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General Information about Journal of Agriculture and Agricultural Technology

Background:

The Journal of Agriculture and Agricultural Technology, Minna, was established in the early 90s with Prof T.Z. Adama as the pioneer Editor-in-Chief. It is housed within the School of Agriculture and Agricultural Technology of the Federal University of Technology, Minna, Nigeria. The journal has been a prominent platform for disseminating research and knowledge in the field of agriculture and related technologies.

Philosophy:

The journal operates with the philosophy of advancing agricultural research and technology through the publication of original works and review articles. It aims to foster innovation, promote sustainable agricultural practices, and contribute to the growth of the agricultural sector. By providing a scholarly space for researchers and experts, the journal plays a vital role in the academic and practical development of agriculture and related areas.

Management:

Under various visionary leadership and editorial teams, the Journal of Agriculture and Agricultural Technology, Minna, has maintained a commitment to quality and excellence. The management is dedicated to upholding rigorous editorial standards, ensuring the publication of high-impact research, and facilitating a dynamic platform for collaboration and knowledge exchange within the agricultural community.

Future Prospects:

The journal has demonstrated remarkable growth over the years, evolving from an annual publication to a biannual one. Looking forward, there are ambitious plans to transition to a quarterly publication schedule. This strategic move reflects the journal's commitment to keeping pace with the rapid advancements in agricultural research and technology and providing a more frequent outlet for the dissemination of groundbreaking findings.

The Journal of Agriculture and Agricultural Technology, Minna, aspires to expand its readership and impact, reaching an even larger community at a faster rate. By doing so, it aims to contribute significantly to the global discourse on innovative solutions to the challenges facing agriculture and related areas. The future prospects include leveraging technology to enhance accessibility, collaborating with international researchers, and maintaining a steadfast commitment to excellence in agricultural research dissemination.

The journal has a rich history, a clear philosophical foundation, effective management, and ambitious plans for the future. Its evolution from an annual to a quarterly publication is a reflects its adaptability and commitment to advancing agricultural knowledge and technology.

EDITORIAL

Journal of Agriculture and Agricultural Technology (JAAT)
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Dear Valued Readers, Colleagues, and Esteemed Contributors,

It is with immense pleasure that the Editorial Board of the Journal of Agriculture and Agricultural Technology (JAAT) presents Volume 14, Issue 3 (Tri-Quarterly Edition, 2025). This marks a significant milestone as we inaugurate the tri-quarterly publication model—an advancement reflecting our steady growth and the increasing quality of scholarly contributions received globally.

Key Highlights of This Edition

- Tri-Quarterly Launch: This issue officially marks JAAT's transition to a tri-quarterly publication schedule, expanding the journal's capacity to disseminate timely and impactful agricultural research.
- Thematic Coverage: The issue features diverse, cutting-edge studies addressing pressing challenges in sustainable agriculture, agrotechnology, and rural development.
- Digital Accessibility: With our Online-First policy now fully implemented, JAAT ensures open and early access to peer-reviewed research worldwide.
- Archival Modernization: Previous volumes are fully digitized for comprehensive online access (https://journal.futminna.edu.ng/index.php/jaat/issue/archive), with corresponding print editions to follow shortly after digital release.

Acknowledgements and Gratitude

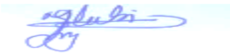
- Editorial Board: We extend our profound appreciation to members of the Editorial Board for their unwavering commitment to scholarly excellence and rigorous peer review, even amidst an intensified 2024–2025 publication schedule.
- Peer Reviewers: Our deepest gratitude goes to our reviewers whose expertise and diligence continue to uphold JAAT's high academic standards.

- Institutional Support: We recognize the invaluable encouragement and partnership of the School of Agriculture and Agricultural Technology and the Federal University of Technology, Minna for their continued institutional support.
- Contributors and Readers: Finally, we thank our authors and readers for their enduring trust, engagement, and commitment to advancing agricultural science and technology.

Looking Ahead

As JAAT embraces its new tri-quarterly rhythm, we remain committed to excellence, inclusivity, and innovation. We look forward to curating special thematic issues and expanding our international collaborations in agricultural science, technology adoption, and climate-resilient food systems.

We invite continued submissions, readership, and participation in our journey to make JAAT a leading voice in African and global agricultural research.



Prof. O. J. Alabi
Editor-in-Chief
Journal of Agriculture and Agricultural Technology (JAAT)
Federal University of Technology, Minna, Nigeria

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GROWTH AND YIELD OF RICE (*Oryza sativa* L.) AS INFLUENCED BY PLANTING METHODS AND WEED MANAGEMENTIN BADEGGI AND LAFIA, NIGERIA

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ABSTRACT

A multi-locational field experiment was conducted during the rainy seasons of 2022 at the Teaching and Research Farm of the Faculty of Agriculture, Nasarawa State University, Keffi Shabu-Lafia Campus, and at the National Cereals Research Institute, Baddegi, Niger State, Kusotachi experimental site to study the influence of planting method, weed management on growth and yield of lowland rice in Baddegi and Lafia. The treatment was a factorial combination of two planting methods (dibbling and transplanting), six methods of weed control (weedy check, hoe weeding at 3 and 6 WAS, Cyhalofop-butyl + MCPA, Metsulfuron methyl, MCPA 2–methyl–4–chlorophenoxyacetic acid, Pretilachlor + Pyribenzoxium), and two locations (Lafia and Badeggi) laid in a split-split plot design in three replications. Location *was assigned to the main plot, planting method to the sub-plot, and weed management to the sub-sub-plot. The results showed that rice grown at Badeggi recorded taller plants and higher grain yield. In contrast, Lafia produced shorter plants but higher tiller number, crop resistance index, and weed control efficiency in both years. The transplanting method significantly enhanced plant height, tillering ability, crop resistance index, weed control efficiency, and grain yield compared with dibbling across locations. Weed management practices also influenced growth and yield. Late applications of Pretilachlor + Pyribenzoxim produced the tallest plants, while both early and late applications of MCPA consistently resulted in higher grain yield, crop resistance index, and weed control efficiency. The weedy check performed the worst across all parameters. These findings suggest that Badeggi provides a more favourable environment for rice production, while the transplanting method combined with the timely application of MCPA enhances competitiveness against weeds and improves grain yield across locations.*

Key words: Rice, location, planting method, weed management, grain yield.

INTRODUCTION

Rice (Oryza sativa L.) is a primary food crop cultivated widely over 161 million hectares in more than 100 countries across the globe (FAOSTAT, 2020). Globally, rice ranks third in production after wheat and maize (Ejebe, 2013). It is cultivated on almost 11% of the earth's cultivated land and across a wide range of ecosystems (Oluwaseyi *et al*., 2016). China and India account for 28% and 22% of global rice production, respectively (Bandumula, 2018).

Rice is a major staple food in many parts of the world. It supplies more carbohydrates, proteins, fats, and also minerals needed for survival and a healthy life (Ejebe, 2013). Rice supplies about 50% of the total daily calories in the human diet and is a source of income for more than 100 million households worldwide (Muthayya *et al*., 2014). It stands out as the major food crop for about half of the human race, and consumption of rice is growing faster than that of any other staple in Africa and worldwide, simply because it has become a convenient food for the growing world population (Oluwaseyi *et al*., 2016). All over the world, increases of 26% and 50% are demanded in rice production to meet the needs of the growing human population by 2035 and 2050, respectively (Rao *et al*., 2017).

In Nigeria, demand for rice has increased steadily over the past decades, while demand for sorghum and millet fluctuates annually. Rice demand in Nigeria was estimated at 5 million metric tons, while local production was around 2.21 million metric tons, and about 2.79 million metric tons were imported to bridge the gap (Udah *et al*., 2021). However, rice production is affected by weeds. Weeds are among the major pests in agriculture, competing with crops for nutrients through rapid growth and development.

In a paddy field, weeds compete with rice plants for available nutrients, water, light, and space. Under adverse conditions, weeds negatively affect leaf architecture, plant developmental patterns, plant growth cycles, tillering ability, and yield and yield attributes of rice (Materu *et al*., 2018). Transplanting is the most common method of planting rice, while dibbling and broadcasting are reported to be gaining ground (Gill *et al*., 2014). Akhgari and Kaviani (2011) defined dibbling (direct seeding) of rice as the process of establishing a rice crop from seeds sown in the field rather than by transplanting rice seedlings from the nursery. It helps rice farmers reduce production costs. Poor weed management is also responsible for reductions in rice yield, depending on weed type and infestation level (Neog *et al*., 2015). A good weed management program is essential throughout crop growth to overcome various weed challenges. Manual weed control is not a quick method; thus, it requires a lot of time and labour. Herbicides provide effective, economical, and rapid weed control when applied at a proper dose and at the appropriate stage of crop growth (Bhullar *et al*., 2018). Among all measures taken in rice weed control, chemical weed control is commonly used to overcome weed infestation. It is reliable, easy, quick, time-saving, and cost-effective. Rice growers in Nigeria give little attention to the use of metsulfuron-methyl, cyhalofop-butyl + MCPA, quinclorac, pyrazosulfuron-ethyl, MCPA (2-chloro-4-diphenoic acid), and pretilachlor + Pyribenzoxim herbicides for weed control in rice production due to a paucity of information about these herbicides. However, this study aims to evaluate the effects of these herbicide applications under two locations and two planting methods (dibbling and transplanting) on rice production. The objective of this study, therefore, is to determine the effects of planting methods and weed management on weed control, growth, and yield of lowland rice in two locations in Nigeria.

MATERIALS AND METHODS

The field experiment was conducted at two locations during the 2022 cropping season at the Teaching and Research Farm (of the Faculty of Agriculture, Shabu-Lafia Campus, Nasarawa State University Keffi, Nasarawa State, Latitude 08.330N, Longitude 08.330E) and at the National Cereals Research Institute (NCRI), Badeggi, Niger State, at experimental site Kusotachi, latitude 9°3'24.58 "N, Longitude 6°08′36.31″ E). The treatment was a factorial combination of two locations (Lafia and Badeggi), two planting methods (dibbling and transplanting) and six methods of weed control (Weedy check, Hoe weeding at 3 and 6 WAS, cyhalofop-butyl + MCPA at the rate of 3 L a.i/ha, Metsulfuron methyl at the rate of 250 g a.i/ha, MCPA (2 chloro 4 diphenoic acid), at the rate of 1 kg a.i/ha and Pretilachlor + Pyribenzoxim at the rate of 1.25 L a.i/ha at 0 and 6 WAS thus all the herbicide applied base on the treatment combination were carried out as early and late timing of application and were laid in a split-split plot design in three replications. Location was assigned to the main plot; planting method to the sub plot; and weed management to the sub-sub plot. Treatment was laid out in a split-split plot design and replicated three times. The gross plot size was 3 m x 4 m (12 m^2) while the net plot size was 1.5 m x 4m (6 m^2). Before field establishment, the experimental site was cleared using a pre-planting herbicide (Glyphosate 1.08kg a.i/ha), applied with a 15 L knapsack sprayer. The soil was ploughed manually, and the site was marked into plots. A one-meter unplanted border was maintained between plots, while a 0.5 m unplanted border was maintained between each replication. Rice seed (FARO 44) was pre-soaked for 1 day for both dibbling (80kg/ha) and transplanting (40kg/ha), then removed and placed in a jute bag. After 2 days of sprouting, the pre-germinated seeds were sown (dibbling) on the same day the nursery bed was prepared for transplanted seedlings. The nursery was ready in dry soil conditions on a 3 by 4 m wide seed bed, with the topmost soil filled to a 10 cm level before the pre-germinated seeds were broadcast and later covered with a layer of half-burned paddy husk to facilitate uprooting. A 21-day-old seedling was later transplanted from the nursery bed to the permanent field, with one seedling sown per hole. A spacing of 20 cm by 20 cm between and within the plants was maintained for both planting methods. Broadcasting methods of fertilizer application were used at 3 WAS, with NPK fertilizer applied at 20 kg N/ha, 10 kg P2O5/ha, and 10 kg K2O/ha. After 6 WAS, N in the form of UREA was applied at 46 kg N/ha.

