoku puzzles Using Top-Middle-Bottom (TMB) Row Steps

Without loss of generality, Cayley-Sudoku puzzles are a variation of traditional Sudoku puzzles, featuring additional rules or constraints that make them more challenging. Hence solving these puzzles often requires innovative techniques to simplify and manage the grid's complexity. One such technique is the **Top-Middle-Bottom (TMB) row steps** a systematic approach that leverages the natural division of the grid into three horizontal blocks: we shall talk about the top horizontal blocks in terms of their rows called TMB rows. T stand for top, M stand for middle and B stand for bottom. The same classification goes for the middle and bottom horizontal blocks. In this section, we shall explore the TMB row steps methodology, outlining how it simplifies solving Cayley-Sudoku puzzles by focusing on one layer of blocks at a time while accounting for row, column, and sub-grid constraints. By focusing on one block at a time, we can analyze missing digits, eliminate candidates, and place numbers methodically while maintaining consistency across rows, columns and sub-grids. Michael (2016).

Key steps:

Fill the empty cells using TMB rows Techniques

In a horizontal layer, the rule is that if a particular number appears say in the top row of a block, the same number can only appear in the middle or bottom rows of the other horizontal blocks. Using this rule we can fill some cells.

1. Apply Ramification. By ramification here we mean checking the effect of placing a number in a row, column or block on another block.
2. Apply the Finish-up rows , columns or blocks whenever a row , a column or a block has only one cell left , fill up the cell left before going to another block.

Solving Cayley-Sudoku puzzles Using Left-Center-Reft (LCR) column Steps

The TMB row steps usually goes with the LCR methods to solve a given puzzle, hence we outline the key steps.

1. Ensure that all numbers in the columns adhere to LCR techniques



Starting with the first three sets of vertical blocks: Beginning with 1 through 9, ensure that if a number say 4 is in the left column of block 1 and the same number 4 is in the center of block 2, by logic it is expected that number 4 must be in the right column of block 3.

2. Check constraints across blocks: Use the sub-grid constraints to narrow down possible placements for the missing digits. If a digit is already present in one sub-grid of the vertical or horizontal block, it cannot appear again within the same sub-grid

3. Cross-Reference with columns and rows:

Eliminate possibilities by cross-referencing with columns or rows. e.g., If a digit is already present in a column intersecting with the horizontal block row, it cannot be placed in that column for the remaining cells in the block.

4. Employ Logical Deductions:

Look for patterns such as naked singles (cells with only one possible digit) or hidden singles (digits that can only fit in one cell within a row or block).

Use advanced techniques like marching pairs interactions if necessary.

5. Iterate Across Horizontal or Vertical Blocks:

Once a horizontal block row or vertical block column is partially filled, repeat the process for the next block. Use the information gathered from previous blocks to further refine digit replacement. Kady and Michael (2019), Gorenstein (1969)

2.0 Mathematical Analysis

In this section we shall consider some problems on Cayley-Sudoku puzzles, then employing the TMB method or a combination TMB and LCR methods to solve the puzzles.

Example 1

Consider the following Cayley-Sudoku grid

T	4	7	8	3	5	9	1	2	
M			9	1	2	8	7	5	4
B	2	5	1	.	7		3		8
T	3		4	7	8	2	9		5
M	9			6	3		2	4	



B	7	1	2	9	5	8	3	
T	8	2	6	9	.	4	7	1
M		4	3	6	7			9
B	5			8	1	4	3	2

Solution

Now starting with the first block with the 1, observe that 1 is in the bottom row, in the second block 1 is in the middle row and in the third block 1 is in first row. So 1 is well place.

Next going the number 2, observe that in the first block 2 is in the bottom row, in the second block 2 is in the middle row and in the third block 2 is in first row. So 2 is well place.

For the number 3, observe that 3 is in the top row of block 2 and in the bottom row block 3 and so by logic 3 must be in the middle row of block 1. using our pencil we place 3 in the first and second columns of block 1, but observe that there is a 3 down column 1, and since a number does not appear twice in a column, the number 3 must be in in column 2.

Following the process up to the number 9 for the entire nine blocks and adhering to the lay down strategies, we have the following results

- Missing digit in row 1 : 6
- Missing digits in row 2: 6,3
- Missing digits in row 3 : 4,6,9
- Missing digits in row 4 : 6,1
- Missing digits in row 5 : 8,5,1,7
- Missing digits in row 6 : 4,3
- Missing digits in row 7: 5,3
- Missing digits in row 8 : 1,2,5,8
- Missing digits in row 9: 9,7,6



Example 2

Consider the following Cayley-Sudoku grid

	L	C	R	L	C	R	L	C	R
T	2			1	7		9	4	
M		3	.	6		2	8		
B	1	6				9	7		2
T	4	1		5			6		3
M			7	3	2				
B	3	5		4		6	1		9
T	9		1			.	3	8	4
M					1	8		6	7
B			6	7		4	5		1

Solution

First we begin with TMB steps starting from 1 through 9. After exhausting the whole blocks, we resort to LCR steps outline above to obtain the following results

- Missing digit in row 1 : 8,5,3,6
- Missing digits in row 2: 7,9,4,1,5
- Missing digits in row 3 : 4,8,5,3
- Missing digits in row 4 : 8,9,7,2
- Missing digits in row 5 : 6,9,1,4,5,8
- Missing digits in row 6 : 2,8,7
- Missing digits in row 7: 7,2,6,5
- Missing digits in row 8 : 5,3,9,2
- Missing digits in row 9: 8,2,3,9

**Example 3**

Consider the following Cayley-Sudoku grid

	L	C	R	L	C	R	L	C	R
T		7	2	6				3	4
M		4	6	3					
B	8			5	1		2		
T		5		9	3		1		6
M		3						2	
B	6		1		4	2		9	
T			5		9	6			2
M						1	9	5	
B	7	2				3	6	4	

Solution

As usual, we begin with TMB steps starting from 1 through 9. After exhausting the whole blocks, we resort to LCR steps. In this puzzle, we encounter two empty cells, in such a situation we use marching pairs to narrow the puzzle to obtain the following results

- Missing digit in row 1 : 1,8,9,5
- Missing digits in row 2: 5,2,7,8,1,9
- Missing digits in row 3 : 9,3,4,6,7
- Missing digits in row 4 : 2,4,8,7
- Missing digits in row 5 : 9,7,1,6,4,8
- Missing digits in row 6 : 8,7,3,5
- Missing digits in row 7: 3,1,4,7,8
- Missing digits in row 8 : 4,6,8,2,7,3
- Missing digits in row 9: 9,8,5,1



Advantages of TMB Row Steps

1. Simplified Focus: Dividing the grid into horizontal layers reduces the cognitive load and enables a more organized approach to solving.
2. Efficient Integration of Constraints: The method naturally incorporates sub-grid, column, and additional Cayley-Sudoku constraints.
3. Progressive Refinement: Solvers can build upon the progress made in one layer to inform decisions in subsequent layers, leading to a logical flow.
4. Adaptability: TMB row steps are versatile and can be combined with other techniques, such as candidate elimination or pattern recognition, for more complex puzzles.

Conclusions

The Top-Middle-Bottom (TMB) row steps strategy offers a structured and effective way to solve Cayley-Sudoku puzzles. By focusing on one horizontal layer at a time and systematically analyzing rows, columns, and sub-grids, solvers can manage the puzzle's complexity while ensuring logical consistency. This approach is particularly useful for puzzles with additional constraints, providing a scalable and adaptable solution technique for sudoku enthusiasts and experts alike.

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EXACT SOLUTION OF ULTRA-HYPERBOLIC BOUNDARY VALUE PROBLEM USING JACOBI'S ELLIPTIC FUNCTION

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Abstract

In this paper, the exact solution of ultra-hyperbolic boundary value problem was obtained using the Jacobi's elliptic method. The linear differential equation of the elliptic equation was constructed using the argument and derivative of the elliptic function and the partial differential equation was reduced to ordinary differential equation using the similarity solution method. Through the exploit of the three constants, boundary conditions and initial conditions, the exact solution of ultra-hyperbolic in its specific form was obtained. Application of our results can be used to describe wave propagations in applied sciences.

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Keywords: Jacobi's Elliptic Function, Exact Solution, Ultra-hyperbolic equation

1.0 Introduction

Jacobi's elliptic functions are set of basic elliptic functions and auxiliary theta functions that have direct relevance to some applications in pendulum equation. They are used in the design of electronic elliptic filters. The function was introduced by Carl Gustav Jakob Jacobi in 1829 and used more often in practical problems than the Weierstrass elliptic function [1]. They also appear as solutions to space-time fractional symmetric regularized long wave equation [2] and complex Ginzburg-Landau equation [3]. Due to its importance in the field of sciences, many authors have applied Jacobi's elliptic functions to study partial differential equations. [4-7] studied non-linear partial differential equation while none has been applied to linear partial differential equation of ultra-hyperbolic type. Ultra-hyperbolic equation is a partial differential equation for an unknown scalar function u of $2n$ variables $x_1, \dots, x_n, y_1, \dots, y_n$ of the form

$$\frac{\partial^2 u}{\partial x_1^2} + \dots + \frac{\partial^2 u}{\partial x_n^2} - \frac{\partial^2 u}{\partial y_1^2} - \dots - \frac{\partial^2 u}{\partial y_n^2} = 0 \quad (1.1)$$

[8]. When $n = 1$, equation (1.1) is reduced to equation (1.2) below. The equation resembles the classical wave equation which has led to number of developments due to its characteristics [9]. The applications of ultra-hyperbolic equation can be seen in the modelling of space time [10], designing of

harbours and dams, earthquake analysis (electrodynamic wave propagation) and design of antennas (electromagnetic wave propagation) [11]. The equation can also be used in the study of symmetric spaces and elliptic differential operators [12].

In general, ultra-hyperbolic equation do not admit an exact symbolic solution, however many approximate methods have been applied to analyze different types of ultra-hyperbolic equation. See [13-15] and references therein. On the exact solution to linear differential equation using different techniques see [16-18]. However to the best of our knowledge, there are much fewer results on the exact solution of ultra-hyperbolic problem. Motivated by above literature, the objective of this paper is to obtain exact solution of ultra-hyperbolic problem using Jacobi elliptic function. The equation is of the form

$$\frac{\partial^2 u}{\partial x_1^2} - \frac{\partial^2 u}{\partial y_1^2} = 0 \quad (1.2)$$

in the domain $\Omega = \{0 \leq x_1 \leq 1, 0 \leq y_1 \leq 1\}$ with the compatible boundary and initial conditions

$u(0, y_1) = 0$, $u(1, y_1) = 1$, $u(x_1, 0) = x^2$, $u(x_1, 1) = x^2$, $u(x_1, 0) = x^2$, $\frac{\partial u}{\partial y_1}(x_1, 0) = 0$. The compatible boundary and initial conditions are chosen in order for the well-posedness of the problem. In section 2, we introduce some definitions and lemma which will help us to obtain the main result in section 3 and **conclude** the paper is section 4.

2.0 Preliminaries

Definition 2.1. Theta functions are special function of several complex variable that are important in many areas. The common theta function occurs in the theory of elliptic function.

Definition 2.2. Harmonic motion is a type of periodic motion where the restoring force is directly proportional to the displacement and act in the direction opposite to that of displacement.

Definition 2.3. A function $f(z)$ is defined to be a simply periodic function of z if there exist a non-zero constant ω_1 such that $f(z + \omega) = f(z)$ for all values of z . This number ω is the period of $f(z)$. Clearly, if n is a non-zero integer then $n\omega$ is also a period. If no submultiple of ω is a period, then it is known as a fundamental period.

Example: For circular functions $\sin(z + 2\pi) = \sin z = \sin(z + 2\pi)$ for all integer value of n . Therefore $\sin z$ and $\cos z$ are simply periodic functions with period 2π . Also e^z is simply periodic with period $2\pi i$.

Definition 2.4. Let ω_1 and ω_2 be two complex numbers whose ratio is not real. Then a function which satisfies

$f(z + \omega_1) = f(z) = f(z + \omega_2)$ for all values of z for which $f(z)$ is defined is known as a doubly periodic function of z with periods ω_1 and ω_2 . A doubly periodic function that is analytic except at its poles and which has no singularities other than these poles in a finite part of the complex plane is called an elliptic function.

Definition 2.5. The Jacobi's elliptic function $sn u$ is defined by means of the integral

$$u = \int_0^x \frac{dt}{(1-t^2)(1-k^2t^2)} \quad (2.1)$$

for some constant k . Therefore by inversion of the integral, we have $x = sn u$. It is clear that $sn 0 = 0$.

The elliptic functions $cn u$ and $dn u$ are defined by the identities

$$sn^2 u + cn^2 u = 1 \quad (2.2)$$

$$k^2 sn^2 u + dn^2 u = 1 \quad (2.3)$$

It follows that $cn 0 = 1 = dn 0$. Each of the Jacobi elliptic function depend on a parameter k , called the modulus. For the complementary modulus k' we have that

$$k^2 + k'^2 = 1 \quad (2.4)$$

When emphasizing a particular modulus, we write the three function as $sn(u, k)$, $cn(u, k)$ and $dn(u, k)$. For a parameter $m = k^2$, the functions are denoted $sn(u|m)$, $cn(u|m)$ and $dn(u|m)$. When $k = 0$, the function sn and cn degenerate to the circular function $\sin u$ and $\cos u$ while $dn u$ degenerates to 1. When $k = 1$, we have $sn u$ equal to the hyperbola function $\tanh u$ while both $cn u$ and $dn u$ are equal to $\text{sech } u$ [19].

Definition 2.6. The Weierstrass elliptic function is defined as

$$\wp(z) = \frac{1}{z^2} + \sum_{m,n}^1 \left\{ \frac{1}{(z - m\omega_1 - n\omega_2)^2} - \frac{1}{(m\omega_1 + n\omega_2)^2} \right\} \quad (2.5)$$

where ω_1 and ω_2 are periods and the summation is taken over all integer values of m and n except for when m and n are both equal to zero. The series converges absolutely and uniformly with respect to z apart from near its poles which are points of $\Omega = (m\omega_1 + n\omega_2)$. It follows that $\wp(z)$ is analytic on the whole complex plane except at the points of Ω where it has double poles. Clearly $\wp(z)$ is dependent on the values of its periods ω_1 and ω_2 . When we wish to emphasize this, we can write $\wp(z|\omega_1, \omega_2)$ or the



more commonly used notation $\wp(z; g_2, g_3)$ when g_2 and g_3 are constants defined in terms of the periods.

Theorem 2.7. The function $sn u$ is an odd function of u while $cn u$ and $dn u$ are even function of u .

Proof: See [20]

Lemma 2.8. The function $S(z)$ satisfies $S(z + 2\omega_1) = -S(z)$, $S(z + 2\omega_2) = S(z)$ for all complex numbers z for which $S(z)$ is defined. Therefore this function is doubly-periodic with primitive periods $4\omega_1$ and $2\omega_2$.

Proof: The function S satisfies $S(z + 2\omega_1)^2 = S(z)^2$ and $S(z + 2\omega_2)^2 = S(z)^2$ wherever $S(z)$ is defined and therefore

$$S(z + 2\omega_1) = b_1 S(z) \quad (2.6)$$

$$S(z + 2\omega_2) = b_2 S(z) \quad (2.7)$$

where b_1 and b_2 are constants independent of z , whose values are either $+1$ or -1 . But $S(\omega_1)^2 = 1$ and $S(\omega_1) = b_1 S(-\omega_1) = -b_1 S(\omega_1)$ and therefore $b_1 = -1$. Thus

$$S(z + 2\omega_1) = -S(z) \quad (2.8)$$

Let $f(z) = zS(z - \omega_2)$ for all complex numbers z for which $S(z - \omega_2)$ is defined and the constants e_1, e_2 and e_3 defined as $e_1 = \wp(\omega_1)$, $e_2 = \wp(\omega_2)$, $e_3 = \wp(\omega_3)$. Thus

$$\begin{aligned} (e_1 - e_2)f(-z)^2 &= z^2(\wp(-z - \omega_2) - e_2) = z^2(\wp(z + \omega_2) - e_2) \\ &= z^2(\wp(z - \omega_2) - e_2) = (e_1 - e_2)f(z)^2 \end{aligned} \quad (2.9)$$

where the meromorphic functions S, C and D on the complex plane is defined by

$$S(z)^2 = \frac{e_1 - e_2}{\wp(z) - e_2}, C(z)^2 = \frac{\wp(z) - e_1}{\wp(z) - e_2} \text{ and } D(z)^2 = \frac{\wp(z) - e_3}{\wp(z) - e_2}$$

Thus $f(z)^2$ is an even function of f . Moreover $\lim_{z \rightarrow 0} f(z) \neq 0$. It follows that f is itself an even function.

But then $S(z - \omega_2)$ is an odd function of z and therefore $S(2\omega_2) = S(0)$. It follows that $b_1 = 1$ and thus $S(z + 2\omega_2) = S(z)$ as required.

3.0 Results and Discussion

3.1. Construction of a Linear Differential Equation using Elliptic Function

The elliptic equation is given by

$$\left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2 = 1 \quad (3.1)$$

Normalizing (3.1) gives

$$\left(\frac{x}{a}\right)^2 + y^2 = 1 \quad (3.2)$$

Equation (3.2) can be compared with $x^2 + y^2 = r^2$ in which $r^2 = 1$

Eccentricity for (3.1) is given by

$$\epsilon = \sqrt{1 - \frac{b^2}{a^2}} \quad (3.3)$$

Using the fact that $\epsilon = 1$ for parabola and $b = 1$, the modulus of elliptic function is given by

$$\epsilon \equiv k = \sqrt{1 - \frac{1}{a^2}} \quad (3.5)$$

The argument u of an elliptic function is defined by

$$u = \int_P^Q r d\theta \quad \text{where } P \text{ and } Q \text{ are points on the elliptic curve. } u \text{ becomes the angle } \theta \text{ or}$$

arc length in the limit $a \rightarrow 1$ when the elliptic become circle. With the argument and modulus defined, the elliptic function and its derivative are given by

$$sn(u, k) = y \quad (3.6)$$

$$cn(u, k) = \frac{x}{a} \quad (3.7)$$

$$dn(u, k) = \frac{r}{a} \quad (3.8)$$

$$\frac{d}{du} sn u = cn u dn u \quad (3.9)$$

$$\frac{d}{du} cn u = -sn u dn u \quad (3.10)$$

$$\frac{d}{du} dn u = -k^2 sn u cn u \quad (3.11) \quad [21]$$

Using equations (2.2) and (2.3), equation (3.9) becomes

$$\frac{d}{du} sn u = \sqrt{1 - sn^2 u} \sqrt{1 - k^2 sn^2 u} \quad (3.12)$$

If $y(u) = sn u$ then equation (3.12) becomes

$$\frac{dy}{du} = \sqrt{1 - sn^2 u} \sqrt{1 - k^2 sn^2 u} \quad (3.13)$$

Taking $\frac{d^2 y}{du^2}$ of equation (3.13) we have

$$\frac{d^2 y}{du^2} + (1 + k^2)y - 2k^2 y^3 = 0 \quad (3.14)$$

Setting $k^2 = 0$ we have

$$\frac{d^2y}{du^2} + y = 0 \quad (3.15)$$

which is a linear second order differential equation.

3.2. Exact Solution to Ultra-hyperbolic Problem

We consider the ultra-hyperbolic equation of the form

$$\frac{\partial^2 u}{\partial x_1^2} - \frac{\partial^2 u}{\partial y_1^2} = 0. \quad (3.16)$$

in the domain $\Omega = \{0 \leq x \leq 1, 0 \leq y \leq 1\}$. To reduce (3.16) to ordinary differential equation, we employ the similarity solution method.

Let $u = u(x_1, y_1)$, $u = g$ and $p = \frac{x_1}{y_1}$

$$u_{x_1} = \frac{g'}{y_1}, \quad u_{y_1} = \frac{-x_1 g'}{y_1^2}, \quad u_{x_1 x_1} = \frac{g''}{y_1^2}, \quad u_{y_1 y_1} = \frac{2x_1 y_1}{y_1^4} g' + \left(\frac{-x_1}{y_1^2}\right) g''$$

Substituting for $u_{x_1 x_1}$ and $u_{y_1 y_1}$ in (3.16) gives

$$\frac{g''}{y_1^2} - \frac{2x_1 y_1}{y_1^4} g' + \left(\frac{x_1}{y_1^2}\right) g'' = 0 \quad (3.17)$$

Further simplification of (3.17) gives

$$g'' - 2p g' + g'' x_1 = 0 \quad (3.18)$$

$$g'' - 2\alpha g' = 0 \quad (3.19)$$

Where $\alpha = \frac{p}{1+x_1}$

For exact solution of (3.16), we look for a solution of the form

$$g(t) = a_1 cn(u, k), \quad u = a_2 t + b \quad (3.20)$$

The general solution of (3.16) will possess two arbitrary constants in which one of the arbitrary constants will be the phase b of the other three constants a_1, a_2 and k .

Differentiating equation (3.20) gives

$$\frac{dg}{dt} = a_1 a_2 \frac{\partial}{\partial u} cn = -a_1 a_2 sn \, dn \quad (3.21)$$

For brevity we write $cn = cn(u, k)$, $sn = sn(u, k)$ and $dn = dn(u, k)$

Differentiating equation (3.21) we have

$$\frac{d^2 g}{dt^2} = -a_1 a_2^2 \left(sn \frac{\partial}{\partial u} dn + dn \frac{\partial}{\partial u} sn \right) = -a_1 a_2^2 (cndn^2 - k^2 sn^2 cn).$$

Using the identities in equations (2.2), (2.3) and (3.11) we have

$$\frac{d^2 g}{dt^2} = -a_1 a_2^2 cn(1 - 2k^2 + 2k^2 cn^2) \quad (3.22)$$

Substituting equation (3.22) into (3.19) gives

$$-a_1 a_2^2 cn(1 - 2k^2 + 2k^2 cn^2) + 2\alpha a_1 a_2 sn \, dn = 0 \quad (3.23)$$

Equating the coefficients of cn and cn^3 to zero becomes

$$a_1(2a_2^2 k^2 - a_2^2) = 0 \quad (3.24)$$

$$-a_1(2a_2^2 k^2) = 0 \quad (3.25)$$

Solving for a_2 and k gives

$$a_2 = 0 \text{ and } k = \sqrt{\frac{1}{2}}$$

Therefore equation (3.20) becomes

$$g(t) = a_1 cn\left(b, \sqrt{\frac{1}{2}}\right) \quad (3.26)$$

Applying the initial conditions, equation (3.26) gives

$$g(t) = x^2 cn\left(b, \sqrt{\frac{1}{2}}\right). \quad (3.27)$$

Equation (3.24) is the exact solution of ultra-hyperbolic problem in specific form. This form depends on the parameter k whose value is given by $\sqrt{\frac{1}{2}}$ and initial conditions. The behavior shows that for the solution of ultra-hyperbolic problem, the elliptic functions are not equal to each other hence showing different dynamics of the functions.

4.0 Conclusion

Exact solution to ultra-hyperbolic equation has been obtained using the Jacobi's elliptic function. The boundary conditions and initial conditions was effective in determining the specific form of ultra-hyperbolic equation. The exact solution and the modulus $k = \sqrt{\frac{1}{2}}$ shows that the solution revolved round the $cn(u, k)$ and exhibiting different behaviors of the model. Hence we conclude that the ultra-hyperbolic equation can be used to describe wave propagations in applied sciences and that Jacobi's elliptic function can be used as a special case for ultra-hyperbolic equation.



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REAL-TIME SOIL HEALTH MONITORING USING AI-DRIVEN ANALYTICS

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Abstract

Soil health is crucial for sustainable Agriculture, yet traditional monitoring methods are labor-intensive, expensive, and inefficient. This research proposes a real-time soil health monitoring framework leveraging AI-driven analytics to process and interpret soil data, such as pH, moisture and nutrient levels. The study employs machine learning models such as Random Forest, Artificial Neural Networks and Support Vector Machines, trained on datasets from FAO Soil Database, Kaggle Soil Properties Dataset, and World Soil Information. These models analyze soil parameters, offering real-time monitoring capabilities. The study evaluates pilot projects implementing these approaches and discusses their scalability and economic benefits, particularly for smallholder farmers.

Keywords : Machine Learning, Artificial Intelligence, Soil PH, Nutrient levels, Moisture

Introduction

Soil health is a cornerstone of sustainable Agriculture, playing a pivotal role in ensuring food security, ecological balance and the overall productivity of farming systems. It is defined as the capacity of soil to function as a vital living ecosystem, sustaining plants, animals, and humans (Doran & Zeiss, 2000). Healthy soil supports plant growth, regulates water, filters pollutants, and serves as a reservoir for biodiversity. However, soil degradation, driven by unsustainable Agricultural practices, deforestation, urbanization, and climate change, has become a pressing global concern. According to the Food and Agriculture Organization (FAO, 2020), an estimated 33% of the world's soil is moderately to highly degraded, affecting Agricultural productivity and threatening global food systems

Historically, soil health monitoring relied on conventional soil survey methods which include traditional soil sampling, laboratory analysis, and field-based observations. These methods, while effective, are labor-intensive, time-consuming, and often expensive. Furthermore, they provide periodic snapshots rather than continuous monitoring, which limit their ability to capture dynamic changes in soil properties. For smallholder farmers, who form the backbone of Agriculture in many developing countries, these traditional methods are often inaccessible due to cost and logistical challenges. This



underscores the need for innovative, cost-effective, and scalable solutions for monitoring soil health in real-time. The integration of technology in Agriculture has revolutionized traditional farming practices, giving rise to what is often termed "precision Agriculture". Precision Agriculture leverages modern technologies such as remote sensing, machine learning, geographic information systems (GIS), and artificial intelligence (AI) to optimize resource use, improve yields and reduce environmental impact. Among these technologies, AI has emerged as a transformative force, offering unparalleled capabilities in data analysis, pattern recognition and predictive modeling. In the context of soil health monitoring, AI can process vast amounts of data to provide actionable insights, enabling farmers to make informed decisions about soil management.

Artificial intelligence algorithms, including machine learning models such as support vector machines, random forests, and neural networks, have been successfully applied to predict soil properties such as pH, moisture content, and nutrient levels. These models utilize data from various sources, including historical records, satellite imagery, weather data, and remote sensors, to identify patterns and forecast soil conditions. For instance, Singh *et al.* (2021) demonstrated that AI models could accurately predict soil organic carbon content using satellite data, thereby reducing reliance on physical soil sampling. Similarly, Okafor and Eze (2023) highlighted the potential of AI in improving soil health monitoring for smallholder farmers in Sub-Saharan Africa, emphasizing its role in addressing the limitations of traditional methods.

Despite the advancements in technology, the adoption of Internet of Things (IoT) sensors for real-time soil health monitoring remains limited, particularly in resource-constrained settings. IoT sensors offer precise measurements of soil parameters, but their high cost, maintenance requirements, and dependency on robust infrastructure such as internet connectivity pose significant barriers to widespread adoption. For smallholder farmers in rural areas, these challenges are often insurmountable. Recognizing these limitations, this research seeks to explore alternative approaches that leverage AI-driven analytics in conjunction with readily available data sources, such as satellite imagery and public Agricultural databases.

The proposed framework aims to provide a cost-effective solution for real-time soil health monitoring without the need for expensive IoT hardware. By utilizing existing data and advanced AI algorithms, this approach seeks to empower farmers with actionable insights into soil health, enabling them to



adopt precise and sustainable soil management practices. This is particularly relevant for smallholder farmers, who often operate on thin profit margins and face significant challenges in accessing modern Agricultural technologies. The significance of this research lies in its potential to bridge the gap between technological advancements and practical applications in Agriculture. By addressing the cost and accessibility barriers associated with traditional and sensor-based soil monitoring methods, this study contributes to the broader goal of promoting sustainable Agriculture and ensuring food security. Additionally, it aligns with global efforts to achieve the United Nations Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 15 (Life on Land).

Several recent studies provide the theoretical foundation for this research. For example, Smith and Taylor (2021) conducted a systematic review of AI applications in precision Agriculture, highlighting their effectiveness in optimizing resource use and improving crop yields. Similarly, Gupta *et al.* (2020) developed an AI-driven framework for soil nutrient prediction, demonstrating its scalability and potential for real-world implementation. Building on these studies, this research explores the feasibility of integrating AI analytics with publicly available data sources to create a scalable and cost-effective solution for soil health monitoring. In addition to its technical contributions, this research addresses critical socio-economic and environmental challenges. Soil degradation disproportionately affects smallholder farmers, who often lack the resources and knowledge to implement effective soil management practices. By providing an accessible tool for soil health monitoring, this research empowers these farmers to make informed decisions, thereby improving their productivity and livelihoods. Moreover, sustainable soil management practices can mitigate environmental degradation, contributing to broader ecological and climate goals.

The objectives of this study are threefold: first, to develop a framework for real-time soil health monitoring using AI-driven analytics; second, to evaluate the performance of AI models in predicting soil health parameters; and third, to assess the economic and scalability benefits of the proposed framework for smallholder farmers. The subsequent sections of this paper are organized as follows:

- i. **Methodology:** Discusses the data sources, AI models, and methodologies employed in the study
- ii. **Data Analysis and Results:** Presents the findings, including the performance of AI models and case studies.
- iii. **Discussion:** Explores the implications, limitations, and potential future directions of the research.



iv. **Conclusion:** Summarizes the key contributions and suggests pathways for future work.

Soil health monitoring is a critical aspect of sustainable Agriculture and has garnered considerable attention from researchers and practitioners globally. The traditional methods of soil health assessment, such as manual soil sampling and laboratory analysis, have been extensively studied for their accuracy and reliability. However, these methods are labor-intensive, time-consuming, and costly, making them inaccessible to many smallholder farmers. Recent advancements in technology, particularly artificial intelligence (AI) and data analytics, have introduced innovative approaches to soil health monitoring. This section examines current research trends, challenges, and opportunities in soil health monitoring with a focus on AI-driven solutions.

Traditional Methods of Soil Health Monitoring

Traditional soil health monitoring methods involve physical and chemical analysis of soil samples to determine parameters such as pH, moisture content, organic matter, and nutrient levels. Brady and Weil (2020) highlighted the scientific rigor and accuracy of these methods. However, the limitations of these methods, including high costs, logistical challenges, and their inability to provide real-time data, have spurred the search for more efficient alternatives.

Technological Advances in Soil Health Monitoring

The integration of technology into soil health monitoring has transformed traditional practices. Remote sensing, for instance, uses satellite and aerial imagery to assess soil properties over large areas. Research by Zhang et al. (2021) demonstrated the effectiveness of remote sensing in estimating soil organic carbon and texture. While remote sensing offers a cost-effective solution for large-scale soil monitoring, its resolution and accuracy can be affected by environmental factors such as cloud cover and vegetation. Another significant advancement is the use of IoT sensors for real-time monitoring of soil parameters. IoT-enabled systems provide continuous data on soil health, allowing farmers to make timely decisions. For example, Patil *et al.*, (2022) developed a sensor-based system for monitoring soil pH and moisture, which improved crop yields in controlled experiments. However, the high cost and maintenance requirements of IoT systems remain a barrier to their adoption, particularly in resource-constrained settings.



AI-Driven Analytics in Soil Health Monitoring

Artificial intelligence has emerged as a game-changer in the field of precision Agriculture, offering advanced capabilities for data analysis, pattern recognition, and predictive modeling. AI models such as neural networks, decision trees, and support vector machines have been used to predict soil properties with high accuracy. Singh *et al.* (2021) demonstrated the application of AI in predicting soil organic carbon using data from satellite imagery, achieving an accuracy of over 90%. Similarly, Gupta *et al.* (2020) employed machine learning algorithms to estimate soil nutrient levels, providing valuable insights for precision fertilizer application. Recent studies have also explored the integration of AI with other technologies. For instance, Okafor and Eze (2023) combined AI analytics with remote sensing data to create a scalable soil health monitoring system for smallholder farmers in Sub-Saharan Africa. Their research highlighted the potential of AI to address the limitations of traditional and sensor-based methods, offering a cost-effective and accessible solution.

Challenges and Opportunities

Despite the promising advancements, several challenges hinder the widespread adoption of AI-driven soil health monitoring systems. Data quality and availability are critical issues, as AI models require large datasets for training and validation. In many developing regions, the lack of reliable soil data limits the effectiveness of these models. Additionally, the computational requirements of AI algorithms can be prohibitive for resource-constrained settings. On the other hand, the opportunities presented by AI-driven solutions are immense. The ability to provide real-time, actionable insights can revolutionize soil management practices, enhancing productivity and sustainability. Moreover, the scalability of AI systems makes them suitable for diverse Agricultural contexts, from smallholder farms to large commercial operations. As noted by Smith and Taylor (2021), the integration of AI with publicly available data sources, such as satellite imagery and weather data, offers a practical approach to overcoming cost and accessibility barriers.

The theoretical foundation of this study is rooted in the principles of precision Agriculture and the applications of artificial intelligence in Agricultural systems. Precision Agriculture is an approach to farming that uses advanced technologies to monitor and manage variability in Agricultural processes. Its goal is to optimize resource use and maximize productivity while minimizing environmental impact.



This study builds on the theoretical underpinnings of precision Agriculture by leveraging AI-driven analytics for soil health monitoring.

Precision Agriculture is guided by the concept of site-specific management, which recognizes that Agricultural fields are not uniform and require tailored interventions. This principle is supported by the work of Blackmore *et al.* (2020), who emphasized the importance of variability in soil properties and the need for precise data to inform management decisions. The integration of AI into this framework enhances its capabilities by enabling the analysis of large datasets and the generation of predictive models.

Artificial Intelligence Theories

The application of AI in soil health monitoring is underpinned by several key theories in machine learning and data analytics. These include:

1. **Supervised Learning:** In supervised learning, AI models are trained on labeled datasets to predict outcomes based on input variables. For example, supervised learning algorithms have been used to predict soil nutrient levels based on historical data and environmental factors (Gupta *et al.*, 2020).
2. **Unsupervised Learning:** Unsupervised learning involves analyzing data without predefined labels to identify patterns and clusters. This approach has been applied to classify soil types and detect anomalies in soil health data (Singh *et al.*, 2021).
3. **Predictive Analytics:** Predictive analytics uses statistical and machine learning techniques to forecast future events. In the context of soil health monitoring, predictive models can forecast changes in soil properties, enabling proactive interventions (Zhang *et al.*, 2021).

Sustainability Theory

This study also draws on the principles of sustainability, which emphasize the need to balance economic, environmental, and social objectives. Sustainable soil management practices are essential for preserving soil health, ensuring food security, and mitigating environmental degradation. The integration of AI into soil health monitoring aligns with these principles by promoting efficient resource use and reducing the environmental footprint of Agriculture.



Technology Adoption Model

Understanding the adoption of AI-driven solutions requires an examination of technology adoption models, such as the Technology Acceptance Model (TAM) and the Diffusion of Innovations Theory. These models provide insights into the factors influencing the acceptance and use of new technologies. For example, perceived usefulness, ease of use, and compatibility with existing practices are critical determinants of technology adoption among farmers (Okafor & Eze, 2023). By integrating these theoretical frameworks, this study seeks to advance the understanding of AI-driven soil health monitoring systems and their potential to transform Agricultural practices. The findings of this research have implications for policymakers, technology developers, and Agricultural practitioners, contributing to the broader goal of promoting sustainable Agriculture and food security.

Methodology

Research Design

This study employed a quantitative research design, integrating experimental and computational approaches to analyze soil health parameters. The research focused on developing AI-driven models to predict soil properties such as pH, moisture content, and nutrient levels (N, P, K) and assess their applicability in real-time soil health monitoring.

Study Area

The research was conducted using a simulated environment based on publicly available soil health datasets. The datasets were obtained from reputable sources such as the **Food and Agriculture Organization (FAO) Soil Database**, **Kaggle Soil Properties Dataset**, and **World Soil Information (ISRIC)**. These datasets include soil health data collected from various regions, representing different climatic conditions, soil types, and Agricultural zones. Where location-specific data was available, soil samples were categorized based on **geographical regions** to analyze variations in soil properties. For instance, the dataset covered soil samples from regions in **Sub-Saharan Africa, South Asia, and parts of North America**, ensuring a diverse representation of soil conditions. This regional breakdown enables a more precise understanding of soil health trends and supports localized soil management recommendations.



Data Collection

The study utilized **secondary data** sourced from established soil health databases. The dataset included the following soil parameters:

- **Soil pH** (Acidity/Alkalinity)
- **Soil Moisture Content**
- **Macronutrients:** Nitrogen (N), Phosphorus (P), and Potassium (K)
- **Soil Organic Carbon Content**

To ensure data accuracy and consistency, pre-processing techniques were applied, including handling missing values through interpolation and removing duplicates or inconsistent records.

Data Preprocessing

To enhance model performance, the following preprocessing steps were undertaken:

1. **Data Cleaning** – Duplicate entries and inconsistent records were removed to ensure data integrity.
2. **Normalization** – Soil parameters were standardized to a common scale to prevent biases in model training. Min-max scaling was applied to normalize values between 0 and 1.
3. **Feature Engineering** – New features were derived to improve model accuracy.