Five randomly selected tagged plants from each plot were used for periodic observation during the crop growth periods at 4, 6, 8, 10, and 12 WAS. The net plot was harvested manually, grain collected, dried to 13.5% moisture content, and the weight was recorded. This was determined by weighing grains from the net plot, dividing by net area, and multiplying by 10,000. Grain yield × 10,000 (Bukar and Lassa, 2021). The data were subjected to analysis of variance (ANOVA) using Statistica software, while the Least Significant Difference (LSD) was used to separate treatment means at the 5% level of probability.

RESULTS AND DISCUSSION

The results of the physical and chemical soil analyses before land preparation in Lafia and Badeggi revealed that the soil was sandy clay and sandy loam, respectively, with slightly acidic pH (Table 1). The results also indicated that organic carbon, total nitrogen, and available phosphorus were low in both locations. However, there is a moderate amount of calcium, sodium, and potassium in both locations, whereas potassium and sodium were high. Conversely, the cation exchange capacity (CEC) was high at Lafia and low at Baddegi.

The results of the meteorological distribution obtained from Lafia showed that the average annual relative humidity was 786.65%, average solar radiation was 117.4 MJ/m2/day, average sunshine was 76.46 hours, average minimum temperature was 278.2 °C, and average maximum temperature was 419.6 °C. Total annual rainfall was 2499 mm. At the Badeggi location, the average yearly relative humidity was 71.61%, the annual average solar radiation was 180.54 MJ/m2/day, and the average yearly sunshine was 63.11 hours. Annual minimum temperature was 279.4 °C, average yearly maximum temperature was 407.57 °C, and the annual total rainfall was 1458 mm in the year 2022 (Figure II - VII).

Plant height differed significantly at 4, 6, 8, 10, and 12 weeks after sowing (WAS) for rice across locations, planting methods, and weed management (Table 2). Generally, the Badeggi location consistently produced taller plants than the Lafia location, which consistently recorded shorter plants throughout the sampling periods in this study. The planting method had a significant effect on plant height at 10 and 12 WAS in this study. The transplanting method consistently produced significantly taller plants than the dibbling method, which consistently produced shorter plants.

Weed management had a significant effect on rice plant height across the study's sampling periods. The weedy check and early and late applications of Cyhalofop + MCPA produced taller plants than the other weed controls, which recorded shorter plants at 4 WAS. At 6 WAS, early application of Metsulforun methyl produced significantly taller plants, not statistically different from the weedy check, early application of Cyhalofop + MCPA, and early application of Pretilachlor + Pyribenzoxium, compared with late application of MCPA, which produced the shortest plants. At 8 WAS, weedy check recorded the tallest plants, which were statistically similar to 2 HW at (3 + 6 WAS), early and late applications of Metsulforun methyl, early and late applications of Cyhalofop butyl + MCPA, early application of Pretilachlor + Pyribenzoxium, and late application of Pretilachlor + Pyribenzoxium recorded shorter plants. At 10 WAS, the use of 2 HW at (3 + 6 WAS), early applications of Metsulforun methyl, and late application of Pretilachlor + Pyribenzoxium produced taller plants than all other weed controls, whereas early and late applications of MCPA produced shorter plants that were statistically similar. At 12 WAS, late applications of Pretilachlor + Pyribenzoxim produced significantly taller plants than all other weed controls, whereas late applications of Cyhalofop butyl + MCPA produced the shortest plants.

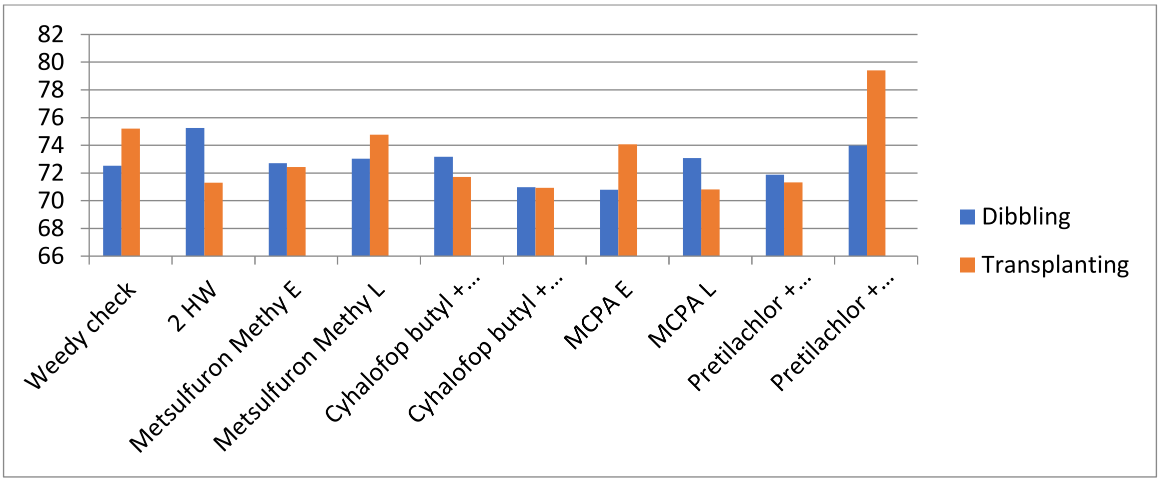

Figure I: Theinteraction between planting method and weed control on plant height

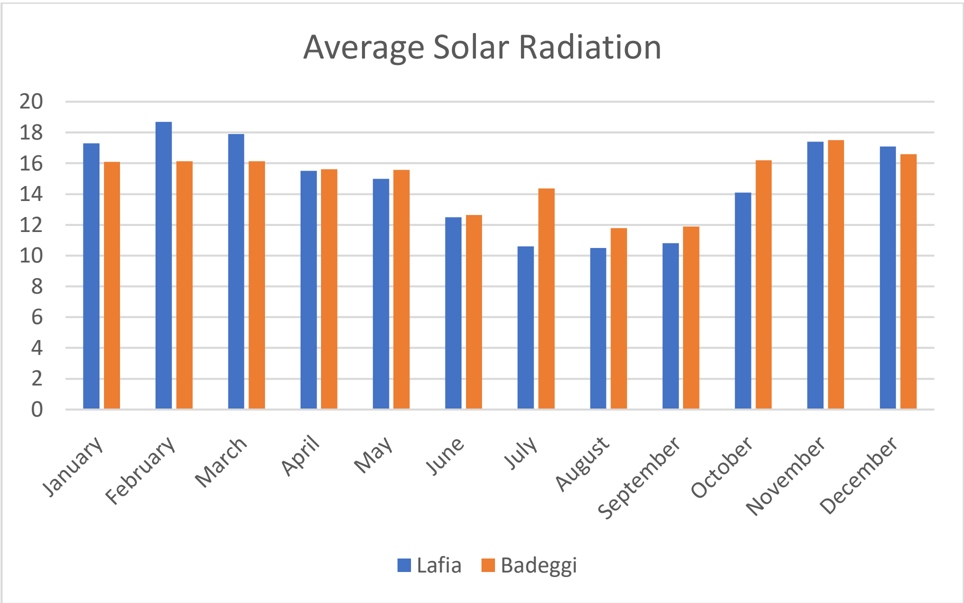

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Figure II: Average solar radiation of Lafia and Badeggi.

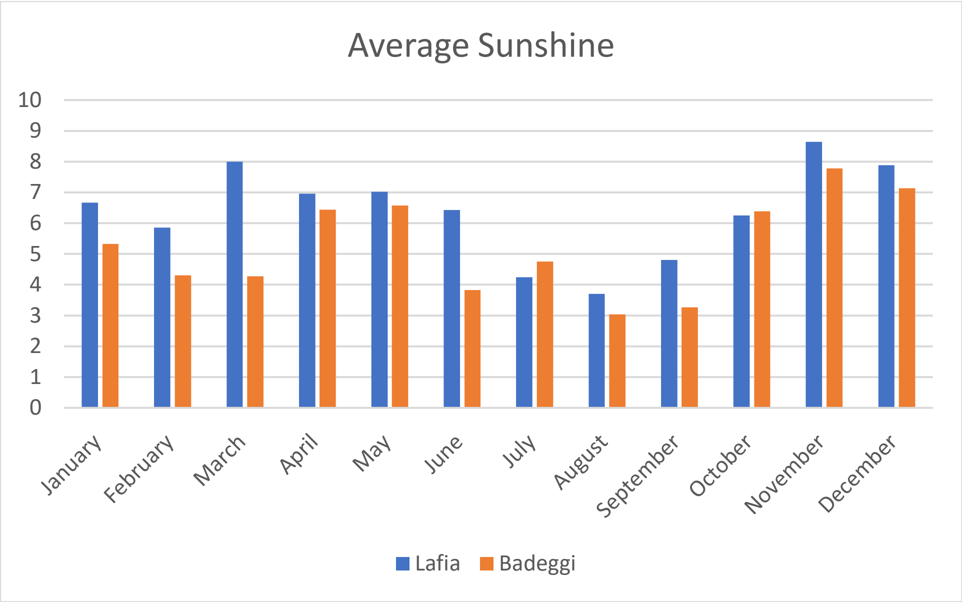

Figure III: Average sunshine hours of Lafia and Badeggi.

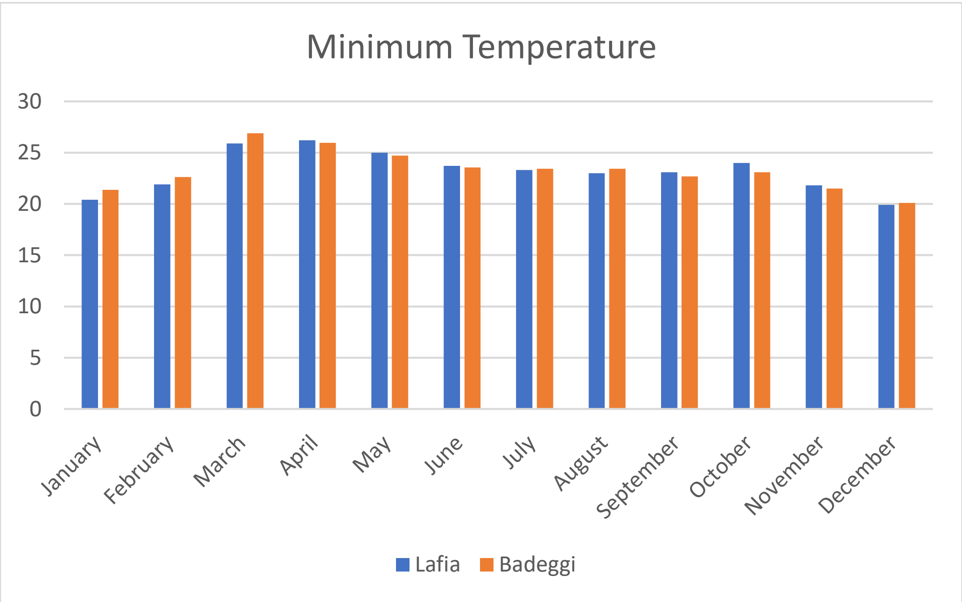

Figure IV: Minimum temperature of Lafia and Badeggi.

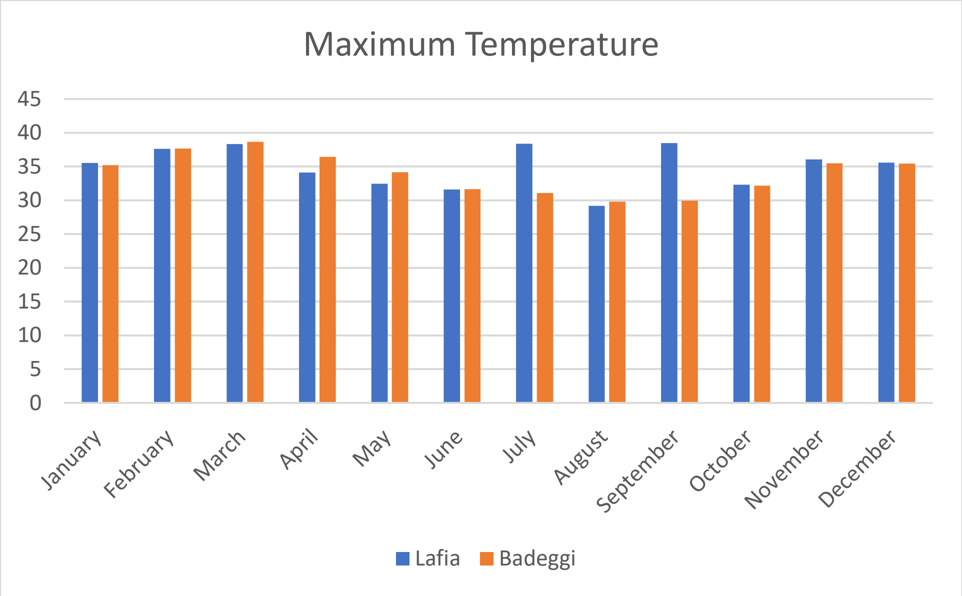

Figure V: Maximum temperature of Lafia and Badeggi.

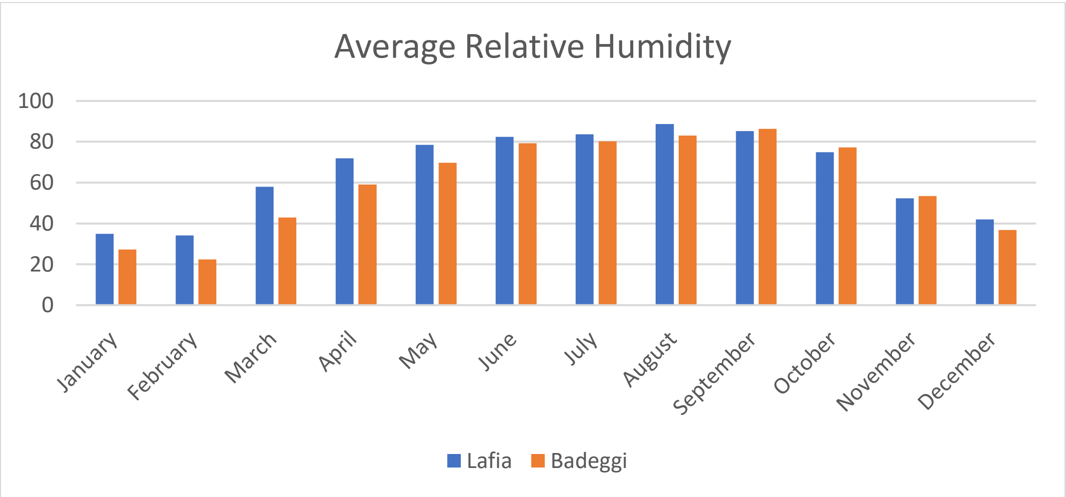

Figure VI: Average relative humidity of Lafia and Badeggi.

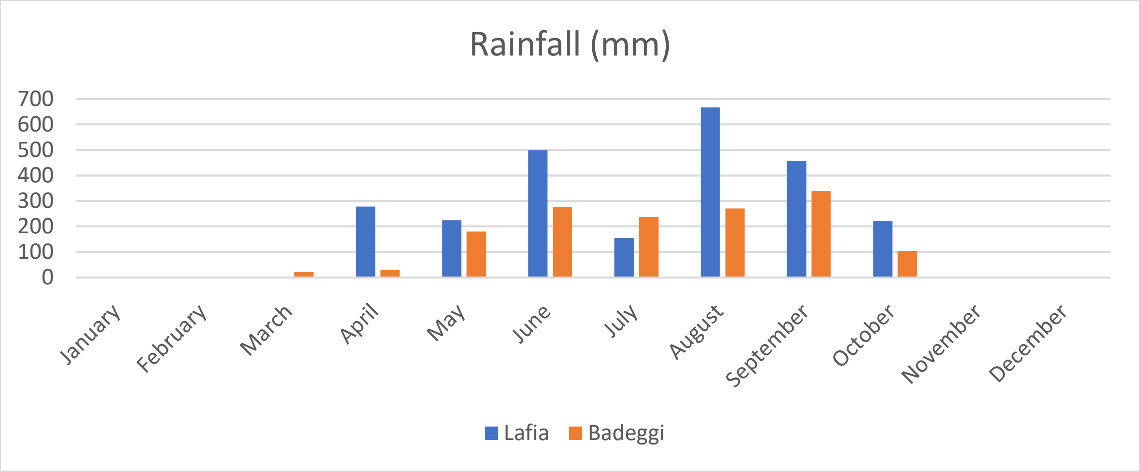

Figure VII: Monthly rainfall of Lafia and Badeggi.

Table 1: Physical and Chemical Properties (0 – 15 cm depth) of the Experimental soil before Planting at Lafia and Badeggi in 2022 Wet Season

Parameters	Lafia	Badeggi
Physical properties (%)		
Clay	21.6	20
Silt	5.4	5.4
Sand	73	74.6
Textural class	Sandy clay	Sandy loam
Chemical properties		
pH (H_2O)	5.7	6.9
pH ($CaCl_2$)		
Organic carbon (%)	1.91	1.80
Total nitrogen (%)	0.21	0.28
Available phosphorus (PPM)	3.20	8.43
Ca^{2+}	2.25	3.21
Mg^{2+}	1.22	2.15
K^+	0.24	0.30
Na^+	0.14	0.19
Exchangeable bases (cmol kg^{-1})	3.85	5.85
Exchangeable acid (cmol kg^{-1})	0.78	0.67
CEC	4.63	6.52

Table 2: Effect of location, planting methods and weed control on plant height at 4 - 12 WAS of rice

	Plant height (cm)				
Treatment	4 WAS	6 WAS	8 WAS	10 WAS	12 WAS
Location (L)					
Lafia	21.92a	28.70b	32.54b	49.92b	66.34b
Badeggi	37.76a	54.91a	59.35a	69.81a	79.48a
LSD (0.05)	0.578	1.954	3.071	0.883	1.304
Planting method (PM)					
Dibbling	29.78a	41.69a	46.28a	59.52b	72.56b
Transplanting	29.89a	41.93a	45.61a	60.21a	73.29a
LSD (0.05)	0.473	0.274	2.159	0.382	0.232
Weed management (WM)					
Weedy check	30.27a	42.87ab	47.55a	59.55bc	73.86b
2 HW (3 + 6 WAS)	29.20b	42.31bc	46.86ab	61.49a	73.28bc
Metsulforun Methyl (E)	29.19b	43.34a	47.28ab	61.33a	72.58de
Metsulforun Methyl (L)	29.64b	41.54de	46.56ab	59.41c	73.90b
Cyhalofopbuthyl + MCPA (E)	30.31a	42.67ab	47.17ab	58.60d	72.44e
Cyhalofopbuthyl + MCPA (L)	30.46a	40.30fg	47.03ab	59.68bc	70.94g
MCPA (E)	29.58b	40.94ef	45.60abc	57.48e	72.44e
MCPA (L)	29.28b	39.98g	43.68bc	57.22e	71.95ef
Pretilachlor + Pyribenzoxium (E)	29.55b	42.63ab	45.74abc	60.24b	71.61f
Pretilachlor + Pyribenzoxium (L)	29.28b	41.80cd	42.02c	61.98a	76.68a
LSD (0.05)	0.585	0.740	3.83	0.706	0.654
Interaction					
L × PM	NS	NS	NS	NS	NS
L × WM	NS	NS	NS	NS	NS
PM × WM	NS	NS	NS	NS	*
L × PM × WM	NS	NS	NS	NS	NS

Means in the same column followed by the same letters are not significantly different according to Fisher's protected LSD test (P <0.05);[1]Weeks after sowing; Early[2]; Late[3]; [4]Significant difference at 5% level of probability; [5]Not significant.

Figure 1 shows the interaction between planting method and weed control on plant height at 12 WAS was significant. The combination of transplanting method with late application of Pretilachlor + Pyribenzoxim produced the tallest plants, whereas the combination of dibbling method with early application of MCPA produced the shortest plants.

The effect of planting method and weed control on the number of tillers per plant of rice at 5 - 7 WAS is shown in Table 3 below. Location significantly affected the number of tillers: Lafia consistently produced significantly more tillers than Badeggi, which consistently recorded fewer tillers per plant. The number of tillers per plant was significantly different among planting methods at 7 WAS in this study only. The transplanting method produced significantly more tillers per plant than the dibbling method. Weed management had a significant effect on the number of tillers per plant at 5-7 WAS in this study. At 5 WAS, late application of MCPA produced significantly more tillers per plant than all other weed controls, whereas late application of Pretilachlor + Pyribenzoxium produced the lowest number of tillers per plant, which was not statistically different from 2 HW (3+6 WAS) or early application of Pretilachlor + Pyribenzoxium. At 6 WAS, early application of MCPA produced significantly more tillers per plant than all the other weed controls compared with the weedy check and late application of Pretilachlor + Pyribenzoxium, which consistently produced fewer tillers per plant, though similar with 2 HW (3 + 6 WAS), early application of Metsulforun Methyl, late application of Metsulforun Methyl and early application of Pretilachlor + Pyribenzoxium. At 7 WAS, early application of MCPA significantly produced more tillers per plant than all the other weed controls compared with the weedy check, 2 HW (3 + 6 WAS), and early application of Cyhalofop butyl + MCPA, which had the lowest number of tillers, though statistically not different from late application of Cyhalofop butyl + MCPA.

The effects of planting method and weed management on rice grain yield are presented in Table 3. Location differed significantly in grain yield, with Badeggi producing the highest yield and Lafia the lowest. The planting method had a significant effect on rice grain yield. The transplanting method recorded the highest grain yield, while the dibbling method recorded the lowest at Lafia. Weed management also significantly affected rice grain yield, with early and late MCPA applications yielding statistically similar maximum grain yield; these yields were, however, higher than those of all other weed management methods. The weedy check recorded the lowest grain yield.