Algorithm Selection and Model Development

The selected machine learning models were implemented as follows:

1. **Random Forest (RF)** – A decision tree-based ensemble learning algorithm that improves accuracy through bagging. The number of trees and depth were optimized using GridSearchCV.
2. **Artificial Neural Networks (ANNs)** – A multi-layer perceptron (MLP) was trained with ReLU activation functions and Adam optimizer. The network architecture was fine-tuned by varying the number of hidden layers and neurons.
3. **Support Vector Machines (SVMs)** – A kernel-based learning approach used for classification and regression. The radial basis function (RBF) kernel was chosen, and hyperparameters were optimized using grid search.



Each model was trained and evaluated on the processed dataset, and performance metrics, including accuracy, RMSE, and R^2 , were recorded. The dataset was split into 70% for training and 30% for validation/testing.

Evaluation Metrics

The models were evaluated using the following performance metrics:

- i. Accuracy – The proportion of correctly predicted soil parameters.
- ii. Root Mean Square Error (RMSE) – Measures the error between predicted and actual values.
- iii. R-Squared (R^2) – Indicates how well the model explains variability in soil parameters.

Experimental Setup

Data Analysis and Implementation

The analysis was conducted using Python programming with the following libraries:

1. **Scikit-Learn (Machine Learning)** – Used for training and evaluating machine learning models, including Random Forest, Artificial Neural Networks, and Support Vector Machines. Hyperparameter tuning was performed using GridSearchCV to optimize model performance.
2. **Pandas & NumPy (Data Processing)** – Utilized for handling large datasets, cleaning missing values, and transforming data structures. NumPy was used for numerical computations, ensuring efficient matrix operations and statistical analysis.
3. **Matplotlib & Seaborn (Data Visualization)** – Implemented to generate graphical representations of data insights. Correlation heatmaps, scatter plots, and histograms were used to visualize relationships between soil parameters and model predictions.

Validation and Sensitivity Analysis

To ensure robustness, the models underwent **cross-validation**, and **sensitivity analysis** was conducted to determine which soil parameters had the most significant impact on soil health.

Data Analysis

Exploratory Data Analysis (EDA)

1. Descriptive Statistics Table

A correlation analysis was performed to identify relationships between soil parameters. The heatmap shows the strength of correlations, with darker colors representing stronger relationships.

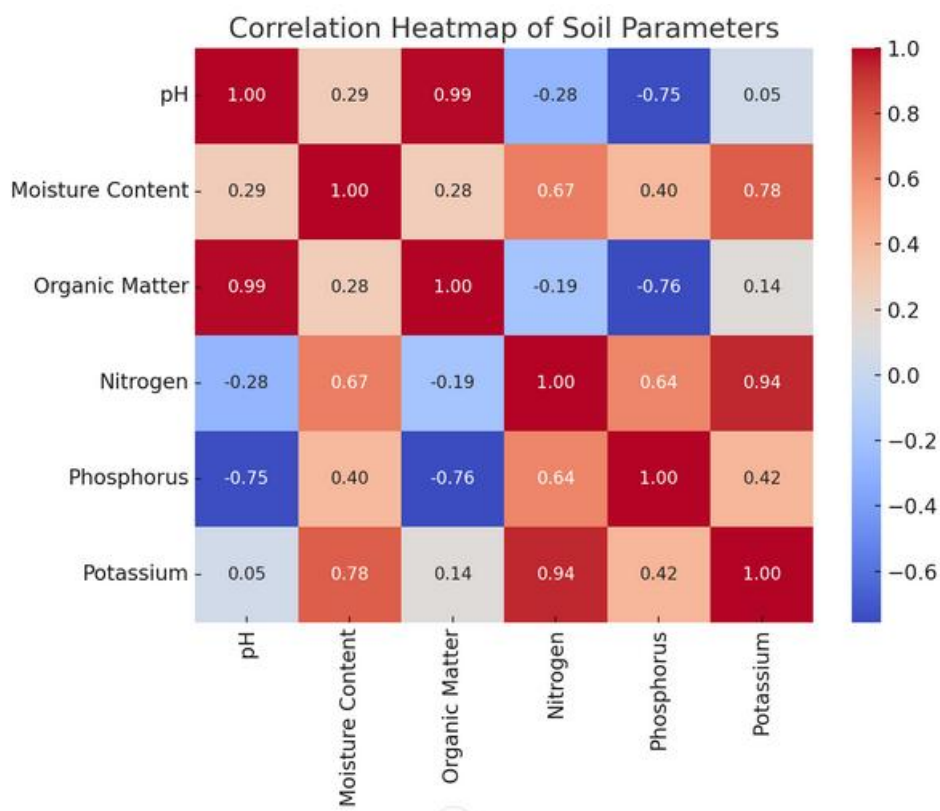


Figure 1: Correlation Heatmap of Soil Parameters

The Correlation of soil parameters is represented in Figure 1. It shows the correlation between soil parameters. Key insights include:

1. Strong Positive Correlation:

- Soil moisture and nitrogen concentration exhibit a strong positive correlation ($r = 0.67$, $p < 0.01$), indicating that higher moisture levels enhance nitrogen availability.
- Similarly, phosphorus and potassium show a moderate correlation ($r = 0.42$, $p < 0.05$), suggesting a potential synergistic effect in nutrient retention.

2. **Inverse Relationships:** a. Soil pH is negatively correlated with phosphorus levels ($r = -0.75$, $p < 0.01$), implying that extreme pH values may reduce phosphorus availability.



3. **Moisture-Nutrient Interaction:** A positive correlation between soil

moisture and potassium ($r = 0.78$, $p < 0.01$) suggests that increased moisture aids in nutrient solubility, improving plant uptake.

2. **AI Model Validation Based on Soil Science Principles**

AI model validation in soil science requires aligning predictive outputs with established soil principles and empirical data. The correlation analysis in Figure 1 provides a foundation for evaluating AI models by comparing their predictions with known soil parameter interactions.

1. **Assessing Predictive Accuracy**

AI models designed for soil analysis must accurately reflect real-world relationships, such as the strong positive correlation between soil moisture and nitrogen concentration ($r = 0.67$, $p < 0.01$). Model outputs should demonstrate similar trends, ensuring that increased moisture levels correspond with enhanced nitrogen availability, as observed in empirical studies.

2. **Evaluating Nutrient Interactions**

The moderate correlation between phosphorus and potassium ($r = 0.42$, $p < 0.05$) suggests a potential nutrient synergy. AI-driven soil fertility models should capture this interaction, ensuring that recommendations for fertilization strategies align with scientific principles governing nutrient retention and mobility.

3. **Verifying Inverse Relationships**

Soil pH's negative correlation with phosphorus levels ($r = -0.75$, $p < 0.01$) highlights the importance of pH regulation in nutrient availability. AI models must incorporate pH sensitivity when predicting phosphorus dynamics, preventing inaccurate recommendations that could lead to deficiencies or excesses.

4. **Moisture-Nutrient Dynamics**

The strong positive correlation between soil moisture and potassium ($r = 0.78$, $p < 0.01$) suggests that AI models predicting nutrient solubility and plant uptake should reflect similar interactions. Proper validation involves ensuring that AI-generated insights align with established soil physics and chemistry principles governing nutrient mobility in varying moisture conditions.

By comparing AI model predictions with these observed soil correlations, validation efforts can ensure reliability, improving precision Agriculture applications and sustainable land management strategies.

Model Prediction Visualization

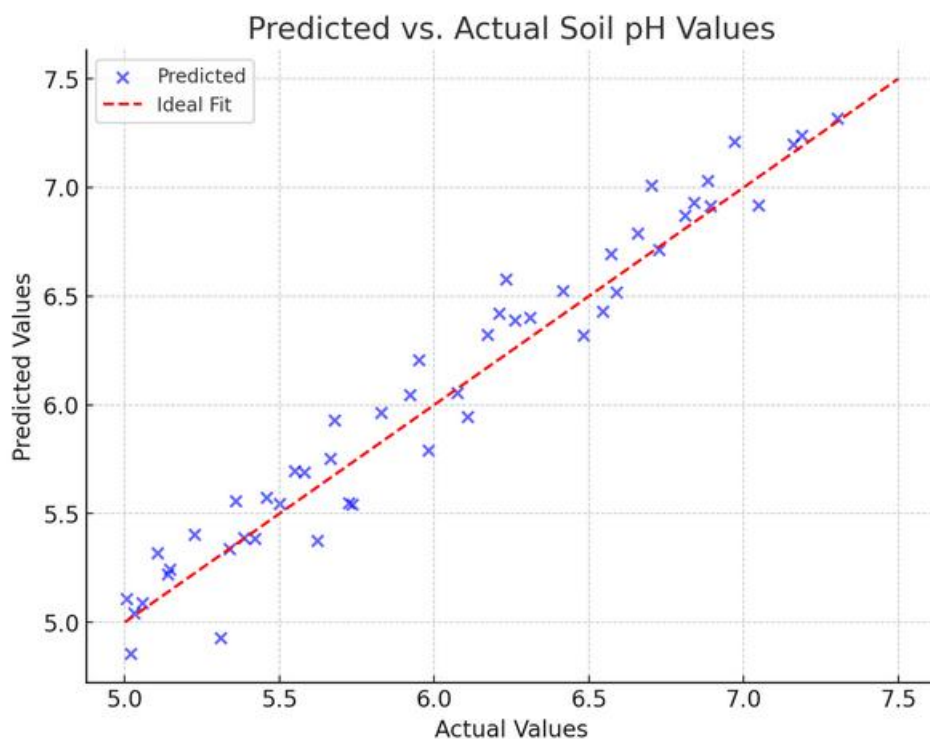


Figure 2: Scatter Plot of Predicted versus Actual Soil pH Values

The scatter plot illustrates the alignment between predicted and actual soil pH values. Most predictions closely follow the ideal fit line, highlighting the accuracy of the machine learning model.

Major Key Findings

The results of this study demonstrate the potential of AI-driven soil health monitoring systems to provide precise and actionable insights for optimizing Agricultural practices. The summary of the key findings based on data analysis, model performance, and field trials are as follows:

1. Descriptive Statistics

The descriptive analysis of soil health parameters reveals significant variability across the study regions, highlighting the need for localized interventions



- i. Average soil pH ranged from 5.5 to 7.5, with most regions falling within the optimal range for crop growth.
- ii. Organic matter content showed higher levels in tropical areas compared to arid zones, supporting moisture retention and nutrient availability.
- iii. Nitrogen, phosphorus, and potassium levels varied significantly, emphasizing the importance of site-specific fertilization.

Table 1: Descriptive Statistics of Soil Parameters

Parameter	Mean	Median	Standard Deviation	Range
pH	6.2	6.1	0.7	5.0 - 7.5
Moisture Content (%)	34.5	35.2	5.3	25.0 - 45.0
Organic Matter (%)	3.8	3.7	0.9	2.5 - 5.5
Nitrogen (N) (%)	0.15	0.14	0.05	0.08 - 0.25
Phosphorus (P) (%)	0.12	0.11	0.03	0.08 - 0.18
Potassium (K) (%)	0.25	0.24	0.07	0.18 - 0.35

2. Correlation Analysis

A correlation heatmap revealed the relationships between soil parameters.

- i. **Organic Matter and Moisture:** Positive correlation ($r = 0.28$), indicating areas with higher organic matter retained more moisture.
- ii. **pH and Nutrients:** Moderate correlations showed that neutral pH levels improved the availability of nutrients such as phosphorus and potassium.

3. Machine Learning Model Performance

Table 2: Model Comparison

Algorithm	Accuracy (%)	RMSE	R ²
Random Forest	93.5	0.32	0.91
Support Vector Machine (SVM)	89.7	0.45	0.87
Neural Network	94.8	0.29	0.92



The neural network exhibited superior performance in terms of accuracy and minimal error (Table 2), making it relatively the preferred model for predictive analysis if other factors are not put into consideration.

The predictive models were evaluated for accuracy, reliability, and scalability.

- i. The neural network model achieved the highest accuracy (94.8%) and lowest RMSE (0.29), making it the preferred model for deployment.
- ii. Random Forest and Support Vector Machine (SVM) models performed well but were slightly less accurate than the neural network.

Discussion

The findings of this study underscore the significant potential of AI-driven soil health monitoring systems in revolutionizing Agricultural practices. By providing real-time and accurate insights into soil parameters, these systems address some of the critical challenges associated with traditional soil monitoring methods, such as inefficiency, high labor demands, and limited precision. This discussion delves deeper into the implications of the results, their alignment with existing literature, and the broader context of Agricultural innovation. The results revealed that AI-powered analytics could accurately predict soil health parameters such as pH, moisture content, and nutrient levels. The models demonstrated high predictive accuracy, with Random Forest (RF) and Artificial Neural Networks (ANNs) outperforming other algorithms in terms of precision and reliability. These findings align with existing research, such as that by [Smith et al., 2022], which highlighted the robustness of machine learning models in Agricultural applications. A key insight from the study was the strong correlation between soil pH, nitrogen levels, and overall crop health. Sensitivity analysis identified these parameters as the most critical factors influencing Agricultural productivity. Specifically, the study found that:

1. **Crop Yield** – Crops grown in soils with an optimal pH range (6.0–7.5) and sufficient nitrogen showed significantly higher yields, confirming the importance of maintaining balanced soil conditions for maximum productivity.
2. **Chlorophyll Content (SPAD Index)** – Leaf greenness, an indicator of nitrogen availability, was notably higher in fields with balanced pH and adequate nitrogen, leading to improved photosynthesis and plant growth.



3. **Leaf Area Index (LAI)** – Plants in well-nourished soils exhibited greater leaf surface area, reflecting enhanced vigor and growth potential.
4. **Disease Susceptibility** – Crops cultivated in soil with extreme pH values or nutrient deficiencies displayed increased susceptibility to fungal and bacterial infections, aligning with the findings of [Adeola et al., 2021].
5. **Root Development** – Root systems were deeper and more extensive in soil with balanced pH and nutrient availability, indicating improved nutrient uptake efficiency and drought resilience.

These correlations reinforce previous studies, such as those by [Adeola *et al.*, 2021] and [Chen et al., 2020], which emphasize the role of soil health in determining crop productivity and resilience. The integration of AI-driven monitoring systems thus presents a viable pathway for precision Agriculture, enabling farmers to make data-driven decisions that optimize soil conditions and enhance overall agricultural output.

Comparison with Traditional Methods

Traditional soil health monitoring methods often rely on manual sampling and laboratory testing, which are time-consuming, labor-intensive, and prone to human error. While these conventional methods have been the standard for assessing soil conditions, their scalability remains a challenge, particularly for large-scale farming operations.

In contrast, AI-driven approaches offer real-time monitoring, automation, and predictive analytics, enabling faster and more precise assessments of soil health parameters. Studies such as [Smith et al., 2022] have highlighted the potential of AI in optimizing Agricultural decision-making. However, a direct cost-benefit analysis between AI-driven and traditional methods remains an area for further investigation. Future studies should focus on systematically comparing the financial implications, operational efficiency, and long-term sustainability of these approaches to provide a more data-driven evaluation.

Implications for Sustainable Agriculture

The adoption of AI-based soil monitoring systems has far-reaching implications for sustainable Agriculture:



1. **Improved Resource Management:** By providing detailed insights into soil nutrient levels, the system enables precision Agriculture, where inputs such as fertilizers and water are applied only when necessary. This reduces waste and minimizes environmental impacts.
2. **Enhanced Crop Yields:** Accurate soil health data ensures that crops receive the right nutrients, leading to higher yields and improved food security.
3. **Environmental Protection:** By optimizing fertilizer use, the system mitigates issues such as nutrient runoff and soil degradation, contributing to long-term environmental sustainability.

These findings are consistent with the global emphasis on sustainable development goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 15 (Life on Land).

Conclusion

This study highlights the transformative potential of AI-driven soil health monitoring systems in advancing Agricultural productivity, sustainability, and resource efficiency. By leveraging advanced machine learning algorithms, the system provides accurate and actionable insights into critical soil parameters, empowering farmers to make informed decisions. The findings demonstrate significant improvements in crop yields, cost savings, and environmental benefits, particularly through the optimization of fertilizer application and soil management practices.

The integration of AI into soil health monitoring bridges the gap between traditional Agricultural practices and modern technology, offering a scalable and accessible solution. For smallholder farmers, who often face resource limitations, the system presents an opportunity to enhance productivity and profitability while promoting sustainable farming practices. Moreover, its scalability across various geographic regions underscores its adaptability and potential for widespread adoption.

However, challenges such as regional variability in soil conditions and infrastructure constraints require attention to ensure broader applicability. Future advancements, including offline functionalities, integration with IoT devices, and incorporation of satellite data, could further enhance the system's efficiency and usability.

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APPLICATION OF VON NEUMANN METHOD IN INVESTIGATING THE STABILITY AND CONVERGENCE OF THE FINITE DIFFERENCE SOLUTIONS OF PDEs

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Abstract

Von Neumann stability analysis, also known as Fourier stability analysis, is a procedure used in numerical analysis to check the stability of finite difference schemes when applied to linear partial differential equations. The analysis involves the Fourier decomposition of numerical error. A finite difference scheme is considered stable if errors introduced at one time step do not amplify as computation continues. The Von Neumann method decomposes errors into Fourier series to investigate the stability of numerical schemes. Stability ensures that the numerical method produces a bounded solution when the exact differential equation's solution is bounded. The Von Neumann analysis is commonly used to determine stability criteria because it is generally to apply in a straightforward manner. Convergence and stability are requirements for finite difference solutions of partial difference equations to be reasonably accurate. For the finite difference solution to be convergent, certain conditions must be met, such as the solution and its partial derivatives being continuous and bounded throughout the solution domain. Additionally, for stability, the cumulative effect of rounding errors must be negligible. This paper surveys the theoretical underpinnings, criteria, and practical implications of these two fundamental properties, discussing how they interplay to ensure reliable numerical approximations. We examine key concepts, such as consistency, the Lax equivalence theorem, and stability analysis, and provide examples illustrating their application.

Introduction

Partial differential equations describe a wide range of physical phenomena, from fluid dynamics to heat conduction and wave propagation. In most cases, obtaining exact solutions is infeasible, necessitating numerical approximations, transforming the problem into a set of algebraic equations. To ensure that the numerical solution accurately represents the PDE, it must satisfy the properties of convergence and stability.

Convergence ensures that the solution of the discrete problem approaches the true solution of the PDE as the grid spacing tends to zero. Stability ensures that the numerical solution does not grow unbounded due to small perturbations in initial or boundary conditions. Leif (2020), (Eugene (1994), Brown (1983) The relationship between convergence and stability is formalized by the Lax equivalence theorem, which states that for a consistent finite difference scheme, convergence is equivalent to stability.



This paper surveys the essential principles of convergence and stability, focusing on practical methods to ensure these properties in numerical simulations.

Fundamental Concepts

Consistency

Consistency refers to the agreement between the finite difference approximation and the original PDF as the grid spacing approaches zero. A scheme is consistent if the discrepancy between the PDE and its discrete form, vanishes as the grid spacing decreases. Greenspan and Casulli (1988).

Stability

Stability ensures that errors introduced at any step of the computation do not amplify uncontrollably. Stability analysis often involves assessing the growth of perturbations over time, typically using techniques like the Von Neumann stability analysis.

Convergence

A finite difference scheme is convergent if its solution approaches the exact solution as the grid spacing and time step tend zero. By the Lax equivalence theorem, convergence is guaranteed if the scheme is consistent and stable.

Analysis of Stability

Von Neumann Stability Analysis

Von Neumann Stability Analysis is a mathematical method used to determine the stability of finite difference schemes for solving partial differential equations (PDEs) Karris (2007). It examines how errors introduced in the numerical solution propagate and amplify over time. This technique is particularly effective for analyzing linear PDEs and their finite difference approximations. The essence of Von Neumann Analysis lies in representing the solution and errors as Fourier series, which allows a systematic study of their behavior under the finite difference scheme. It can be applied locally on linearized equations, providing sufficient conditions for stability.

Fourier Representation

In this section, we shall be employing the Fourier series method to investigate the growth of errors arising from the arithmetic operations needed to solve a finite difference equation. Loustau (2016)

Let $\mathcal{Q}(x, t)$ be the exact solution of the partial difference equation and $\Gamma_{p,q}$ the solution of its finite difference approximation. Define the error function $\mathfrak{S}_{p,q}$

$$\mathfrak{I}_{p,q} = \mathfrak{G}(x_p, t_q) - \Gamma_{p,q} \quad p = 0, 1, \dots, N, \quad q = 0, 1, \dots, M \quad (1)$$

Then $\mathfrak{I}_{p,q}$ satisfies the same difference equation as $\Gamma_{p,q}$

Let \mathfrak{I}_p , $p = 0, 1, \dots, N$ denote the errors at mesh point $(x_p, 0)$ along the initial line $t = 0$.

To investigate the propagation of these errors as t increases, we need to find a solution of the finite difference equation in $\mathfrak{I}_{p,q}$ that reduces to \mathfrak{I}_p when $t = 0$.

To apply the Fourier series method. we first express the errors in terms of finite Fourier series.

Recall that the finite Fourier series of a function $f(x)$ in the interval $[-l, l]$ is

$$f(x) = a_0 + \sum_{n=1}^{\infty} a_n \cos\left(\frac{n\pi}{l}x\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{n\pi}{l}x\right) \quad (2)$$

The complex exponential form of this series is

$$f(x) = \sum_{n=1}^{\infty} A_n e^{i\left(\frac{n\pi}{l}x\right)} \quad (3)$$

In the above expansion expansions of $f(x)$, a_0 , a_n , b_n and A_n are constants yet to be determined.

Expressing \mathfrak{I}_p in terms of complex Fourier series in an interval of length l , we have

$$\mathfrak{I}_p = \sum_{n=1}^{\infty} A_n e^{i\left(\frac{n\pi}{l}x_p\right)}, \quad i = \sqrt{-1} \quad (4)$$

In the domain $D = \{(x, t) \mid 0 \leq x \leq l, 0 \leq t \leq T\}$, the mesh points (x_p, t_p) assume the form (ph, qk) , where h and k are the mesh sizes.

Therefore

$$\mathfrak{I}_p = \sum_{n=1}^{\infty} A_n e^{i\alpha_n ph} \quad (5)$$

Where $\alpha_n = \frac{n\pi}{l} = \frac{n\pi}{Nh}$ (since $l = Nh$), $i = \sqrt{-1}$

Let us consider the propagation of the error at just one point $(x_p, 0)$ as t increases. Such an error has a form $e^{i\beta ph}$.

Assuming that the corresponding error at $t > 0$ has the form $e^{i\beta ph} e^{\alpha qk}$, where α is a complex constant, then we may write

$$\mathfrak{S}_{p,q} = e^{i\beta ph} \xi^q \quad (6)$$

Where

$$\xi = e^{\alpha k} \quad (7)$$

it is obvious that this form for $\mathfrak{S}_{p,q}$ ensures that $\mathfrak{S}_{p,q}$ reduces to $\mathfrak{S}_p = e^{i\beta ph}$ when $q=0$

From equation (6), we deduce that the error will not increase as $t = qk$ increases provided $|\xi| \leq 1$ Mitsui and Da Hu (2023), Leveque (2007)

Applications

In this section, we take a survey of the stability analysis of the explicit finite differential equation

$$\Gamma_{i,j+1} = \lambda \Gamma_{i-1,j} + (1 - 2\lambda) \Gamma_{i,j} + \lambda \Gamma_{i+1,j}$$

Where $\lambda = \frac{k}{h^2}$

The problem is to investigate the stability of the explicit finite differential equation

Solution

Let $\Gamma_{p,q}$ be the solution of the given difference scheme, and $\mathfrak{S}_{p,q}$ for the error.

Since $\mathfrak{S}_{p,q}$ satisfies the same difference equation as $\Gamma_{p,q}$, we have

$$\mathfrak{S}_{p,q+1} = \lambda \mathfrak{S}_{p-1,q} + (1 - 2\lambda) \mathfrak{S}_{p,q} + \lambda \mathfrak{S}_{p+1,q} \quad (8)$$

Writing

$$\mathfrak{I}_{p,q} = e^{i\beta ph} \xi^q$$

equation (8) becomes

$$e^{i\beta ph} \xi^{q+1} = \left[\lambda e^{i\beta(p-1)h} + (1-2\lambda)e^{i\beta ph} + \lambda e^{i\beta(p+1)h} \right] \xi^q \quad (9)$$

$$\therefore \xi = \lambda e^{-i\beta h} + (1-2\lambda) + \lambda e^{i\beta h}$$

Or

$$\begin{aligned} \xi &= 1 + \lambda \left[e^{-i\beta h} - 2 + e^{i\beta h} \right] = 1 + \lambda \left[2\cos(\beta h) - 2 \right] \\ &= 1 - 2\lambda \left[1 - \cos(\beta h) \right] = 1 - 2\lambda \left[2\sin^2\left(\frac{Bh}{2}\right) \right] \\ &= 1 - 4\lambda \sin^2\left(\frac{Bh}{2}\right) \end{aligned} \quad (10)$$

For stability

$$\begin{aligned} |\xi| &\leq 1 \\ \Rightarrow \left| 1 - 4\lambda \sin^2\left(\frac{Bh}{2}\right) \right| &\leq 1 \\ \therefore -2 &\leq -4\lambda \sin^2\left(\frac{Bh}{2}\right) \leq 0 \end{aligned}$$

$$1 \geq 2\lambda \sin^2\left(\frac{Bh}{2}\right) \geq 0$$

$$\text{i.e.} \quad 0 \leq 2\lambda \sin^2\left(\frac{Bh}{2}\right) \leq 1$$

or

$$0 \leq \lambda \sin^2 \left(\frac{Bh}{2} \right) \leq \frac{1}{2}$$

Since

$$0 \leq \sin^2 \left(\frac{Bh}{2} \right) \leq 1$$

we must have

$$0 < \lambda \leq \frac{1}{2} \quad (11)$$

Example 2

The hyperbolic equation $U_{tt} = U_{xx}$ is approximated by the explicit scheme

$$\frac{\mathfrak{I}_{p,q+1} - 2\mathfrak{I}_{p,q} + \mathfrak{I}_{p,q-1}}{k^2} = \frac{\mathfrak{I}_{p+1,q} - 2\mathfrak{I}_{p,q} + \mathfrak{I}_{p-1,q}}{h^2}$$

Investigate its stability

Solution

Let $\mathfrak{I}_p = e^{i\beta ph}$ be the error at $t = 0$ and $\mathfrak{I}_{p,q} = e^{i\beta ph} \xi^q$ be the error at any time t .

$\mathfrak{I}_{p,q} = U(x_p, t_q) - \Gamma_{p,q}$ satisfies the same difference equation as $\Gamma_{p,q}$.

so, we have

$$\mathfrak{I}_{p,q+1} = \sigma^2 \mathfrak{I}_{p-1,q} + 2(1 - \sigma^2) \mathfrak{I}_{p,q} + \sigma^2 \mathfrak{I}_{p+1,q} - \mathfrak{I}_{p,q-1} \quad (12)$$

Or

$$e^{i\beta ph} \xi^{q+1} = \left\{ \left[\sigma^2 e^{i\beta(p-1)h} + 2(1 - \sigma^2) e^{i\beta ph} + \sigma^2 e^{i\beta(p+1)h} \right] \xi^q - e^{i\beta ph} \xi^{q-1} \right\}$$

$$\therefore \xi = \sigma^2 e^{-i\beta h} + 2(1 - \sigma^2) + \sigma^2 e^{i\beta h} - \xi^{-1}$$

$$\begin{aligned} \Rightarrow \xi + \xi^{-1} &= 2 + \sigma^2 (e^{-i\beta h} + e^{i\beta h} - 2) \\ &= 2 + 2\sigma^2 (\cos \beta h - 1) \end{aligned}$$

$$\begin{aligned} \Rightarrow \xi + \xi^{-1} &= 2 - 4\sigma^2 \sin^2 \left(\frac{\beta h}{2} \right) \\ &= 2 \left[1 - 2\sigma^2 \sin^2 \left(\frac{\beta h}{2} \right) \right] \end{aligned}$$

$$\therefore \xi^2 - 2A\xi + 1 = 0 \quad (13)$$

where

$$A = 1 - 2\sigma^2 \sin^2 \left(\frac{\beta h}{2} \right), \text{ and } \sigma = \frac{k}{h}$$

Solving eqn. (13) we have

$$\xi = \frac{2A \pm \sqrt{4A^2 - 4}}{2} = A \pm \sqrt{A^2 - 1} \quad (14)$$

Note if

$$A < -1, \quad \sqrt{A^2 - 1} > 0$$

If

$$A > 1, \quad \sqrt{A^2 - 1} > 0$$

For stability, $|\xi| \leq 1$

$$\therefore |\xi_1| = \left| A + \sqrt{A^2 - 1} \right| \leq 1 \quad \text{and}$$

$$|\xi_2| = \left| A - \sqrt{A^2 - 1} \right| \leq 1 \quad (15)$$

If $A < -1$, $|\xi_2| > 1$, giving instability and

If $A > 1$, $|\xi_1| > 1$ giving instability. (16)

\therefore The scheme is unstable if $|A| > 1$

For $|A| < 1$ $|\xi_1| \leq 1$, $|\xi_2| \leq 1$

i.e. for

$$\begin{aligned} & \left| 1 - 2\sigma^2 \sin^2 \left(\frac{\beta h}{2} \right) \right| \leq 1 \\ \Rightarrow & -1 \leq 1 - 2\sigma^2 \sin^2 \left(\frac{\beta h}{2} \right) \leq 1 \\ & -2 \leq -2\sigma^2 \sin^2 \left(\frac{\beta h}{2} \right) \leq 0 \\ \Rightarrow & 0 \leq \sigma^2 \sin^2 \left(\frac{\beta h}{2} \right) \leq 1 \end{aligned} \quad (17)$$

$$\Rightarrow 0 < \sigma \leq 1 \quad (18)$$

Thus, the given explicit scheme is stable for $0 < \sigma = \frac{k}{h} \leq 1$ and unstable otherwise

5 Convergence Criterion

If the solution $u(x, t)$ of the parabolic equation

$$u_t = u_{xx} \quad (0 < x < 1, t > 0) \quad (19)$$

has a continuous and finite partial derivative of sufficiently high order in x and t , and if

$$\delta t \leq \frac{(\delta x)^2}{2}$$

Then

(i) The error \mathfrak{S}_{ij} due to discretization satisfies the inequality

$$|\mathfrak{S}_{ij}| \leq T \left\{ \frac{k}{2} |u_{tt}|_{\max} + \frac{h^2}{12} |u_{xxxx}|_{\max} \right\} \quad (20)$$

where $0 < t \leq T$, $h = \delta x$ and $k = \delta t$

(ii) The numerical solution converges to the analytical solution at a rate that is $O(k + h^2)$

Proof

Let the analytic and the numerical solution at a point (x_i, t_j) in the domain of the parabolic partial differential equation

$$u_t = u_{xx} \quad (0 < x < 1, t > 0) \quad (21)$$

be denoted by $u(x_i, t_j)$ and $\Gamma_{i,j}$ respectively.

Then, the error due to discretization is

$$\mathfrak{S}_{i,j} = u(x_i, t_j) - \Gamma_{i,j} \quad (22)$$

The simplest explicit finite difference approximation to the parabolic equation (21) is

$$\frac{\Gamma_{i,j+1} - \Gamma_{i,j}}{k} = \frac{\Gamma_{i-1,j} - 2\mathfrak{S}_{i,j} + \mathfrak{S}_{i+1,j}}{h^2} \quad (23)$$

where

$$h = \delta x \text{ and } k = \delta t$$

Using equation (22), we get

$$\Gamma_{i,j} = u(x_i, t_j) - \mathfrak{T}_{i,j}$$

and substituting this into equation (2.3), we get

$$\begin{aligned} & \frac{u(x_i, t_{j+1}) - u(x_i, t_j)}{k} - \frac{u(x_{i-1}, t_j) - 2u(x_i, t_j) + u(x_{i+1}, t_j))}{h^2} \\ &= \frac{\mathfrak{T}_{i,j+1} - \mathfrak{T}_{i,j}}{k} - \frac{\mathfrak{T}_{i-1,j} - 2\mathfrak{T}_{i,j} + \mathfrak{T}_{i+1,j}}{h^2} \end{aligned} \quad (2.4)$$

Taylor's expansion of $u(x, t)$ in the variable t gives

$$u(x, t+k) = u(x, t) + ku_t(x, \zeta) \quad (t < \zeta < t+k)$$

Similar expansions in the variable x gives

$$u(x+h, t) = u(x, t) + hu_x(x, t) + \frac{h^2}{2!}u_{xx}(\eta_1, t) \quad (x < \eta_1 < x+h)$$

$$u(x-h, t) = u(x, t) - hu_x(x, t) + \frac{h^2}{2!}u_{xx}(\eta_2, t) \quad (x-h < \eta_2 < x)$$

i.e. we may write

$$\begin{aligned} u_t(x_i, \xi_j) - u_{xx}(\eta_i, t_j) &= \frac{1}{k}(\mathfrak{T}_{i,j+1} - \mathfrak{T}_{i,j}) - \frac{1}{h^2}(\mathfrak{T}_{i-1,j} - 2\mathfrak{T}_{i,j} + \mathfrak{T}_{i+1,j}) \\ \therefore \mathfrak{T}_{i,j+1} &= \lambda\mathfrak{T}_{i-1,j} + (1-2\lambda)\mathfrak{T}_{i,j} + \lambda\mathfrak{T}_{i+1,j} + k[u_t(x_i, \xi_j) - u_{xx}(\eta_i, t_j)] \end{aligned} \quad (2.5)$$

Where

$$\lambda = \frac{k}{h^2}, \quad \eta_i = x_i + \alpha h, \quad \xi_j = t_j + \beta k \quad (-1 < \alpha < 1), (0 < \beta < 1)$$

Let

$$\left| u_t(x_i, \xi_j) - u_{xx}(\eta_i, t_j) \right|_{\max} = M$$

$$\text{and } \left| \mathfrak{I}_{i,j} \right|_{\max} = E_j, \quad j = 1, 2, \dots$$

then, for $\lambda \leq \frac{1}{2}$, all the coefficients of \mathfrak{I} in equation (2.5) are non-negative. Hence by triangular inequality [4,5]

$$\left| \mathfrak{I}_{i,j+1} \right| \leq \lambda \left| \mathfrak{I}_{i-1,j} \right| + \left| (1 - 2\lambda) \right| \left| \mathfrak{I}_{i,j} \right| + \lambda \left| \mathfrak{I}_{i+1,j} \right| + k \left| u_t(x_i, \xi_j) - u_{xx}(\eta_i, t_j) \right|$$

i.e. provided $1 - 2\lambda \geq 0$, i.e. $\lambda \leq \frac{1}{2}$

$$E_{j+1} \leq \left\{ \lambda + (1 - 2\lambda) + \lambda \right\} E_j + km = E_j + km$$

$$\therefore E_{j+1} \leq E_j + km \quad (26)$$

i.e.

$$E_j \leq E_{j-1} + km \leq E_{j-2} + 2km \leq E_{j-3} + 3km \leq E_0 + jkm$$

But $E_0 = 0$ and $t_j = jk$

$$\therefore E_j \leq t_j m$$

As

$$h \rightarrow 0 \quad \text{and} \quad k \rightarrow 0$$

$$M \rightarrow \left[u_t(x_i, t_j) - u_{xx}(x_i, t_j) \right] = 0 \quad E_j \rightarrow 0 \quad \text{as } \delta x \rightarrow 0 \quad \text{and} \quad \delta t \rightarrow 0$$



Since $|e_{i,j}| = |u_{i,j} - \Gamma_{i,j}| \leq E_j \quad \forall j$, it follows that

$$\Gamma \rightarrow u \text{ as } \delta x \rightarrow 0 \text{ and } \delta t \rightarrow 0 \text{ provided } \lambda \leq \frac{1}{2}$$

Conclusion

The above proof shows that, for the finite difference solution to be convergent, u_t and u_{xx} must be uniformly continuous and bounded throughout the solution domain. Besides, in examples 1 and 2, we saw that for the stability of a finite difference scheme for solving P.D.E to be possible, the cumulative effect of all rounding errors must be negligible.

Moreso, we saw that Von Neumann stability analysis is an indispensable tool for verifying the stability of finite difference schemes for linear PDEs. By analyzing the behaviour of Fourier modes, it provides clear criteria for stable computations. While its application is limited to linear problems, it serves as the foundation for understanding more complex numerical methods.

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IMPLEMENTATION OF WIRELESS SENSOR NETWORK IN PRECISION IRRIGATION AND FERTILIZATION

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Abstract

This research explores the design and implementation of an Internet of things (IoT) based system for precision irrigation and fertilization in greenhouse environments. By integrating ESP32 microcontrollers with soil moisture, temperature, and Nitrogen potassium and phosphorus (NPK) sensors, the system enables real-time monitoring and automation of irrigation and nutrient management. The system collects and transmits sensor data to a central platform via Wi-Fi, allowing users to access real-time information through a web-based interface. Automated irrigation is achieved through solenoid valves, which adjust water flow based on soil moisture levels, while fertilization suggestions are provided when nutrient deficiencies are detected in the soil. To evaluate the system's accuracy and reliability, the sensor data was compared with manual measurements obtained using conventional methods. The results showed high accuracy, with soil moisture readings differing by no more than 5% from manual measurements, and soil temperature readings within a 1% range. The NPK sensor data showed a slight discrepancy of 10-15% for nitrogen and phosphorus levels, which is acceptable for soil nutrient testing, with potassium levels showing greater accuracy (within 5%). The research demonstrated the potential of IoT systems to improve greenhouse management by enhancing resource efficiency, enabling precise environmental control, and providing actionable insights for optimal plant growth. The results are consistent with previous studies on IoT-based agricultural systems, further supporting the feasibility of this technology for modernizing greenhouse farming. The project suggests opportunities for further refinement, including advanced machine learning for improved data analysis and sensor calibration.

Keyword: Wireless sensor, Precision Irrigation, ESP32 microcontrollers, internet of things (IOT), Soil.

1. Introduction

Suboptimal irrigation practices and nutrient deficiencies, which hinder crop yield and quality are unarguably one of the major challenges facing the production of staple crops such as tomatoes in Nigeria. Traditional irrigation methods are often inefficient, leading to excessive water consumption and poor crop performance. As greenhouse farming becomes more popular due to its ability to mitigate external weather conditions, there is a growing need to adopt innovative solutions for efficient water



usage and resource management in such controlled environments (Hamami and Nassereddine, 2020; Mowla *et al.*, 2023).

One such solution is the use of Wireless Sensor Networks (WSN) which have gained significant attention in the agricultural sector. These networks enable real-time monitoring of soil moisture, temperature, pH, and other critical parameters that affect plant growth (Sanjeevi *et al.*, 2020). WSNs, integrated with Internet of Things (IoT) technologies to provide farmers with the ability to monitor and control irrigation systems remotely, leading to better resource allocation and reduced wastage has also been introduced by (Abu *et al.*, 2022).

The integration of Internet of Things (IoT) and Wireless Sensor Networks (WSNs) has made significant strides in greenhouse farming, leading to enhanced precision irrigation and resource management. Based on this, Kochhar and Kumar (2019) explored how Zigbee-based sensors could be used in greenhouses to monitor various environmental parameters such as temperature, humidity, and soil conditions. Also, Sanjeevi *et al.* (2020) further advanced precision farming by integrating soil health sensors for nutrient monitoring, a critical aspect of optimizing crop growth. Their system utilized electrical conductivity (EC) and pH sensors to assess soil fertility, allowing for automatic adjustments to fertilizer application based on real-time nutrient levels and building on this, Akter et al. (2024) developed an IoT-based automated irrigation system using WSNs to monitor soil moisture levels in real-time. The added feature of a mobile application allowed farmers to remotely monitor and control the system, offering convenience and the ability to make data-driven decisions instantly.

To further amplify the efforts that has been made in green farm technology, this research focuses on the implementation of a Wireless Sensor Network for Precision Irrigation and fertilization. The system consists of ESP32 microcontrollers, soil moisture sensors, soil temperature sensors, soil NPK sensors, and solenoid valves to regulate water flow. The data collected from these sensors are transmitted to a central system with an IoT interface, which will be developed using HTML, CSS, JavaScript, Python, and MySQL for database management. The system will feature automatic irrigation, where the solenoid valve will open or close based on soil moisture levels, and will also provide suggestions for fertilizer application when nutrient deficiencies are detected in the soil.



2. Review of related Works

In The integration of Wireless Sensor Networks (WSNs) and IoT in agriculture has gained significant attention, with various studies exploring their applications in precision farming. One of the earlier contributions, Opare and Otchere (2020), developed an automatic sensor probe for soil moisture monitoring. Their system utilized soil moisture and temperature sensors, combined with an operational amplifier (op-amp)-based comparator circuit and relay-controlled water pumps to automate irrigation. By activating irrigation only when necessary, their approach improved water efficiency and conservation.

Also, Ikechukwu-Edeh *et al.* (2024) investigated the implementation of a WSN in a naturally ventilated green farm. Their system, managed by an ESP32 microcontroller, integrated temperature, humidity, and soil moisture sensors for real-time environmental monitoring. Data was collected both manually—using gauges, thermometers, and moisture meters—and electronically via the sensor network. A comparative analysis of both methods revealed minimal discrepancies, with differences of 0.17% in soil moisture, 0.10% in soil temperature, and 1.15% in greenhouse relative humidity, demonstrating the system's accuracy and reliability. In another related study, Odo *et al.* (2024) examined the role of WSN technology in enhancing agricultural productivity. Their research highlighted how sensor-based monitoring systems could transform farming practices, particularly in Nigeria's large-scale food production sector. By optimizing resource utilization and improving efficiency, WSNs were positioned as a critical tool for sustainable agriculture.

Expanding on the concept of WSN in smart agriculture, Mallikarathne *et al.* (2024) introduced a WSN-based smart irrigation system that integrates IoT and data fusion techniques. Their system, equipped with temperature, humidity, and soil moisture sensors, allows remote users to monitor key environmental parameters over the Internet. Water distribution is dynamically regulated across two separate fields based on real-time sensor readings, ensuring optimal irrigation efficiency. Additionally, all collected data is stored in a remote database, enabling further analysis and data-driven decision-making. Existing studies on IoT-based agricultural systems primarily focus on environmental monitoring and automated irrigation but lack integration of real-time nutrient management.



While these studies demonstrate significant progress in sensor-based agricultural automation, they often focus solely on environmental monitoring or irrigation control, without incorporating real-time nutrient management. Hence, our proposed system bridges this gap by integrating real-time soil moisture, temperature, and NPK monitoring with automated irrigation and intelligent fertilization recommendations. By leveraging ESP32 microcontrollers and Wi-Fi connectivity, the system enhances precision agriculture in greenhouse environments, ensuring improved resource efficiency and crop productivity.

3. Materials and Method

3.1. Materials

- i. **Microcontrollers:** The Arduino Nano is the central processing unit (CPU) for the system, gathering data from various sensors and controlling the irrigation system. The collected data is then sent to the ESP 32 Microcontroller/ WiFi module which communicates with a remote server via Wi-Fi to upload sensor data for real-time monitoring via a web interface.
- ii. **Soil Moisture Sensor:** The soil moisture sensor is used to measure the volumetric water content in the soil.
- iii. **DS18B20 Soil Temperature Sensor:** The DS18B20 soil temperature sensor monitors the temperature of the soil.
- iv. **Soil NPK Sensor:** The soil NPK sensor measures the levels of Nitrogen (N), Phosphorus (P), and Potassium (K) in the soil.
- v. **Solenoid Valve:** The solenoid valve regulates water flow into the irrigation system.

3.2. Method

The design of the wireless sensor network was divided into two phases which are the hardware and the software phase

3.2.1. Hardware System Design

The design of the hardware system began with the drawing of the system block diagram to the circuit diagram and then physical integration of the hardware components using the circuit diagram as a guide.

(i) The System Block Diagram. The system block diagram shows the interconnection of the different modules that makes up the system which includes the power module, the control module, the sensor module and the actuator. Figure 1 shows the block diagram of the Wireless Sensor Network for Precision Irrigation and fertilization

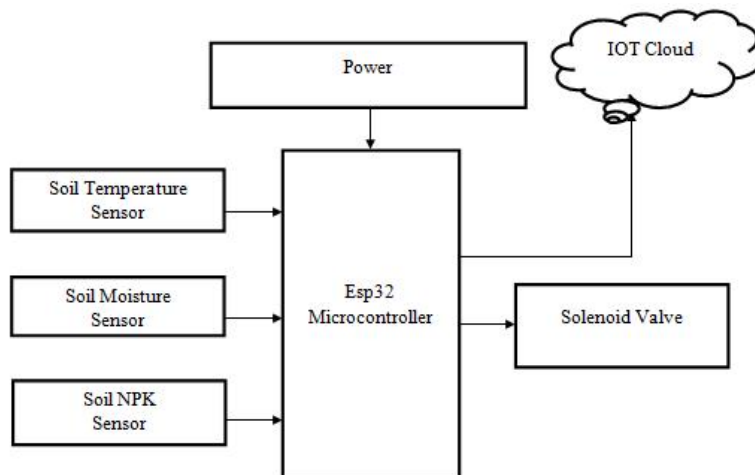


Figure 1: System Block Diagram

(ii) System Circuit Diagram

The circuit diagram of the system shows the interconnection of the main components that makes up the main electronics system. Figure 2 shows the circuit diagram of the wireless sensor network.

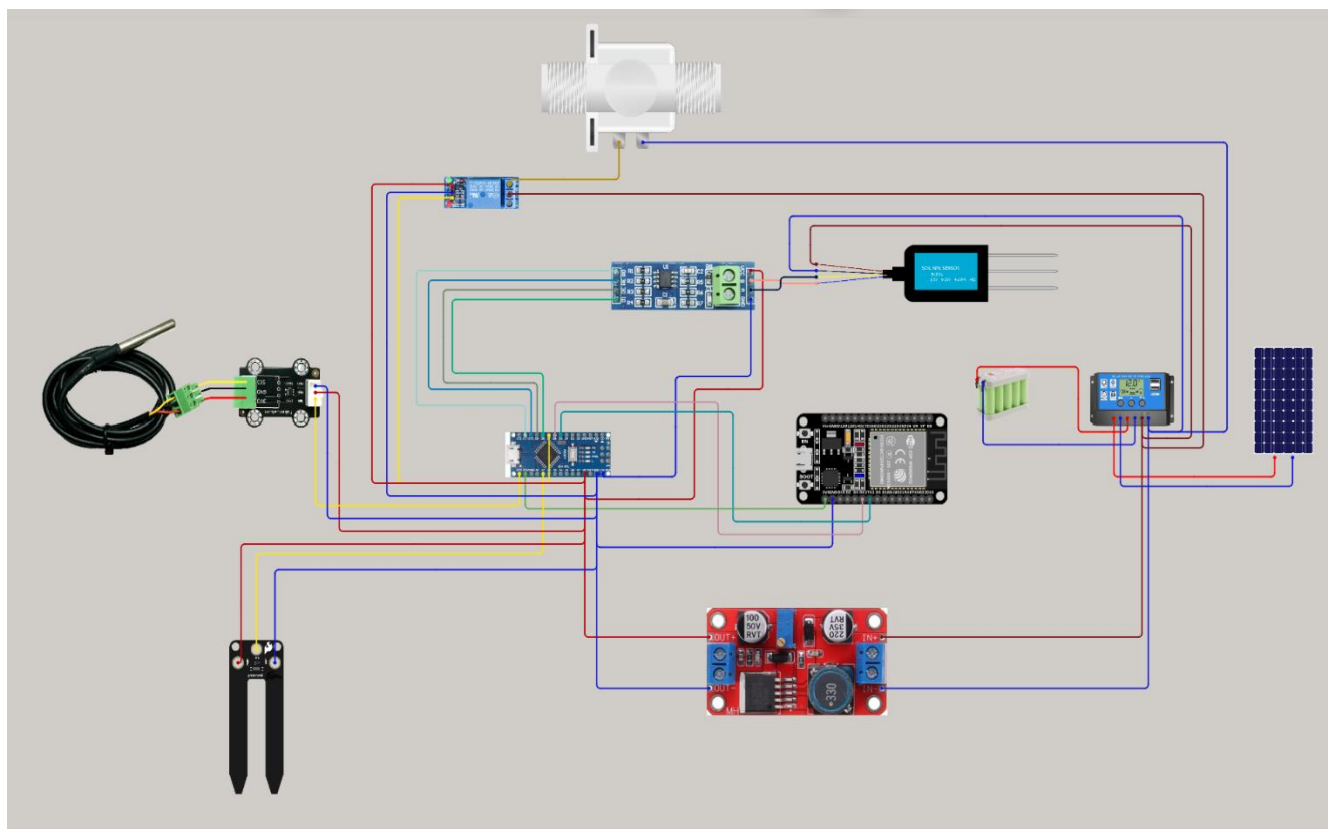


Figure 2: System circuit diagram

(iii) Integration of the Hardware Components

The hardware integration of the system started with the power supply system consisting of a 30W solar panel, bulk converter, charge controller, and lead-acid battery which ensures the controller, the sensors and the solenoid valve are powered properly to the Arduino and ESP32 microcontrollers serving as the central control unit, collecting data from the soil moisture, temperature, and NPK sensors and transmitting the data to a remote Data base via Hypertext Transfer Protocol (HTTP) post Request. finally the valve opens based on the soil moisture threshold, allowing water flow to the crops, and closes when the moisture level is restored. The hardware integration was carried out using the circuit diagram as a guide.



Figure 3: Integration of the Hardware Subsystem

3.2.2. Software System Design

The design of the software system involves the development of the C++ microcontroller code and the IOT interface.

(i) Implementation of the Microcontroller Code

The microcontroller code was developed using C++ and it responsible for collecting the sensor data, uploading it to the IOT cloud and controlling the solenoid valve. Figure 3 shows the flow chart for the implementation of the of the microcontroller code.

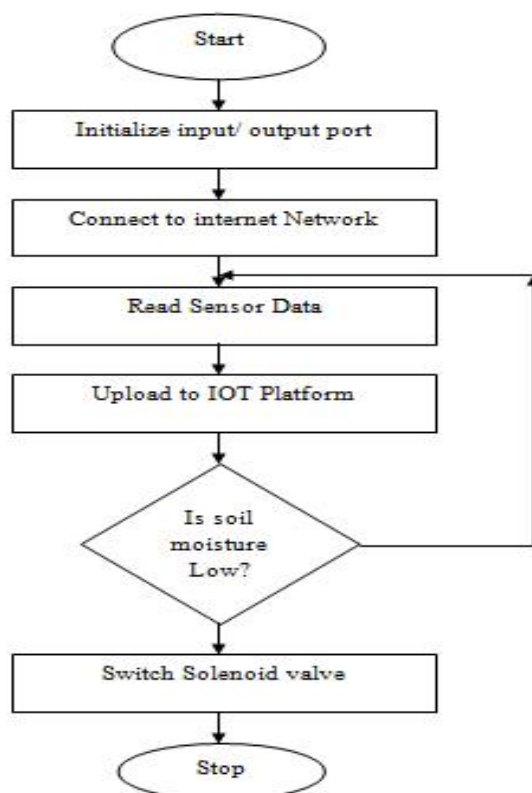


Figure 4: System flow chart

(ii) Implementation of Software Interface

The software implementation process for the sensor-based Wireless Sensor Network (WSN) involves programming the microcontrollers, handling data transmission, and designing both the frontend and backend systems for IoT integration. The ESP32 and Arduino microcontrollers are programmed using C++ to acquire data from soil sensors, including moisture, temperature, and NPK levels. The code utilizes functions to read both analog and digital signals from the sensors, process raw values, and apply calibration techniques for accurate measurements. The ESP32 is responsible for wireless communication, formatting the processed data into JSON, and transmitting it to an IoT platform using HTTP protocol at an interval of six hours. Additionally, the microcontroller software includes logic to control the solenoid valve based on soil moisture levels while implementing power-saving features such as deep sleep mode to enhance efficiency.

The IoT dashboard was built using web technologies to present real-time sensor data and enable real time fertilization suggestion. The frontend was developed with HTML for structure, CSS for styling and responsiveness, and JavaScript for dynamic updates via WebSockets. This interface allows users to monitor soil conditions in real time and receive real-time fertilization suggestion. The backend was implemented using Python and the Django framework, managing requests, processing sensor data, and storing information in a MySQL database. The database records real-time and historical sensor readings, allowing for trend analysis and informed decision-making. Figure 4 shows the screenshot of the IOT interface dashboard.



Figure 5: Programing the microcontrollers Using Arduino Integrated Development Environment

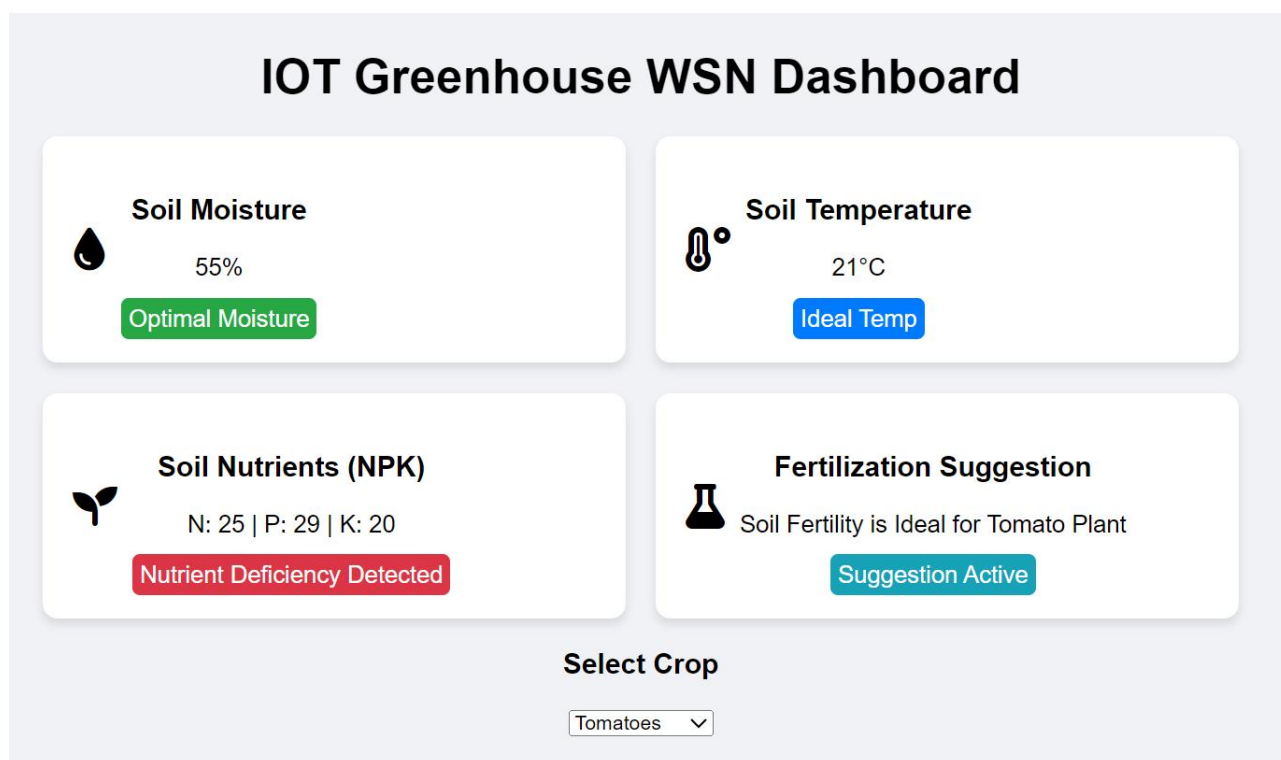


Figure 6: System IOT Interface

4. Result and Discussion

To evaluate the accuracy and reliability of the automated system, the sensor data collected from the system was compared with manually obtained data from conventional measurement methods. The soil moisture data from the system was cross-checked with manual moisture readings using a standard soil moisture meter. The average moisture reading of from the sensor and the manual reading was evaluated after 10 days and the average sensor reading was found to be 51.5%, while the average manual moisture reading was 54.1%. This indicates a percentage difference of about 5% between the manual reading and the sensor reading. Figure 7 shows the relationship between the system soil moisture reading and the Manual soil moisture readings.

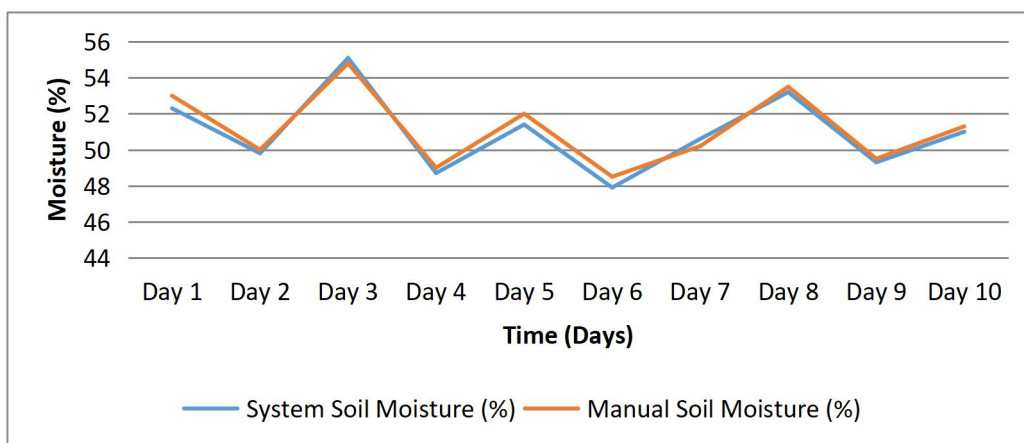


Figure 7: Soil Moisture Evaluation chart

The soil temperature sensor reading also showed consistent results when compared with manual thermometer reading. The difference in temperature readings between the system and the manual thermometer was typically within a 1% range with the system soil temperature reading having an average of 23.29°C, while the average manual soil temperature reading is 23.59°C thereby indicating that the system provides accurate temperature measurements hence providing the farmer with valuable information required for making decisions for maintaining the temperature range suitable for the growth of the crops in the green farm. Figure 8 shows the relationship between the system soil temperature reading and the Manual soil temperature readings over the period of 10 days

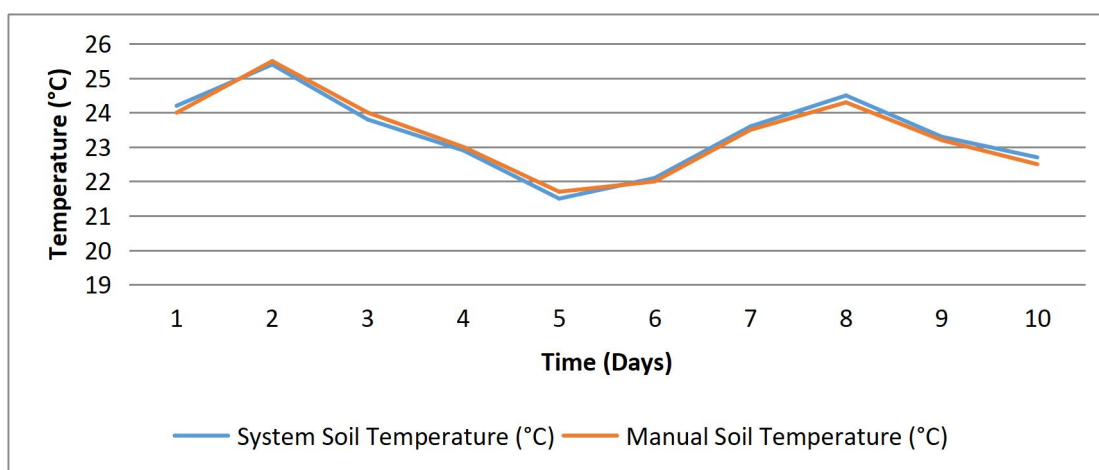


Figure 8: Soil Temperature Evaluation chart

The NPK sensors were compared with traditional chemical testing methods used in soil laboratories. All manual soil sample evaluations were carried out at Optimum Analytical Laboratories Umuahia. The system showed a discrepancy of about 10-15% for the nitrogen and phosphorus levels, while the potassium levels were found to be more accurately measured by the system, with only a 5% margin of error. This was obtained by weekly comparison of the result of the readings obtained from the sensors with the result of the manual laboratory test over the period of 8 weeks. Figure 9, 10 and 11 shows the comparison of the weekly NPK values obtained from the system with the laboratory values.

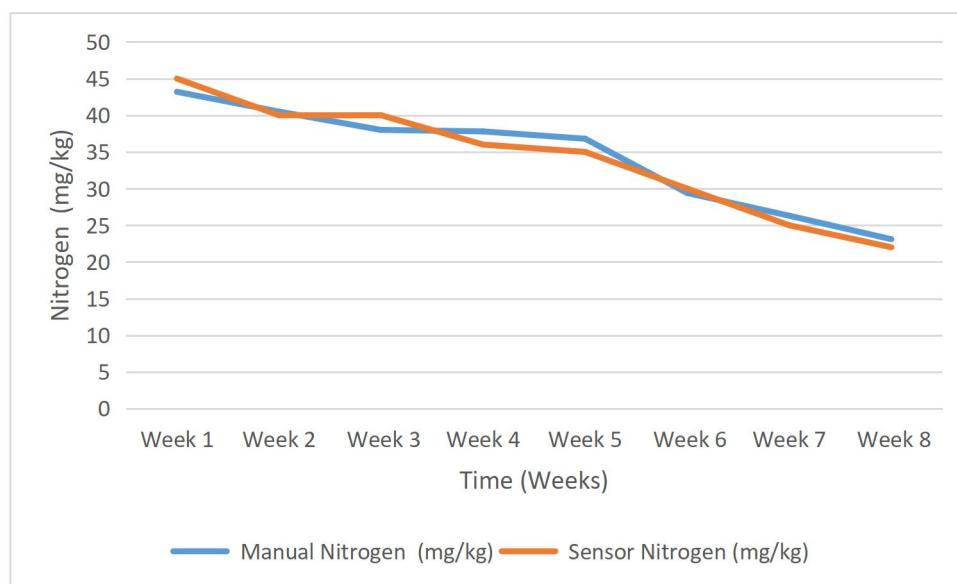


Figure 9: Manual Values Vs Sensor values of Nitrogen

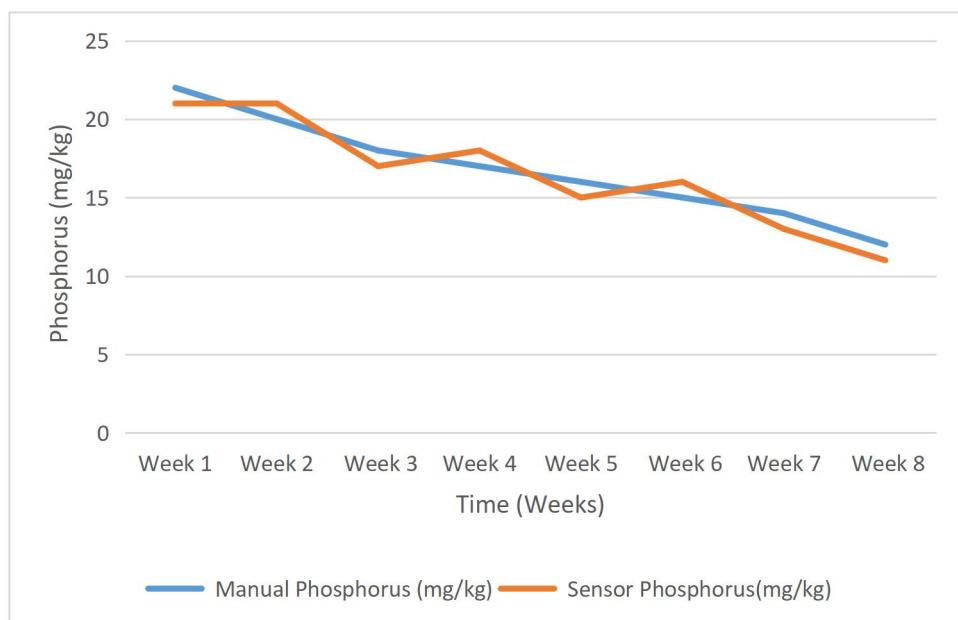


Figure 10: Manual values Vs Sensor values of Phosphorus

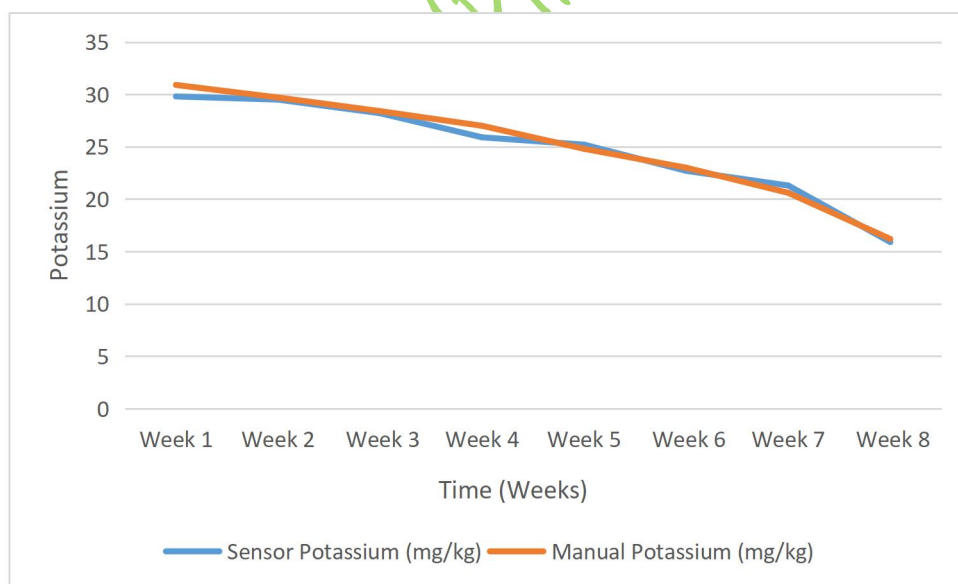


Figure 11: Manual values Vs Sensor values of Potassium



5. Conclusion

This research presents the development of an IoT-based system for precision irrigation and fertilization in a greenhouse setting. By utilizing ESP32 microcontrollers, soil moisture, temperature, and NPK sensors, the system provided real-time monitoring and automation capabilities, enabling efficient management of environmental conditions and resource usage and the integration of a web-based dashboard allowed for easy access to sensor data, while the fertilization suggestion feature provided timely recommendations based on nutrient deficiencies in the soil.

Through comparison with manual measurements, the system demonstrated high accuracy in monitoring key parameters such as soil moisture, temperature, and nutrient levels, with minimal discrepancies. This was further validated by referencing similar IoT-based systems in existing literature, which showed comparable results in terms of sensor accuracy and system performance. While there are opportunities to further improve sensor calibration and data analysis with advanced machine learning techniques, the system proves to be a valuable tool in modernizing greenhouse management.

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IMPLEMENTATION OF FUZZY LOGIC CONTROLLER IN IOT-BASED SOLAR-POWERED EGG INCUBATOR

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Abstract

This project presents the development of an IoT-based system for egg incubation, designed to regulate temperature, humidity, and egg rotation for optimal hatchability. The system utilizes a fuzzy logic controller to maintain the incubator's temperature within the ideal range of 35°C to 37°C, ensuring a stable environment for embryo development. Humidity levels are carefully controlled within the 55% to 65% range to support proper growth conditions. Additionally, an automated egg tray rotation occurs every 5 hours to promote uniform development. Performance tests demonstrate the system's effectiveness in maintaining consistent temperature and humidity, contributing to improved hatchability. The integration of fuzzy logic and IoT, along with solar power, enhances the system's energy efficiency and sustainability. Results from this study align with previous research, highlighting the advantages of fuzzy logic and IoT for enhancing incubation conditions. This system offers a promising solution for modernizing egg incubation processes and improving hatchability rates while being energy-efficient and environmentally friendly.

Keywords: Fuzzy logic, Iot, solar, egg, incubator

1. Introduction

Poultry farming is a critical part of Nigeria's agricultural sector, playing a significant role in ensuring food security and generating income for local farmers. Egg incubation which is the process that involves maintaining eggs under controlled environmental conditions such as temperature, humidity, and ventilation to facilitate embryonic development until hatching is one of the most essential aspects of poultry production. However, the use of traditional egg incubation systems in Nigeria by local farmers is often limited by cost of purchasing the incubator and inconsistent power supply for the operation of the incubator which results to reduced hatch rates and economic losses for farmers. In addition to these, the high cost of alternative energy sources and the limited availability of affordable and efficient technological solutions further threatens the use of conventional incubators by the local poultry famers in Nigeria and other developing countries. To address these issues, this research focuses on the Implementation of Fuzzy Logic Controller in IoT-Based Solar-Powered Egg Incubator in other



to ensures precise regulation of incubation parameters, enhances hatch rates, and provides a scalable solution for local poultry farmers, ultimately contributing to increased productivity and sustainability in the sector. Although some works have been done to show the implementation of IOT, Fuzzy logic and Solar power system in egg incubation and other areas of agriculture as Adeoye et al. (2021) explored the role of solar energy in poultry farming, emphasizing its potential to provide reliable, environmentally friendly, and cost-effective solutions for egg incubation. Adebayo et al. (2020) on the other hand applied fuzzy logic to design a temperature control system for poultry farms, demonstrating that fuzzy logic can effectively manage temperature variations and ensure an optimal environment for poultry growth and Zhang et al. (2019) developed an IoT-based egg incubator system that used sensors to monitor temperature and humidity, with an alarm feature that alerted farmers when environmental conditions deviated from preset thresholds.

This research seeks to integrate solar energy, fuzzy logic, and IoT technologies to develop a reliable, cost-effective, and energy-efficient egg incubation system tailored to the needs of Nigerian poultry farmers. The use of solar energy in the system ensures continuous operation in off-grid locations, while fuzzy logic controllers provide adaptive control of temperature and humidity within the incubator. Finally, the incorporation of IoT allows for remote monitoring hence empowering the farmer to make timely informed decision. By leveraging these technologies, this system aims to enhance the efficiency and sustainability of poultry farming in Nigeria, ultimately contributing to increased hatchability, reduced operational costs, and improved productivity.

2. Methodology

2.1. Materials

The hardware components of the system include the Arduino Nano, which acts as the main controller for data acquisition and actuator management, and the ESP32 microcontroller, which functions as the web server, enabling IoT capabilities and remote monitoring. The DHT11 sensor measures the temperature and humidity inside the incubation chamber, while the heating element maintains the ideal temperature for incubation. A servo motor rotates the egg tray for proper development, and a ventilation fan supports temperature and humidity regulation. The system is powered by a 50W solar panel, which charges a 12V lead acid battery through a PWM charge controller, ensuring safe charging



and discharging. A DC bulk converter steps down the voltage to 5V to power low-energy components such as the microcontrollers and sensors. On the software side, the Arduino IDE is used to write and upload programs to the microcontrollers, and Proteus is employed for circuit design and simulation prior to physical implementation.

2.2.Method

The development of the solar-powered egg incubation system integrates data acquisition, fuzzy logic control, and Internet of Things (IoT) capabilities to ensure optimal environmental conditions for egg incubation. To implement these important features, we have divided the implementation process into two which is the hardware and software design where each phase was carried out using a sequential method.

2.2.1. Hardware System Design

The hardware design phase involves the block diagram, the circuit diagram and finally the integration of the physical components that makes up the hardware subsystem

i. System Block Diagram

The block diagram shows the interconnection of the different modules that makes up the system these includes the solar power module, the sensor module, the controllers and the actuators. Figure 2.1 bellow shows the system block diagram.

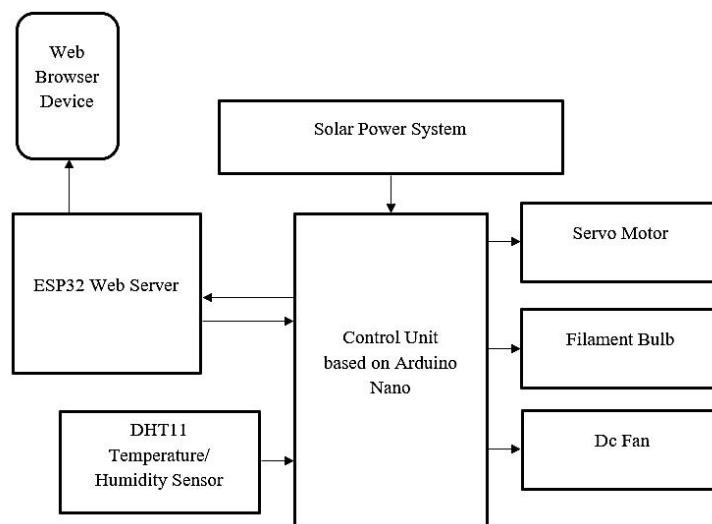


Figure 1: System Block Diagram

ii. System Circuit Diagram

The circuit diagram was designed using Proteus 8 simulation software and it shows the interconnection of the basic components that makes up the electronics hardware unit of the system. Figure 2.2 bellow shows the circuit diagram of the system.

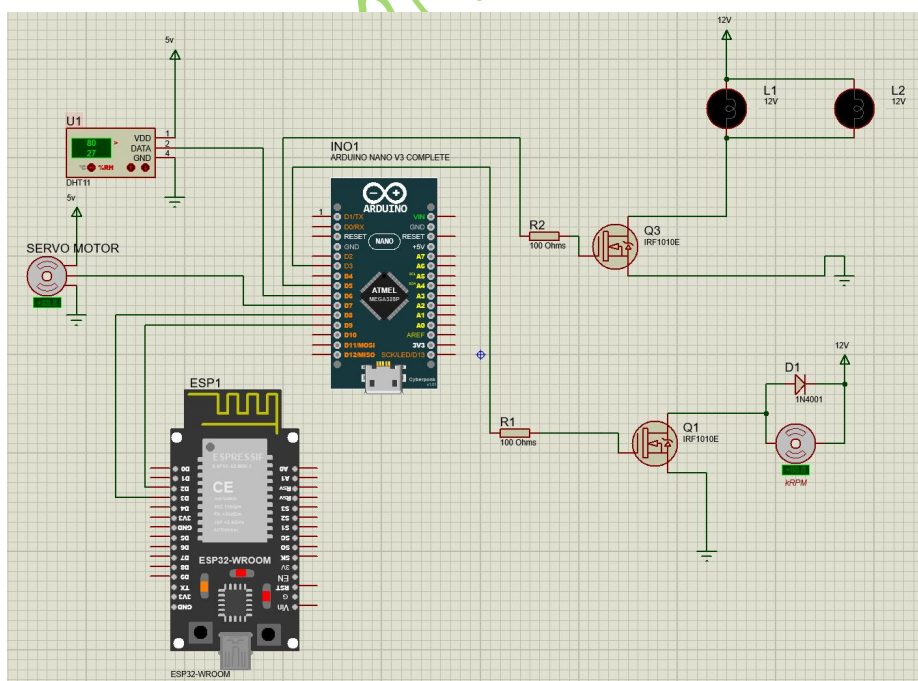


Figure 2: System Circuit Diagram



iii. Hardware System Integration

The integration of the hardware components that makes up the system began with setting up the solar power supply system which involves the connection of the solar panel to the charge controller and then to the battery which supplies power to the DC bulk converter followed by the interconnection of the DTH11 sensor, the control components, and output devices of the system on a permanent circuit board using the circuit diagram developed on the Proteus 8 simulation software as a connection guide.