The effects of planting method and weed control on the crop resistance index and weed control efficiency of rice are presented in Table 4. The Lafia location had a higher crop resistance index than the Badeggi location, which had the lowest. Weed control efficiency was highest at Lafia, compared with Badeggi, which recorded the lowest.

The planting method significantly affected all the parameters. The transplanting method produced the highest crop resistance index and weed control efficiency, while the dibbling method recorded the lowest.

Weed control also had a significant effect on all the parameters. Early application of MCPA produced the highest crop resistance index among all other weed controls. The weedy check gave the lowest crop resistance index. The late application of MCPA achieved the highest weed control efficiency among all other weed controls. The weedy check had the lowest weed control efficiency.

The interaction between planting method and weed control on crop resistance index and weed control efficiency was significant Table 5. The combination of transplanting with early application of MCPA produced the highest crop resistance index, followed by the dibbling-and-transplanting method, and the weedy check recorded the lowest. The combination of transplanting method with late application of MCPA significantly produced the highest weed control efficiency compared to all the other combinations, compared with the combination of dibbling and transplanting methods with weedy check, which produced statistically similar lowest weed control efficiency.

Table 3: Effect of location, planting methods and weed management on number of tillers and grain yield

	Number of tillers			
Treatment	5 WAS	6 WAS	7 WAS	Grain yield kg/ha
Location (L)				
Lafia	4.31a	10.42a	13.09a	4164.6b
Badeggi	4.01b	6.28b	10.18b	4313.8a
LSD (0.05)	0.11	1.51	0.68	124.34
Planting method (PM)				
Dibbling	4.27a	8.26a	10.97b	3891.5b
Transplanting	4.04a	8.43a	12.30a	4586.8a
LSD (0.05)	0.25	0.18	0.28	22.08
Weed management (WC)				
Weedy check	4.15b-e	8.10d	10.74e	1533.7i
2 HW (3 + 6 WAS)	3.91ef	8.13cd	10.82e	3519.6h
Metsulforun Methyl (E)	4.48ab	8.18cd	11.62cd	5457.9b
Metsulforun Methyl (L)	4.23b-e	8.28bcd	11.70c	5268.7c
Cyhalofopbuthyl + MCPA (E)	4.10cde	8.21bcd	10.97e	4519.6e
Cyhalofopbuthyl + MCPA (L)	4.28a-d	8.66ab	11.12de	4615.0d
MCPA (E)	4.12cde	9.02a	14.12a	6089.6a
MCPA (L)	4.61a	8.58abc	13.18b	6056.3a
Pretilachlor + Pyribenzoxium (E)	3.98def	8.19bcd	11.75c	3868.8f
Pretilachlor + Pyribenzoxium (E)	3.67f	8.05d	11.69c	4577.1d
LSD (0.05)	0.34	0.47	0.57	54.47
Interaction				
L × PM	NS	NS	NS	NS
L × WC	NS	NS	NS	NS
PM × WC	NS	NS	NS	NS
L × PM × WC	NS	NS	NS	NS

Means in the same column followed by the same letters are not significantly different according to Fisher's protected LSD test (P <0.05);[1]Weeks after sowing; Early[2]; Late[3]; [4]Significant difference at 5% level of probability; [5]Not significant

Table 4: Effect of location, planting methods and weed control on weed persistence index, crop resistance index, and weed control efficiency of rice

Treatment	Crop resistance index	Weed control efficiency
Location (L)		
Lafia	5.34a	63.82a
Badeggi	5.33b	63.17b
LSD (0.05)	3.64	0.203
Planting method (PM)		
Dibbling	5.13b	59.85b
Transplanting	5.55a	67.14a
LSD (0.05)	0.031	0.243
Weed management (WM)		
Weedy check	1.00f	0.00j
2 HW (3 + 6 WAS[1])	4.32e	67.45i
Metsulforun Methyl (E)[2]	7.56b	81.84c
Metsulforun Methyl (L)[3]	7.84b	80.89d
Cyhalofopbuthyl + MCPA (E)	5.34d	74.09f
Cyhalofopbuthyl + MCPA (L)	6.07c	76.08e
MCPA (E)	8.45a	84.56b
MCPA (L)	7.75b	87.19a
Pretilachlor + Pyribenzoxium (E)	5.42d	69.58h
Pretilachlor + Pyribenzoxium (L)	5.25d	70.94g
LSD (0.05)	0.390	0.613
Interaction		
L × PM	NS	NS
L × WM	NS	NS
PM × WM	*	*
L × PM × WM	NS	NS

Means in the same column followed by the same letters are not significantly different according to Fisher's protected LSD test (P <0.05);[1]Weeks after sowing; Early[2]; Late[3]; [4]Significant difference at 5% level of probability; [5]Not significant.

Table 4: Interaction between planting method and weed control on weed persistence index, treatment efficient index, crop resistance index, weed management index and weed control efficiency of rice

	Weed management									
	Weedy check	2 HW	Metsulforun Methyl (E)	Metsulforun Methyl (L)	Cyhalofopbuthyl + MCPA (E)	Cyhalofopbuthyl + MCPA (L)	MCPA (E)	MCPA (L)	Pretilachlor + Pyribenzoxium (E)	Pretilachlor + Pyribenzoxium (L)
Planting method	**Crop resistance index**									
Dibbling	1.00i	4.57g	7.25d	7.40cd	5.40f	5.59f	7.23d	7.34cd	5.20f	5.22f
Transplanting	1.00i	4.08gh	7.87bc	8.28b	5.28f	6.55e	9.68a	8.15b	5.64f	5.29f
LSD (0.05)					0.560					
	Weed control efficiency									
Dibbling	0.00o	64.88n	74.85f	73.37g	69.83k	70.85ij	77.88e	81.32d	68.32l	70.25jk
Transplanting	0.00o	70.02jk	88.83c	88.42c	78.35e	81.32d	91.23b	93.07a	70.83ij	71.63hi
LSD (0.05)					0.867					

Means in the same column followed by the same letters are not significantly different according to Fisher's protected LSD test (P <0.0

DISCUSSION

The results of this study revealed significant variations in plant height, tiller production, yield, crop resistance index, and weed control efficiency of rice across locations, planting methods, and weed management practices.

Effect of Location

Location significantly influenced rice growth and yield performance. Badeggi consistently produced taller plants and higher grain yield, whereas Lafia recorded shorter plants but higher tiller number, crop resistance index, and weed control efficiency. This suggests that environmental conditions at Badeggi were more favorable for vegetative growth and yield accumulation, whereas those at Lafia favored greater tillering and better crop-weed competition. Similar location-dependent differences in rice performance were reported by Ekeleme *et al*. (2019), who found that rice growth and yield varied significantly across Nigerian agro-ecologies due to differences in soil fertility, rainfall distribution, and weed pressure. Likewise, Adigbo *et al*. (2020) observed that rice yield potential varied across environments, underscoring the strong influence of location-specific factors. Lafia recorded higher values than Badeggi, likely reflecting the stronger weed pressure and crop-weed interaction at Lafia.

Effect of Planting Method

The planting method significantly affected rice growth and yield attributes. Transplanting consistently produced taller plants, more tillers, a higher crop resistance index, greater weed control efficiency, and ultimately higher grain yield than dibbling. The superiority of transplanting could be due to better crop establishment, vigorous early growth, and enhanced canopy cover that suppressed weed emergence. This agrees with the findings of Oloyede *et al*. (2021), who reported that transplanting rice yielded higher yields and better weed suppression than direct seeding methods transplanting consistently enhanced both crop resistance and weed control efficiency, demonstrating its advantage in ensuring a competitive rice stand. Similar findings were reported by Singh *et al*. (2020), who observed that transplanted rice had significantly lower weed biomass and higher weed control efficiency compared with direct-seeded rice under temperate conditions.

Effect of Weed Management

Weed management significantly influenced all measured rice parameters. Plant height response varied across sampling periods, with the weedy check producing taller plants at early growth stages, likely due to competition-induced etiolation, as noted by Rao *et al*. (2019). However, consistent and practical herbicide applications such as Metsulfuron methyl, Cyhalofop + MCPA, and Pretilachlor + Pyribenzosulfuron ensured better growth at later stages.

For tiller production, MCPA application (both early and late) consistently gave the highest number of tillers, while Pretilachlor + Pyribenzosulfuron produced fewer tillers, indicating differential crop-herbicide interactions. These findings align with those of Yusuf *et al*. (2022), who observed that selective herbicides differ in their effects on rice tillering.

Grain yield was highest under early and late MCPA applications, suggesting that MCPA provided the most effective weed suppression, thereby reducing competition and allowing better assimilate partitioning into grain. The weedy check yielded the least, underscoring the yield penalty of weed competition. This aligns with the report of Mamadou *et al*. (2020), who stated that uncontrolled weed infestation in rice fields can cause up to 80% yield losses.

Among weed control treatments, early application of MCPA gave the highest crop resistance index, while late application of MCPA recorded the highest weed control efficiency. This indicates that the timely and strategic application of MCPA is crucial for maximizing both rice competitiveness and weed suppression. Similar results were obtained by Ndiritu *et al*. (2021), who highlighted that proper timing of herbicide use is critical in achieving maximum weed control efficiency in rice systems.

Interaction Effects

The interaction between planting method and weed management was significant for plant height, crop resistance index, and weed control efficiency. The combination of transplanting with late application of Pretilachlor + Pyribenzosulfuron gave the tallest plants. In contrast, transplanting combined with early MCPA produced the highest crop resistance index, and transplanting with late MCPA recorded the highest weed control efficiency. These findings emphasize that optimal integration of planting method and herbicide strategy can greatly enhance rice growth and competitiveness against weeds. This corroborates the report of Johnson *et al*. (2018), who found that integrated weed management, combining an appropriate establishment method and herbicide application, improves rice productivity.

CONCLUSION

The study found that rice performance was significantly influenced by location, planting method, and weed management practices. Rice grown at Badeggi consistently produced taller plants and higher grain yield, whereas rice at Lafia recorded shorter plants but higher tiller number, crop resistance index, and weed control efficiency. These findings demonstrate that site-specific environmental conditions strongly determine rice growth and productivity. The transplanting method proved superior to dibbling across most measured parameters, and transplanting produced taller plants, higher tiller number, greater crop resistance index, higher weed control efficiency, and ultimately higher grain yield. This confirms that transplanting is a more reliable method for achieving better crop establishment, greater weed competitiveness, and enhanced yield performance. Weed management significantly influenced plant height, tillering, yield, and rice competitiveness. At early growth stages, the weedy check produced taller plants due to competition-induced elongation, while late application of Pretilachlor + Pyribenzosulfuron produced the tallest plants at maturity. The application of MCPA consistently enhanced tillering, yield, crop resistance index, and weed control efficiency. The weedy check showed the lowest overall performance, highlighting the severe impact of uncontrolled weeds on rice productivity.

RECOMMENDATIONS

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

1. Rice cultivation at Badeggi should be prioritized for higher yield potential, while production at Lafia requires more targeted management to optimize crop competitiveness and weed suppression.
2. The transplanting method should be adopted over dibbling for sustainable rice production, as it ensures better crop establishment, stronger weed competition, and higher yield.
3. The timely application of selective herbicides, such as MCPA, should prioritize effective weed control. Early or late applications can be used to maximize both yield and weed control efficiency. Integrated approaches combining transplanting with MCPA are particularly recommended for enhanced rice productivity.