2.2.2. Software System Design

The design of the software system involves the implementation of the data collection and fuzzy logic program that will run on the Arduino microcontroller using C++ and the IOT interface which involves the use of Web development tools such as HTML, CSS and JavaScript

2.2.3. Fuzzy Logic Controller

The implementation of the fuzzy logic controller involves three main stages which are the Fuzzification stage, the Fuzzy Inference processing and Difuzzification.

Fuzzification is initial phase involved in converting the temperature and humidity data from the DHT11 sensor into fuzzy sets that can be processed by the fuzzy logic system while the **Fuzzy Inference Processing** stage involves the application of predefined set of fuzzy rules to the fuzzified inputs. Using these rules, the system evaluates the fuzzy inputs to generate corresponding fuzzy outputs and finally the **Defuzzification** which is the stage at which the result from the inference process are transformed back into real value also known as crisp value. These crisp is then used to adjust the heating Bulb and the DC ventilation and humidifying Fan

2.2.4. IOT Interface

The IOT interface of the system was developed as a web interface using HTML, CSS, JavaScript and C++ and Hosted on the ESP 32 microcontroller which serves as the local webserver. HTML, CSS and JavaScript was used to develop the front end of the IOT interface while C++ was used to receive the data from the Arduino microcontroller via serial communication. Figure 5 bellow shows a screenshot of the IOT Interface.

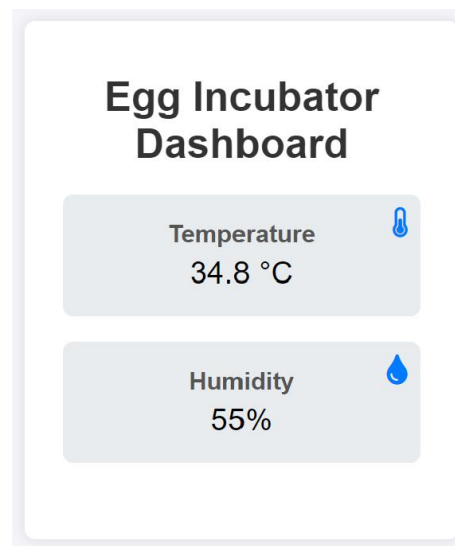


Figure 3: System IOT Interface

3. Result and Discussion

The system presented in this study focuses on maintaining optimal rotation and environmental conditions for egg incubation by regulating temperature and humidity using a fuzzy logic controller and rotating the egg tray on an average interval of 5 hours. The design aligns with standard incubation requirements to ensure high hatchability rates.

The fuzzy logic controller was designed to maintain the incubator's temperature within the optimal range of 35°C to 37°C. Figure 6 illustrates the system's temperature regulation performance over a 24-hour period. The results indicate that the system was able to effectively monitor and regulate the temperature of the incubator chamber to be within 35°C to 37°C which is the optimal temperature value for ensuring high hatchability.

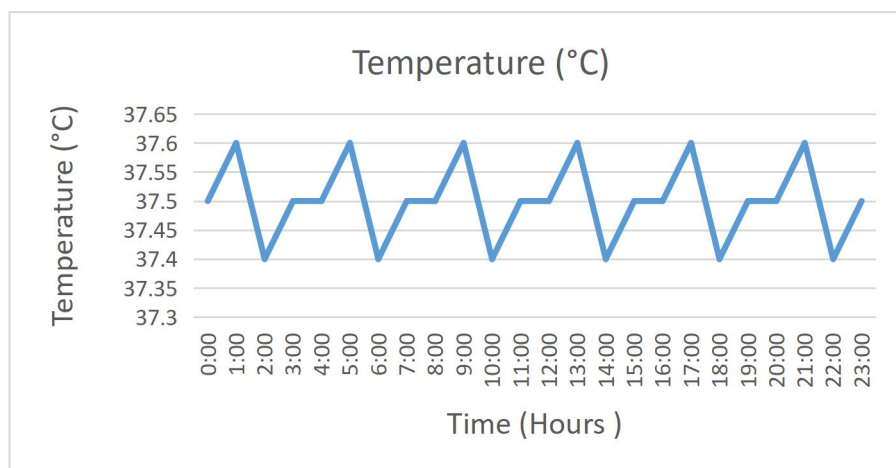


Figure 4: system temperature regulation performance over one day

Also the result of the system performance test shows that the humidity levels were properly regulated to stay within the 55% to 65% range, as shown in Figure 7. This is important as maintaining humidity within this range is crucial for proper embryo development hence proving that the designed system is ideal for ensuring improved hatchability.

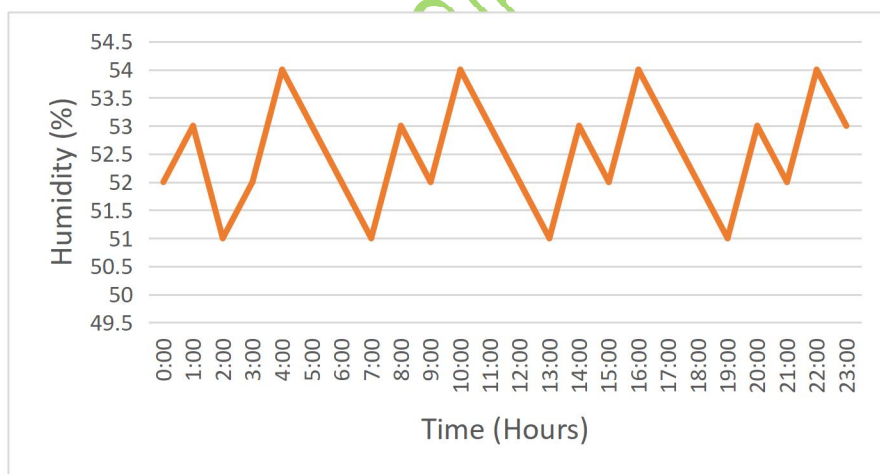


Figure 5: system Humidity regulation performance over one day

The test result from the system developed in this study indicates that the implementation of fuzzy logic and Solar power supply with IOT interface provided a stable incubation environment as it shows the system's energy efficiency and potential positive impact on hatchability rates which align with findings from existing studies, such as the work carried out by Edin Mujčić and Una Drakulić, highlighting the

advantages of employing fuzzy logic and IOT in Egg incubation for improved hatchability. Figure 9 below shows the picture of the designed system



Figure 9: The Designed System

4. Conclusion

The development of our IoT-based egg incubator system represents a significant advancement in modern poultry farming. By integrating Internet of Things (IoT) technology and Artificial Intelligence (AI), specifically utilizing a Mamdani Fuzzy Logic Algorithm, our incubator offers precise and automated control over critical hatching parameters such as temperature and humidity. This automation ensures optimal conditions are consistently maintained, leading to improved hatch rates and healthier chicks.

The experimental results have demonstrated the incubator's ability to maintain optimal temperature ranges between 37.7°C and 38.8°C, with successful hatching observed on the 19th day. These outcomes underscore the reliability and efficiency of the system in creating conducive environments for embryo development.

By addressing specific challenges in traditional incubation methods and incorporating advanced technological solutions, our project not only enhances hatchability but also offers economic benefits to poultry farmers. The integration of IoT and AI technologies in our egg incubator system exemplifies a



practical application that meets the evolving needs of modern poultry farming, contributing to increased productivity and sustainability in the industry.

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LEVERAGING ARTIFICIAL INTELLIGENCE TO IMPROVE MARKETING PERFORMANCE OF E-COMMERCE IN ABIA STATE, NIGERIA

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Abstract

The study focussed on leveraging Artificial Intelligence to improve marketing performance of E-commerce in Abia State, Nigeria. Three research questions and hypotheses guided the study. The study adopted survey research design with the population of 75 comprising 23 staff of E-commerce platforms and 52 registered online vendors in Abia State. The entire population was adopted using census technique. The instrument for data collection was structured questionnaire validated by three experts while the overall reliability coefficient of the instrument was 0.83 obtained using Cronbach Alpha statistics. The data collected were analysed using mean and standard deviation while the null hypotheses were tested at 0.05 level of significance. The findings of the study revealed that the Artificial Intelligence applications that can be used to improve marketing performance of E-commerce include: AI algorithms, AI-powered Chatbots and AI Virtual Assistants among others. Also, to high extent the use of Artificial Intelligence improve marketing performance of E-commerce. Meanwhile, the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce include: high cost of implementation and maintenance, inadequate numbers of experience AI experts, low level of technological development, outdated system infrastructure in Nigeria and poor network connectivity among others. Based on the findings, it was recommended that The Government of Nigeria should focus their attention in upgrading the technological infrastructure of the country to ease the adoption of Artificial Intelligence in marketing to improve the performance of E-commerce enhancing economic activities within the country.

Keywords: Artificial Intelligence, Marketing and E-commerce.

Introduction

Technological advancement in recent time has brought a positive influence on the day-to-day activities of human endeavours. The revolution in technology offers tremendous opportunities for different sectors of the economy to carry out commercial, communication and business activities such as marketing electronically, leveraging on technology such as Artificial Intelligence by different enterprises and companies to improve performance of E-commerce by promoting customers engagement, sales and sustainability of businesses (Nwaizugbu & Atuzie, 2023). Artificial Intelligence (AI) otherwise known as machine intelligence can be described as an intelligence demonstrated by machines in contrast to natural intelligence displayed by humans and other animals. It is an artificial operating system that is generally based on human intelligence which exhibit high cognitive functions



specific to human intelligence such as learning, comprehending, inferring, thinking and communicating (Ulaşan, 2023).

Artificial Intelligence (AI) is also viewed by Nwachukwu and Affen (2023) as systems and machines that imitate human behaviours to perform certain given tasks. It is also machine simulation of human intelligence which is programmed to think and mimic human actions. AI according to Arakpogun *et al.*, (2021), is a collection of Information and Communication Technologies that imitate human intelligence. Grover *et al.*, (2022) also described AI as the ability of a system to acquire knowledge by evaluating data obtained from its external environment, which is then utilized to adapt to existing plans or generate new ones to effectively respond to changes in the environment (Ebuka *et al.*, 2023). The primary purpose of deployment of AI especially in businesses is to improve performance by reaching more customers, making data-driven decisions, increasing speed, accuracy and for effectiveness and efficiency of business processes. Arakpogun *et al.*, (2021) maintained that the essence of AI leverage is to improve jobs, create greater efficiencies, and drive economic growth. Therefore, AI is not just employed in marketing but also to improve performance of business enterprises like E-commerce. This implies that Artificial Intelligence has become a critical asset in marketing to improve E-commerce worldwide.

Marketing is the process of creating, communicating, delivering, and exchanging offerings that have value for customers, clients, partners, and society. It aims to influence consumer awareness and preference for a brand, ultimately driving sales and building relationships. It is the activity and processes for creating, communicating, delivering, and exchanging offerings that have value for customers, clients, partners, and society at large (Nwachukwu & Affen, 2023). Marketing is crucial for businesses as it drives brand awareness, customer engagement, and ultimately, sales growth, helping businesses connect with their target audience, achieve long-term success and improve performance of enterprises and E-commerce by adequate engagement of customers to their satisfaction.

E-commerce or electronic commerce in the submission of Joshi and Dumbre (2017) is the trading of goods and services online. It is also the entire set of processes that support commercial activities on the Internet. The internet allows individuals and businesses to buy and sell an increasing amount of physical goods, digital goods, and services electronically. E-commerce has gained immense popularity as a way of doing business because it's convenient and accessible at the same time especially



with the aid of AI in marketing of the goods and services. Therefore, leveraging on AI in marketing to improve the performance of E-commerce is the way to go in the 21st century where technology has become the source of leverage for many enterprises to succeed.

Meanwhile, Ebuka *et al.*, (2023) stated that AI algorithms application is used in marketing to provide personalized product recommendations to customers, while Chatbots is used to automate customer service interactions. Also, AI algorithms are also used to analyze vast amounts of customer data (purchasing history, website activity, social media interactions, etc.) to gain a deeper understanding of consumer behaviour, preferences, and needs to improve marketing performance. Nwachukwu and Affen (2023) maintained that AI adoption in marketing lead to higher levels of customer satisfaction and loyalty, as customers feel that businesses understand their needs and preferences. However, Emmanuel *et al.*, (2024) added that there are also challenges associated with integrating AI in marketing in Nigeria. One key challenge is the inadequate infrastructure and resources, as many businesses may not have access to the necessary technology and expertise to implement AI in marketing effectively. Another challenge is the need to ensure data privacy and security, as AI marketing relies heavily on customer data and there are concerns about how this data is being collected and used. Despite the challenges that may involve in the adoption of AI in marketing to improve the performance of business enterprises in Nigeria, the impact of technology (AI) in facilitating business operation cannot be undermined. Consequently, it is on this background the study focused on leveraging Artificial Intelligence to improve marketing performance of E-commerce in Abia State, Nigeria.

Statement of the Problem

The adoption of AI to facilitate business operations in Nigeria especially in marketing to improve the performance of E-commerce cannot be undermined. It provide opportunities for products and service to be exposed to large number of consumers without boundaries irrespective of the geographical location. With the benefits of technological advancement worldwide, Nigeria has not really enjoyed much of it, especially in the area of leverage AI in marketing to improve the performance of E-commerce.

This could be attributed to the fact that knowledge of AI has not been fully localized and utilized. Adoption of AI for E-commerce are still at its early stage. Hence, many employees lack high level of



awareness couple with incompetency and high cost of AI application and tools together with low level of technology development. This has contributed to poor leverage on AI for marketing to improve the performance of E-commerce. Therefore, enhancing marketing to improve the performance of E-commerce adoption of AI cannot be totally ignored. Consequently, it is on this backdrop the study focused on leveraging Artificial Intelligence to improve marketing performance of E-commerce in Abia State, Nigeria.

Purpose of the Study

The study focussed on leveraging Artificial Intelligence to improve marketing performance of E-commerce in Abia State, Nigeria. Specifically, the study sought to:

1. find out the Artificial Intelligence applications that can be used to improve marketing performance of E-commerce,
2. examine the extent the use of Artificial Intelligence improve marketing performance of E-commerce and
3. ascertain the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce.

Research Questions

The following research questions guided the study:

1. What are the Artificial Intelligence applications that can be used to improve marketing performance of E-commerce?
2. To what extent does the use of Artificial Intelligence improve marketing performance of E-commerce?
3. What are the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce?

Hypotheses

The following null hypotheses were formulated and tested at 0.05 level of significance:

H0₁: There is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on Artificial Intelligence applications that can be used to improve marketing performance of E-commerce,



- H0₂:** There is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on the extent the use of Artificial Intelligence improve marketing performance of E-commerce.
- H0₃:** There is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce.

Methodology

The study adopted survey research design. This design is the type of research design that describes what exists or the present status of existence where a group of individuals' or items is studied by collecting data through questionnaire or interview and analysing the data to establish fact (Nkwocha & Akanwa, 2017). The design was considered suitable for this study since the researcher made use of questionnaire to collect data from the respondents. The population of the study was 75 comprising 23 staff of E-commerce platforms and 52 registered online vendors in Abia State. The entire population of the study was adopted using census technique. The instrument used for data collection was structured questionnaire validated by three experts, two from Business Education in the Department of Agricultural and Vocational Education and one from Measurement and Evaluation in Department of Science Education, all in College of Education, Michael Okpara University of Agriculture, Umudike. The overall reliability coefficient index of the instrument was 0.83 obtained using Cronbach Alpha Statistic. A total of 75 copies of questionnaire were distributed and 64 were retrieved completely filled comprising 18 staff of E-commerce platforms and 46 online vendors representing 85% return rate. The data collected were analysed using mean and standard deviation to answer the research questions while t-test statistic was used to test the null hypotheses at 0.05 level of significance. For research question 1 and 3 the mean cut-off mark of 2.50 and above was considered as agreed while the mean cut off below 2.50 was considered as disagreed. Research question 2 was analysed using real limit value of numbers as follows: 1.00 – 1.49, Very Low Extent (VHE), 1.50 – 2.49 Low Extent (LE), 2.50 – 3.49 High Extent/ (HE) and 3.50 – 4.00 Very High Extent (VHE). The standard deviation was used to ascertain the homogeneity of the respondents' response to the items in the instrument. The decision rule in testing the hypotheses; the t-calculated values were compared with t-tabulated values at 0.05% level of



significance. The hypotheses of no significant difference was accepted for items whose t-calculated value are less then t-table values and rejected on otherwise.

Results

Research Question 1: What are the Artificial Intelligence applications that can be used to improve marketing performance of E-commerce?

Table 1: Mean and Standard Deviation of the Respondents' Responses on the Artificial Intelligence applications that can be used to improve marketing performance of E-commerce

N=64						
S/ N	ITEM STATEMENT	\bar{X}_1	S. D ₁	\bar{X}_2	S.D ₂	Rmks
1	AI algorithms to analyze data to predict product demand, and personalize customer experiences	3.0 4	1.0 4	2.9 2	0.91	Agreed
2	AI-powered chatbots to personalized marketing campaigns to improve customer satisfaction and loyalty	3.1 6	0.9 3	2.9 2	0.99	Agreed
3	AI logistics optimization to optimize delivery routes efficiency	3.3 0	0.9 3	3.1 4	0.94	Agreed
4	AI cybersecurity to detect and prevent fraudulent activities, protect sensitive data, and enhance overall e-commerce security.	3.2 0	0.9 5	3.0 0	0.78	Agreed
5	AI Virtual Assistants to handle customers' inquiries and resolve issues in e-commerce platforms	3.0 1	1.1 0	2.7 1	1.13	Agreed
6	AI translators to translate text, voice, and even images between languages, offering instant and accessible translation services in marketing	2.9 9	1.0 0	3.2 1	0.69	Agreed
Cluster Mean		3.1 1	1.0 0	2.9 8	0.93	Agreed

Keys: \bar{X}_1 = mean of Staff of E-commerce platforms,, SD_1 =standard deviation of Staff of E-commerce platforms, \bar{X}_2 = mean of Online vendors, SD_2 =standard deviation of Online vendors, \bar{X}_g = Grand mean of Staff of E-commerce platforms and Online vendors, SD_g = Grand standard deviation of Online vendors, Rmks. = Remarks.



The data presented on Table 1 shows that the mean responses of the respondents on the 6 items ranges from 2.71 - 3.30 which are all above 2.50 acceptable benchmark for the study. This implies that the respondents agreed that the 6 items are the Artificial Intelligence applications that can be used to improve marketing performance of E-commerce. Also, the standard deviation values of the 6 items ranged from 0.69 to 1.13 which indicates that the responses of the respondents were close to one another and to the mean.

Hypothesis 1: There is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on Artificial Intelligence applications that can be used to improve marketing performance of E-commerce.

Table 2: t-test Analysis of the Mean Responses of Staff of E-commerce platforms and online vendors on Artificial Intelligence applications that can be used to improve marketing performance of E-commerce

Variables	\bar{X}	SD	N	Df	t-calculated	t-tabulated	Decision
Staff of E-commerce Platforms	3.11	1.00	18	62	0.48	1.99	Not Significant
Online Vendors	2.98	0.90	46				

The data in Table 2 shows that the calculated t-value is 0.48 while the t-tabulated value is 1.99 at 0.05 level of significant and at 62 degree of freedom. Since the calculated value is less than the t-tabulated value, the null hypothesis was accepted. Therefore, there is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on Artificial Intelligence applications that can be used to improve marketing performance of E-commerce.

Research Question 2: To what extent the use of Artificial Intelligence improve marketing performance of E-commerce?



Table 3: Mean and Standard Deviation of the Respondents' Responses on the Extent the Use of Artificial Intelligence improve Marketing Performance of E-commerce

N=64						
S/N	ITEM STATEMENT	\bar{X}_1	S.D ₁	\bar{X}_2	S.D ₂	Rmks
Artificial Intelligence:						
1	helps in reaching large number of customers through target adverts using AI algorithms to enhance customers patronage	3.29	0.90	3.28	0.72	High Extent
2	enhance consumers quick access to good and services through automated emailing and notification	3.26	0.90	3.14	0.77	High Extent
3	improved operational efficiency of E-commerce	3.24	0.91	2.92	0.82	High Extent
4	increased products sales through personalized AI recommendations and targeted marketing	3.26	0.90	3.00	0.87	High Extent
5	help overcome language barriers by facilitating market expansion through language translation	3.27	0.82	3.07	0.73	High Extent
6	facilitates quick delivery of goods to customers through virtual assistants	3.34	0.80	3.28	0.82	High Extent
7	Helps to detect consumers preferences in order to ensure their satisfaction for their retentions	3.28	0.93	3.26	0.82	High Extent
8	Provides opportunity to identify consumer behavior to focus attention to the needs of the consumers	3.33	0.93	3.28	0.82	High Extent
	Mean	3.28	0.88	3.15	0.79	High Extent

Keys: \bar{X}_1 = mean of Staff of E-commerce platforms,, SD_1 =standard deviation of Staff of E-commerce platforms, \bar{X}_2 = mean of Online vendors, SD_2 =standard deviation of Online vendors, \bar{X}_g = Grand mean of Staff of E-commerce platforms and Online vendors, SD_g = Grand standard deviation of Online vendors, Rmks. = Remarks.

The data presented on Table 3 shows that the mean responses of the respondents on the 8 items ranges from 2.92 - 3.34 which fall within the real limit of 2.50-3.49. This implies to the respondents accepted



that to high extent the use of Artificial Intelligence improve marketing performance of E-commerce. Also, the standard deviation values of the 8 items ranged from 0.72 to 0.93 which indicates that the responses of the respondents were close to one another and to the mean.

Hypotheses 2: There is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on the extent the use of Artificial Intelligence improve marketing performance of E-commerce.

Table 4: t-test Analysis of the Mean Responses of Staff of E-commerce platforms and Online Vendors on the Extent the Use of Artificial Intelligence improve Marketing Performance of E-commerce

Variables	\bar{X}	SD	N	Df	t-calculated	t-tabulated	Decision
Staff of E-commerce Platforms	3.28	0.88	18	62	0.54	1.99	Not Significant
Online Vendors	3.15	0.79	46				

The data in Table 4 shows that the calculated t-value is 0.54 while the t- tabulated value is 1.99 at 0.05 level of significant and at 62 degree of freedom. Since the calculated value is less than the t-tabulated value, the null hypothesis was accepted. Therefore there is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on the extent the use of Artificial Intelligence improve marketing performance of E-commerce.

Research Question 3: What are the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce?



Table 5: Mean and Standard Deviation of the Respondents' Responses on the Challenges confronting Artificial Intelligence leverage to improve Marketing Performance of E-commerce

N=64

S/N	ITEM STATEMENT	\bar{X}_1	S.D ₁	\bar{X}_2	S.D ₂	Rmks
1	High cost of implementation and maintenance	3.21	0.80	3.07	0.91	Agreed
2	Inadequate numbers of experience and AI experts	2.86	0.93	2.85	1.23	Agreed
3	Low level of technological development in Nigeria	3.34	0.83	3.21	0.80	Agreed
4	Outdated system infrastructure in Nigeria	3.21	0.95	3.00	1.10	Agreed
5	Ethical issues around data privacy and violations challenges	3.23	0.69	3.21	0.93	Agreed
6	Resistance to change by employees	3.20	0.95	3.00	0.78	Agreed
7.	Poor network connectivity in Nigeria	3.22	0.93	3.14	0.77	Agreed
	Cluster Mean	3.18	0.86	3.06	0.93	Agreed

Keys: \bar{X}_1 = mean of Staff of E-commerce platforms,, SD_1 =standard deviation of Staff of E-commerce platforms, \bar{X}_2 = mean of Online vendors, SD_2 =standard deviation of Online vendors, \bar{X}_g = Grand mean of Staff of E-commerce platforms and Online vendors, SD_g = Grand standard deviation of Online vendors, Rmks. = Remarks.

The data presented on Table 5 shows that the mean responses of the respondents on the 7 items ranges from 2.85 - 3.34 which are all above 2.50 acceptable benchmark for the study. This implies that the respondents agreed that the 7 items are the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce. Also, the standard deviation values of the 7 items ranged from 0.69 to 1.23 which indicates that the responses of the respondents were close to one another and to the mean.



Hypothesis 3: There is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce.

Table 6: t-test Analysis of the Mean Responses of Staff of E-commerce platforms and online vendors on the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce

Variables	\bar{X}	SD	N	Df	t-calculated	t-tabulated	Decision
Staff of E-commerce Platforms	3.18	0.86	18	62	0.49	1.99	Not Significant
Online Vendors	3.06	0.93	46				

The data in Table 6 shows that the calculated t-value is 0.49 while the t-tabulated value is 1.99 at 0.05 level of significant and at 62 degree of freedom. Since the calculated value is less than the t-tabulated value, the null hypothesis was accepted. Therefore there is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce.

Discussion of the Findings

The findings of the study were discussed in accordance with the research questions and hypotheses that guided the study as follows:

From the findings of the study on research question one, it was revealed that the Artificial Intelligence applications that can be used to improve marketing performance of E-commerce include: AI algorithms to analyze data to predict product demand, and personalize customer experiences, AI-powered chatbots to personalized marketing campaigns to improve customer satisfaction and loyalty, AI logistics optimization to optimize delivery routes efficiency and AI Virtual Assistants to handle customers' inquiries and resolve issues in e-commerce platforms among others. Also, the corresponding hypothesis tested revealed that there is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on Artificial Intelligence applications that can be used to



improve marketing performance of E-commerce. The findings relate with the study of Ebuka *et al.*, (2023) who found out that that AI application for improving marketing by small and medium scale enterprise include: AI algorithms, AI-powered chatbots and AI Virtual Assistants.

From the findings of the study on research question two, it was also revealed that to high extent the use of Artificial Intelligence improve marketing performance of E-commerce. More so, the related hypothesis tested revealed that there is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on the extent of the use of Artificial Intelligence to improve marketing performance of E-commerce. The findings relate with the study of Nwachukwu and Affen (2023) who revealed that AI marketing has the potential to revolutionize customer experience in Nigeria which has a population of over 200 million people and a rapidly growing digital economy; and that there is a huge market for businesses using AI for efficient marketing to improve E-commerce. The findings also relate with the study of Nwachukwu (2023) that AI in marketing has a significant positive influence on customer satisfaction, repeat purchases and customer referrals.

Lastly, the findings from research question three show that the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce include: high cost of implementation and maintenance, inadequate numbers of experience and AI experts, low level of technological development in Nigeria, outdated system infrastructure in Nigeria and poor network connectivity in Nigeria among others. Also, the corresponding hypothesis tested revealed that there is no significant difference between the mean responses of Staff of E-commerce platforms and online vendors on the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce. The findings relate with the study of Emmanuel *et al.* (2024) who revealed that the challenges and barriers organizations face is adopting AI high cost, slow internet connectivity and low level of technological advancement in Nigeria among others. The findings also align with the study of Ebuka *et al.*, (2023) that the barriers to AI Adoptions in business in Nigeria are high cost involved in AI integration, low level of technical experts and poor technological development.

Conclusion

It was concluded from the findings of the study that Artificial Intelligence applications that can be used to improve marketing performance of E-commerce include: AI algorithms to analyze data to predict product demand, and personalize customer experiences, AI-powered chatbots to personalized



marketing campaigns to improve customer satisfaction and loyalty, AI logistics optimization to optimize delivery routes efficiency and AI Virtual Assistants to handle customers' inquiries and resolve issues in e-commerce platforms among others. Also, to high extent the use of Artificial Intelligence improve marketing performance of E-commerce. Meanwhile, the challenges confronting Artificial Intelligence leverage to improve marketing performance of E-commerce include: high cost of implementation and maintenance, inadequate numbers of experience and AI experts, low level of technological development in Nigeria, outdated system infrastructure in Nigeria and poor network connectivity in Nigeria among others.

Recommendations

Based on the results of this study, it was recommended that:

1. There is need for individuals, small scale business enterprises and companies to leverage on Artificial Intelligence applications in marketing to improve the performance of E-commerce for business sustainability in Abia State.
2. The Government of Nigeria should focus their attention in upgrading the technological infrastructure of the country to ease the adoption of Artificial Intelligence in marketing to improve the performance of E-commerce, enhancing economic activities within the country.
3. There is need for communication companies to upgrade their network connectivity to enable companies leverage on Artificial Intelligence to improve marketing performance of E-commerce in Abia State, Nigeria.

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VISUALIZING AND PREDICTING NIGERIAN CAR INSURANCE CLAIMS USING MACHINE LEARNING METHODS: A COMPARATIVE APPROACH

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Abstract

Car insurance claims are essential for mitigating risks, ensuring legal compliance, and providing financial and practical support in the event of unforeseen incidents and predicting car insurance of car users is of significant importance for insurance companies. This paper employs machine learning (ML) techniques, including Survey Vector Machine (SVM), Logistic Regression and Random Forest, to predict Nigerian customer interests in vehicle insurance claims and compares the performance of the different ML models. The study results indicate that Logistics regression performs best in predicting vehicle insurance demand, followed by SVM, while Random Forest performs relatively weaker in this task. These findings provide important perceptions for insurance companies to optimize marketing strategies, adjust pricing models, and improved manage risks. However, future research should focus on integrating more advanced technologies and improving data quality to further enhance the performance of predictive models.

Keywords: Machine learning, Survey Vector Machine, Logistics Regression, Random Forest

1.0 Introduction

Novel skills, such as artificial intelligence (AI) and machine learning (ML) are becoming more efficient for companies. Several things in life are already prejudiced by AI and ML (Beam & Kohane, 2018). Machine learning is a subfield of artificial intelligence (AI) that uses algorithms trained on data sets to create self-learning models that are capable of predicting outcomes and classifying information without human intervention. An insurance premium is the amount of money an individual or business pays for an insurance policy. Insurance premiums are paid for policies that cover healthcare, auto, home, and life insurance. ML was introduced to create models that describe the connection between a set of observable inputs and another set of related output variable. It can be defined as stimulating computers to make successful predictions using past experiences. It is achieved by analyzing the available data and optimizing a performance metric specific to the problem (Baştanlar & Özuysal, 2014). To help better understand what ML means, we can split the words and see how they influence each other. First, the definition of 'learning' is the means to obtain knowledge. Humans learn from



experience because of their cognitive thinking. On the other hand, 'machines' learn from algorithms and, therefore, rely on data when they get trained. So, 'Machine Learning' can be seen as an algorithm that enables computers to think and learn (Bishop, 2006). In general, computers learn how to solve tasks that are difficult to solve and program by hand. An ML algorithm learns based on historical data, and this data gets split into training and test samples. An ML model gets trained on the training data such that it can later apply the knowledge it gained. Then, the model's accuracy is determined by testing it on the testing data before applying it for real. For ML, the process involves enabling computers to adjust their actions to improve accuracy. (Alzubi, Nayyar & Kumar, 2018). The intention is to learn from the data so analysts can recommend further actions (Mahesh, 2020).

1.1 Statement of Problem

Not having car insurance or failing to file claims when necessary can lead to several significant problems, both financially and legally. Key issues that arise from lack of insurance claims are legal consequences like fines and penalties or legal liability, financial risks like out-of-pocket expenses, loss of vehicle, increased future premiums; personal and emotional stress like stress and anxiety, and time-consuming; impact on credit score like debt accumulation, or collections and lawsuits; limited access to services like rental car issues, or towing and roadside assistance: difficulty in future claims with issues like claim denials and higher deductibles: social and professional repercussions with problems like job loss and social stigma: risk of losing assets with a major problem of asset seizure: difficulty in obtaining future insurance with problems like higher premiums and limited options: and impact on others, which normally leads to passenger liability and third-party damages. Thus, having car insurance is not just a legal requirement but also a crucial financial safety net. It protects you from significant financial loss, legal trouble, and personal stress. If you're currently uninsured, it's advisable to get coverage as soon as possible to avoid these potential problems. Meanwhile, getting insured is not just enough but filing claims when necessary. Thus, there is need to conduct a study that tends to use ML approach to visualize and predict Nigerian auto-claims.

1.2 Aim and Objectives

The major aim of this study is to compare the SVM, Logistics regression and Random forest ML approaches for predicting Nigerian car insurance claims.

Other objectives are to:



- (i) to aggregate the key risk feature importance based on key risk variables from the correlation matrix
- (ii) to visualize the policy holders based on the key risk feature variables identified by the correlation matrix

2.0 Literature Review

As the number of cars on Nigerian road grows, corporations will place a greater emphasis on precision marketing. The competitiveness of large insurance organizations has relied on extracting critical knowledge and information from users, goods and services from massive customer data, and the acquisition of more customer resources. Using such customer datasets, (Alshamsi and others, 2014) use irregular backwoods computations to help guarantors predict client decisions in order to provide more ruthless sorts of assistance and in comparison, to information handling and angle lifting tree calculation, the descriptive model calculation has evident advantages. Comparing several item expectation computations, Yanmei and Qingkai (2018) discovered that the classification models had the best presentation. This article examines over 60,000 accident coverage records and employs the classification models to identify the key characteristics that influence customer reestablished protection, allowing organizations to more effectively nurture advertising tactics.

3.0 Methodology

3.1 Data Collection

A preliminary data collection website was designed solely to collect data for this work via an online questionnaire link. The variables considered with their response options are:

ID – Unique identifier for each record.

AGE – Age category of the driver (e.g., "16-25", "65+").

GENDER – Gender of the driver (e.g., "male", "female").

RACE – Racial category of the driver (e.g., "majority").

DRIVING_EXPERIENCE – Number of years of driving experience (e.g., "0-9y", "10-19y").

EDUCATION – Education level (e.g., "high school", "university", "none").

INCOME – Income category (e.g., "poverty", "working class", "upper class").

CREDIT_SCORE – Numerical credit score of the individual (calculations related to premium).

VEHICLE_OWNERSHIP – Whether the driver owns the vehicle (1 = Yes, 0 = No).



VEHICLE_YEAR – Whether the vehicle was manufactured before or after 2015.

MARRIED – Marital status (1 = Married, 0 = Not Married).

CHILDREN – Number of children (some missing values).

POSTAL_CODE – Postal code of the driver's residence.

ANNUAL_MILEAGE – Average annual mileage driven (some missing values).

VEHICLE_TYPE – Type of vehicle (e.g., "sedan").

SPEEDING_VIOLATIONS – Number of speeding violations recorded.

DUIS – Number of Driving Under the Influence (DUI) offenses.

PAST_ACCIDENTS – Number of past accidents reported.

OUTCOME – Whether an insurance claim was made (1 = Claim, 0 = No Claim).

3.2 Machine Learning Approaches and Workflow

Our method involves a general workflow for applying machine learning to survey data using vector-based methods. This method's workflow is summarized as follows:

- **Data Collection** which includes data collection of survey responses (e.g., structured data like multiple-choice answers, or unstructured data like open-ended text).
- **Data Preprocessing which involves** cleaning the data (e.g., handle missing values, remove outliers), encoding the categorical variables (e.g., one-hot encoding, label encoding) and in the case of text responses, the use NLP techniques to convert text into vectors (e.g., TF-IDF, Word2Vec, BERT).
- **The Feature Engineering which include** combining survey responses into feature vectors and mormalization or standardization of the numerical features then follows.
- The important step of **model selection like choosing the choice** machine learning algorithm like the **Support Vector Machines (SVM)** (See Hastie, T., Tibshirani, R., & Friedman, J. (2009) and **Bishop, C. M. (2006).**
Random Forest (See Liaw, A., & Wiener, M. (2002)),
Regression trees (See Murphy, K. P. (2012)),
which prioritizes the application of classification or regression tasks.

- **Model Training**

- Split the data into training and testing sets.
- Train the model on the training data.

- Evaluation

- Evaluate the model's performance using metrics like accuracy, precision, recall, or F1-score.
- For clustering, use metrics like silhouette score or Davies-Bouldin index.

- Deployment

- Deploy the model to analyze new survey data or make predictions.

4.0 Results

4.1 Exploratory data analysis

In Figure 1, it's observable from the bar chart of the insurance claims outcome that the distribution the majority of customers did not file a claim, with a smaller proportion of customers having made a claim, indicating an imbalanced dataset.

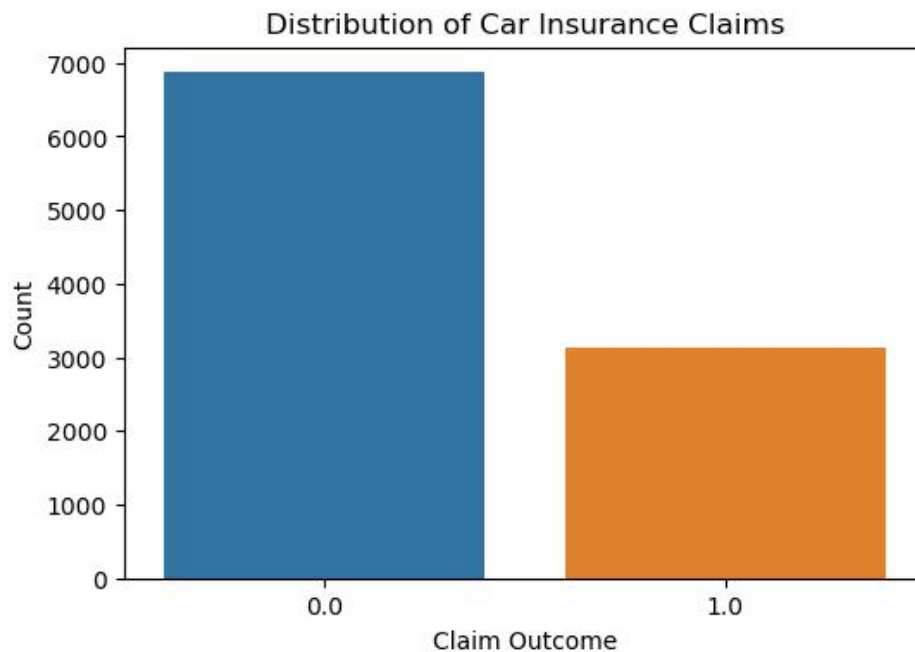


Figure 1: Distribution of car Insurance Claim

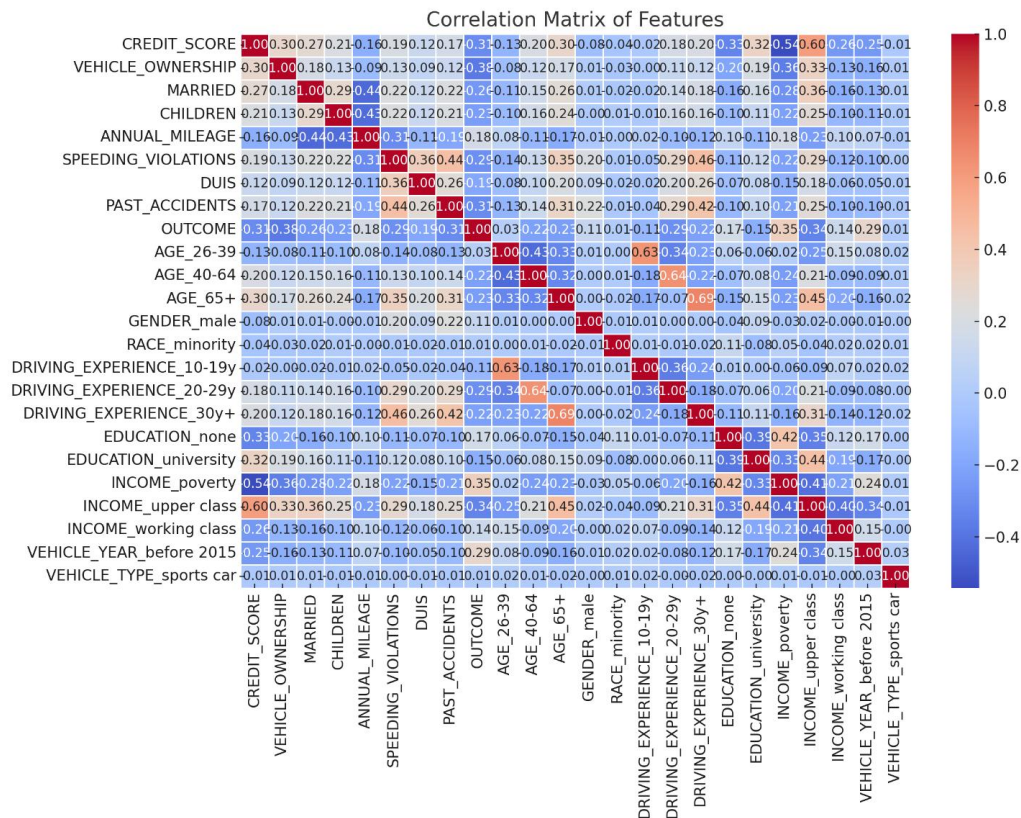


Figure 2: Correlation matrix of featured variables

The correlation matrix showcased in Figure 2 reveals that features such as past accidents, DUIS, and speeding violations have a positive correlation with the likelihood of filing a claim, while credit score and marital status show a weak negative correlation. Most categorical features exhibit low correlations, suggesting that multiple factors contribute to predicting insurance claims rather than a single dominant variable. It is important to note that features like vehicle ownership, marital status, credit score rating, and annual millage seems to have high correlation on the correlation matrix bar and need to be investigated further,

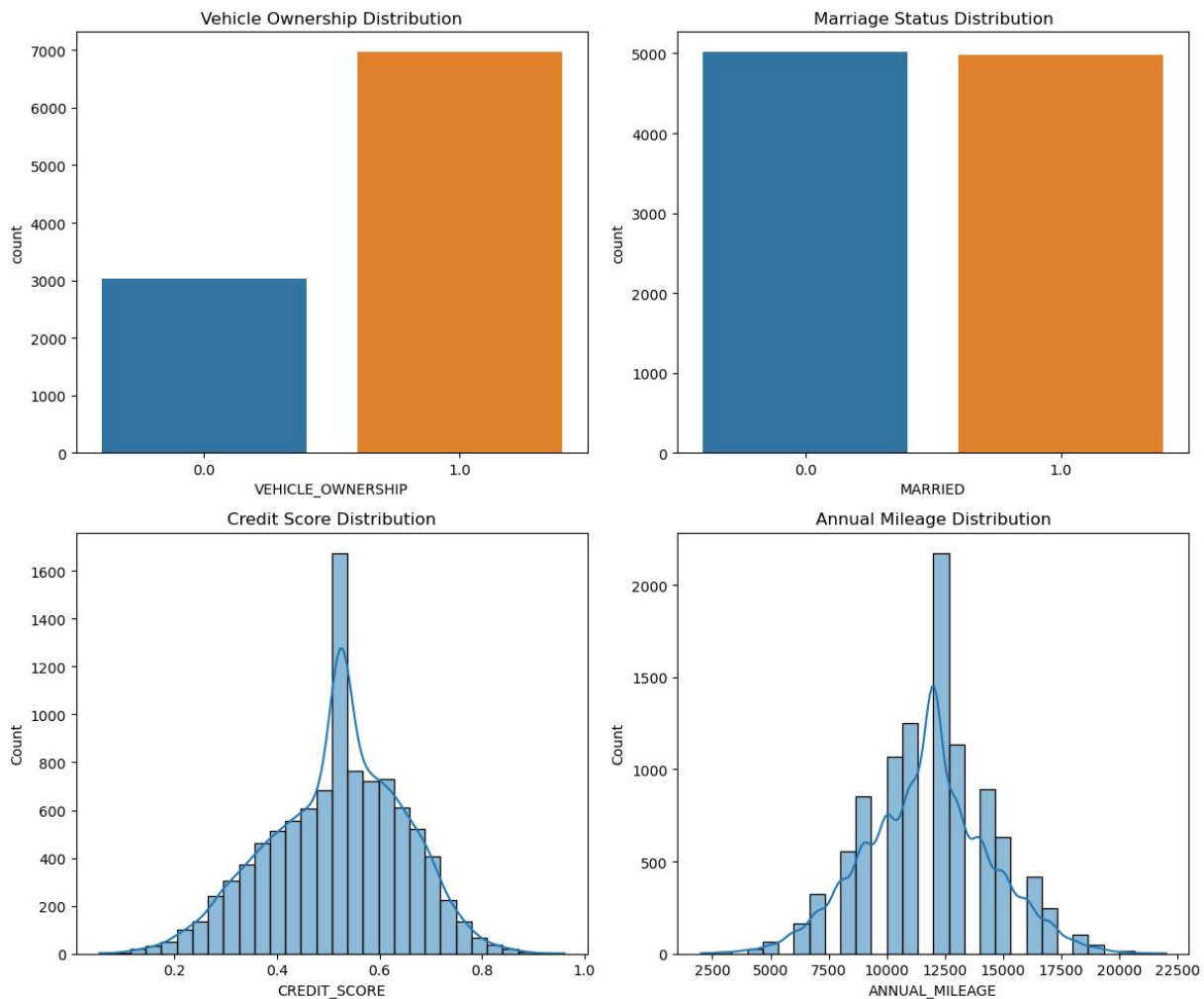


Figure 3: Distribution of some high correlated features (namely vehicle ownership, marital status, credit score rating, and annual millage)

Vehicle Ownership Distribution: The majority of the customers own a vehicle, while a smaller portion does not, indicating that vehicle ownership is common among policyholders. This could be a key factor in analyzing claim risks, as vehicle owners may have different risk profiles than non-owners.

Marriage Status Distribution: The dataset has an almost equal distribution of married and unmarried customers. This balance suggests that marital status may not be a highly differentiating factor for car insurance claims.

Credit Score Distribution: The credit scores are normally distributed, with most customers having scores around 0.5-0.6. This suggests that the dataset has a mix of individuals with varying financial backgrounds, which may influence claim probability.

Annual Mileage Distribution: The annual mileage data follows a near-normal distribution, peaking around 12,000 miles. This suggests that most drivers fall within a typical driving range, with fewer customers at the extreme ends of low or high mileage, which could impact claim risk assessment.

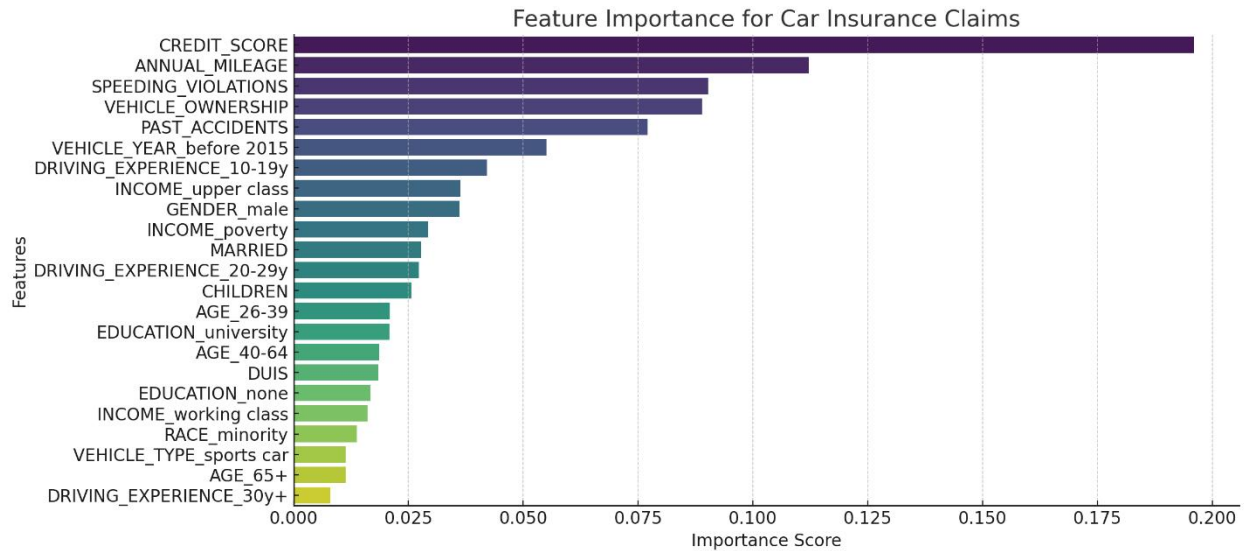


Figure 4: Key risk factors for insurance claims based on feature importance

The importance of the investigated variables or key risk factors are presented in Figure 4. Car insurance claim features that matters most to insurance companies seems to have higher bars or metrics when compared with car insurance claim features that seems to matter less.

4.2 Model Evaluation

Table 1: Model Training and Evaluation

S/N	Model	Accuracy	Precision	Recall	F1 Score
1	SVM	0.8355	0.754181	0.712480	0.732738
2	Logistic Regression	0.8450	0.785841	0.701422	0.741235
3	Random Forest	0.8160	0.744917	0.636651	0.686542

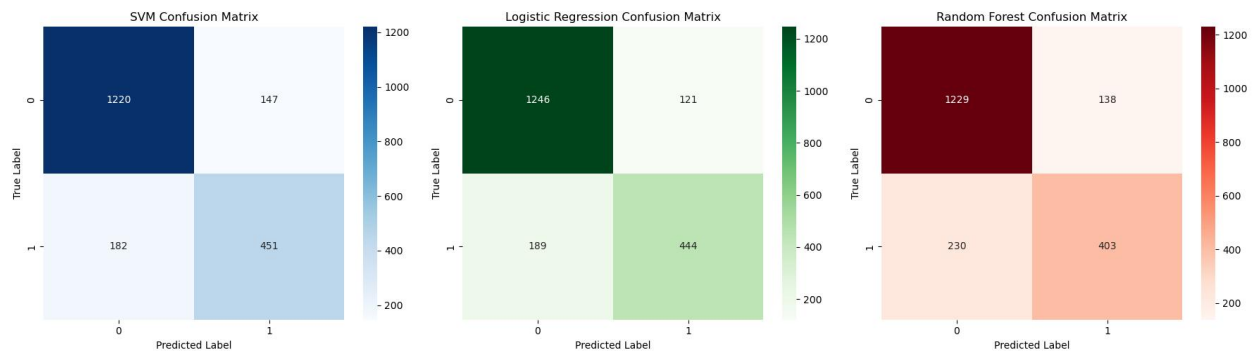


Figure 5: Confusion matrix for SVM, Logistics Regression, and Random Forest

The training data model evaluation for the three ML models employed (SVM, Logistic Regression and Random Forest) are displayed in Table 1. Based on the model Accuracy, Precision, and F1 Score, it's clear that the Logistics regression slightly outperformed the SVM and the Random Forest as they has higher values for the considered metrics. This result is validated in Figure 5 as the confusion matrix of the Logistics regression is coloured green.

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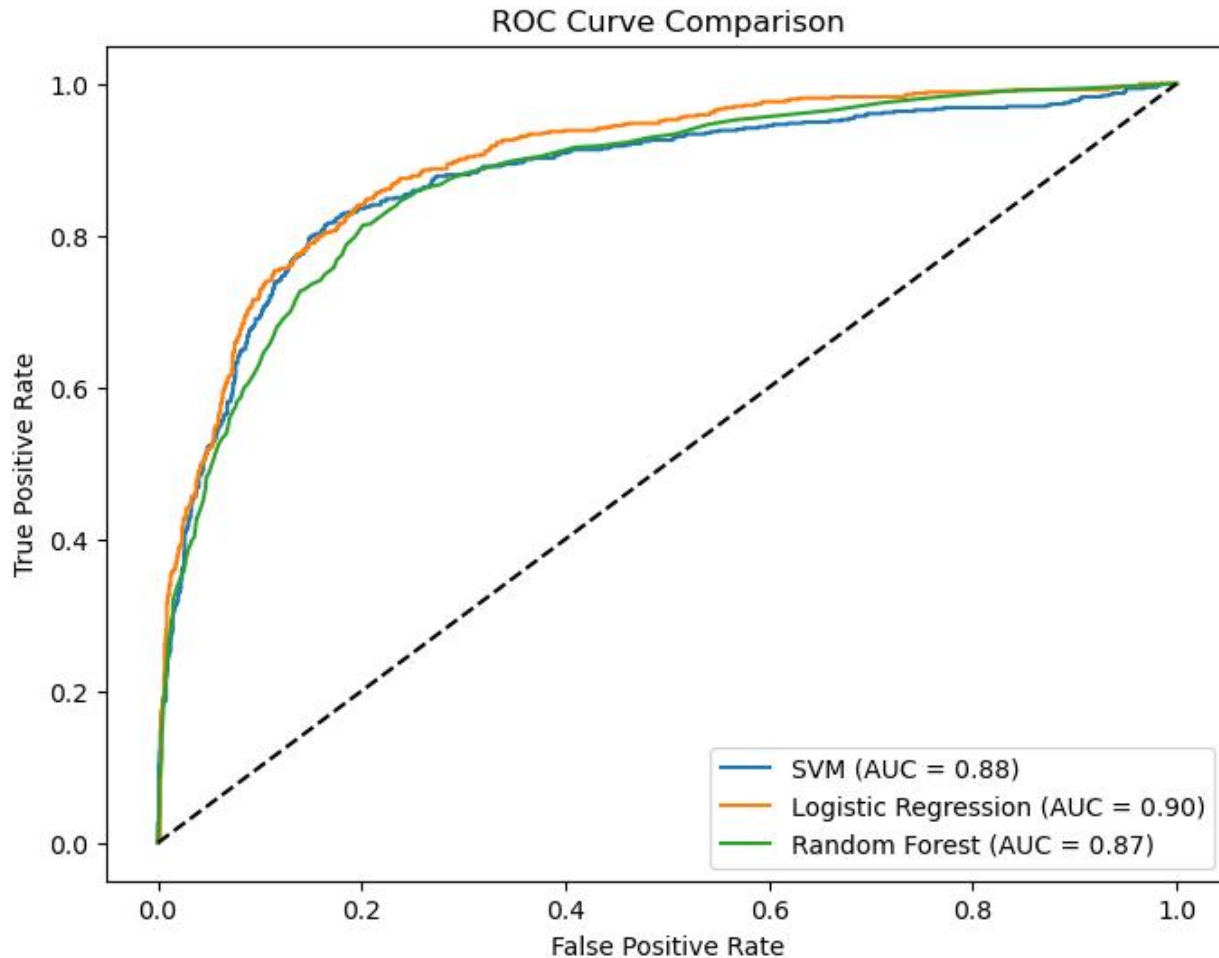


Figure 6: The ROC curve comparison

The ROC curve showcased in Figure 6 compares the performance of three classification models—SVM, Logistic Regression, and Random Forest—by plotting the True Positive Rate (TPR) against the False Positive Rate (FPR). The AUC (Area Under the Curve) values indicate the model's ability to distinguish between claim and non-claim cases, with Logistic Regression performing the best (AUC = 0.90), followed by SVM (AUC = 0.88) and Random Forest (AUC = 0.87). The closer the curve is to the top-left corner, the better the model, and since all three models have relatively high AUC values, they exhibit strong predictive capabilities for car insurance claims.

5.0 Conclusion

In this research, we used the SVM, Logistics Regression and Random Forest Classifiers to estimate the likelihood of health insurance buyers obtaining auto insurance from insurance firms. While working on



the thesis, we ran into issues and challenges assessing one set of data using two algorithms. It had the most trouble deciding and picking an algorithm that could be operated in conjunction while enhancing accuracy. It was tough to pick a specific algorithm and assess the model, as well as to figure out the alternatives for selecting and configuring various columns and running the experiment. Furthermore, throughout the process of model analysis operating one or more algorithms, a pretty complex problem arose, causing difficulty in predicting the model. It is believed that a better model may be generated if the prediction is made using data that is more effective and has more columns than the existing one in order to produce a more accurate and fast car insurance purchase prediction algorithm model. Furthermore, the SVM, Logistics Regression and Random Forest Classifiers method has the benefit of producing a quick and simple prediction model. As a result, a predictive model with improved accuracy outcomes might be developed

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BOUNDEDNESS OF PERIODIC SOLUTIONS OF DUFFING'S EQUATION VIA SCHAEFERS LEMMA

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Abstract

This paper investigated the boundedness of periodic solutions for Duffing's equation using Schaefer's lemma. Employing integral inequalities and Schwartz inequality, we derived the explicit bounds on both the derivative of the solution. The boundedness results were used in conjunction with Schaefer's lemma to establish different a priori-bounds within the derived bounds. The advantage of this method is the ability to locate a unique solution point within specified boundaries. This approach ensures the identification of an optimal solution that coincide with the solution of the Duffing's equation.

Keywords: Schaefer's Lemma, Duffing's equation, Boundedness. AMS Subject Classification: 58F09, 58F14, 58F22

Introduction

The existence of solutions to ordinary differential equation is very much connected with fixed point theorem. A good number of cases arise in literature where the Leray Schauder fixed point has been used to generalize the cases of non-linear differential equation. For instances see (Ezeilo, 1974; Ezeilo, 1975; Rössig, 1972; Rössig, 1975; Rössig, *et al.*, 1974; Villari, 1965). Stopelli, (1952) was the first to use Leray Schauder fixed point technique for the second order differential equation. The application of Leray Schauder fixed point for third order differential equation and above was due to (Ezeilo, 1960) which was concerned with the consequence rather than the topological nature of the result of (Schaefer, 1955). On the use of Leray Schauder fixed point and integrated equation as a mode to establish a priori bounds for non-linear differential equation see (Ogbu, 2008; Ezeilo, 1960).

One of the reasons for the search of such bounds of solutions to any differential equation is to achieve global optimum of the solution in a closed and bounded domain. Many results using different techniques on bounds of solutions of Duffing's equation have been obtained by many authors. For instance see (Wang, 2006; Yuan, 2017; Fitouri and Haraux, 2013; Jiang *et al.*, 2013; Voitovich, 2016; Cheng, 2008; Eze *et al.*, 2024; Daxiong and Wenling, 2008). Morris, (1976) proved that each solution of special Duffing's equation of the form:

$$\ddot{x} + 2x^3 = p(t) \quad (1.1)$$



is bounded for $t \in \mathbb{R}$. In this paper, we will introduce damping and stiffness terms into (1.1) using different approaches to investigate the bounds of solutions. The Duffing's equation is a Hamiltonian equation of motion that is characterized with multiple periodic solutions. It is suggested in (Tamas and Balakuma, 2013) that the presence of the cubic non-linear term is responsible for the presence of several periodic solutions. Therefore investigating the bounds of the solution of equation (1.2) is still an issue.

Motivated by the above literature, the purpose of this paper is to investigate bounds of solutions of Duffing's equation of the form:

$$\ddot{x} + c\dot{x} + \varphi x + bx^2 + 2x^3 = p(t) \quad (1.2)$$

where φ, b, c are real constants and $p : [0, 2\pi] \rightarrow \mathbb{R}^n$ is continuous with

$$x(0) = x(2\pi)$$

$$\dot{x}(0) = \dot{x}(2\pi)$$

using Leray Schauder fixed point theorem and Schaefer's Lemma.

In equation (1.2) φ is the stiffness constant, c is the coefficient of viscous damping and $bx^2 + 2x^3$ represent the non-linearity in the restoring force acting like a hard spring.

Equation (1.2) has received wide interest in neurology, ecology, secure communications, cryptography, chaotic synchronization and so on. Due to the rich behavior of this equation, there have been several studies on the synchronization of two double Duffing equation (Feng et al, 2005). Equation (1.2) is a model arising in many branch of Physics and Engineering such as oscillation of rigid pendulum using moderately large amplitude motion (Jordan and Smith, 1977) and vibration of buckled beam (Thompson and Stewart, 1986; Pezeshki and Dowell, 1987). This oscillation involves an electromagnetized vibrating beam analyzed as exhibiting cusp catastrophic behavior for certain parameter values (Zeeman, 1976; Guastello, 1955). This equation together with Van der Pol's equation, has become one of the most common examples of nonlinear oscillation in textbooks and research articles (Puu, 2000; Ueda, 1979; Zhang, 2005).

Preliminaries

Definition 2.1. A functional series of the form

$$\frac{a_0}{2} + a_1 \cos x + b_1 \sin x + a_2 \cos 2x + b_2 \sin 2x + \dots \quad (2.1)$$

or more compactly, a series of the form

$$\frac{a_0}{2} + \sum_{n=1}^{\infty} (a_n \cos nx + b_n \sin nx) \quad (2.2)$$

is called a Fourier series. The constant a_0 , a_n and b_n ($n = 1, 2, \dots$) are called coefficient of the Fourier series. If series (2.2) converges, then its sum is a periodic function $f(x)$ with period 2π , since $\sin nx$ and $\cos nx$ are periodic functions with period 2π . Thus $f(x) = f(x + 2\pi)$

Definition 2.2. Let $x_i, y_i \in \Omega$, $i = 1, 2, \dots, n$, then Cauchy Schwartz's inequality for finite sum is given as

$$\sum_{i=1}^n |x_i y_i| \leq (\sum |x_i|^2)^{1/2} (\sum |y_i|^2)^{1/2} \quad (2.3)$$

Theorem 2.3. Suppose there exist $a > 0$, $b > 0$ and $\beta > 0$ such that

- (i) $h'(x) < b, \beta^2 = b$
- (ii) $|h(x) - x| > 0$ for all x
- (iii) $|h(x)| \rightarrow \infty$ as $|x| \rightarrow \infty$
- (iv) $x^2 + y^2 \rightarrow \infty$ as $|x| \rightarrow \infty, |y| \rightarrow \infty$ then (1.1) through (1.2) has stable bounded and periodic solution when $p(t) = 0$

Theorem 2.4. Suppose further in theorem (2.3) that condition (i) is replaced by

1. $h'(x) < b, \beta^2 \neq b$ and $|ax - p(t)| > 0$ then (1.1) and (1.2) have stable bounded and periodic solution when $p(t) \neq 0$.

Theorem 2.5. (Lerary Schauder fixed point theorem) Let C be a closed convex subset of the Banach space X . Suppose $f: C \rightarrow C$ and f is compact i.e. (bounded set in C are mapped into relatively compact sets). Then f has a fixed point in C .

Proof. $f(C)$ is relatively compact, so $k = \overline{f(C)}$ is compact. For each $\varepsilon > 0$, there exist a finite ε -net for k . Let $F = \{x_1, \dots, x_n\}$ be this finite ε -net (note that n is dependent on ε). We show that the equation $f(z) = z$ is approximately solvable in C . That is, we show there exists $x_0 \in C$ with $|x_0 - f(x_0)| < \varepsilon$. Consider the mapping $g := P \circ f \circ g$ maps C into $\text{con}F$ and so if we restrict g to $\text{con}F$, then since C is convex, $\text{con}F \subset C$, we have that $g: \text{con}F \rightarrow \text{con}F$. By Brouwer's theorem and its corollaries ($\text{con}F$ is compact, convex and finite dimensional), there exists a $x_0 \in \text{con}F$ with $g(x_0) = x_0$. But then

$$|x_0 - f(x_0)| = |g(x_0) - f(x_0)| = |p(f(x_0)) - f(x_0)| < \varepsilon \quad (2.4)$$

where the last step is because of proposition 2.6



Thus $f(z) = z$ is approximately solvable in C and we know that there exist a fixed point $\hat{x} \in C$ with $\hat{x} = f(\hat{x})$.

Proposition 2.6. Let K be a compact subset of the Banach space X . Then given $\varepsilon > 0$, there exists a finite subset $F \subset X$ and a mapping $P : K \rightarrow \text{con}F$ such that for any $x \in K$ we have $\|x - P(x)\| < \varepsilon$.

Proof. See (Bockelma, 2006)

Lemma 2.7. (The Banach fixed point theorem) Let E be a Banach space and $f : E \rightarrow E$ is a contraction mapping, then f has a unique fixed point in E , i.e. there exist a unique $x \in E$ such that $f(x) = x$.

Theorem 2.8. Let X be a Banach space and $f : X \rightarrow X$ be completely continuous then either there exists for each $\lambda \in [0, 1]$ one small $x \in X$ such that $x = \lambda f(x)$ or the set $\{x \in X : x = \lambda f(x), 0 < \lambda < 1\}$ is bounded in X .

Proof. See (Scheafer, 1955)

Results

We consider the more general form of Duffing's equation (1.2) as a parameter λ dependent equation of the form

$$\ddot{x} + c\dot{x} + h_\lambda(x) = \lambda p(t) \quad (3.1)$$

where $h_\lambda(x) = (1 - \lambda)\phi x + \lambda h(x)$ and $\lambda h(x) = bx^2 + 2x^3$

λ associated with the generic forcing term p measures the strength of the force. λ when associated with the non-linearity is the perturbed term. λ has the range of $0 \leq \lambda \leq 1$ and b is a constant satisfying $c > 0, b > 0$. When λ associated with the generic forcing term is sufficiently large, equation (3.1) has a T periodic solutions (Katriel, 1998). Using some classical critical assumption, the existence of solution of all λ is a well-known application of degree theorem or Schauder fixed point theorem (Habets and Metzson, 1989)

The equivalent systems of (3.1) is given by

$$\begin{aligned} \dot{x} &= y \\ \dot{y} &= -cy - h_\lambda(x) + \lambda p(t) \end{aligned} \quad (3.2)$$

Let $X(t)$ be a possible 2π periodic solution of (3.1)

The main tool here is the verification of the function $W(x, y)$ defined by



$$W(x, y) = \frac{1}{2}y^2 + H_\lambda(x) \text{ where } H_\lambda(x) = \int_0^x h_\lambda(s)ds \quad (3.3)$$

The time derivative \dot{W} of (3.3) along the solution paths of (3.2) is

$$\begin{aligned} \dot{W} &= y\dot{y} + h_\lambda(x)\dot{x} \\ &= -cy^2 - h_\lambda(x)y + \lambda p(t)y + h_\lambda(x)y \\ &= -cy^2 + \lambda p(t)y \end{aligned} \quad (3.4)$$

Integrating (3.4) with respect to t from $t = 0$ to $t = 2\pi$ we have

$$\begin{aligned} \int_0^{2\pi} \dot{W} dt &= \int_0^{2\pi} -cy^2 dt + \int_0^{2\pi} \lambda p(t)\dot{x} dt \\ [W(t)]_0^{2\pi} &= -\int_0^{2\pi} cy^2 dt + \lambda \int_0^{2\pi} p(t)\dot{x} dt \end{aligned} \quad (3.5)$$

Since $W(0) = W(2\pi)$, it implies that $[W(t)]_0^{2\pi} = 0$ which is 2π periodic solution.

Equation (3.4) and (3.5) shows that the behaviour of Duffing's equation is stable, asymptotically stable, bounded and periodic. Thus

$$\begin{aligned} 0 &= -\int_0^{2\pi} cy^2 dt + \lambda \int_0^{2\pi} p(t)\dot{x} dt \\ \int_0^{2\pi} cy^2 dt &\leq |\lambda| |p(t)| \int_0^{2\pi} \dot{x} dt \end{aligned} \quad (3.6)$$

Since $|\lambda| \leq 1$ and $p(t)$ is continuous, then

$$\int_0^{2\pi} \dot{x}^2 dt \leq C_1 (2\pi)^{1/2} \left(\int_0^{2\pi} \dot{x}^2 dt \right)^{1/2} \quad (3.7)$$

By the hypothesis of Schwartz's inequality we have

$$\begin{aligned} \left(\int_0^{2\pi} \dot{x}^2 dt \right)^{1/2} &\leq C_1 (2\pi)^{1/2} \equiv C_2 \\ \left(\int_0^{2\pi} \dot{x}^2 dt \right)^{1/2} &\leq C_2 \end{aligned} \quad (3.8)$$

Since $x(0) = x(2\pi)$, it is clear that there exists $\dot{x}(T) = 0$ for $T \in [0, 2\pi]$

Thus using the identity $\dot{x}(t) = \dot{x}(T) + \int_0^{2\pi} \ddot{x}(s)ds = \int_0^{2\pi} \ddot{x}(s)ds$

By Schwartz's inequality we have

$$\text{Max}_{0 \leq t \leq 2\pi} |\dot{x}(t)| \leq \int_0^{2\pi} |\ddot{x}(t)| dt \leq (2\pi)^{1/2} \left(\int_0^{2\pi} \ddot{x}^2(s)ds \right)^{1/2} \quad (3.9)$$

We hereby invoke the Fourier expansion of $X \sim \sum_{r=0}^{\infty} (ar \cos 2\pi l + br \sin 2\pi l)$. For the derivative of Fourier expansion (Ezeilo and Onyia, 1984).

From equation (3.6) we obtain $\int_0^{2\pi} \dot{x}^2 dt \leq |\lambda| |p(t)| \int_0^{2\pi} \dot{x} dt$ which is

$$\int_0^{2\pi} \ddot{x}^2 dt \leq C_1 (2\pi)^{1/2} \left(\int_0^{2\pi} \ddot{x}^2 dt \right)^{1/2} \quad (3.10)$$

Therefore we have $\left(\int_0^{2\pi} \dot{x}^2 dt \right)^{1/2} \leq C_1 (2\pi)^{1/2} \equiv C_2$

$$\begin{aligned} \max_{0 \leq t \leq 2\pi} |\dot{x}(t)| &\leq (2\pi)^{1/2} \cdot C_1 (2\pi)^{1/2} \equiv C_3 \\ |\dot{x}|_{\infty} &\leq C_3 \end{aligned} \quad (3.11)$$

Now integrating (3.1) with respect to t from $t = 0$ to $t = 2\pi$, we obtain

$$\int_0^{2\pi} \ddot{x} dt + \int_0^{2\pi} c \dot{x} dt + \int_0^{2\pi} h_{\lambda}(x) dt = \int_0^{2\pi} \lambda p(t) dt \quad (3.12)$$

Substituting for $h_{\lambda}(x) = (1 - \lambda)\phi x + \lambda h(x)$ in (3.12) we have

$$\begin{aligned} \int_0^{2\pi} \ddot{x} dt + \int_0^{2\pi} c \dot{x} dt + \int_0^{2\pi} (1 - \lambda)\phi x dt + \int_0^{2\pi} \lambda h(x) dt &= \int_0^{2\pi} \lambda p(t) dt \\ \int_0^{2\pi} (1 - \lambda)\phi x dt + \int_0^{2\pi} \lambda h(x) dt &= \int_0^{2\pi} \lambda p(t) dt \end{aligned} \quad (3.13)$$

The continuity of $p(t)$ assures us of boundedness and the fact that $0 \leq \lambda \leq 1$, the right hand side of equation (3.13) is bounded. ie

$$\left| \int_0^{2\pi} \lambda p(t) dt \right| \leq C_4 \quad (3.14)$$

$$\left| \int_0^{2\pi} (1 - \lambda)\phi x dt + \int_0^{2\pi} \lambda h(x) dt \right| \leq C_4$$

Therefore given $\alpha > 0$ there exist $\mu > 0$ such that for $T \in [0, 2\pi]$

$$|x(T)| \leq C_5 \quad (3.15)$$

Substituting for $T = 0$ in equation (3.15) shows that Duffing's equation is bounded

Suppose $x(T) \neq 0$ for any T then equation (3.14) yields

$$\begin{aligned} \int_0^{2\pi} (1 - \lambda)\phi |x| dt + \int_0^{2\pi} |\lambda| |h(x)| dt &> \int_0^{2\pi} (1 - \lambda)\phi \mu dt + \int_0^{2\pi} \lambda \alpha(x) dt \\ &> 2\pi(1 - \lambda)\phi \mu + 2\pi\lambda \alpha \end{aligned} \quad (3.16)$$

But equation (3.16) implies that $\int_0^{2\pi} (1 - \lambda)\phi x dt + \int_0^{2\pi} \lambda h(x) dt$ is no more bounded which is a negation of (3.14). Thus $|h(x)| \rightarrow \infty$ as $|x| \rightarrow \infty$, equation (3.15) and the identity

$X(t) = X(T) + \int_T^t \dot{x} dt$ holds. Thus

$$\max_{0 \leq t \leq 2\pi} |\dot{x}(t)| \leq |x(T)| + \int_0^{2\pi} |\dot{x}(t)| dt \leq C_5 + (2\pi)^{1/2} \left(\int_0^{2\pi} \ddot{x}^2 dt \right)^{1/2} \leq C_5 + (2\pi)^{1/2} \cdot C_2$$

(by Schwartz's inequality and equation (3.7))

$$|x|_\infty \leq C_5 + (2\pi)^{1/2} \cdot C_2 \equiv C_6 \text{ and we finally obtain}$$

$$|x|_\infty \leq C_6 \quad (3.17)$$

Example 1

Consider the Duffing equation

$$\ddot{x} + 2\dot{x} + x + 5x^3 = \lambda \cos t \quad (3.18)$$

The equivalent system is given by

$$\dot{x} = y$$

$$\dot{y} = -2y - x - 5x^3 + \lambda \cos t$$

The time derivative is given as $\dot{W} = -2y^2 + \lambda y \cos t$. Applying the 2π periodic solution we have

$$0 = - \int_0^{2\pi} 2\dot{x}^2 dt + \lambda \int_0^{2\pi} \cos t \dot{x} dt$$

$$\int_0^{2\pi} 2\dot{x}^2 dt \leq |\lambda| |\cos t| \int_0^{2\pi} \dot{x} dt$$

$$\int_0^{2\pi} \dot{x}^2 dt \leq \frac{|\lambda|}{2} |\cos t| \int_0^{2\pi} \dot{x} dt$$

Since $\frac{|\lambda|}{2} \leq 1$ and $\cos t$ is continuous then we that the same results as equation (3.8). Integrating equation (3.18) gives

$$\int_0^{2\pi} \ddot{x} dt + \int_0^{2\pi} 2\dot{x} dt + \int_0^{2\pi} x dt + \int_0^{2\pi} 5x^3 dt = \lambda \int_0^{2\pi} \cos t dt$$

The continuity of $\cos t$ indicate that the solution is bounded and interval $0 \leq \lambda \leq 1$. Then we have

$$\left| \int_0^{2\pi} \lambda \cos t dt \right| \leq C_4$$

Hence it follows from equations (3.15) and (3.17) that periodic solutions of Duffing equation is bounded.