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COMPARATIVE ANALYSIS OF THE IMPACT OF IFAD-VCDP PARTICIPATION ON NET FARM INCOME OF BENEFICIARY AND NON-BENEFICIARY RICE FARMERS IN NASARAWA STATE, NIGERIA

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ABSTRACT
The study assessed the impact of IFAD-VCDP participation on net farm income, a comparative analysis of beneficiary and non-beneficiary rice farmers in Nasarawa State, Nigeria. The study employed a multistage sampling technique to select 260 IFAD-VCDP beneficiary and 260 non-beneficiary rice farmers, using a structured questionnaire. The primary data collected from respondents were analysed using descriptive and inferential statistics. The results showed that the mean age of respondents was 42 years for beneficiaries and 45 years for non-beneficiaries, respectively, with an average educational level of 12 years for beneficiaries and 6 years for non-beneficiaries. The farming experience averaged 14 and 18 years for beneficiaries and non-beneficiaries, respectively. The average number of extension contacts was 12 times per year for beneficiaries and once per year for non-beneficiaries. The net farm income showed that the IFAD-VCDP beneficiaries had a total revenue of ₦1,765,918 and a total cost of ₦457,846, resulting in a gross margin of ₦ 1,308,072. For the non-beneficiary, the total revenue was ₦1,065,456, the total cost was ₦497,031, and the gross margin was ₦568,425. On average, IFAD-VCDP beneficiaries and non-beneficiaries made an NFI of ₦1,308,070 and ₦568,425, respectively, per hectare of rice

production. The results also revealed that IFAD-VCDP rice farmer beneficiaries had an average yield of 3.83 tons/ha, while non-beneficiaries had an average yield of 2.26 tons/ha. The results further revealed an average annual income of ₦3,014,385 for the beneficiaries and ₦1,302,135 for the non-beneficiaries, respectively. As a result of the impact of the programme on the target beneficiary, the study recommended the need to extend IFAD-VCDP intervention to cover all other rice-producing LGAs in the State, ensuring that more farmers benefit from the intervention.

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Keywords: Beneficiary, IFAD-VCDP, Impact, Net Farm Income, Non-beneficiary, Yield.

INTRODUCTION

The International Fund for Agricultural Development (IFAD) is a specialised agency of the United Nations (UN) established in 1977 as one of the major outcomes of the 1974 World Food Conference. It was resolved at the conference that an international institution be established immediately to finance agricultural development projects, primarily for food production in developing countries. The institution would focus on alleviating the poverty of rural dwellers through investment in farming activities, as agriculture is seen in developing countries as a sector with viable potential to move the rural poor out of poverty and with the capacity to feed the world. In Sub-Saharan Africa, for instance, maximising the potential of agriculture would yield faster growth in reducing poverty than investment in other sectors (IFAD, 2014).

The International Fund for Agricultural Development (IFAD) has, over the years, undertaken interventions in the rice value chain in Nigeria through its Value Chain Development Programme (VCDP). VCDP is a six-year programme of the Federal Government of Nigeria funded by the International Fund for Agricultural Development (IFAD). The programme aims to improve the yield and food security of poor rural households engaged in the production, processing and marketing of rice and cassava on a sustainable basis. VCDP was initially implemented in six states: Anambra, Benue, Ebonyi, Ogun, Niger, and Taraba. As a result of the programme's success, VCDP received additional funding in 2019 for expansion into three states: Kogi, Nasarawa, and Enugu, making a total of nine participating states in the Additional Financing 1 (AF1) phase of the programme (Sallawu *et al*., 2019). Nasarawa State is one of the states in Nigeria that is benefiting from this intervention. The programme started in 2020. The Fund covered five (5) out of the 13 Local Government Areas in the State (Doma, Lafia, Wamba, Nasarawa and Karu). The programme strongly emphasises the development of commodity-specific Value Chain Action Plans at the local government level, which serve as the basis for rolling out sustainable activities to reduce poverty and accelerate economic growth. The objective is to enhance rural incomes and food security in a sustainable manner.

The intervention in Nigeria is focused on value chain development because of the challenges faced by small-scale farmers, such as low productivity, poor access to markets, poor processing technology, lack of adequate information, high cost of farm inputs, inadequate credit system, the vicious cycle of poverty and the recent challenge, which seem formidable, climate change (IFAD, 2013). The partnership between IFAD and the Federal Government of Nigeria focuses on small-scale farmers of cassava and rice, recognising the potential economic value of these crops. IFAD adopted the value chain approach to enhance productivity, promote agro-processing, and access to markets and opportunities, facilitating improved engagement between the private sector and farmers' organisations. The programme, through commodity-specific value chain action plans (VCAP) at different local governments in the participating states engages with actors along the chain; producers, processors, marketers and their farmer organisations as well as public and private institutions, service providers, policy and regulatory environment to deliver relevant and sustainable activities that would lead to gradual transformation of the sector and contribute to achieving food security, and expanding income-generating activities and employment opportunities (Enenchi, 2021).

The goal of the programme according to Sallawu *et al*. (2019) is to reduce poverty among the rural dwellers, increase food security and accelerate economic growth on a sustainable basis. The specific programme development objectives are to: (i) increase incomes and food security of poor rural households engaged in production, processing and marketing of rice and cassava in the targeted LGAs are enhanced on a sustainable basis. (ii) develop agricultural market access for smallholder farmers and small to medium-scale agro-processors. (iii) enhance smallholder productivity through the adoption of improved practices, thus increasing the volume and quality of marketable produce by strengthening farmers' organisations as well as supporting smallholder production.

Since the commencement of the IFAD-VCDP programme in Nasarawa State in 2020, there have been limited empirical studies examining the impact of IFAD-VCDP on the Net Farm Income of beneficiaries. It is also not ascertained if there is any significant difference in the yield and income level of beneficiary compared to non-beneficiary rice farmers in Nasarawa state. The scarcity of these vital findings poses serious research gaps that need to be filled. This study was therefore designed to fill these identified research gaps.

The objectives of the study were to:

1. Describe the socioeconomic characteristics of IFAD-VCDP beneficiary and non-beneficiary rice farmers in the study area.
2. Estimate the Net Farm Income of IFAD-VCDP beneficiary and non-beneficiary rice farmers in the study area;
3. Determine the yield and income of IFAD-VCDP beneficiary and non-beneficiary rice farmers in the study area.

Statement of the Hypothesis

The hypothesis for this study stated in the null form is:

Ho1: There is no significant difference in the yield and income of IFAD-VCDP beneficiary and non-beneficiary rice farmers in the study area.

Ho2: There is no significant difference in the gross margin of IFAD-VCDP beneficiary and non-beneficiary rice farmers.

METHODOLOGY

The study area

The study was conducted in Nasarawa State, Nigeria. Nasarawa State is situated in the central part of the Middle Belt region of Nigeria. The State lies between latitudes 70°45' and 90°25' North of the equator and longitudes 70 ° and 90°37' East of the Greenwich meridian. It lies within the Guinea Savanna region and has a tropical climate. The State shares a boundary with Kaduna State to the North, Plateau State to the East, Taraba and Benue states to the South, and Kogi and the Federal Capital Territory to the West. The State is made up of thirteen Local Government Areas. The major tribes in the states are Afo, Agatu, Alago, Arum, Bassa, Berriberi, Ebira, Eggon, Fulani, Gade, Gbagi, Gwandara, Hausa, Kantana, Kulere, Mada, Migili, Nandu, Nyankpa, Rindre, and Tiv, among others (NADP, 2024).

The State has a climate typical of the tropical zone. It has an average temperature of 28.4 0C. Rainfall varies from place to place, with an annual average ranging from 1100 mm to 2000 mm. The State is characterised by two distinct seasons: a dry season and a rainy season. Rain falls between April and October, while the dry season starts from November to early March. The State is composed of plains and hills, reaching elevations of up to 300ft above sea level at specific points. Agriculture is the dominant source of livelihood. Mixed farming is widely practised. The State is well-suited for the production of a wide variety of crops, including rice, yams, cassava, sorghum, maise, millet, cowpeas, tomatoes, sesame, groundnuts, and bananas. Permanent tree crops planted by the farmers include orange, mango, cashew, oil palm, and guava. Farmers in the area also keep livestock such as goats, sheep, pigs, cattle, and poultry (NADP, 2024).

Sampling procedure and sample size

A multistage sampling technique was used to select the respondents for this study.

Stage 1: Three out of five participating IFAD-VCDP LGAs were selected, one from each of the state's agricultural zones, using purposive sampling. This includes Doma from the Southern Agricultural Zone, Wamba from the Central Agricultural Zone, and Karu from the Western Agricultural Zone.

Stage 2: This involves the purposive selection of four communities in each of the three selected LGAs. This was due to high participation in VCDP activities under IFAD. This resulted in a total of 12 communities being used for the study.

Stage 3: A comprehensive list of IFAD-VCDP participating farmers from the selected communities was obtained during a preliminary survey. The data indicate that a total of 750 registered IFAD-VCDP farmers were present in the selected communities of Nasarawa State. (Nasarawa State IFAD-VCDP Office, 2024).

The Taro Yamane formula was applied to calculate the representative sample size from the total population of 750 beneficiaries of IFAD-VCDP in the three selected LGAs of Nasarawa state. This was because it provides a sample size that is sufficient to accurately represent the population. Through this formula, a sample size of 260 rice farmers was selected for the study. Bourley's proportional distribution was used to determine the number of participating rice farmers in each community. Selection of 34.6 % (As determined by Bourley's formula) of the beneficiaries of