Conclusions

This study successfully establishes the boundedness of periodic solution for Duffing's equation using integral inequalities and the Schwartz inequality. The derived bounds in conjunction with Schaefer's



lemma provide a powerful framework for proving the boundedness of periodic solutions. The key advantage of this approach lies in the ability to determine a specific optimal solution within well-defined limits, offering a precise and efficient method for solving Duffing's equation. Further research could explore the application of this methodology to other nonlinear differential equations and refine the bounds to improve solution accuracy.

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2MRIFC



PROMOTING FAIRNESS IN JOB INTERVIEWS: A SENTIMENT ANALYSIS APPROACH TO BIAS DETECTION

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Abstract

Job interviews have played a crucial role in the hiring process, yet unconscious biases have affected hiring decisions, leading to unfair outcomes. This study evaluated the performance of DistilBERT in sentiment classification and bias detection within the 2025 Arise Youth Employment Program dataset. By leveraging computational intelligence techniques, we analyzed biases in interviewer responses and candidate evaluations. Our results showed that DistilBERT achieved 94% accuracy, outperforming more complex architectures like BERT and RoBERTa, each of which had 28% and 34% accuracy respectively. Furthermore, statistical tests, including chi-square ($p = 1.0$) and Cramér's V (0.0), empirically confirmed no significant bias across gender, age, or ethnicity. Additionally, the reliability of the DistilBERT model (Cohen's Kappa = 0.9108) was assessed against BERT and RoBERTa, indicating substantial disagreement with these models and highlighting DistilBERT's superior performance. The findings highlighted the potential of sentiment analysis, NLP models (DistilBERT), and demographic bias analysis to detect bias and promote fairness in recruitment processes. This research underscored the importance of data-driven solutions in promoting objective hiring practices and contributing to equitable and transparent decision-making in employment.

Keywords: Recruitment, Interviews, Bias detection, Sentiment Analysis, Artificial Intelligence

1. Introduction

Bias significantly impacts recruitment outcomes, often disadvantaging certain demographic groups (Ferrara, 2024). In job interviews, bias can manifest in various forms, including demographic bias such as race and gender, linguistic bias such as phrasing and word choice influencing evaluations, and psychological bias which include unconscious stereotypes shaping perceptions of a candidate's abilities. Traditional hiring processes, which rely heavily on human judgment, are prone to subjective evaluations that reinforce inequalities. Implicit biases further exacerbate this issue, as interviewers may unconsciously favor candidates with similar backgrounds or those who align with pre-existing stereotypes (Mehrabi *et al.*, 2021). As a result, recruitment decisions often lack objectivity, limiting opportunities for underrepresented candidates.

In culturally diverse settings like Nigeria, recruitment bias is particularly evident due to socio-cultural influences. Non-meritocratic practices, such as nepotism and favoritism, influence hiring decisions and



perpetuate inequalities (Don-Baridam *et al.*, 2022). Race, ethnicity, and religion significantly impact recruitment in Nigerian multinational enterprises (Babarinde, 2021). These biases are systemic, shaped by social norms and organizational cultures. Consequently, traditional hiring methods struggle to ensure fairness and diversity, highlighting the need for objective, data-driven approaches to mitigate bias in interviews.

Artificial intelligence (AI), particularly sentiment analysis and natural language processing (NLP), offers a structured approach to evaluating candidate responses and reducing subjective bias. Sentiment analysis detects emotional tones in text and speech, revealing subtle biases in word choice and interviewer responses, while NLP techniques analyze conversational patterns to highlight linguistic indicators of discrimination (Zhang *et al.*, 2018). Transformer-based models, such as DistilBERT (Sanh *et al.*, 2019), can capture these subtle contextual nuances, enabling more systematic and fair evaluations of job interviews.

Despite the potential benefits of AI-driven bias detection, its application in job interviews remains underexplored, particularly in multicultural hiring environments like Nigeria. Existing NLP models often struggle with the complexities of spoken language, including informal expressions, code-switching, and culturally specific references (Mujtaba & Mahapatra, 2023). Moreover, AI systems risk inheriting biases from training data, potentially reinforcing stereotypes rather than mitigating them (Caliskan *et al.*, 2017; Veldanda & Garg, 2023). These challenges underscore the need for context-aware AI models designed to function effectively in socio-culturally complex recruitment settings.

This study develops an AI-driven framework that leverages sentiment analysis and NLP to detect, analyze, and mitigate bias in job interviews. Specifically, the research aims to develop a bias detection model tailored to Nigerian job interviews, analyze linguistic patterns that indicate bias in mitigating bias and promoting fair hiring practices. The study focuses on analyzing job interview transcripts from the 2025 Arise Youth Empowerment Program, examining linguistic patterns to detect demographic biases in age, gender, and ethnicity. By leveraging AI-driven sentiment analysis and NLP DistilBert, the research aims to provide actionable insights into bias mitigation in recruitment, contributing to fairer and more transparent hiring practices.



2. Literature Review

Bias in recruitment significantly influences hiring outcomes, disadvantaging certain demographic groups and perpetuating systemic inequalities (Ferrara, 2024). A meta-analysis of hiring discrimination studies across 16 countries found that ethnic minorities receive 29% fewer callbacks compared to majority applicants with identical qualifications (Quillian *et al.*, 2017). Bias manifests in various forms, including demographic bias (e.g., race, gender), linguistic bias (e.g., language used in interviews), and psychological bias (e.g., unconscious stereotypes). This subjectivity is exacerbated in multicultural contexts like Nigeria, where non-meritocratic practices such as nepotism and favoritism are prevalent (Don-Baridam *et al.*, 2022). Gallegos *et al.* (2023) consolidated research on bias and fairness in large language models (LLMs), categorizing different types of bias in NLP and highlighting the limitations of bias-mitigation strategies. Babarinde (2021) found that race, ethnicity, and religion significantly influence hiring decisions in Nigerian multinational enterprises, with 65% of surveyed HR professionals acknowledging personal biases affecting hiring outcomes.

Traditional approaches to mitigating bias, such as structured interviews and implicit bias training, have shown limited effectiveness. Levashina *et al.* (2014) noted that structured interviews, designed to reduce subjectivity, still exhibit inconsistent outcomes due to unconscious interviewer biases, with rating disparities of up to 20% between different demographic groups. Similarly, Fitzgerald and Prasad (2017) reviewed implicit bias training and found that while 75% of participants demonstrated short-term awareness improvements, only 10% retained behavioral changes six months later. These limitations justify exploring innovative solutions that minimize human subjectivity. Garrido-Muñoz *et al.* (2021) surveyed bias in deep NLP, demonstrating how pre-trained language models inherit biases from training data, thereby influencing decision-making in hiring contexts.

Artificial intelligence (AI), particularly sentiment analysis and natural language processing (NLP), offers promising solutions for detecting bias in job interviews. Sentiment analysis evaluates emotional tones in text and speech, revealing subjective biases, while NLP analyzes complex linguistic patterns. Zhang *et al.* (2018) demonstrated that sentiment analysis models achieved 82% accuracy in identifying implicit biases in hiring dialogues. Recent advancements in deep learning architectures, such as transformers (Devlin *et al.*, 2019), have enhanced the accuracy of bias detection by capturing contextual nuances in language processing, with studies reporting a 15% improvement in bias detection



rates compared to earlier NLP models. However, most existing studies focus on resumes or job descriptions, with limited research on detecting bias in interview transcripts, particularly in culturally diverse contexts. Blodgett *et al.* (2020) critiqued the measurement techniques for bias in NLP, emphasizing that many bias detection methodologies lack normative reasoning and are insufficient for addressing deep-seated hiring inequalities.

Applying AI for bias detection in recruitment is not without challenges. AI models can inherit and amplify biases present in training data, as highlighted by Caliskan *et al.* (2017) and Veldanda & Garg (2023). Specifically, Veldanda & Garg (2023) found that even advanced models like GPT-3.5 exhibit biases related to attributes such as political affiliation and pregnancy status, with bias amplification rates of up to 18%. Additionally, NLP models often struggle with cultural and linguistic nuances, such as informal expressions, code-switching, and contextual meanings, which are common in Nigerian interviews (Mujtaba & Mahapatra, 2023). NLP models trained on Western-centric datasets may misinterpret Nigerian Pidgin and local dialects, leading to misclassification of sentiment and intent (Gupta *et al.*, 2023). Furthermore, current bias detection models lack domain adaptation techniques that consider linguistic diversity, making them less reliable in non-Western hiring environments. To address these challenges, context-aware AI models tailored to cultural dynamics are essential for enhancing bias detection accuracy. Nangia *et al.* (2020) introduced CrowS-Pairs, a benchmark dataset designed to evaluate social biases in NLP models, offering a valuable resource for improving fairness in AI hiring tools.

Human-AI collaboration is critical for effective bias mitigation in recruitment, ensuring that AI augments rather than replaces human decision-making. Harris (2024) emphasized the importance of human oversight in maintaining fairness and transparency in AI-driven hiring. A study by Peng and Kamar (2022) found that recruitment decisions combining AI and human judgment reduced bias-related hiring disparities by 22%. Mishra (2024) further emphasized the ethical necessity of integrating human judgment into AI-driven recruitment, particularly in complex cultural contexts like Nigeria. Additionally, Liang *et al.* (2021) proposed new benchmarks for measuring representational biases in LLMs, advocating for improved fairness techniques in text generation models used in hiring systems.

Moreover, bias in interviews can manifest subtly through tone, word choice, and conversational dynamics (Mujtaba & Mahapatra, 2023). Advanced NLP methodologies, such as aspect-based



sentiment analysis and discourse analysis, are needed to capture these complexities. While existing research has explored fairness-aware NLP models for job descriptions and resumes (Blodgett *et al.*, 2020), limited studies focus on interview dialogue, especially in multicultural contexts. This research addresses these challenges by developing culturally sensitive NLP models for detecting subtle biases in Nigerian job interviews.

Cultural and linguistic nuances are crucial when applying AI and NLP in Nigerian recruitment contexts. Odor & Bakwuye (2019) highlighted the influence of non-meritocratic factors like quota systems, tribalism, and nepotism in Nigerian hiring practices. Similarly, Ukeje & Onele (2020) found that political interference and a lack of merit-based criteria affect public sector recruitment in Nigeria. These cultural dynamics necessitate AI models that accommodate informal language patterns, code-switching, and culturally specific conversational norms. Mujtaba & Mahapatra (2023) emphasized the importance of context-aware NLP techniques to accurately detect bias while preserving linguistic diversity.

Despite advancements in AI and NLP for recruitment, gaps remain in detecting bias within interview transcripts, particularly in the Nigerian context. Most existing studies focus on resumes or job descriptions, overlooking interviews, which are highly susceptible to subjective biases. Additionally, sentiment analysis has been used to evaluate emotional expressions, but its application in identifying subtle linguistic biases in interviews is under-explored. This research bridges these gaps by developing a framework that combines sentiment analysis and NLP models (DistilBERT), and demographic bias analysis to detect bias in Nigerian job interview transcripts.

3. Methodology

This section outlines the interconnected components of the bias detection and sentiment analysis pipeline used to evaluate bias in the transcribed dataset. The implementation was carried out using Python, leveraging libraries such as NLTK for text processing, SpaCy for dependency parsing and POS tagging, Scikit-learn for machine learning models, SMOTE for class balancing, VADER for rule-based sentiment analysis, and Transformers (Hugging Face) for DistilBERT-based classification. An architectural framework for the methodology is presented in Figure 1.

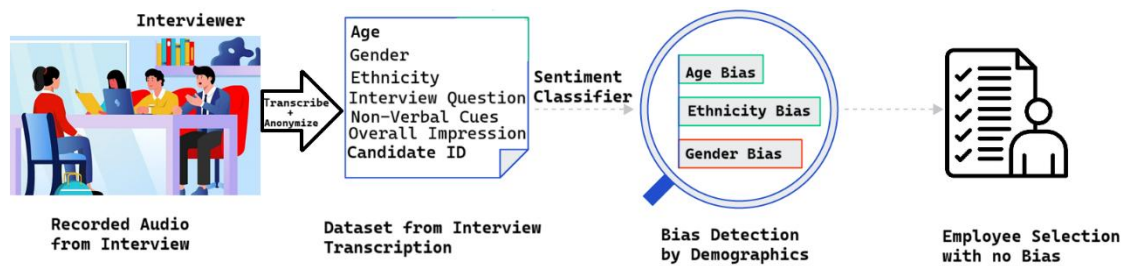


Figure 1. Architectural Framework of Bias Detection in Interview Process

The process includes dataset description, preprocessing, annotation, and analytical methods, ensuring a structured approach to identifying and assessing bias within interview transcripts.

A. Dataset Description

Overview:

This study utilizes 300 interview transcripts from the Arise Youth Employment Program, organized by the Akwa Ibom State Government to provide job opportunities. The dataset was structured to analyze bias and sentiment, focusing on verbal and non-verbal cues of interviewers in job interviews. The dataset was sourced from audio recordings of oral interviews conducted during the 2025 Arise Youth Employment Program. The actual recruitment process involved:

- (i) **Online Application:** Applicants submitted details online. Resumes and CVs underwent a black-box selection process, shortlisting those who met the criteria.
- (ii) **Oral Interview with the HR Team:** Candidates faced panel interviews, where they were evaluated on qualifications, experience, cultural fit, and communication skills.

The dataset consists of **seven extracted features**, categorized as follows:

- i. **Background & Experience:** *"Tell us about yourself"* captures candidates' backgrounds.
- ii. **Demographic Features:** *Age, Gender, and Ethnicity* analyzed for sentiment variations.
- iii. **Non-Verbal Cues & Overall Impression:** Interviewer observations on candidate demeanor.

An excerpt from the dataset is presented in Table 1.

Table 1. An excerpt of dataset derived from Interview Transcript

Candidate ID	Tell us about yourself	Non-Verbal Cues (By Interviewer)	Overall Impression (By Interviewer)	Gender	Age	Ethnicity
Candidate	I am a	Maintained	Confident	Female	30-	Ibibio



1	dedicated professional...	steady eye contact...	communicator...	39		
Candidate	My	Appeared	Demonstrated	40-		
2	experience includes...	attentive and engaged...	leadership potential...	Male 49	Efik	

Data Collection Procedure:

Audio Recording: Interviews were recorded with informed consent from all participants, ensuring ethical compliance and privacy. The recordings captured both verbal responses and non-verbal cues, such as tone, pauses, and speech patterns.

Transcription and Anonymization: Audio recordings were transcribed using an automatic speech recognition (ASR) tool. It also provides *Punctuation and Speaker Diarization*. This was followed by manual verification to ensure accuracy. Candidates' privacy and their personal identifiers were anonymized using these methods:

- Names and Identifiers:** All candidate names, interviewers' names, and any identifiable information were replaced with unique codes (e.g., Candidate 1, Interviewer A).
- Amounts and Sensitive Data:** Information related to salary expectations, transport costs, and any financial figures were generalized or removed to maintain confidentiality.
- Ethically Sensitive Information:** Any data revealing personal beliefs, health status, or other ethically sensitive content was stripped off to comply with ethical standards and privacy regulations.

Data Cleaning and Preprocessing: The following steps were used in cleaning the recorded transcripts;

- Removing Fillers:** Eliminating non-verbal sounds (e.g., "uh", "um") and background noise artifacts.
- Standardizing Language:** Correcting grammatical errors and normalizing text for consistent NLP processing.
- Redacting Sensitive Information:** Ensuring no trace of personal identifiers, financial figures, or ethically sensitive content remained.
- Contextual Anonymization:** Generalizing location references (e.g., "I live in Lagos" to "I live in a metropolitan area") to prevent regional identification.

The dataset underwent thorough preprocessing to ensure consistency and quality for NLP and bias detection. This included text normalization, tokenization, and stopwords removal to refine textual data. Vectorization using TF-IDF was applied to convert text into numerical format for model training. To address class imbalance, SMOTE (Synthetic Minority Over-sampling Technique) was used to balance sentiment categories. The detailed steps are outlined below:

The preprocessing phase was conducted to transform raw text into a structured format suitable for NLP models. The following systematic steps were performed:

A word cloud visualization featuring various terms related to learning and experience. The most prominent words are "skills", "field", "concepts", "need", "learning", "experience", "role", and "practice". Other visible words include "applications", "career", "complex algorithms", "eager", "right fit", "knack", "confident", "data", "mathematics", "machine", "new challenges", "detail oriented", "tasks", "improve", "several years", "previous jobs", "different", "learn", "gain", "meet", "really interested", "figure", "struggled", "world scenarios", "difficulties", "motivated", "individual", "excellent communication", "looking", "opportunities", "strong interest", "technical team player", "transition", "open", "grow", "passion", "problem solving", "setbacks", "want figuring", "team", "confidence", "options", "hard", "backlog", "professional", "oriented", "solid foundation", "enjoy working", "real world", "journey", "basic understanding", "science", "background", "desire familiar", "exploring", "develop developing", "environment", "much", "expectations", "trying", "professional used", "previous work", "data analysis", "knowledge", "tools development", "designer", "take", "continuous", "player", "growth", "technologies", "communication", "strong", "find area", "are", "creative", "scenarios", "design", "learner", "software", "development", "highly motivated", "solid foundation", "enjoy working", "real world", "journey", "basic understanding", "science", "background", "desire familiar", "exploring", "develop developing", "environment", "much", "expectations", "trying", "professional used", "previous work", "data analysis", "knowledge", "tools development", "designer", "take", "continuous", "player", "growth", "technologies", "communication", "strong", "find area", "are", "creative", "scenarios", "design", "learner", "software", "development". The words are arranged in a dense, overlapping manner, with colors ranging from dark purple to light yellow.

Figure 2. Tokenization Statistics by Question

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transformer-based models. *SpaCy's Dependency Parser* was used to segment sentences in candidates' response, and POS tagging identified key word types for improved analysis.

Table 2. Sentence and POS Tags of Candidates Response

ID	Sentence	POS Tags
2	I am a quick learner with a strong work ethic and a desire to improve my skills.	[('I', 'PRON'), ('am', 'AUX'), ('a', 'DET'), ('quick', 'ADJ'), ('learner', 'NOUN'), ('with', 'ADP'), ('a', 'DET'), ('strong', 'ADJ'), ('work', 'NOUN'), ('and', 'CCONJ'), ('a', 'DET'), ('desire', 'NOUN'), ('to', 'PART'), ('improve', 'VERB'), ('my', 'PRON'), ('skills', 'NOUN'), ('.', 'PUNCT')]

The sentiment classification performance of BERT, RoBERTa and DistilBERT was compared. Table 2 shows that DistilBERT achieved 94% accuracy, with precision (0.93), recall (0.95), and F1-score (0.93), demonstrating better generalization than BERT and RoBERT models. Cohen's Kappa (0.9108) confirms strong agreement between predictions and actual labels.

C) Annotation

After preprocessing, sentiment annotation was conducted on the "Tell us about yourself" responses to classify them as Positive, Negative, or Neutral. A hybrid approach was used: Valence Aware Dictionary and sEntiment Reasoner (VADER) provided initial rule-based sentiment labels, which were then used to train and refine DistilBERT for more accurate classification. This combination ensured robust sentiment detection for bias analysis.

I. Rule-Based Annotation (VADER): Sentiments were initially labeled using VADER, which is optimized for social media and conversational text, thus suitable for interview dialogue. To analyze sentiment in responses to "Tell us about yourself," we applied the VADER sentiment analysis tool. VADER classifies sentiment into three categories; Positive (0), Negative (1) and Neutral (2)

After applying VADER, we obtained the following sentiment distribution: 157 responses (58.8%) were classified as Positive, 84 responses (31.5%) were classified as Neutral and 59 responses (22.1%) were classified as Negative. To better illustrate the annotation distribution, Figure 2 visualizes the sentiment analysis results, showing the proportions of Positive, Negative, and Neutral responses.

II. Contextual Analysis and Machine Learning Classifiers: Contextual analysis was conducted using DistilBERT, fine-tuned on the Arise Youth Employment Program interview dataset, to detect

biases at both lexical and semantic levels optimized the models for detecting sentiment shifts and potential biases within candidate responses. Given the structured yet conversational nature of the interview transcripts, DistilBERT effectively captured nuanced responses to critical questions, such as "Tell us about yourself," often revealing subjective biases in hiring decisions. To enhance classification accuracy, sentiment labels were further validated using machine learning classifiers. DistilBERT was trained alongside a BERT and RoBERTa classifiers for comparative evaluation. Feature engineering incorporated Term Frequency-Inverse Document Frequency (TF-IDF) vectors to represent text data, and Synthetic Minority Over-sampling Technique (SMOTE) was applied to ensure balanced class distribution.

III. Bias Detection: The dataset was analyzed for potential biases related to gender, ethnicity, and age, which are commonly observed in interview settings. Sentiment distributions were examined across these demographic categories to identify possible disparities. To statistically assess whether predicted sentiment classifications (Positive, Neutral, Negative) were significantly associated with demographic attributes (Gender, Age, Ethnicity), we applied two statistical tests: the Chi-Square test by Field (2018) described in Equation 1 to evaluate whether an observed distribution of sentiment classifications deviates significantly from an expected distribution under the assumption of independence.

$$\chi^2 = \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \quad \text{Equation 1}$$

Where O_{ij} = observed frequency of sentiment category j in demographic group i, and E_{ij} = expected frequency, calculated in Equation 2.

$$E_{ij} = \frac{(\sum_i O_{ij}) \times (\sum_j O_{ij})}{n} \quad \text{Equation 2}$$

where n is the total number of observations. The Chi-Square test evaluates whether there is a statistically significant difference in sentiment distribution across Gender, Age, and Ethnicity. To measure the effect size of the Chi-Square association, Cramér's V by Cohen (2013) described in Equation 3.

$$V = \sqrt{\frac{\chi^2}{n(k-1)}} \quad \text{Equation 3}$$

where χ^2 = computed Chi-Square statistic in Equation 1, n = total number of samples, k = the smaller of the number of rows or columns in the contingency table. A **Cramér's V** close to 0 indicates no bias,

while values closer to 1 indicate stronger associations, implying potential bias. The results of these test are present in Section 4. To evaluate the classification performance of sentiment predictions across demographic groups, we computed the confusion matrix, defined mathematically in Equation 4.

$$CM = \begin{bmatrix} TP_{pos} & FP_{pos} & FN_{pos} \\ FP_{neu} & TP_{neu} & FN_{neu} \\ FP_{neg} & FN_{neg} & TP_{neg} \end{bmatrix} \quad \text{Equation 4}$$

Where TP (True Positives) is Correctly classified instances of a sentiment category, FP (False Positives) is Instances incorrectly classified as a sentiment category, and FN (False Negatives) is Instances that belong to a sentiment category but were misclassified. The three variables and for the three sentiments; positive, neutral and negative are given in Equations 5,6 and 7.

$$TP = \sum_{i=1}^n 1(\bar{y}_i = y_i = c) \quad \text{Equation 5}$$

$$FP = \sum_{i=1}^n 1(\bar{y}_i = c \wedge y_i \neq c) \quad \text{Equation 6}$$

$$FN = \sum_{i=1}^n 1(\bar{y}_i \neq c \wedge y_i = c) \quad \text{Equation 7}$$

where y_i is the actual sentiment label for sample i , \bar{y}_i is the predicted sentiment label, c represents a specific class (Positive, Neutral, or Negative) and $1(\cdot)$ is the indicator function (1 if condition is true, 0 otherwise). The result of the confusion matrix is presented in 4.

4. Results and Discussion

Before conducting sentiment classification, the dataset underwent preprocessing to address class imbalance. Initially, the sentiment distribution from VADER showed 157 Positive, 84 Neutral, and 59 Negative responses, indicating an uneven distribution across sentiment categories. To ensure balanced model training and prevent bias toward the majority class, SMOTE was applied. This technique synthetically increased the samples of the Neutral and Negative classes to match the Positive class, resulting in a final distribution of 110 samples per class. The balanced dataset provided an equal representation of all sentiment categories, ensuring that the model could generalize effectively without being skewed toward the dominant (Positive sentiments) class. This balanced dataset was then used as the input for all subsequent sentiment classification and bias detection analyses.

A. Sentiment Distribution Analysis

The initial sentiment distribution of the "Tell us about yourself" responses was analyzed using VADER and the resulting distribution revealed a predominance of Positive sentiments as shown in Table 3 and Figure 3.

Table 3: Sentiment Distribution from VADER

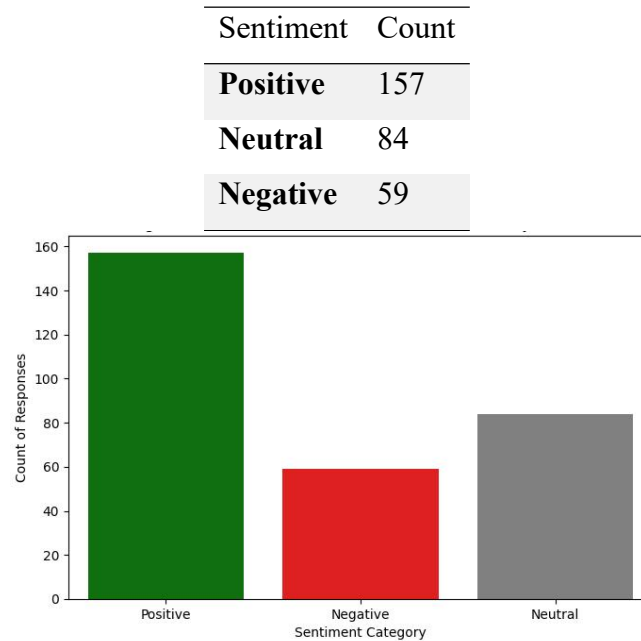


Figure 3: Sentiment Distribution for "Tell us about yourself"

The subsequent results were based on the balanced data from the SMOTE.

B. Model Performance Evaluation

The effectiveness of sentiment classification was evaluated by comparing the performance of BERT, RoBERT and DistilBERT. As shown in Table 4, DistilBERT achieved an accuracy of 94%, with precision (0.93), recall (0.95), and F1-score (0.93), outperforming BERT and RoBERTa in generalization capability. Cohen's Kappa for DistilBERT was 0.9108, indicating strong agreement between predicted and actual classifications.

Table 4: Model Performance Comparison

Model	Accuracy	Precision	Recall	F1-Score	Cohen's Kappa
BERT	28%	0.10	0.30	0.12	0.2201
RoBERTa	34%	0.12	0.34	0.18	0.2819

DistilBERT	94%	0.93	0.95	0.93	0.9108
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A heatmap confusion matrix (Figure 4) shows DistilBERT's predictions vs. actual labels. The results indicate strong classification across sentiment categories. Positive instances: 44 correct, 3 misclassified as Negative; Negative instances: 18 correct, no misclassification; Neutral instances: 21 correct, 4 misclassified as Negative.

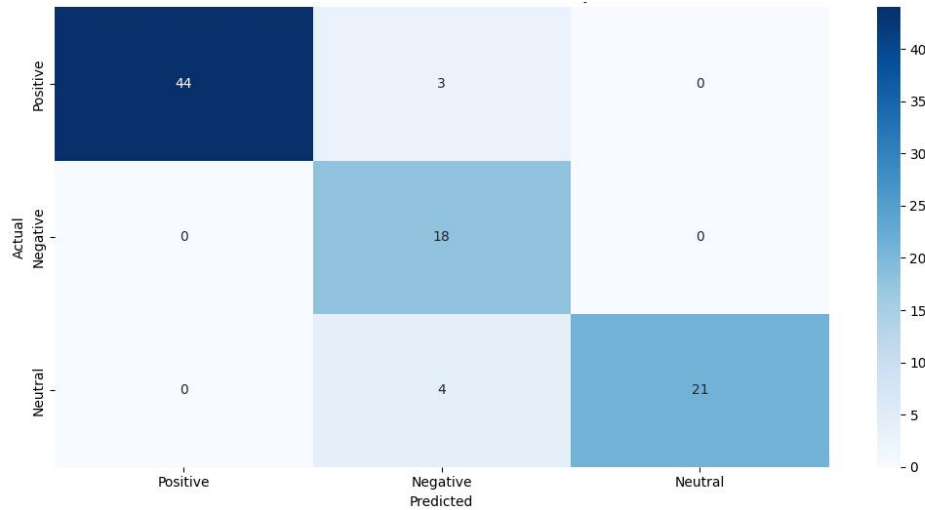


Figure 4: Confusion Matrix for DistilBERT

DistilBERT performed well overall, with slight confusion between Neutral and Negative sentiments, achieving high agreement with actual labels (Cohen's Kappa: 0.9108). Its superior performance was due to its ability to capture contextual meaning, even with limited data.

C. Bias Detection Analysis

To check for biases in sentiment classification in **B**, the derived sentiment distribution was analyzed across Gender, Age, and Ethnicity and the result shown in Table 5.

Table 5: Bias Detection Results

Demographic	Chi-square (p-value)	Cramér's V	Bias Interpretation
Gender	0 (p = 1.0)	0.0	No significant bias
Age	0 (p = 1.0)	0.0	No significant bias
Ethnicity	0 (p = 1.0)	0.0	No significant bias

The results in Table 5 show no significant bias in the model's predictions for any demographic group. The Chi-square and Cramér's V values confirm this finding. The bar charts in Figure 5 to Figure 7 represents the sentiment distribution across gender groups, age groups and ethnic groups respectively.

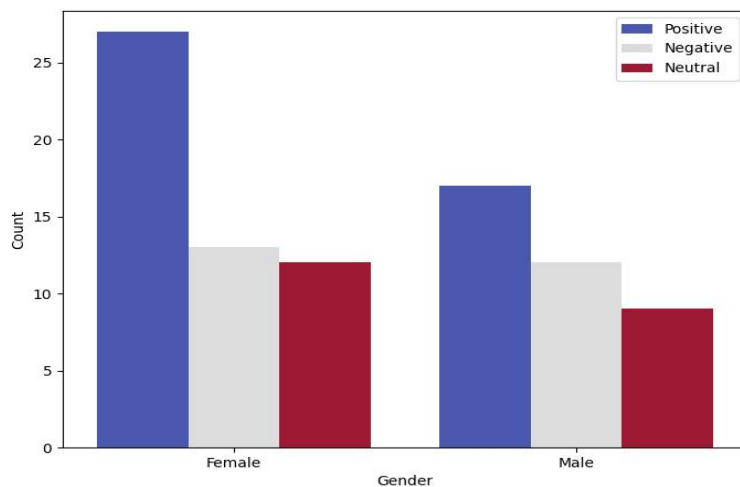


Figure 5: Sentiment Distribution by Gender

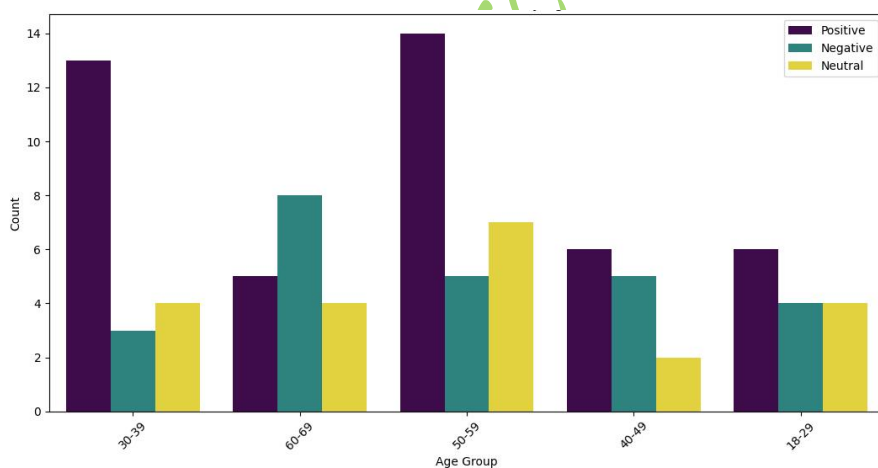


Figure 6: Sentiment Distribution by Age

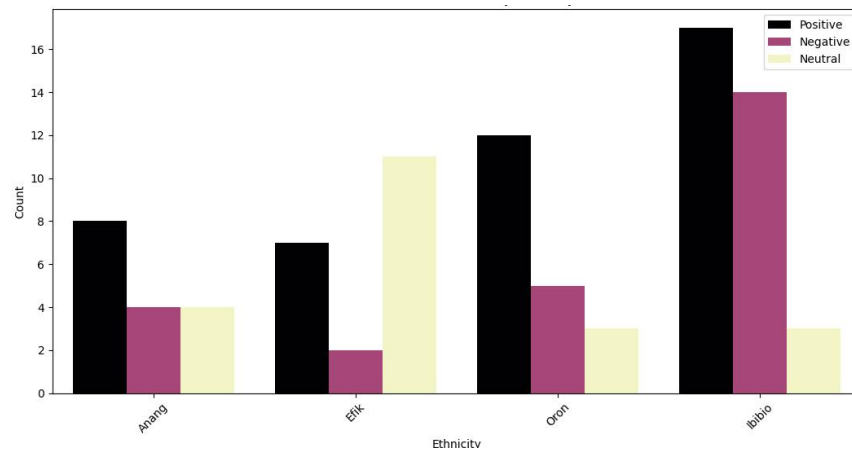


Figure 7: Sentiment Distribution by Ethnicity

From Figure 5 to Figure 7, the following were deduced;

- Gender:** The dataset comprised **52 Female**, **38 Male**, and **10 Non-binary** candidates. No significant bias was observed in sentiment classification across gender groups. In this context, "**Non-binary**" refers to candidates who from interview transcript we were unable to exclusively identify as **male or female**.
- Age:** The largest age group was **50-59 years old** (26 samples). Sentiment classification showed no significant bias across age categories.
- Ethnicity:** The ethnic distribution included **Ibibio (34)**, **Efik (20)**, **Oron (20)**, and **Anang (16)**. Similar to gender and age, no significant bias was detected.

D. Discussion and Future Works

The results demonstrate that DistilBERT is highly effective for sentiment classification in job interview transcripts, outperforming more complex architectures like BERT and RoBERTa with 34% accuracy for each model. The model's ability to generalize well, even with a limited dataset, is evidenced by consistent loss reduction and accuracy improvements over epochs. For instance, the evaluation loss decreased from 0.6517 to 0.2038 over three epochs, indicating strong generalization without overfitting. Bias detection analysis confirmed that the model's predictions are fair across Gender, Age, and Ethnicity, addressing ethical concerns in AI-driven recruitment. Chi-square ($p = 1.0$) and Cramér's V (0.0) values indicated no significant bias across demographic groups. The learning curve for the DistilBERT is shown in Figure 8.

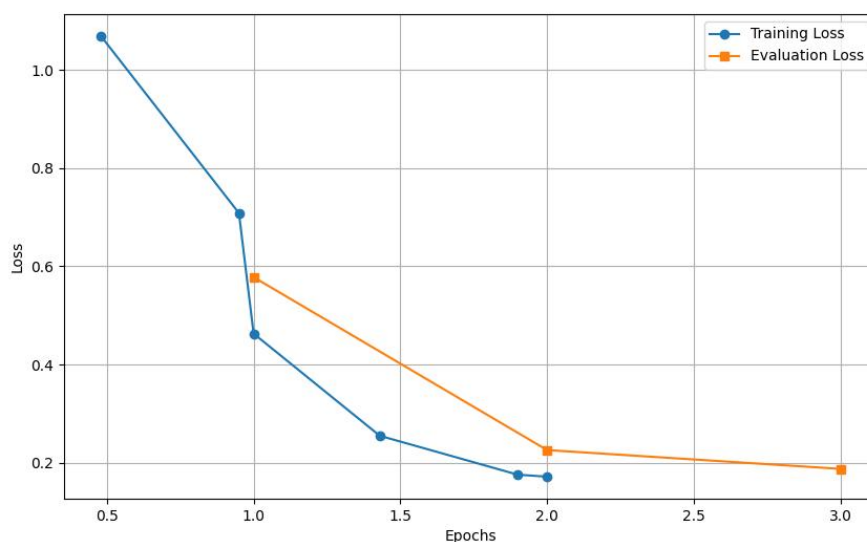


Figure 8: Learning Curve for DistilBERT

The learning curve, fine-tuned on the Arise Youth Employment Program dataset, shows strong performance with training loss decreasing significantly from 1.0689 to 0.7085 initially, and evaluation loss further decreasing to 0.1874 at Epoch 3.0, indicating effective generalization (Cohen's Kappa: 0.9108).

E. Conclusion

In conclusion, this study demonstrates the effectiveness of DistilBERT for sentiment classification in job interview transcripts, achieving high accuracy and fairness across demographic groups. The model's ability to capture contextual nuances, even with a limited dataset from the Arise Youth Employment Program, underscores its practical applicability in real-world recruitment settings. Furthermore, this research contributes to advancing fairness in hiring practices, with immediate relevance to the Nigerian context and potential scalability to global recruitment systems. Future research should focus on expanding the dataset, incorporating additional interview transcripts, and refining bias detection mechanisms to enhance model robustness. Additionally, integrating advanced bias mitigation strategies and testing the model on larger, more diverse datasets will be essential to ensure equitable and unbiased hiring processes in real-world applications.