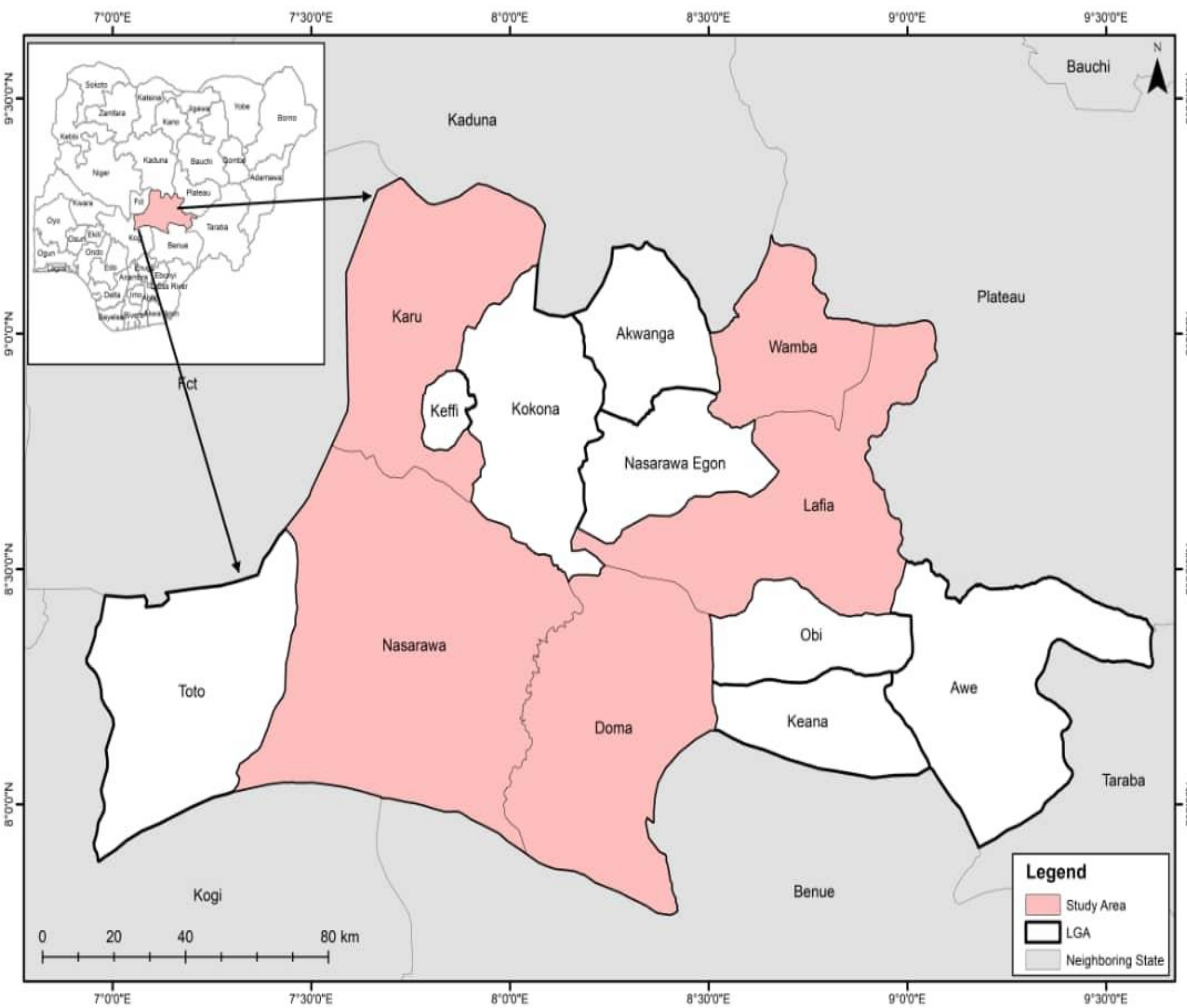

Figure 1: Map of Nasarawa State showing the IFAD-VCDP participating LGA.

IFAD-VCDP from each of the twelve (12) selected communities using a simple random sampling method by balloting. This totals 260 participating rice farmers. To have accuracy and not to introduce bias in the evaluation, an equal number (260) of non-beneficiaries of IFAD-VCDP rice farmers were also randomly selected, giving a total of 520 farmers who served as the respondents for the study.

Taro Yamane formula

$n = N/1+N(e)^2$

Where ,

n = the required sample size from the population under study

N = the whole population under study

e = the precision or sampling error which usually 0.05

Bourley's proportional distribution formula:

$$n_h = \frac{N_h \times n}{N}$$

Where,

n_h= sample size for the stratum h

N_h= population size for the stratum h

N= total population

n = total sample size

Table 1: Sample outlay of IFAD-VCDP beneficiary and non-beneficiary rice farmers in the study area.

LGA	Community	Number of Beneficiary	Sample Selected (34.6 %)	Non-beneficiary Selected
Doma	Rutu	75	26	26
	Doma	82	28	28
	Iwashi	77	27	27
	Yelwa	52	18	18
	Total	**286**	**99**	**99**
Karu	Karu	71	24	24
	Panda	68	24	24
	Karshi	63	22	22
	Gitata	46	16	16
	Total	**248**	**86**	**86**
Wamba	Wamba	61	21	21
	Sisimbaki	55	19	19
	Gbude	53	18	18
	Mararaba	47	16	16
	Total	**216**	**75**	**75**
Total	**12**	**750**	**260**	**260**

Source: Nasarawa State IFAD-VCDP, 2024

Method of data collection

Primary data were used for the study. The data were collected using a structured interview schedule, which was administered to the sampled respondents. The data collected include the socio-economic characteristics of IFAD-VCDP beneficiary and non-beneficiary rice farmers, as well as the net farm income of IFAD-VCDP beneficiaries and non-beneficiaries, and the yield and income of IFAD-VCDP beneficiaries and non-beneficiaries in the study area.

Method of data analysis

The data obtained were analysed using both descriptive and inferential statistics. Descriptive statistics, such as frequency, percentage, and mean scores, were used for the study.

Model Specification

Z - statistics

Z-statistics were used to test whether there are significant differences in the yields and income among IFAD-VCDP beneficiary and non-beneficiary:

Z-value was calculated using the formula below:

$$Z = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

Where,

m1 = mean of beneficiary,

m2 = mean of non-beneficiary,

sd1 = standard deviation of beneficiary,

sd2 = standard deviation of non-beneficiary,

n1 = number of beneficiaries and

n2 = number of non-beneficiaries.

Net farm income

Net farm income was used to assess the profitability of rice production among IFAD-VCDP beneficiary and non-beneficiary rice farmers.

The net farm income model was expressed as follows:

GM = TR – TVC

NFI = GM - TC

Where:

GM = Gross Margin (₦/ha)

NFI = Net Farm Income (₦/ha)

TR = Total Revenue (₦/ha)

TC = Total Cost (₦)

TVC = Total Variable Cost (₦)

TFC = Total Fixed Cost (₦)

TC = TVC+ TFC

RESULTS AND DISCUSSION

Socioeconomic characteristics of IFAD-VCDP beneficiaries and non-beneficiaries

Table 2 shows that the majority of IFAD-VCDP beneficiaries (48.08%) were within the 40-59 years age range, 37.31% were aged 20-39 years, 10.38% were 60 years and above, while 4.23% were under 20 years. For non-beneficiaries of the IFAD-VCDP intervention, 64.23% of the respondents were within the age range of 40-59 years, 19.61% were within the age range of 20-39 years, 11.15% were 60 years and above, and 5.00% were less than 20 years. The mean age of beneficiary rice farmers was 42, and that of non-beneficiary rice farmers was 45 years. This implies that most rice farmers were middle-aged, resourceful, and energetic during their economically active years. The results on sex showed that 53.08% of the IFAD-VCDP beneficiaries were male and 46.92% were female, while for the non-beneficiaries, 59.62% were male and 40.38% were female. The study also revealed that 37.31% of the IFAD-VCDP beneficiaries had a secondary school education, 30.00% attended tertiary education, 22.31% had primary education, and 10.38% had no formal education. For the non-beneficiaries, the results showed that 34.23% had no formal education, 33.84% had primary education, 24.62% attended secondary school, and 7.31% participated at the tertiary level. The average educational level of the beneficiary was 12 years, while that of the non-beneficiary was 6 years. These results were similar to those of Dooember ***et al*****.** (2020) in their study, which reported that the majority (43.1%) of the IFAD-VCDP beneficiaries had a secondary school education in Yewa North and Ijebu North-East, Ogun State, Nigeria.

Regarding household size, 85.38% of the beneficiaries had fewer than 5 members in their household, and 14.62% had more than 5 persons. For the non-beneficiaries, 58.85% had 5-10 persons actively participating in rice production, 40.77% had fewer than 5 persons, and 0.38% had more than 10 persons actively participating. The beneficiary had an average household size of 3 persons, while the non-beneficiary had an average household size of 5 persons. These results show that the non-beneficiaries had larger household members in rice work than the beneficiaries of IFAD-VCDP. The size of a household directly affects the labour supply for farming, as larger households can provide more labour for rice production. A larger household size is believed to provide cheap labour that assists in rice production activities (Omoare and Oyendiran, 2017). The findings in Table 2 also showed that 74.62 % of the beneficiaries had 10-19 years of experience, 13.46 % had 1-10years of experience, 7.31 % had 20-29 years of experience, 3.46 % had 30-39 years of experience, and 1.15 % had more than 40 years of rice farming experience. For the non-beneficiaries of the IFAD-VCDP intervention, 49.23% had 20-29 years of experience, 41.92% had 10-19 years of experience, 8.46% had less than 10 years of experience, and 0.38% had more than 40 years of experience in rice farming. The average number of years of experience in rice production was 14 years for the beneficiaries and 18 years for the non-beneficiaries, respectively. Results from the extension contact survey showed that 100.00% of the beneficiaries had contact with extension agents in a year, and 42.31% of non-beneficiaries had access to extension agents in the same period. This implied that 57.69% of non-beneficiaries did not have access to extension agents. Regarding the number of contacts with extension agents, 68.46% of the beneficiaries had between 10 and 20 contacts in a year, 19.23% had fewer than 10 contacts in a year, and 12.31% had more than 20 extension contacts in a year. For IFAD-VCDP non-beneficiaries, 57.69% had fewer than 5 contacts in a year, and 2.31% had more than 5 contacts. The average number of extension contacts was 12 times per year for the beneficiary and once for the non-beneficiary. The results showed that beneficiaries of IFAD-VCDP had better access to extension agents than non-beneficiaries.

Furthermore, the results showed that all (100%) of the IFAD-VCDP beneficiary rice farmers were members of cooperative societies. In comparison, 52.69% of the non-beneficiary rice farmers did not belong to any farming associations. The average years of membership for the cooperative association were 7 and 2 for beneficiaries and non-beneficiaries, respectively. This showed that IFAD-VCDP beneficiaries had more years of membership in cooperative associations compared to non-beneficiaries, likely due to the programme requirement of membership in a cooperative association to qualify for IFAD-VCDP benefits. It implies that as rice farmers become involved in cooperative societies/associations, it increases their chances of participating in the IFAD Value Chain Development Programme.

Net farm income of rice production among IFAD-VCDP beneficiaries and non-beneficiaries

The various costs incurred for the resources used and the benefits (profit) received from the sales of the products were estimated based on the market price during the period under consideration (2024/2025 farming season) and are presented in Table 3. These include the cost of seed per hectare, the cost of agrochemicals per hectare, the cost of fertiliser per hectare, the cost of transportation, and the cost of labour. The production costs incurred were both variable and fixed costs, as shown in Table 3. The costs and returns of the two groups of farmers were analysed using gross margin (GM).

The results in Table 3 indicated that the gross margin for IFAD-VCDP beneficiary rice farmers was ₦1,386,093 per hectare, while the non-beneficiary rice farmers obtained ₦670,275 per hectare. This was obtained by subtracting the total variable costs (TVC) from the total gross revenue. The total variable costs were obtained by the summation of the average price of seeds, pesticides, herbicides, fertilisers, labour and transportation separately for both IFAD-VCDP

Table 2: Socioeconomic characteristics of IFAD-VCDP beneficiary and non-beneficiary rice farmers.

Characteristics	Freq.	Percent Beneficiary	Mean	Freq.	Percent Non-Beneficiary	Mean
Age						
Less than 20	11	4.23	**42 years**	13	5.00	**45 years**
20-39	97	37.31		51	19.61	
40-59	125	48.08		167	64.23	
61 above	27	10.38		29	11.15	
Sex						
Male	138	53.08		155	59.62	
Female	122	46.92		105	40.38	
Education level						
No formal education	27	10.38	**10 years**	89	34.23	**6 year**s
Primary	58	22.31		88	33.84	
Secondary	97	37.31		64	24.62	
Tertiary	78	30.00		19	7.31	
Household size						
1-5	222	85.38	**3 persons**	106	40.77	5 **persons**
6-10	38	14.62		153	58.85	
11 and above	0	0.00		1	0.38	
Farm size						
<1	0	0.00	**2.7 ha**	15	5.77	**1.9 ha**
1-4	228	87.69		245	94.23	
5 and above	32	12.31		0	0.00	
Farming experience						
Less than 10	35	13.46	**14 years**	22	8.46	**18 years**
10-19	194	74.62		109	41.92	
20-29	19	7.31		128	49.23	
30-39	9	3.46		1	0.38	
40 and above	3	1.15		0	0.00	
Access to credit						
Yes	126	48.08		27	10.38	
No	134	51.12		233	89.62	
Extension visits						
1-10	50	19.23	**12 times**	104	40.00	**1 time**
10-19	178	68.46		0	0.00	
20 and above	32	12.31		0	0.00	
Cooperative Membership						
Member	260	100.0		123	47.31	
Not member	0	0.00		137	52.69	

Source: Field Survey, 2025

beneficiary and non-beneficiary rice farmers. The results show that the estimated total revenue realised by the IFAD-VCDP beneficiary rice farmers was ₦1,765,918, while the revenue obtained by the non-beneficiary rice farmers was ₦1,065,456.

The results in Table 3 further show that the total variable cost incurred by the IFAD-VCDP beneficiary rice farmers was ₦379,825. The non-beneficiary rice farmers incurred a total variable cost of ₦395,181. The total fixed cost incurred by the IFAD-VCDP beneficiary and non-beneficiary rice farmers was ₦78,021 and ₦101,850, respectively. The total revenue was obtained by multiplying the average price (p) by the average quantity of output (q). The net farm income was calculated by subtracting the average total fixed cost from the average gross margin. The IFAD-VCDP beneficiary rice farmers had a net farm income of ₦1,308,070, while the non-beneficiary rice farmers had ₦568,425.

The gross margin ratio for IFAD-VCDP beneficiary and non-beneficiary rice farmers was 78.50% and 62.90%, respectively. This implies that for every ₦1 of revenue generated from rice farming, beneficiaries retain ₦0.7850 and non-beneficiaries retain ₦0.6290 as gross profit after covering the operating costs. This implies that both IFAD-VCDP beneficiary rice farmers and the non-beneficiary rice farmers made a profit from the rice enterprise. Hence, rice farming is a profitable enterprise. However, IFAD-VCDP beneficiary rice farmers made more profit compared to the non-beneficiary rice farmers. This may be due to the incentives given to IFAD-VCDP beneficiary rice farmers. This finding is similar to that of Iordekighir ***et al.*** (2025), who also reported the gross farm income per hectare before the IFAD-VCDP intervention to be ₦551,007.20. After the intervention, it stood at ₦1,046,217.72. This shows a significant increase (difference) of ₦495,210.52 after the intervention, implying that the rice farmers in the study area earned more income as a result of participating in the programme. Similarly, Alabi ***et al.*** (2024) also reported that the gross margin ratio for programme beneficiaries and non-beneficiaries was 74% and 60%, respectively. This implies that the profitability of IFAD-VCDP beneficiary rice farmers was higher compared to non-beneficiaries in Niger State.

Table 3: Net farm income of one hectare of IFAD-VCDP beneficiary and non-beneficiary rice farmers

	Beneficiary			Non-Beneficiary		
Items	**Unit Price (₦)**	**Quantity**	**Amount (₦/ha)**	**Unit Price (₦)**	**Quantity**	**Amount (₦/ha)**
Revenue(R)			**1,765,918**			**1,065,456**
Variable Costs						
Seed	386/Kg	30 Kg	11,580	366 Kg	30 Kg	10,980
Herbicide	2840/L	9 L	25,560	3,691 /L	7 L	25,837
Fertilizer	518 /Kg	253 /Kg	131,054	539 /Kg	218 Kg	117,502
Pesticide	2510/L	4 L	10,040	3,209/L	3 L	9,627
Labour	2039/Manday	89Manday	181,471	2,397/Manday	88Manday	210,936
Transportation	20120	1	20,120	20,299	1	20,299
Total variable cost (TVC)			**379,825**			**395,181**
Gross Margin (R-TVC)			**1,386,093**			**670,275**
Fixed Cost (FC)						
Machineries	35,181	1	35,181	55,850	1	55,850
Rent on Land	42,840	1	42,840	46,000	1	46,000
Total Fixed Cost (TFC)			**78,021**			**101,850**
Total Cost (TC)			**457,846**			**497,031**
Net Farm Income (GM-TFC)			**1,308,070**			**568,425**
Gross Margin Ratio (GMR) = GM x 100 / R			**78.50 %**			**62.90 %**

Source: Field Survey, 2025

Yield and income of IFAD-VCDP beneficiary and non-beneficiary rice farmers

Yield is a critical indicator of agricultural productivity among the IFAD-VCDP beneficiary and non-beneficiary rice farmers. The results on rice yield obtained by the respondents are presented in Table 4. The results showed that 46.54 % of the beneficiary had yield of 3.1 to 4.0 tons/ha, 25.38 % had yield of 2.1 to 3.0 tons/ha, 18.46 % had yield of 4.1 to 5.0 tons/ha, 6.15 % had yield of 1.1 to 2.0 tons/ha, 1.92 % had yield of 1.0 tons/ha and below, 1.54 % had yield of 5.0 tons/ha and above. The results for IFAD-VCDP non-beneficiary revealed that 40.38 % had yield of 2.1 to 3.0 tons/ha, 30.00 % of the non-beneficiary had yield of 1.1 to 2.0 tons/ha, 17.31 % had yield of 3.1 to 4.0 tons/ha, 7.31 % had yield of 1.0 tons/ha and below and 1.15 % had yield of 5.0 tons/ha and above. The average yield for IFAD-VCDP beneficiaries and non-beneficiaries was 3.83 tons/ha and 2.26 tons/ha, respectively. From this result, it is evident that the IFAD-VCDP intervention had a positive impact on beneficiary yield, resulting from the adoption of good agronomic practices, such as improved seed varieties, timely transplanting, fertiliser and herbicide application, and support services. This research aligns with the findings of Oruonye *et al.* (2021), who reported higher yields among beneficiaries of the IFAD-VCDP programme both before and after the intervention in Taraba State.

Ho1: Since the calculated Z-value (3.627) was greater than the tabulated Z-value (1.96) at $P<0.05$, the null hypothesis was rejected, and it was concluded that there was a significant difference in the mean yield of IFAD-VCDP beneficiary and non-beneficiary rice farmers. This suggests that the IFAD-VCDP intervention had a significant impact on rice farming in the study area.

The results in Table 4 further show that among the IFAD-VCDP beneficiary rice farmers, 42.69 % had income of ₦1,000,000-₦1,900,000, 31.18 % of the respondents had income of ₦2,000,000-₦2,900,000, 14.62 % of the respondents had income of less than ₦1,000,000, and 11.54 % had income of ₦3,000,000 and above. The response on income of non-beneficiary of IFAD-VCDP intervention indicates that majority (51.15 %) of the respondents had income of ₦1,000,000-₦1,900,000, 37.69 % of the respondent had income of less than ₦1,000,000, 9.62 % of the non-beneficiary of IFAD-VCDP intervention programme had income of ₦2,000,000-₦2,900,000 and 1.54 % of the respondents had income of ₦3,000,000 and above. This finding aligns with Abdullahi's (2016) study, which reported that the respondents' income before the IFAD-VCDP intervention was poor compared to their income after the intervention, as indicated by an increase in the number of bags harvested and a corresponding rise in income in Niger State, Nigeria. The finding was also similar to Adi *et al.* (2020), who reported a significant difference between the yields and income of the beneficiary before and after joining the IFAD-VCDP in Taraba State, Nigeria, with a yield difference of 4.10 tons after the programme, and their income changed from ₦259,891.30 to ₦597,989.14 before and after the programme. This indicates that IFAD-VCDP has had a positive impact on the livelihoods of farmers in the study area.

Ho1: Since the calculated Z-value (13.31) was greater than the tabulated Z-value (1.96) at P<0.05, the null hypothesis was rejected, and it was concluded that there was a significant difference in the mean income of IFAD-VCDP beneficiaries and non-beneficiary rice farmers.

Table 4: Yield and Income of IFAD-VCDP Rice Farmers Beneficiary and Non-Beneficiary in Nasarawa State

Yield

Yield (Tons/ha)	**Frequency Beneficiary**	**Percent**	**Mean**	**Frequency Non-Beneficiary**	**Percent**	**Mean**
1.0 and below	5	1.92	**3.83**	19	7.31	**2.26**
1.1 to 2.0	16	6.15		78	30.0	
2.1 to 3.0	66	25.38		105	40.38	
3.1 to 4.0	121	46.54		45	17.31	
4.1 to 5.0	48	18.46		10	3.85	
5.1 and above	4	1.54		3	1.15	
Calculated Z-value		**3.627**				
Tabulated Z-value		**1.96**				
P<0.05						

Income

Income (₦)	**Freq Beneficiary**	**Percent**	**Mean**	**Freq Non-Beneficiary**	**Percent**	**Mean**
Below 1000000	38	14.62	2,844,230	98	37.69	
1,325,673						
1000000-19000000	81	31.18		133	51.15	
2000000-29000000	111	42.69		25	9.62	
3000000 and above	30	11.54		4	1.54	
Calculated Z-value		**13.31**				
Tabulated Z-value		**1.96**				
P<0.05						

Source: Field Survey, 2025

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CONCLUSION AND RECOMMENDATIONS

The study's findings revealed that the IFAD-VCDP intervention had a positive impact on rice farming in the study area. The results of the Z-statistic indicate a significant difference in the yield and income of rice farmers who benefited from the IFAD-VCDP compared to those who did not.

The research also showed that rice production was a profitable venture for both IFAD-VCDP beneficiaries and non-beneficiaries. However, the programme had a significant positive impact on the profitability of the beneficiary rice farmers. Based on the findings of the study, it was recommended that;

1. IFAD/FGN need to expand the programme to reach all other rice-producing LGAs in the State, ensuring that more farmers benefit from the programme.
2. The State and Federal governments should complement the efforts of IFAD-VCDP by initiating and executing similar value chain development programmes aimed at enhancing rice yield and income in Nasarawa State, in particular, and Nigeria at large

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EFFECTS OF BOTANICAL SOURCES IN THE CONTROL OF COWPEA WEEVILS (*Callosobruchus maculatus* F.) ON STORED COWPEA (*Vigna unguiculata* L. Walp) SEEDS

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ABSTRACT

Cowpea weevils (Callosobruchus maculatus F.) are a major insect pest of Cowpea in storage. The experiment was carried out at the Entomology laboratory of the Department of Crop Production Technology, Oyo State College of Agriculture and Technology, Igboora, to determine the effects of Neem (Azadirachta indica) and Guinea henweed (Petiveria alliaceae) in the control of Cowpea weevil in stored Cowpea. The Milk variety of clean cowpea seeds was procured from the Towobowo market in Igboora, Oyo State, and stored in a freezer for 2 weeks to disinfect them. Neem and Guinea henweed leaf powders were used at different rates to control the infestation of cowpea weevils. The experimental treatments were arranged in a Completely Randomised Design (CRD) comprising seven treatments (1 g, 2 g, 3 g of neem powder), (1 g, 2 g, 3 g of guinea henweed powder) and a control on 40g of Cowpea seeds replicated three times. Data were collected 7 days after treatment application on the weight of seed content, the number of live *insects, and the mortality count of adult Callosobruchus maculatus. A higher rate of application of Neem leaf powder at 3g resulted in significantly higher seed weights (39.3g, 37.33g, 35.67g) and mortality rates (13.67g, 15.33g, 18.00g) compared to guinea henweed powder. The botanicals at 3 g to 40 g of cowpea (3.75 kg of neem and guinea henweed leaf powders to 50 kilograms of cowpea) were therefore recommended as an alternative in place of chemical preservatives.*

Keywords: Botanicals, Control, Cowpea weevils, Cowpea, Storage

INTRODUCTION

Cowpea (Vigna unguiculata L. Walp) is one of the most important grain-legumes in the farming systems of Nigeria and West Africa at large (Singh *et al*., 2002). It accounts for about 60% of the protein intake in Nigeria (Oparaeke *et al*., 2004). Cowpea provides feed, forage, hay, and silage for livestock, as well as green manure and cover crops that maintain soil productivity (Alemu *et al*., 2016). In the agricultural system, it compensates for the loss of nitrogen absorbed by cereals, thereby having a positive impact on soil properties. This is due to its unique capacity to fix atmospheric nitrogen and perform well even in poor soil (Rosenblueth *et al*., 2018). However, severe damage caused by storage pests lowers the quality and quantity of the crop produce, as they consume portions of the produce, leading to losses that are usually manifested by a reduction in weight (Kumar *et al*., 1996).