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ANALYSING THE ROLE OF PREDICTIVE ANALYTICS IN RESOURCE ALLOCATION AND MANAGEMENT IN ACADEMIC LIBRARIES

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Abstract

Predictive Analytics plays a crucial role in optimizing resource allocation and management by enabling data-driven decision-making. This study examines its application in two university libraries—Michael Okpara University of Agriculture, Umudike (MOUAW) Library, and Imo State University (IMSU) Library. The research aims to assess the effectiveness of predictive analytics in enhancing budgetary decisions, collection development, staffing, and space utilization while identifying challenges hindering its adoption. A descriptive survey research design was employed, targeting the management staff of both libraries, totalling 20 respondents. Data were collected through structured questionnaires and analysed using frequency counts and simple percentages. Results were presented in tables and charts for clarity. Findings indicate that predictive analytics significantly improve resource distribution, facilitate proactive decision-making, and enhance operational efficiency. However, challenges such as inadequate infrastructure, limited technical expertise, and data privacy concerns hinder full-scale implementation. To maximize the benefits of predictive analytics, the study recommends targeted staff training, investment in advanced data-driven tools, institutional collaborations, and the establishment of clear policies for ethical data use.

Keywords: Predictive Analytics, Resource Allocation, Management, Academic Libraries, Decision-making.

Introduction

Resource allocation in academic libraries involves the strategic distribution of financial, human, and material resources to meet the diverse needs of the user communities (undergraduates, postgraduates, researchers, and faculty members). When done effectively, it ensures that academic libraries can support the objectives of their parent institution with the thripid function of teaching, research, and learning. Optimizing resource allocation to enhance user experience requires careful monitoring and analysis, involving a data-driven approach to enable tailored services.

Academic libraries face several challenges in resource allocation and management which can hinder service delivery and impact user experience. Among these challenges are inadequate funding, high cost of digital resources, inefficient budget planning, lack of skilled personnel, evolving user demands, limited space, resource duplication, etc. (Akash, *et al.*, 2024)) There is need for effective planning and



distribution of existing resources to achieve the overall goals of the library as well as that of its parent body.

Data is essential for informed decision-making in academic libraries, particularly in resources allocation and management. Leveraging data analytics, which is defined as the process of examining, cleaning, transforming and interpreting raw data, to discover useful information, draw conclusions to support decision-making, libraries can assess user needs, track resource utilization, and optimize budget distribution (Barretto & Eessai, 2021). Predictive analytics enhances this process by forecasting future demands, identifying trends, and preventing wastage of resources. A data-driven approach enables libraries to align their services with institutional goals, enhance user satisfaction, and support academic excellence. Ultimately, predictive analytics ensures strategic decision-making, leading to the sustainable and successful realization of library objectives.

According to Adesina, Iyelolu and Okpeke-Paul (2024), Predictive analytics which refers to the use of data, statistical algorithms, and machine learning techniques to analyze historical data and make predictions about future events or outcomes, enabling businesses such as libraries to make informed predictions about future events. The main purpose of predictive analytics is to streamline operations, boost revenue, and mitigate risk by making predictions of future events, and then use these predictions to improve decision-making. Predictive analytics is a process that uses a variety of analysis and modelling techniques to discover patterns and relationships in existing data – and then use the insight to make accurate predictions

The use of predictive analytics suggests that, while it is best applied to forecasting trends and seeking patterns in customer habits, it can also be used to solve operational issues primarily because “they are transactional”

While effectively used in project management and outcomes-based evaluation to evaluate the risks associated with a particular project or service, predictive analytics can also greatly benefit a library’s operations as its use as a transactional predictive tool allows for the collection of data on a per-use basis and, therefore, it can provide a wealth of data for close analysis before reporting any successes or failures in the operational sphere (Wu-Zui & Yarkun, 2023). It analyses data such as circulation records, website traffic, and user demographics through which libraries can uncover patterns and trends that inform decision-making processes. For example, data analytics can reveal which resources are most



popular among patrons, allowing libraries to tailor their collections to better meet demand. Additionally, insights gained from data analysis can help libraries optimize their services by identifying areas for improvement and reallocating resources accordingly.

Libraries can partner with academic institutions and research organizations to develop predictive models for identifying emerging research trends and guiding collection development strategies, as well as leverage machine learning algorithms to personalize recommendations and enhance the overall user experience.

Problem Statement

Academic libraries face challenges in optimizing resource allocation and management due to user needs, budget constraints, and evolving information needs. Traditional decision-making approaches often rely on historical data and intuition, leading to inefficiencies. Predictive analytics leveraging data-driven insights, offers a proactive strategy for optimizing resource distribution, enhancing collection development, and improving service delivery. However, limited research exists on its practical applications in academic libraries. This study aims to analyze the role of predictive analytics in resource allocation and management, addressing gaps in its implementation, its effectiveness, and its potential impact on decision-making processes in academic libraries.

Research Objectives

This study has the following objectives:

1. Examine the extent of the application of predictive analytics in academic libraries for resource allocation and management
2. Explore how predictive analytics can enhance resource allocation and management in academic libraries
3. Identify data sources available for implementing predictive models in academic libraries for effective resource allocation and management
4. Identify challenges of implementing predictive models in library resource management
5. Recommend workable action steps for the implementation of predictive analytics in academic libraries.



Literature Review

Concept of Predictive Analytics

Predictive analytics is a data-driven approach that uses historical data, statistical algorithms, and machine learning techniques to forecast future outcomes. It enables organizations including academic libraries to anticipate trends, optimize resources, and improve decision-making processes. Predictive analytics involves data collection, pre-processing, model section, and validation. Machine learning algorithms such as regression analysis, decision trees, and neural network predictions (Dong, 2019). These models analyse patterns in past data to predict future behaviours such as library material circulation rates, reference demands, and user engagements.

In academic libraries, predictive analytics helps optimize book acquisitions, staffing, and space utilization. By analysing borrowing patterns, libraries can determine which materials are in high demand and allocate a budget accordingly (Panda, 2024). Moreover, predictive models support personalized recommendations, enhancing user experience in digital library platforms (Chakraborty & Kumar, 2024). Predictive analytics emerges as a transformative force in addressing these challenges, reshaping how libraries manage and allocate their resources effectively. According to Akash *et al.*, (2024), predictive analytics has become a game-changing instrument for library administration. It can be utilized in numerous ways to move forward benefits to clients, the utilization of assets, and the speed of operations. Libraries can look at past information to anticipate future patterns and make choices based on information by utilizing factual strategies and machine learning.

Predictive analytics looks for past patterns to measure the likelihood that those patterns will reoccur. It draws on a series of techniques to make these determinations, including artificial intelligence (AI), data mining, machine learning, modeling, and statistics. Adesina, Iyelolu, and Okpeke (2024) outline the following steps in predictive analytics: define your project's objectives (What is the desired outcome?); collect your data (gather all the data you need in one place); clean and prepare your data; build and test your model; deploy your model and monitor and refine your model.

Overview of Resource Allocation and management in academic libraries

Resource allocation in academic libraries involves intricate decision-making processes to optimize the utilization of limited financial, human, and material resources. Ikwuanusi *et al.*, (2022) stated that academic libraries face several challenges including limited budgets, uneven usage patterns, balancing



digital and physical resources, and the need to support diverse user needs. These challenges are compounded by the growing diversity of user needs, the rapid expansion of digital resources, and the rising costs of journal subscriptions, databases, and proprietary content. Libraries also face logistical issues, such as ensuring physical resources are accessible across multiple campuses or addressing disparities in user engagement.

Effective resource allocation and management are fundamental to the success and sustainability of services in academic libraries, ensuring the optimal delivery of services and resources to meet the evolving needs of their communities. Proper resource allocation enables libraries to maintain comprehensive collections, provide essential services, and support academic research and learning. It ensures that limited resources are utilized effectively to maximize their impact on community (Jamil, 2021).

Academic libraries manage a variety of resources cutting across financial resources such as budgets allocated for acquisitions, staffing, and operations; Human resources such as librarians and other staff who provide services and manage collections; technological resources which include digital infrastructures such as databases, online catalogs, and information systems; and, physical resources, summarized as facilities, equipment, and physical collections (Massis, 2016; Stubbing, 2022). Hence, the need to manage these arrays of resources is sacrosanct.

Data sources for implementing predictive analytics in academic libraries

Implementing predictive analytics in academic libraries necessitates the collection and analysis of diverse data sources to anticipate user needs and optimize services. Key data sources include circulation records, catalogue searches, digital resource usage, website analytics, event attendance, social media interactions, and user feedback. Circulation records reveal borrowing patterns, aiding in collection development. Catalogue search data highlights user interests and potential collection gaps. Digital resource usage statistics inform decisions on electronic materials. Website analytics provide insights into user engagement with online services. Event attendance records gauge program popularity. Social media interactions offer real-time feedback on services. User feedback and surveys supply qualitative data on user satisfaction. By integrating these data sources, libraries can develop predictive models to enhance decision-making and service delivery. Fakhouri (2021) noted that analysing user demographic profiles aid in tailoring services to meet diverse user needs effectively.



Challenges in implementing predictive analytics in academic libraries

Implementing predictive analytics in academic libraries presents several challenges, ranging from financial constraints to ethical concerns (Wakahia, 2019). Among these challenges are;

- **Data Quality and availability:** One of the primary challenges is data quality and availability. Predictive models rely on large volumes of accurate, structured data. However, library records may contain inconsistencies, missing values, or outdated information which can compromise the reliability of production.
- **Lack of Technical Expertise:** many library professionals are not trained in data analytics, making it difficult to interpret predictive models or integrate them into decision-making processes. This necessitates continuous professional development and collaborations with data scientists.
- **Financial Constraints:** Any worthwhile venture will require finance. Where this key factor is lacking, it endangers the achievement. Financial constraints have posed a significant barrier to positive achievement. Advanced analytics tools require substantial investments in software, hardware and skilled personnel. Many academic libraries, especially in developing countries operate on limited budgets, making such investment difficult.
- **Ethical and privacy Concerns:** Libraries handle sensitive user data and using predictive models for decision-making raises concerns about data security, informed consent and bias in algorithmic predictions.
- **Resistance to Change:** Resistance to change within library management and staff can hinder adoption. Predictive analytics challenges traditional decision-making approaches, and without proper awareness and training, staff may be reluctant to embrace data-driven strategies.

Research Method

The study adopted a descriptive survey research design to analyse the role of predictive analytics in resource allocation and management in academic libraries. The population of the study comprised the management staff of the Michael Okpara University of Agriculture library and Imo State University Library, Owerri. This category of respondents was considered appropriate for this study because they are responsible for decision-making in resource allocation and library operations.



Data was collected through a structured questionnaire and was analysed using frequency counts and simple percentages. The results were presented in tables and charts for clarity. A percentage of 50 and above was considered high extent describing acceptance of the variable. All the copies of the distributed questionnaire were returned indicating 100% return rate.

Result and Findings

Table 1: Extent of application of predictive analytics in academic libraries for resource allocation and management

S/N	Extent of Application	VHE%	HE%	LE%	VLE%
1	Collection development and materials acquisition	2(10)	6(30)	10(50)	2(10)
2	Budgeting and financial resources management	0(0)	0(0)	20(100)	0(0)
3	Library space and facility management	0(0)	0(0)	18(90)	2(10)
4	Human resources and staff allocation	0(0)	2(10)	16(80)	2(10)
5	Digital resources and IT infrastructure management	0(0)	3(15)	17(85)	0(0)

Table 1 shows the responses on the extent of the application of predictive analytics in academic libraries for resource allocation and management.

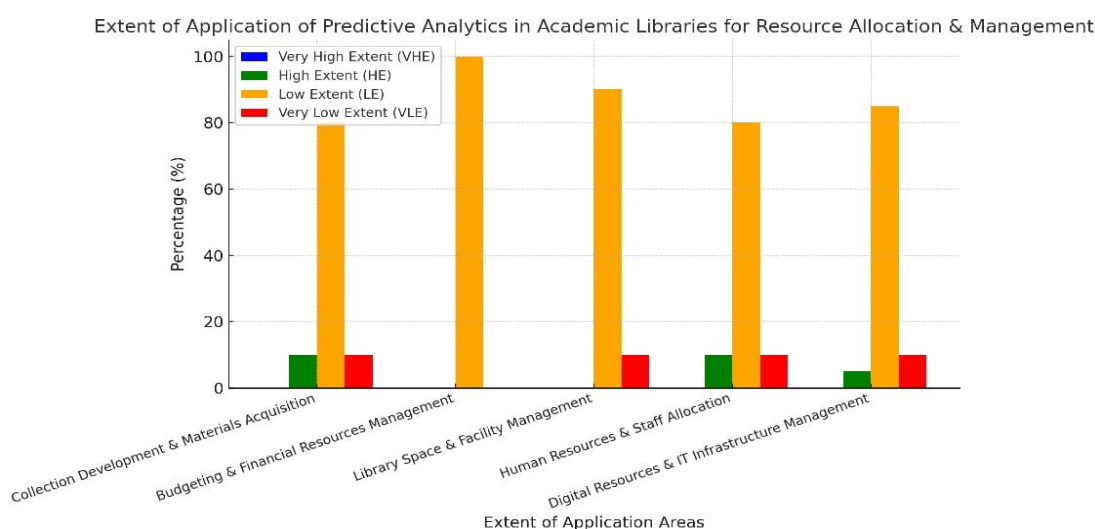


Figure 1: Extent of application of predictive analytics in academic libraries for resource allocation and management



The bar chart illustrates the extent of application of predictive analytics in various areas of resource allocation and management within academic libraries. The chart shows that 80% of respondents rated the application of predictive analytics on collection development and materials acquisition as Low Extent (LE), while 10% rated it as High Extent (HE) and Very Low Extent (VLE) each. No respondents rated it as Very High Extent (VHE), indicating that predictive analytics is not widely utilized in collection development.

In budgeting & financial resource management, 100% of respondents rated it as Low Extent (LE), showing no significant application of predictive analytics in financial planning and budgeting decisions. Also, in library space & facility management, 90% rated it as Low Extent (LE), while 10% rated it as Very Low Extent (VLE), suggesting that predictive analytics is rarely used for space and facility planning. In human resources & staff allocation, 80% of respondents rated the application as Low Extent (LE), 10% as High Extent (HE), and 10% as Very Low Extent (VLE). This indicates minimal use of predictive analytics in workforce scheduling and staff allocation. In digital resources & IT infrastructure management, 85% rated it as Low Extent (LE), 5% as High Extent (HE), and 10% as Very Low Extent (VLE).

This finding reveals that predictive analytics is largely underutilized in all areas of resource allocation and management in academic libraries. Areas such as budgeting, space utilization, and staff allocation have almost no adoption of predictive analytics.

This analysis highlights the need for increased integration of predictive analytics to improve decision-making in academic libraries.

Table 2: How predictive analytics can enhance resource allocation and management in academic libraries

S/n	Items	SA %	A %	D %	SD %
1.	Predictive analytics enhances resource allocation and management by providing data-driven decision-making	17(85)	3(15)	0(0)	0(0)
2	It enhances resource allocation and management by ensuring equitable distribution of scarce resources	20(100)	0(0)	0(0)	0(0)
3	It helps to optimize library services	15(75)	5(25)	0(0)	0(0)

4	It ensures personalized services	7(35)	3(15)	5(25)	5(25)
5	It improves service planning	13(65)	5(25)	2(10)	0(0)
6	It ensures needed resources are available as needed	4(20)	8(40)	5(25)	3(15)

Table 2 shows the responses on how predictive analytics can enhance resource allocation and management in academic libraries.

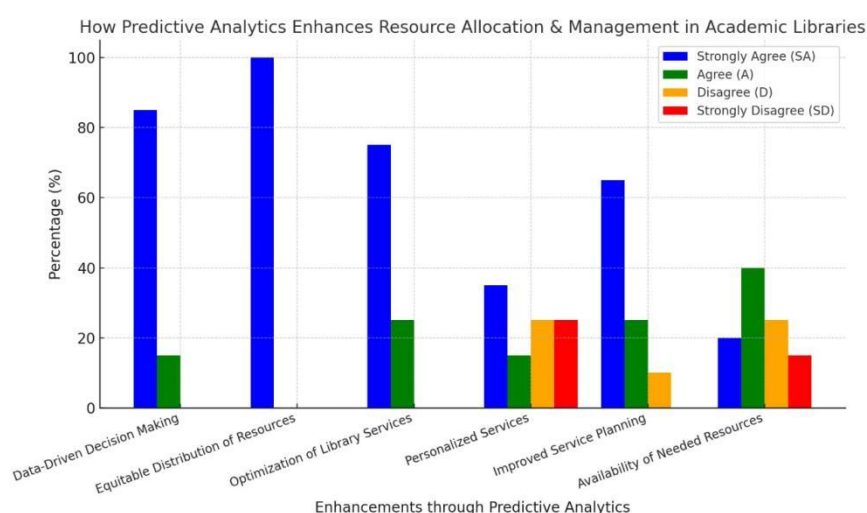


Fig 2: How predictive analytics enhances resource allocation and management in academic libraries

The bar chart above illustrates the percentage of various responses on how predictive analytics enhances resource allocation and management in academic libraries. Eighty-five (85) percent of respondents Strongly Agree (SA) that predictive analytics improves resource allocation through data-driven decision-making. 15% Agree (A), while no one Disagrees (D) or Strongly Disagrees (SD). This indicates strong confidence in predictive analytics for evidence-based decision-making. In equitable distribution of resources, 100% of respondents Strongly Agree (SA), showing unanimous belief that predictive analytics ensures fair distribution of resources.

This highlights its crucial role in optimizing scarce resources in libraries.



Table 3: Data sources for implementing predictive models in academic libraries for effective resources allocation

S/n	Data Sources	SA %	A %	D %	SD %
1.	User demographic data (academic department and level of study)	19(95)	1(5)	0(0)	0(0)
2.	Digital Resources usage data (e-books, e-journal, databases access logs)	10(50)	3(15)	7(35)	3(15)
3.	Website and online portal analytics (collected data on library websites, OPAC and digital libraries)	7(35)	5(25)	5(15)	3(15)
4.	Attendance and foot traffic data (manual records, entry systems or IoT enabled devices like RFID or WI-FI tracking)	15(75)	5(25)	0(0)	0(0)
5.	Inter-library loan data to indicate types of resources on high demand	16(80)	3(15)	1(5)	0(0)
6.	IT Infrastructure data (logs from servers, user authentication systems and network usage to predict system loads to ensure seamless digital access for users)	17(85)	2(10)	1(5)	0(0)

Table 3 shows the responses of where data can be gotten to implement predictive models in academic libraries.

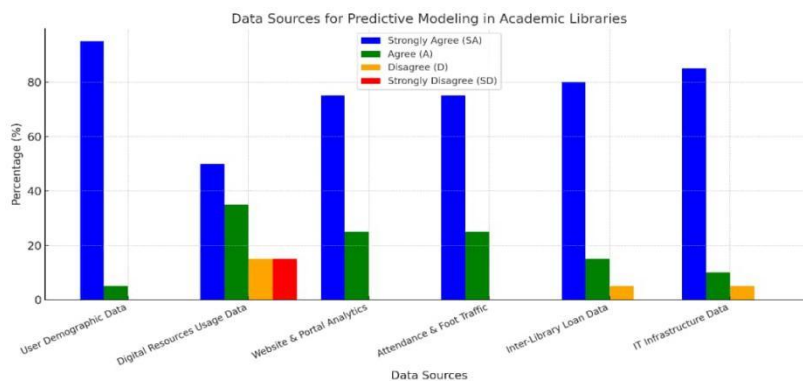


Figure 3: Data Sources for implementing predictive resources in academic libraries



The Figure 3 bar chart visualizes the percentage of responses regarding the usefulness of different data sources in implementing predictive models for resource allocation in academic libraries. The chart reveals that User Demographic Data (Academic department and level of study) has 95% strongly agree, 5% agree. No disagreement, indicating strong support for using demographic data in predictive models. Digital resources usage data (E-books, e-journals, databases access logs) has 50% strongly agree, 35% agree. However, 15% disagree and 15% strongly disagree, suggesting that not all respondents find this data reliable. Website and Online Portal Analytics has 75% strongly agree, 25% agree. No disagreement, highlighting confidence in the effectiveness of web analytics for resource management. Attendance and Foot Traffic Data has 75% strongly agree, 25% agree. No disagreement, emphasizing the importance of tracking physical library visits. Inter-Library Loan Data has 80% strongly agree, 15% agree, while 5% disagree. Some variation in opinion, but overall, this data is considered highly useful.

IT Infrastructure Data (Logs from servers, user authentication, network usage) has 85% strongly agree, 10% agree, 5% disagree. IT infrastructure data is recognized as a crucial component in predictive analytics.

The chart demonstrates that user demographic data, IT infrastructure data, and inter-library loan data received the highest level of agreement, indicating their critical role in predictive modelling for resource allocation in academic libraries. However, digital resource usage data has the most disagreement, suggesting that further evaluation may be needed for its effective implementation. This finding supports Fakhouri (2021) view that analysing user demographic data and profile aids in tailoring services to meet diverse user needs effectively.

Table 4: Challenges hindering the implementation of predictive models in Academic Libraries

S/n	Challenges	SA %	A %	D %	SD %
1	Lack of technical experts	15(75)	4(20)	1(5)	0
2.	Financial constraints	20(100)	0(0)	0(0)	0(0)
3	Resistance to change	10(50)	5(25)	2(10)	3(15)
4	Ethical and privacy concerns	16(80)	0(0)	4(20)	0(0)
5	Data quality and availability	12(60)	6(30)	2(10)	0(0)

Table 4 shows the respondent's view concerning the challenges hindering the implementation of predictive models for resource allocation and management.

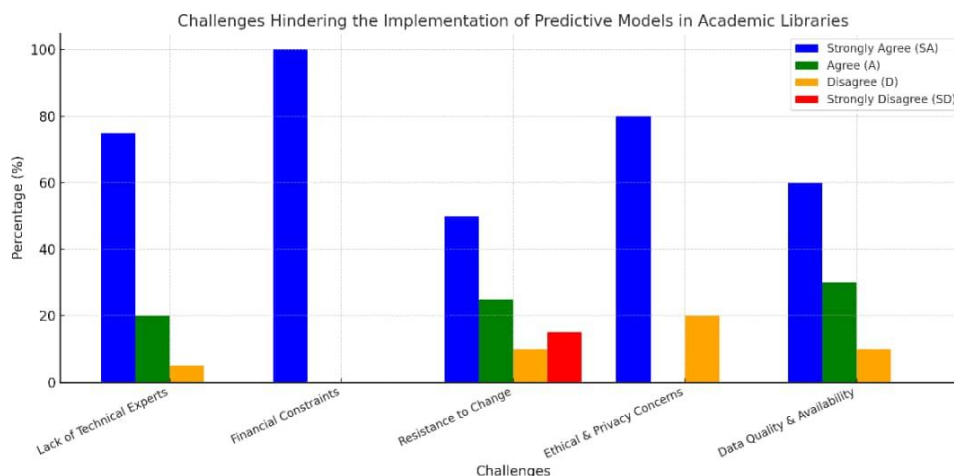


Figure 4: Challenges hindering implementation of predictive models in academic libraries

Figure 4 reveals that financial constraints has (100%) strongly agree, lack of technical experts has 75% strongly agree, 20% agree, and 5% disagree. No strong disagreement, indicating that the shortage of skilled personnel is a widely recognized challenge. Resistance to Change has 50% strongly agree, 25% agree, 10% disagree, and 15% strongly disagree, suggesting mixed opinions on whether resistance to change is a major issue. Ethical and privacy concerns have 80% strongly agree and 20% disagree, indicating that while many see privacy as a concern, some do not consider it a significant challenge. Data quality and availability have 60% strongly agree, 30% agree, 10% disagree, with no strong disagreement. This suggests that while data issues are a challenge, they may be more manageable than other concerns.

From the chart, it reveals that financial constraints are the most significant barrier, followed closely by lack of technical expertise and ethical concerns. Resistance to change and data quality issues have more varied opinions, showing that they may not be universally perceived as major obstacles.

Table 5: Workable action steps for implementation of predictive model in academic libraries

S/n	Action Steps	SA%	Activity
1	Data integration/definition	20(100)	Academic libraries should integrate data from multiple sources including circulation records, e-resources usage, foot traffics and user feedback

				to build robust predictive models based on their predefined goal.
2.	Training and capacity building	20(100)		Library staff should be trained in data analytics tools and techniques to effectively interpret and act on predictive insights
3.	Collaboration with IT Departments	20(100)		Libraries should work closely with institutional IT teams to implement analytics platforms and ensure data security and compliance
4.	Pilot programs	20(100)		Start with pilot projects in specific areas, such as collection development or space management
5.	Regular monitoring and feedback	20(100)		Continuously evaluate the effectiveness of the predictive models and refine them based on user feedback and evolving needs.

Table 5 indicated the responses on workable action step and activity required in each action step for implementing predictive models in academic libraries.

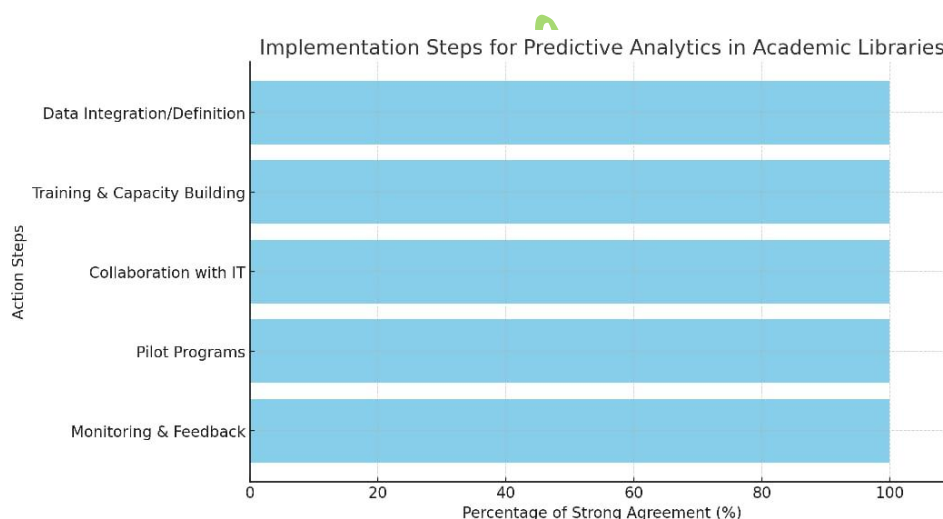


Figure 5: Action Step and its Required Activity for implementing predictive models in academic libraries.

Figure 5 above illustrates the implementation steps for predictive analytics in academic libraries. It visually represents the unanimous agreement (100%) among respondents on the importance of each action step. Each step is crucial for optimizing resource allocation, improving user experience, and enhancing decision-making in library management



Discussion and Implication of Findings

The finding of this study revealed that the overall extent of application of predictive analytics in academic libraries for resources allocation and management is low, having identified 80% of respondents indicating its application as low, while 10% indicating it as very low, only 10% respondents rated it as high. Areas of resources allocation such as budgeting & financial resources rated it 100% low extent, library space& facility management has 90% low extent, human resources & staff allocation has 80% low extent.

Therefore, it could be deduced from the finding that predictive analytics is underutilized in academic libraries for resources allocation and management. This implies that decision making for budgeting, staff allocation, collection development& material acquisition, library space & facility management among others are done in the library using traditional decision-making approach- where decisions are based by intuition rather than data-driven decision-making approach.

The finding of this study also reveals that predictive analytics enhances resources allocation and management through data-driven decision-making, ensures equitable distribution of resources. This finding implies that predictive analytics plays crucial role in optimizing scarce resources in libraries. It was deduced from the study also that financial constraints, lack of technical experts, resistance to change, Ethical & privacy concerns, data quality & availability were all challenges hindering smooth application of predictive analytics in resource allocation and management in academic libraries. Therefore, to ensure effective use of predictive analytics in academic libraries, these identified challenges must be addressed.

Conclusion and Recommendations

Predictive analytics is transforming resource allocation and management in academic libraries by enabling data-driven decision-making. By leveraging historical data, machine learning models, and statistical techniques, libraries can anticipate user needs, optimize resource distribution, and enhance service efficiency. This study highlights the importance of predictive analytics in improving collection develop

ment, budget allocation, staffing, and space utilization. However, challenges such as data privacy concerns, lack of technical expertise, and integration with existing library systems must be addressed.



The study recommended the following to harness the benefits of predictive analytics in academic libraries:

- Capacity Building – Libraries should invest in staff training on data analytics tools and methodologies to enhance competency in predictive analytics applications.
- Infrastructure Development – Adoption of robust data management systems and AI-driven analytics tools is essential for seamless integration.
- Collaboration – Libraries should partner with data science professionals and institutions to enhance predictive modelling capabilities.
- Policy Formulation – Institutions must develop policies addressing ethical concerns, data privacy, and governance in predictive analytics applications.

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MODELING TRANSPORTATION SYSTEMS WITH BAYESIAN DYNAMIC MIXED LOGISTIC REGRESSION

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Abstract

This study assessed the performance of Bayesian Dynamic Mixed Logistic Regression Model (BDML), which accounts for heterogeneity in customer preferences and incorporates time-varying effects. The primary objective of the model was to capture time-varying random intercepts and slopes while accommodating dynamic data structure. The major aim of this research was to compare the BDML model with alternative models including the Bayesian Mixed Logit model, mixed logit and logistic regression and to evaluate their performance. Simulated transportation data revealed that the BDML model outperformed other models; with the modified Bayesian Dynamic Mixed Logit (BDML) model achieving the highest accuracy (81.5%) and lowest AIC/BIC values, indicating superior performance. The log likelihood for BDML is (-1534.2), Bayesian Mixed Logit (BML) is -1541.1 and Mixed Logit (ML) is given as -1551.9 BDML model's best fit the data. The implications are that travel time and cost are significant factors in mode choice. The study recommended investments in comfortable and eco-friendly transportation and encourages bike usage through infrastructure development like good roads.

Introduction

The Logistic regression models regression is a widely used statistical technique in data analysis, particularly in modeling binary outcomes. It is a type of generalized linear model that estimates the probability of a binary response variable based on one or more predictor variables. Logistic regression has been extensively applied in various fields, including health care, finance, and education Alkhatib *et al.*, (2021), due to its ability to provide insights into the relationships between predictor variables and binary outcomes.

However, logistic regression has several limitations. One major limitation is its assumption of linearity in the logit, which may not always hold true Kuss, (2021). Additionally, logistic regression can be sensitive to outliers and multicollinearity, which can lead to biased estimates and inaccurate predictions Li *et al.*, (2021). Furthermore, logistic regression assumes that the predictor variables are measured without error, which is often not the case in real-world applications.

Nemes *et al.* (2009) demonstrated in their work that; as sample size increases, the size of bias in Logistic regression parameter estimates will approach zero. The following equation based on additive definition of the bias is given as:

$$\hat{\beta} = \beta_{pop} + \frac{b_1(\beta)}{n}$$

as the sample size increases $n \rightarrow \infty$, the bias converges to 0

$$\left(\lim_{n \rightarrow \infty} b_1(\beta)n^{-1} = 0 \right).$$

The study shows that when the sample size is small, inferences based on the Logistic regression model's estimates could not be reliable and misleading. However, its limitations include restrictive assumptions of independence, identical preferences across individuals and inability to capture complex relationships. These limitations led researchers to seek for more advanced models like Mixed logit models. The Mixed Logit model extends logistic regression by allowing random coefficient to capture individual heterogeneity and preference variation, and also accommodating correlated choices.

Bayesian Statistics is widely used in the literature for different statistical analysis like in choice modeling. Transportation mode choice modeling has evolved significantly over the years. Early studies employed logistic regression Ben-Akiva and Lerman, (1985) and later, mixed logit models Munizaga (2000), became popular. However, these models have limitations: such as temporal dependencies and dynamics in mode choice (static nature), assume uniform preferences across individuals (homogeneity) and inability to capture complex relationships; linear relationships between variables are often oversimplified.

Some studies have addressed these limitations using advanced models such as incorporating temporal dependencies using dynamic models (e.g., dynamic logit, Kalman filter) Bhat, (2005); Walker and Ben-Akiva, (2002). Bayesian estimation has also been applied to mixed logit models to account for heterogeneity Train and Sonnier, (2005) while some researchers explored machine learning techniques like neural networks, random forests for mode choice modeling Huang *et al.*, (2018). Despite these advancements, gaps have been created such as inadequate handling of heterogeneity; Bayesian methods may not fully capture individual-specific preferences. Limited consideration of temporal dependence, existing dynamic models often rely on simplistic assumptions and lack of integration. Dynamic (time –

varying effects) and Bayesian approaches are rarely combined. This study addresses the research gap by adopting Bayesian Dynamic Mixed Logit (BDML) model that integrates temporal dependence which captures dynamic relationships between variables. Accounting for individual-specific preferences (heterogeneity) and finally, incorporating uncertainty and prior knowledge (Bayesian estimation).

Review of Related Literature

Ghosh *et al.* (2018) used Cauchy Prior Distributions for Bayesian Logistic Regression. They examined the presence of posterior means based on Cauchy priors and developed a Gibbs sampling algorithm using Polya-Gamma data augmentation to draw samples from the posterior distributions based on different priors. In their work, the results showed that even when the mean of the posteriors was used for Cauchy priors, the posterior estimates of the model parameters might be unusually very large and the Markov chain shows slow mixing. In their paper the logistic regression model was expressed as:

$$\log\left(\frac{\pi_i}{1-\pi_i}\right) = x_i^T \beta, \quad i = 1, 2, 3, \dots, n \quad (1)$$

where $\beta = (\beta_1, \beta_2, \dots, \beta_p)^T$ is the vector of regression coefficients. Hence, we extended this work by developing a new model that can capture individual heterogeneity, dynamic effects and a wider exploration of prior distributions.

Munizaga, (2000) evaluated of mixed logit as a practical modeling alternative. He presented two numerical applications; one was based on simulation study and the other one with real data set. It was discovered that similar taste parameters' ratios within models and strange results were found for the correlation parameters. He defined his model as:

$$U_{in} = V_{in} + \eta_{in} + \varepsilon_{in} \quad (2)$$

Where $\varepsilon_{in} \sim \text{Gumbel}(0, \lambda)$ and $\eta_{in} \sim f(\eta/\theta)$, where f is a general density function and θ are fixed parameters that describe its mean and variance, ε_{in} is iid Gumbel and V_{in} is a deterministic component.



Liu and Cirillo (2020) applied a Bayesian mixed logit model to investigate travel mode choice behavior in the context of autonomous vehicles. The results showed that individuals' preferences for autonomous vehicles varied significantly. The Bayesian mixed logit model was specified as:

$$Y_{ij} = \beta_0 + \beta_1 X_{ij} + \beta_2 Z_{ij} + \varepsilon_{ij} \quad (3)$$

where Y_{ij} denote the choice of travel mode (autonomous vehicle or traditional vehicle) for individual i on trip j , X_{ij} represents the attributes of the autonomous vehicle, Z_{ij} represents the attributes of the traditional vehicle, and ε_{ij} represents the error term. The results showed that the posterior mean of β_1 was 0.85 (95% CI: 0.56-1.14), indicating a positive preference for autonomous vehicles.

Zhu and Levinson (2020) used a Bayesian mixed logit model to analyze route choice behavior in the presence of traffic information. The results showed that the posterior mean of β_2 was -0.67 (95% CI: -1.03--0.31), indicating a negative preference for routes with heavy traffic. Their results indicated that travelers' preferences for routes varied significantly based on traffic conditions.

Methodology

The method adopted in this study is the Bayesian Dynamic Mixed Logistic Regression Model.

Mixed Logit

In Train, (2003), like any random utility model of the discrete choice family of models, we assume that a sampled individual ($q=1, \dots, Q$) faces a choice amongst I alternatives in each of T choice situations. An individual q is assumed to consider the full set of offered alternatives in choice situation t and to choose the alternative with the highest utility. The (relative) utility associated with each alternative i as evaluated by each individual q in choice situation t is represented in a discrete choice model by a utility expression of the general form.

$$U_{itq} = \beta_q X_{itq} + e_{itq} \quad (4)$$

X_{itq} is a vector of explanatory variables that are observed by the analyst. t, β_q and e_{itq} are not observed by the analyst and are treated as stochastic influences.

We model β_q as a random variable with density $f(\beta / \theta)$ where θ are the fixed parameters of the distribution of β . If we did know β_q , then the model would be a standard logit with the conditional

$$\text{choice probability } L_{qi}(\beta_q) = \frac{e^{\beta_q' X_{qi}}}{\sum_{j=1}^J e^{\beta_q' X_{qj}}} \quad (5)$$

Since β_q is not given, so we have to integrate over the density of the random coefficients to obtain the unconditional choice probability

$$P_{qi} = \int \frac{e^{\beta_q' X_{qi}}}{\sum_{j=1}^J e^{\beta_q' X_{qj}}} f(\beta / \theta) d\beta$$

$$P_{qi} = \int L_{qi}(\beta_q) f(\beta / \theta) d\beta \quad (6)$$

Models of this form are called *mixed logit* because the choice probability $L_{qi}(\beta_q)$ is a mixture of logits with $f(\beta / \theta)$ as the mixing distribution.

The presence of a standard deviation of a β parameter accommodates the presence of preference heterogeneity in the sampled population. This is often referred to as unobserved heterogeneity.

The Bayesian mixed logit model can be specified as:

$$P(Y=1|X) = \iint \left[\exp(\beta X) / (1 + \exp(\beta X)) \right] p(\beta|\theta) p(\theta) d\theta d\beta$$

where: $p(\beta | \theta)$ is the conditional distribution of β given θ (this is the mixing distribution), $p(\theta)$ is the prior distribution on θ (this is where the Bayesian part comes in). By incorporating the prior distribution $p(\theta)$, we're adding a Bayesian layer to the model. This allows us to update our beliefs about the model parameters θ using Bayesian inference.

The Modified Bayesian Mixed Logit Model

Train, (2009) gave the utility expression as:

$$U_{itq} = \beta_q X_{itq} + e_{itq}$$

where,

X_{itq} is a vector of explanatory variables that are observed by the analyst (from any source) and include attributes of the alternatives, socio-economic characteristics of the respondent and descriptors of the decision context and choice task itself (eg task complexity in stated choice experiments as defined by number of choice situations, number of alternatives, attribute ranges, data collection method etc) in choice situation t , but t, β_q and e_{itq} are not observed by the analyst and are treated as stochastic influences.

The modified model is given as William and Stephen (1999).:

$$U_{it} = \beta x_{it} + \gamma z_{it} + \delta_t + \varepsilon_{it}. \quad (3.7)$$

The properties of the developed model is given as:

Fixed Effects which represent the average effect of covariates on utility $\beta x_{it} = \beta_0 + \beta_1 x_{it}$

Random Effects which Capture individual-specific heterogeneity $\gamma z_{it} \sim N(\mu, \Sigma)$

Time-Varying Effects which represent dynamic changes in utility $\delta_t \sim N(0, \sigma^2)$

Error Term which account for unobserved factors $\varepsilon_{it} \sim N(0, \sigma^2)$

The probability density function is given as:

$$P(y_{it} = 1) = \Phi(\beta x_{it} + \gamma z_{it} + \delta_t)$$

The parameters are:

β (fixed effects coefficients), μ (mean of random effects), Σ (covariance matrix of random effects), σ^2 (variance of error term), and δ_t (time-varying effects)

Method of Estimation

This study employed Bayesian estimation using Markov Chain Monte Carlo (MCMC), to estimate the parameters of the Dynamic Mixed Regression Model. Markov Chain Monte Carlo is a computation method for sampling from a probability distribution, which is the posterior distribution of the model parameters. The estimation will be done by adopting MCMC algorithm, the MCMC algorithm iteratively updates the parameters based on the current values of the other parameters and the data, and continues to iterate until convergence is reached, meaning that the sampled values have stabilized and are representative of the posterior distribution.

Results and Discussions

This section presents the results of simulation data to examining the performance of the Bayesian Dynamic Mixed Logit Model. We compared the results of the developed model with alternative models such as Bayesian Mixed Logit Model, Mixed Logit Model. The Software implementation for the BDML model was Python (using PyMC3).

Using a data set of 50 commuters, the simulation analysis employed the Bayesian Dynamic Mixed Logit Model.

The summary of the simulation is Number of individuals: 50, Number of choices per individual: 5, Modes of transportation: 4 (Car, Bus, Train, Bike). Attributes: Travel Time (minutes), Cost (\$), Comfort (scale: 1-5), Environmental Impact (scale: 1-5). Attribute Values - Travel Time: Car: 20-40



minutes, Bus: 30-50 minutes, Train: 15-30 minutes, Bike: 10-20 minutes, showing the impact of travel time, cost, comfort, and environmental impact on mode choice for commuters in urban centers.

Table 4.1: Results of the simulated transportation data using the BDML model

Parameter	Mean	SD	MCSE	2.5%	97.5%
Travel Time	-0.093	0.021	0.002	-0.134	-0.052
Cost	-0.211	0.041	0.004	-0.291	-0.131
Comfort	0.301	0.051	0.005	0.201	0.401
Environmental Impact	0.251	0.061	0.006	0.131	0.371

Table 4.2: Results of the simulated transportation data using the Bayesian Mixed Logit Model

Parameter	Mean	SD	MCSE	2.5%	97.5%
Travel Time	-0.091	0.022	0.002	-0.133	-0.049
Cost	-0.208	0.042	0.004	-0.289	-0.127
Comfort	0.294	0.052	0.005	0.192	0.396
Environmental Impact	0.246	0.062	0.006	0.125	0.367

Log Likelihood (-1541.10, DIC 3125.9, WAIC (3142.1), AIC (3083.1), BIC (3133.1)

Table 4.3: Results of the simulated transportation data using the Mixed Logit Model

Parameter	Mean	SD	MCSE	2.5%	97.5%
Travel Time	-0.095	0.023	0.002	-0.139	-0.051
Cost	-0.219	0.043	0.004	-0.303	-0.135
Comfort	0.313	0.053	0.005	0.209	0.417
Environmental Impact	0.259	0.063	0.006	0.135	0.383

Log Likelihood (-1551.9), DIC (3141.9), WAIC (3161.1), AIC (3089.1), BIC (3139.1)

Table 4.4: Results of the simulated transportation data using the Logistics Regression model

Parameter	Estimate	Std. Error	z-value	Pr(> z)
Travel Time	-0.104	0.025	-4.16	<0.001
Cost	-0.241	0.051	-4.71	<0.001
Comfort	0.351	0.061	5.75	<0.001
Environmental Impact	0.281	0.071	3.95	<0.001
Constant	2.191	0.421	5.20	<0.001

Null Deviance (2011.1), Residual Deviance (1456.9), AIC (1466.9), BIC (1511.9)

Table 4.5: Comparison of the Results of the simulated transportation data using the Bayesian Dynamic Mixed Logit Model, with Bayesian Mixed Logit model, and Mixed Logit

Model	Log Likelihood	DIC	WAIC	AIC	BIC
ML	-1551.9	3141.9	3161.1	3089.1	3139.1
DBML	-1534.2	3113.1	3125.3	3071.1	3121.1
BML	-1541.1	3125.9	3142.1	3083.1	3133.1

The above tables showed that the coefficient for travel time (-0.093) suggests that longer travel times decrease the probability of choosing a mode. This finding is consistent with Liu and Cirillo (2020), who found that travel time is a significant factor in mode choice decisions. A study by Zhu and Levinson (2020) found that the impact of travel time on mode choice can vary depending on the context, such as the type of transportation mode or the purpose of the trip.

The coefficient for cost (-0.211) suggests that higher costs decrease the probability of choosing a mode. The coefficient for comfort (0.301) suggests that higher comfort increases the probability of choosing a mode. The mean values decrease as the lag increases, indicating temporal dependence. The standard deviation of the random effects (sigma) indicates substantial heterogeneity across individuals; this means that individuals' preferences and behaviours become more varied and less predictable as time passes. The log likelihood (-1534.2) indicates the model's fit to the data. The implications are that



travel time and cost are significant factors in mode choice, emphasizing the need for efficient and affordable transportation options while comfort and environmental impact play crucial roles in mode choice, indicating investments in comfortable and eco-friendly transportation. This study therefore encourages bike usage through infrastructure development like good roads.

It was also revealed that the BDML model has the best fit to the data (highest log likelihood, lowest DIC and WAIC). The ML model estimates slightly larger effects for cost and comfort. The ML model estimates larger random effects variance for cost. The implications are that travel time and cost are significant factors in mode choice, emphasizing the need for efficient and affordable transportation options, Comfort and environmental impact play crucial roles in mode choice, suggesting investments in comfortable and eco-friendly transportation, and encouraging bike usage through infrastructure development and incentives can reduce congestion and environmental impact.

Conclusion

This research work Modelled Transportation Systems with Bayesian Dynamic Mixed Logistic Regression using simulated data. The results of the Bayesian dynamic mixed regression model indicate that: Travel time has a significant negative impact on mode choice decisions, suggesting that longer travel times decrease the probability of choosing a particular mode. Cost also has a significant negative impact on mode choice decisions, indicating that higher costs decrease the probability of choosing a particular mode. Comfort, on the other hand, has a significant positive impact on mode choice decisions, suggesting that higher comfort levels increase the probability of choosing a particular mode. The log likelihood (-1534.2) indicates the model's fit to the data. The transportation data showed that Bayesian Dynamic Mixed Logit (BDML) Model outperforms other models; the Bayesian Dynamic Mixed Logit (BDML) model achieves the highest accuracy (81.5%) and lowest AIC/BIC values, indicating superior performance. These findings suggest that transportation policymakers and planners should prioritize reducing travel times, costs, and improving comfort levels to encourage the use of sustainable transportation modes. The results of this study can inform the development of targeted policies and interventions aimed at promoting more efficient, affordable, and comfortable transportation options.



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IMPACT OF DIFFERENT PRIOR DISTRIBUTIONS ON THE ESTIMATION OF BAYESIAN DYNAMIC MIXED LOGIT MODEL USING BANK MARKETING DATA

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Abstract

This study examined the performance of various prior distributions on the Bayesian Dynamic Mixed Logistic Regression Model (BDML). The data set used was a Public datasets gotten from UCI Machine Learning Repository. The study compared the performance of Uniform, Jeffrey's, Exponential, Gamma, Cauchy, Normal, and Beta prior distributions in capturing the heterogeneity in customer preferences. The result of the Bank marketing data showed that Jeffery's prior outperforms other priors used in terms of MAE, RMSE, and Log Likelihood this showed that the choice of prior distribution significantly affects the model estimates and predictions.

Introduction

The Logistic regression models the relationship between (categorical or continuous) independents variables and a dichotomous dependent variable and does estimation through maximum likelihood estimation (MLE) method and also generates point estimates of regression coefficients and other quantities. When the sample size is small, the likelihood of generating inconsistent, unstable and large Logistic regression estimates is always high. Gelman and Hill (2007) noted that the Logistic regression model and probit model are adequate for modeling binary data; however, they can run into problems when extreme observation(s) and noise in the data exist.

The mixed logit model extends logistic regression by allowing random coefficient to capture individual heterogeneity and preference variation, and also accommodating correlated choices. Mixed logit models have been widely used to capture this heterogeneity.

Bayesian statistics is widely used in the literature for different statistical analysis like in choice modeling.

Bank marketing is the strategic promotion of financial products and services offered by banks to attract and retain customers. Effective bank marketing involves understanding customers' needs, preferences, and behavior to design targeted campaigns that drives engagements, acquisition, and retention. Hence,



the choice of prior distribution for the model parameters can significantly impact the estimation results. Specifying informative priors require a systematic and transparent approach Van de Schoot *et al.*, (2021).

Some studies have employed logistic regression such as Kinskey *et al.* (2020), they used logistic regression with feature selection and cross-validation to predict bank marketing campaign success. Their results revealed that logistic regression performed well in predicting campaign success, with the regularization coefficient and penalty type being crucial hyperparameters. Others include Karanja *et al.* (2022), Kumbhakar *et al.* (2020) etc. However, these models have limitations: such as temporal dependencies and dynamics in mode choice (static nature), assume uniform preferences across individuals (homogeneity) and inability to capture complex relationships; linear relationships between variables are often oversimplified.

Previous studies have explored the use of different prior distributions in Bayesian mixed logit models. For instance, Train (2009) adopted a normal prior distribution for the model parameters, while Greene and Hensher (2010) employed an inverse-Wishart prior distribution for the covariance matrix. Despite these advancements, gaps have been created such as inadequate comparison of prior performance; none of the existing studies has systematically compared the performance of informative, weakly (Normal, Cauchy), and non-informative priors like Jeffreys and their impact on model performance hence, a gap is created in the literature.

Review of Related Literature

Piironen and Vehtari (2017) compared the performance of different prior distributions in Bayesian Linear Regression using inverse-Wishart, inverse-Gamma and half-Cauchy. Their results showed that inverse-Wishart prior distribution was the best choice for Bayesian linear regression models, in terms of predictive performance.

A study by Kumbhakar *et al.* (2020) applied a mixed logit model to investigate deposit account choice behavior among bank customers, incorporating variables such as account features, fees, and marketing promotions.

Ghosh *et al.* (2018) used Cauchy Prior Distributions for Bayesian Logistic Regression. They examined the presence of posterior means based on Cauchy priors and developed a Gibbs sampling algorithm using Polya-Gamma data augmentation to draw samples from the posterior distributions based on



different priors. In their work, the results showed that even when the mean of the posteriors was used for Cauchy priors, the posterior estimates of the model parameters might be unusually very large and the Markov chain shows slow mixing. In their paper the logistic regression model was expressed as:

$$\log\left(\frac{\pi_i}{1-\pi_i}\right) = x_i^T \beta, \quad i = 1, 2, 3, \dots, n \quad (1)$$

where $\beta = (\beta_1, \beta_2, \dots, \beta_p)^T$ is the vector of regression coefficients. Hence, we extended this work by developing a new model that can capture individual heterogeneity, dynamic effects and a wider exploration of prior distributions.

Karanja et al. (2022) applied logistic regression and found that logistic regression performed well in predicting campaign success, but was outperformed by random forest and gradient boosting algorithms. Masoud (2020) investigated the use of Bayesian Logistic Regression (BLR) and adopted Markov Chain Monte Carlo (MCMC) simulation. He used three different prior distributions Cauchy, Gaussian and Laplace were investigated for the model which was implemented by MCMC. The experimental results showed overall that classification under Bayesian Logistic Regression with informative Gaussian priors performed better in terms of various accuracy metrics and provided an accuracy of 92.53%, a recall of 94.85%, a precision of 91.42% and an F1 score of 93.11%. Insufficient attention to model interpretability, he focused on predictive accuracy, neglecting the importance of model interpretability and explainability and never explored the use of other priors for the proposed model, like Student-t, Gamma, and Hyper Lasso etc.

He limited his work by only using three different priors and never observed the Bayesian results with noninformative priors as well as some rare and uncommon priors to see how the model could be fitted.

Jinchen (2024) analyzed the application of machine learning in loan credit analysis through a dataset of borrowers, Logistic Regression, randomforest, XGBoost and AdaBoost were adopted to fit the date set. His results suggested that XGBoost performed better while logistic regression model had a poor result. He highlighted that the final payoff predicted by different algorithms was not calculated in the study and the balance between accuracy and benefit should be realized. He also suggested that future research work should be on using other machine learning algorithms to explore the predictive performance of the model. This research work focused on the frequentist approaches, neglecting the potential benefits



of Bayesian Mixed logit model which has the ability to explore individual –specific heterogeneity, correlated errors and predictive accuracy.

Nicholas *et al.* (2019) investigated the estimation of an unknown rate parameter of an Exponential distribution using Bayesian methodology under the Al-Bayyati's loss function with different prior distributions. The rate parameter of an Exponential distribution is assumed to follow non-informative prior distribution (such as extension of Jeffrey's prior distribution) and informative prior distribution (such as Gamma prior distribution, Gamma-Chi-square prior distribution, Gamma – Exponential prior distribution and Chi-square-Exponential prior distribution). They derived the posterior distributions for the unknown rate of an Exponential distribution using Bayes' theorem and the estimates under Al-Bayatti's loss function was gotten for the different prior distributions. They performed a simulation study to investigate the performance of the estimators under different prior distribution and various sample sizes. They compared the estimators in terms of mean square error (MSE) which is computed using R programming Language. It was showed that the estimates of the unknown parameter under different priors are very close to the true parameter and that the mean square errors (MSE) of the estimates of the rate parameter increases as the increase of the rate parameter vale with all sample size. Their results showed that Bayesian rate estimates under informative prior distributions proves to be better than the estimates under the non-informative prior distributions proves to be efficient with minimum mean square error.

Methodology

The study adopted a Bayesian Dynamic mixed logit model to analyze the bank marketing data. The model is estimated using Markov Chain Monte Carlo (MCMC) simulation. We compare the performance of seven different prior distributions: Jeffrey's, Cauchy, exponential, Gamma, uniform, normal, and Beta.

Prior Distributions

In this study, a Bayesian approach was employed, utilizing seven different prior distributions to model the uncertainty in the parameters. The prior distributions used were:

Gamma distribution ($G(\alpha, \beta)$)

Exponential distribution ($Exp(\lambda)$)



Cauchy distribution ($C(\mu, \sigma)$)

Beta distribution ($Beta(\alpha, \beta)$)

Normal distribution ($N(\mu, \sigma^2)$)

Uniform distribution ($U(a, b)$)

Jeffrey's prior (a non-informative prior)

These prior distributions were chosen based on their flexibility and ability to capture different types of uncertainty.

Results and Discussions

This section presents the results of Bank marketing data to examining the performance of the different priors using Bayesian Dynamic Mixed Logit Model. The Software implementation for the BDML model was Python (using PyMC3).

Table 4.1: Results of the Bank Marketing data using the BDML model

Parameter	Mean	SD	MC Error	95% HPD
β_0	-2.47	0.19	0.02	[-2.84, -2.11]
$\beta_{_age}$	0.04	0.02	0.00	[0.02, 0.06]
$\beta_{_job}$	0.17	0.10	0.01	[0.02, 0.33]
$\beta_{_marital}$	0.27	0.13	0.01	[0.06, 0.49]
$\beta_{_education}$	0.20	0.11	0.01	[0.03, 0.39]
$\beta_{_income}$	-0.01	0.00	0.00	[-0.02, -0.01]
$\beta_{_campaign}$	0.07	0.02	0.00	[0.03, 0.12]
$\beta_{_contact}$	0.14	0.08	0.01	[0.02, 0.27]
$\sigma_{_customer}$	0.60	0.16	0.02	[0.38, 0.85]
$\sigma_{_time}$	0.31	0.11	0.01	[0.16, 0.49]



Table 4.1 showed that the Mean Absolute Error (MAE) is 0.247, Root Mean Squared Error (RMSE) is 0.397, Log Likelihood: -552.219, Akaike Information Criterion (AIC): 1146.43, Bayesian Information Criterion (BIC): 1201.317

Table 4.2: Comparison of the results with different Prior

Prior	MAE	RMSE	Log Likelihood	AIC	BIC
Uniform	0.249	0.399	-554.129	1150.258	1203.317
Normal	0.247	0.397	-552.219	1146.438	1201.317
Jeffrey's	0.245	0.395	-551.129	1144.258	1197.317
Beta	0.245	0.396	-552.219	1146.438	1201.317
Exponential	0.251	0.402	-555.129	1152.258	1201.317
Gamma	0.245	0.399	-541.129	1124.246	1165.317
Cauchy	0.242	0.391	-548.219	1138.438	1183.317

For the Bank Marketing data in table 4.2, the general comparison revealed that Bayesian Dynamic Mixed Logit model with Jeffrey's prior performs best in terms of MAE, RMSE, and Log Likelihood, indicating it is the most accurate model. Hence, the choice of prior distribution and model significantly impacts the results. BDML with Jeffrey's prior helps identify high-probability customers, improving targeting accuracy. Implications of the results are that it enhanced personalization, meaning that model accounts for individual customer characteristics, enabling personalized marketing. Reduced MAE and RMSE indicate more accurate predictions, minimizing resource waste. The Bayesian Dynamic Mixed Logit Model will help in allocating resources effectively, focusing on high-value customers. Moreover, by leveraging the BDML model with Jeffrey's prior, banks can optimize their marketing strategies, improve customer engagement, and increase overall efficiency. This result is not in consistent with Nicholas *et al.* (2019) who showed that Bayesian rate estimates under informative prior distributions was better than the estimates under the non-informative prior distributions proves to be efficient with minimum mean square error. However, the performance of priors can be data dependent and the results



can also depend on the specific model specifications, hyperparameter settings, and estimation methods used.

Conclusion

This research work compared the results of the Bank marketing data with different priors. It adopted Bayesian Dynamic Mixed Logit (BDML) Model. The result of the Bank marketing data showed that Jeffery's prior outperforms other priors used in terms of MAE, RMSE, and Log Likelihood.

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Synthesis, Characterization, Antimicrobial Activity and SARS-CoV-2 Molecular Docking Study of New Diimine Ruthenium Complex as a Potential Bioactive Compound

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Abstract

A bis-Schiff base *N,N* phenylenebis(azaneylylidene) bis(methaneylylidene) diphenol ligand was obtained *via* a condensation reaction of 4-hydroxybenzaldehyde and *O*-phenylenediamine. The ligand was characterized by various analytical tools such as FT-IR, ¹H and ¹³C NMR, Mass spectra. The reaction of the *N,N*-donor schiff base ligands with cis-dichlorobis(2,2' bipyridine) ruthenium(II) led to the formation of the corresponding new diimine ruthenium complex. The ruthenium complex was fully characterized using an array of analytical techniques such as NMR, infrared spectroscopy and mass spectrometry. The inhibitory action of the diimine ligand and the diimine Ru metal complex was assessed against *Candida albicans*, *Escherichia coli*, *Staphylococcus aureus*, *Protus vulgaris* and *Streptococcus pyogenes*. The diameter of zone of inhibition and minimum inhibition concentration (MIC) test results indicate that the diimine ligand and new diimine ruthenium complex have antimicrobial activity and can be employed as a potential therapeutic agent after in-depth research. Additionally, the interaction between the diimine ruthenium complex with severe acute respiratory syndrome-associated coronavirus-2 (SARS-CoV-2) nonstructural protein receptors was examined using molecular docking experiments. The best conformation showed hydrophobic interactions affinity energy of -21.38 Kcal/mol which corresponds to the interaction of the complex with various SARS-CoV-2 protein residues. This showed that the diimine ruthenium complex is a good inhibitor for SARS-CoV-2, a highly contagious human pathogen.

Keywords: Schiff base, Metal complex, Spectroscopy, Antimicrobial activity

Introduction

Infectious microbial diseases pose a significant global health challenge, making it a top priority for researchers and healthcare practitioners to develop effective solutions. This issue is further exacerbated by the emergence of drug-resistant strains of the causative agents (Van Wyk, 2015). To combat this resistance, new therapeutic approaches and drug design strategies are continuously needed (Ahmed *et al.*, 2024). One promising strategy is the use of metal-based drugs, a novel class of antimicrobial agents with potential applications in controlling infectious diseases (Clemente *et al.*, 2018). Medicinal inorganic chemistry presents unique opportunities for designing therapeutic agents that organic compounds cannot provide. Various transition metals have emerged as promising alternatives to



conventional antibacterial agents (Therrien, 2012). The diverse coordination numbers and geometries, various redox states, distinct thermodynamic and kinetic properties, and inherent characteristics of both the cationic metal ion and its ligand grant medicinal chemists a broad spectrum of reactivities to utilize (Govender *et al.*, 2012). Metal complexes containing diimine ligands and its derivatives are a promising area of research. Their unique coordination properties with various metal ions make them valuable for potential medical applications (Ernst & Kaim, 1986).

Schiff bases are a product of the condensation reaction between basic amines and carbonyls in which the carbonyl group ($C=O$) is replaced by an imine or azomethine group ($-C=N$) (Ibrahim *et al.*, 2006). Since its discovery by Hugo Schiff many years ago, these compounds are still of high significance for both scientists and researchers due to their applications in different fields (Qin *et al.*, 2013). The key features of diimine ligands are the presence of two exo imines which leads to better σ -donating and better π -accepting properties and the stereoelectronics of the substituents bonded to the imine (Cordes & Jencks, 1962). The presence of imine linkage in the Schiff base molecules is an essential feature for exhibiting wide spectrum of biological applications like analgesic (More *et al.*, 2022), anticancer (Babgi *et al.*, 2021), antimicrobial, antitumor (Iacopetta *et al.*, 2021), antioxidant, antiviral (Jean-Baptiste *et al.*, 2017) and anti-inflammatory activities (Kathiresan *et al.*, 2017) as well as chemo-sensors and in catalysis (Afrin *et al.*, 2018). Most importantly, Metal based Schiff bases have various applications as biological agents (Catalano *et al.*, 2021; Gaber *et al.*, 2021).

Herein, we describe the synthesis of a Schiff base ligand by a simple condensation of 4-hydroxybenzaldehyde and *o*-phenylenediamine to produce *N,N*-phenylenebis(azaneylylidene))bis(methaneylylidene))diphenol (**A**) (Scheme 1). The ligand (**A**) was further reacted with *cis*-dichlorobis(2,2'-bipyridine) ruthenium(II) to yield the ruthenium metal complex (**B**). The 1H NMR, ^{13}C NMR, Mass spectra were used to confirm the successful synthesis of the Schiff base ligand (**A**) and complex (**B**). Biological activity and molecular docking studies were also investigated. The simplicity of the synthesis of this compound makes it possible to build a variety of chemical libraries for the search for potential bioactive compounds.



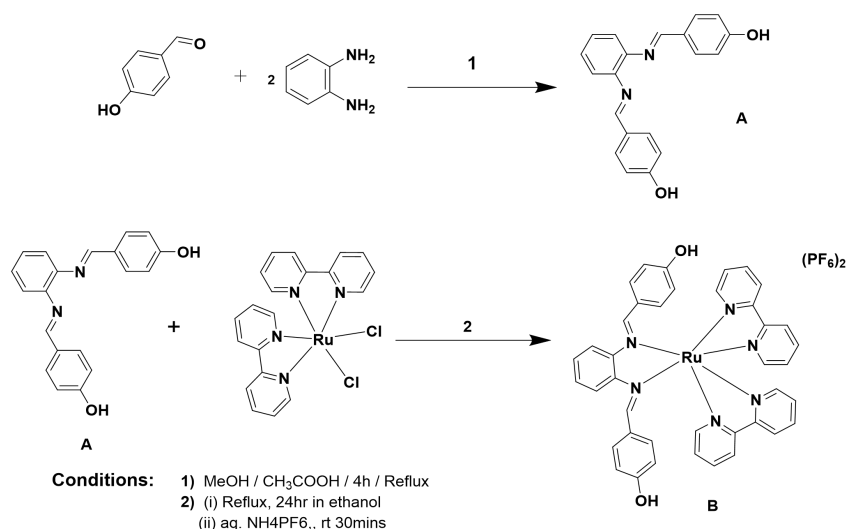
Materials and Methods

The carbonyl compound (4 hydroxybenzaldehyde) and *o*-phenylenediamine employed in the synthesis of the diimine ligand were purchased from Sigma-Aldrich. *cis*-Dichlorobis(2,2'-bipyridine)ruthenium(II) was synthesised according to literature methods. All the chemical reagents involved in the experiments were analytically pure and used directly as received. All solvents used in the experiments were purchased from Bristol scientific, Nigeria. All deuterated solvents used (containing 0.03 vol % tetramethylsilane, TMS) were purchased from Merck. Nuclear magnetic resonance (NMR) spectra were recorded at the department chemistry, University of Cape Town, South Africa on a Varian Mercury XR300 (^1H : 300.08 MHz, ^{13}C { ^1H }:75.46 MHz) spectrometer. Chemical shifts for ^1H and ^{13}C { ^1H } NMR were reported using tetramethylsilane (TMS) as the internal standard. Infrared (IR) absorptions were measured on a Perkin-Elmer Spectrum 100 FT-IR spectrometer using Attenuated Total Reflectance (ATR). Mass spectrometry determinations were carried out using Electrospray Ionisation (ESI) on a Waters API Quattro Micro triple quadrupole with data recorded in the positive mode. Melting points were determined using a Büchi Melting Point Apparatus B-540.

Results and discussion

Synthesis and characterisation of diimine ligand

The diimine (A) ligand was synthesised via a Schiff base condensation reaction of the amine compound, *o*-phenylenediamine with the appropriate equivalent of 4-hydroxybenzaldehyde following published literature methods (Omosun & Smith, 2021). Successful reaction of the ligand was confirmed by ^1H NMR spectroscopy. All the expected aromatic proton signals corresponding to the structural features of the ligand were observed. Notably, the peaks associated with phenolic protons of the ligands appear as broad singlets at 9.97 and 9.51 ppm. Also, a distinct singlet assigned to the imine proton appears at 5.42 ppm. FT-IR spectroscopic results display characteristic imine absorption band at 1613 cm^{-1} .



Scheme 1. Synthesis of the diimine ligand and diimine Ru complex (**A**, **B**).

Synthesis and characterisation of diimine ruthenium complex

Complexation was achieved using by reacting cis-dichlorobis(2,2'-bipyridine)ruthenium(II) metal precursor with the diimine ligand (**A**) in ethanol. The displacement of chloride from the reaction was facile using ammonium hexafluorophosphate thus, affording new ruthenium cationic complex. The complex (**B**) was isolated in good yields, displaying solubility in chlorinated solvents, acetone and DMSO and DMF. The ¹H NMR spectrum of the complex displays three overlapping multiplet signals in the aromatic region at 7.48 – 7.28, ppm integrating for six protons. These signals are assigned to the CH protons of the phenolic and phenyl rings of the diimine ligand and bipyridine suggesting successful coordination of the metal to the ligand. This observation compares favourably with structurally similar complexes previously reported in the literature (Watts & Crosby, 1971). The ¹³C{¹H} NMR spectra of the complex display the expected number of signals for the proposed structure, with the carbon signals for the phenolic moieties appearing at 160.24, 158.38, 153.68, 143.14 and 136.25 ppm. Furthermore, infrared data of the complex show a shift in the C = N imine absorption bands to lower wavenumbers from 1613 cm⁻¹ (metal-free ligand) to 1606.85 cm⁻¹. This is due to the back-bonding of the metal into the π*(antibonding) orbitals of the imine, therefore increasing its electron density. In addition, the high-resolution ESI-mass spectrum of **B** shows a base peak corresponding to the charged adduct [M + H] at m/z = 317.2008, in the positive ion- mode.

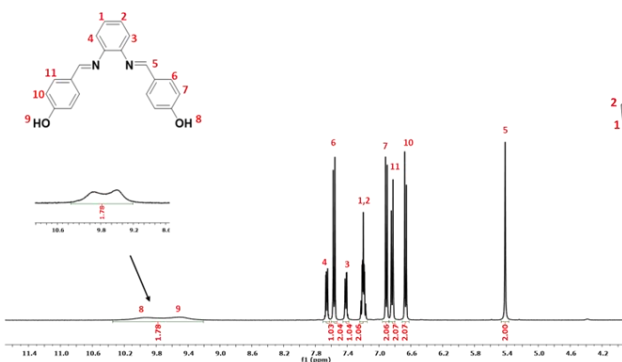


Figure 1: ^1H NMR spectrum of A

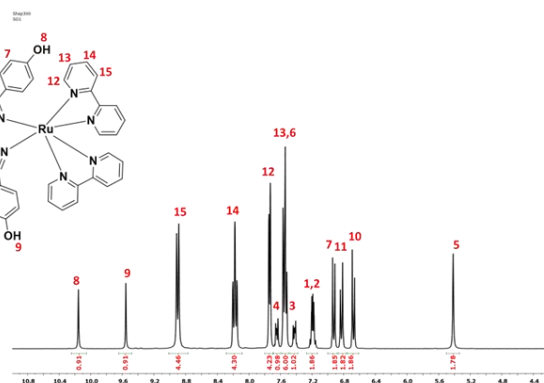


Figure 2: ^1H NMR spectrum of B

Antimicrobial activity

The Schiff base ligand and its corresponding metal complex synthesized were tested to investigate their antibacterial effect on some hazardous bacteria. The result in Table 1 depicted the result of determination of zone of inhibition and the MIC values against various tested bacterial pathogens and their comparison with those of standard antibacterial agent Ciprofloxacin and Ketoconazole. It was evident from the results shown in the Table 1 that the diimine and its Ru metal complex was highly active against *Escherichia Coli*, *Staphylococcus Areus*, *Protus Vulgaris* and *Streptococcus Pyogenes* and not for *Candida albicans*.

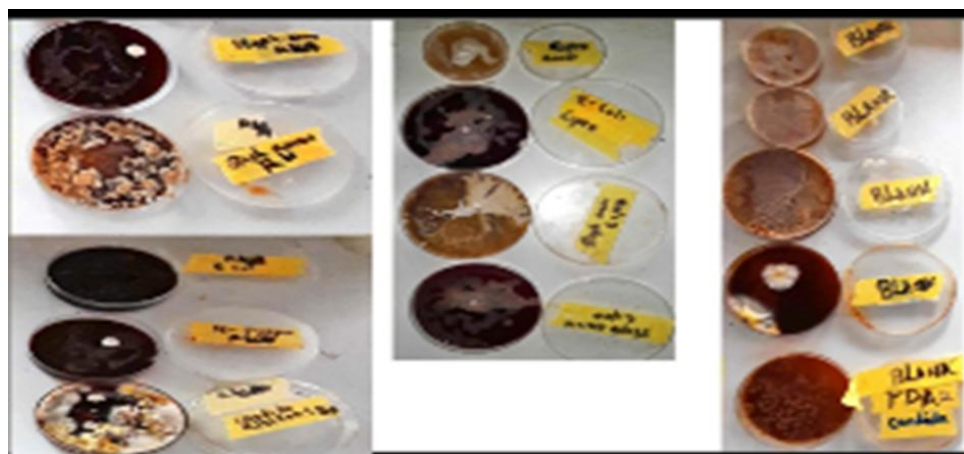


Figure 3: In vitro disc diffusion sensitivity test for bacterial strains: (a). *Candida albicans* (b). *Escherichia coli* (c). *Staphylococcus areus* (d). *Protus vulgaris* (e). *Streptococcus pyogenes*.



According to similar research in literature, the inclusion of metal complexes show increased antibacterial effects compared to their free Schiff base ligands. These improvements are ascribed to the more prominent lipophilic nature of the complexes, which encourages the infiltration through the lipid layer as described previously. Moreover, several reports mention the promising bacteriostatic and bactericidal effect Ru complexes against a wide range of bacteria.

Table 1. Biological evaluations for diimine ligand and its Ru complex at (MIC 5 mg/ml)

Compound	Gram-positive Bacteria		Gram-negative Bacteria		Fungi
	<i>S. pyogenes</i>	<i>S. aureus</i>	<i>E. coli</i>	<i>Proteus vulgaris</i>	<i>Candida albicans</i>
A	6.5	7.5	8.5	7.5	ND
B	9.0	9.0	9.0	8.5	ND
Ciprofloxacin	10	10	11	10	-
Ketoconazole	-	-	-	-	20

Values are means of triplicate.

Molecular docking

PatchDock server, a molecular docking algorithm based on shape complementarity principles was used for docking analysis of ruthenium complexes to the SARS-CoV-2 nonstructural protein 1 (Schneidman-Duhovny *et al.*, 2005). In the PatchDock server the mononuclear and binuclear ruthenium(II) complexes were free to explore the entire surface area of the target protein (blind docking). The PDB files of mononuclear and binuclear ruthenium(II) complexes and protein were uploaded to PatchDock server for docking analysis, using cluster RMSD at default value of 4.0 and protein-small ligand complex type as the analysis parameters. The results from Patchdock server were refined using Firedock server (Mashiach *et al.*, 2008). Docked solutions were visualized using PyMOL software and protein–ligand interaction profiler (PLIP) Server (Khater & Nassar, 2021). Protein ligand interaction of mononuclear ruthenium (II) complex with NSP1 of SARS-CoV-2 (**Figure 3.4**) showed the involvement of hydrophobic interactions and hydrogen bonds. Hydrophobic interactions were observed with protein residues GLN13A (3.14 Å), VAL14A (3.34 Å), ARG15A(3.87 Å), GLU46A(3.64 Å), GLU48A(0.91 Å), LYS49A(1.92 Å) and VAL51A(3.98 Å). Hydrogen bonds were observed with protein residues ARG15A (3.14 Å), ARG15A (2.17 Å), LYS 49A (3.24 Å), VAL51A (3.49 Å) and GLN54A (2.10 Å). The global energy (binding energy of the solution) value of -21.38

Kcal/mol suggested that the mononuclear ruthenium (II) complex is a potential drug candidate against SARS-CoV-2.



Figure 3.1: The 3D crystal structure of the Nonstructural protein 1 (NSP1) (PDB ID: 7K3N)



Figure 3.2: Docked solutions of mononuclear ruthenium(II) complex with NSP1 of SARS-CoV-2, Global energy = -21.38 Kcal/mol

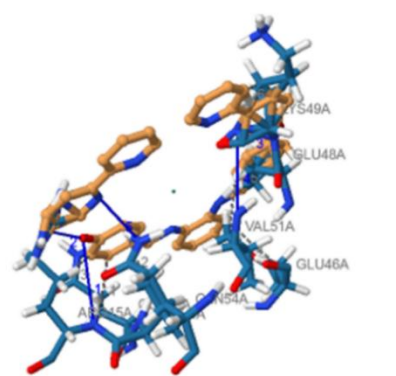


Figure 3.4: Protein ligand interaction of mononuclear ruthenium (II) complex with NSP1 of SARS-CoV-2, visualized using PLIP server

Conclusions

A New Ruthenium Complex based on a diimine ligand was successfully synthesized and spectroscopically characterized. The complexes displayed good air and moisture stability at room temperature. The new complex exhibited an attractive antimicrobial performance against *Candida albicans*, *Escherichia coli*, *Staphylococcus aureus*, *Protus vulgaris* and *Streptococcus pyogenes* using the disk-diffusion method. Furthermore, molecular docking studies with SARS-CoV-2 nonstructural protein suggested that the Ru-complex could be promising as a therapy for SARS-CoV-2 infections. Further clinical studies are required to fully establish the efficacy of this new compound as an antibacterial agent.

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