Callosobruchus maculatus (Coleoptera: Chrysomelidae: Bruchinae) is an agricultural insect pest of Cowpea in Africa and Asia that presently ranges throughout the tropical and subtropical world. It is a cosmopolitan field-to-store pest that initiates its attack shortly before harvest and continues to develop in storage. Adults lay eggs on the seeds, and the larvae bore into the grains, feeding on the cotyledons and causing substantial losses. The damage affects the quality of the seeds and taints the taste of the crops, thus affecting the market value. This beetle is responsible for most of the losses which occur in stored cowpea seeds. The postharvest infestation of cowpea beetles, therefore, constitutes a major problem contributing to significant food shortages and loss of food value in tropical and subtropical countries worldwide. The weevil causes the loss of produce mainly due to the consumption of cowpea seed cotyledons by larvae.

The control of cowpea weevil has been achieved through fumigation or spraying with chemicals of different toxicological classes. Synthetic insecticides are expensive for small-scale farmers and require specialised equipment and training for their practical use. The widespread use of these products in recent years has led to numerous problems, including the emergence of resistant populations and high levels of insecticide residues in foodstuffs, which harm both consumer health and the environment.

In addition to the problems mentioned above, many producers, especially those in family farms, neglect controlling the weevil due to a lack of financial resources. In this scenario, the use of insecticidal plants stands out as a promising alternative for weevil control, as these plants typically have low costs, easy application, biodegradability, and may be available on the producer's property. Among the promising plant species for controlling the cowpea weevil are products derived from neem (Azadirachta indica), which stand out because they contain substances, especially Azadirachtin, that act as an insecticide. Neem leaf powder caused increased adult mortality of weevils in cowpea seeds, without causing changes in the viability characteristics of the seeds.

Also, Petiveria alliacea (commonly known as guinea henweed or garlic weed) is a medicinal plant with demonstrated insecticidal properties. Research indicates that extracts from this plant are effective against cowpea weevils (Callosobruchus maculatus), a major pest of stored cowpea grains (Adedire and Lajide, 2003; Boeke *et al*., 2004).
However, there is a dearth of information regarding the appropriate application rates of these botanicals. Therefore, the study was conducted to investigate the effects of varying application rates of Azadirachta indica and Petiveria allicea on the control of cowpea weevils in stored cowpea.

MATERIALS AND METHODS

The experiment was conducted at the Entomology Laboratory (Latitude 7 ° 24' 42'' N, Longitude 3 ° 17' 44'' E, and Altitude 134 m) of the Crop Production Technology Department, Oyo State College of Agriculture and Technology, Igboora. Igboora is situated in the Ibarapa Central Local Government Area of Oyo State, at an elevation of 397m above sea level. It shares its boundaries with Abeokuta, Ibadan, and the Oke-Ogun region. It is located in the derived savanna zone and experiences distinct dry and wet seasons, with average monthly high and low temperatures of 33°C and 22°C, respectively.

Clean cowpea seeds (milk variety) were procured from Towobowo market in Igboora, Oyo State, and stored in a freezer for 2 weeks to disinfect them. The initial stock of adult **Callosobruchus maculatus** was obtained from infested cowpeas at the Towobowo market in Igboora. It was maintained on beans in a 7L rearing plastic jar under laboratory conditions for 30 days. This helped in raising adult male and female weevils of uniform size and age.

Neem and Petiveria leaf powders were sourced from the Ladoke Akintola University of Technology, Ogbomoso, Department of Crop and Environmental Protection, and were applied at 1 g, 2 g, and 3 g to 40 g of cowpea seeds in 200 ml transparent plastic jars, with each replication repeated three times. The plastic jar was stirred vigorously to ensure a uniform coating of the grain by the powder treatment samples. Thereafter, 10 newly emerged adult **C. maculatus** from the rearing plastic jar were introduced into the transparent plastic jars, covered with muslin cloth, and secured with a rubber ring to allow proper ventilation. The control jar was not treated with a botanical.

The treatments were laid out in a Completely Randomised Design (CRD) and replicated three times. Data collection commenced 7 days after the application of treatments. The weight of seed content in the jar was measured weekly using a measuring scale. The number of live insects was visually counted on a weekly basis. Mortality counts for adult insects were conducted weekly by emptying the contents of the jars, removing and counting the dead insects, and then replacing the remaining contents. The data collected were subjected to Analysis of Variance (ANOVA), and significant means were separated using Tukey's Honest Significant Difference (HSD) Test at a 5% probability level.

RESULTS AND DISCUSSION

Effect of Neem and **Petiveria** leaf powders on the number of live bean weevils

There was a significant ($P \leq 0.05$) difference in the population of **Callosobruchus maculatus** among the treatments at 7, 14, and 21 days after treatment. The application of botanicals significantly reduced the population of cowpea weevils when compared to the control. The application of neem at 3 g produced the lowest significant ($P \leq 0.05$) weevil population of 1.33, 3.00, and 5.00 at 7, 14, and 21 days after treatment, respectively. At 21 days after treatment, Neem at 3 g, **Petiveria** at 1g and Neem at 2 g produced similar effects (5.00, 7.00 and 7.67) on the number of live insects. It was significantly lower ($P \leq 0.05$) compared to other treatments.

Table 1: Effect of botanicals on number of live bean weevils

Treatment	7 days	14 days	21 days
Control	16.33a	18.67a	20.67a
Neem 1 g	15.67a	17.00b	19.00a
Neem 2 g	3.67c	5.33d	7.67c
Neem 3 g	1.33c	3.00e	5.00c
Petiveria 1 g	3.00c	4.67e	7.00c
Petiveria 2 g	6.67b	9.00c	10.67b
Petiveria 3 g	7.33b	9.00c	12.33b

Means with the same letter along the column are not significantly different using Tukey's Honest Significant Difference (HSD) Test at $P \leq 0.05$.

Effect of Neem and **Petiveria** leaf powders on the number of mortalities

There was a significant difference ($P \leq 0.05$) in the mortality rate of Callosobruchus maculatus among the treatments at 7, 14, and 21 days after treatment. The application of botanicals significantly ($P \leq 0.05$) increased the mortality rate of cowpea weevils when compared to the control. The application of Neem at 2 g produced significantly ($P \leq 0.05$) higher insect mortality compared to 1 g of Neem on days 7 (17.67, 13.00), 14 (20.67, 18.00), and 21 (25.33, 20.67) after treatment, respectively. At 21 days after treatment, Neem powders (1 g and 3 g) and Pertieria leaf powder (1 g and 2 g) produced a similar effect on the mortality of bean weevils. The control produced the lowest significant ($P \leq 0.05$) mortality rates of 5.33, 10.00, and 11.00 at 7, 14, and 21 days after treatment, respectively.

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Effect of Neem and Petiveria leaf powders on the weight of cowpea seeds

There was a significant ($P\leq 0.05$) difference in the effect of botanicals on the weight of cowpea seed. The control produced the lowest significant ($P\leq 0.05$) seed weight at 7 (33.33 g), 14 (31.13 g) and 21 (27.67 g) days after treatment, while seed treated with 3 g of Neem leaf powder produced the highest significant ($P\leq 0.05$) seed weights (37.33 g and 35.67 g) at 14 and 21 days after treatment respectively. However, application of Petivera leaf powder at 1 g, 2 g and 3 g produced similar effects on the weight of cowpea seed at 14 and 21 days after treatment.

Table 2: Effect of Neem and *Petiveria* leaf powders on number of mortality of bean weevils

Treatment	7 days	14 days	21 days
Control	5.33c	10.00c	11.00d
Neem 1g	13.00b	18.00b	20.67c
Neem 2g	17.67a	20.67a	25.33a
Neem 3g	13.67b	15.33b	18.00c
Petiveria 1g	12.33b	14.00b	16.33c
Petiveria 2g	12.33b	16.00b	17.67c
Petiveria 3g	16.00a	18.67b	19.33b

Means with the same letter along the column are not significantly different using Tukey's Honest Significant Difference (HSD) Test at $P \leq 0.05$.

Table 3: Effect of Neem and *Petiveria* leaf powders on weight of cowpea seeds (g)

Treatment	7days	14days	21days
Control	33.33c	31.13c	27.67d
Neem 1g	39.40a	33.67b	30.00b
Neem 2g	35.80b	32.67b	35.67a
Neem 3g	39.33a	37.33a	29.00c
Petiveria 1g	38.40a	37.03b	33.33b
Petiveria 2g	37.27b	33.73b	29.67b
Petiveria 3g	37.17b	34.33b	30.67b

Means with the same letter along the column are not significantly different using Tukey's Honest Significant Difference (HSD) Test at $P \leq 0.05$.

DISCUSSION

Based on the result presented above, the application of botanicals significantly reduced the population of cowpea weevils when compared to the control. The application of neem at 3 g produced the lowest significant ($P \leq 0.05$) weevil population of 1.33, 3.00, and 5.00 at 7, 14, and 21 days after treatment, compared to other treatments, except for 1 g of **Petiveria**. This may be due to the higher presence of *Azadirachtin*, which is a major bioactive compound in neem that can disrupt the growth and reproduction of cowpea weevils. This result corroborates the findings of Liamngee ***et al***. (2020), who reported that neem leaf powder significantly ($P \leq 0.05$) reduced weevil emergence by up to 85% when used at appropriate dosages. Additionally, neem contains volatile compounds, such as limonoids and Salannin, which create an unfavourable environment that deters female weevils from laying eggs on treated seeds (Oyewole and Agwu, 2021). Additionally, **Petiveria** leaf powder contains bioactive compounds, including flavonoids, organosulfur compounds, and alkaloids, which disrupt insect metabolism, growth, and reproduction (Kubo ***et al***., 2006; Ntukuyoh ***et al***., 2012). The application of neem at 2 g resulted in the highest significant ($P \leq 0.05$) insect mortality at days 14 (20.67%) and 21 (25.33%) after treatment, compared to other treatments. The application of neem at 3g produced the highest significant ($P \leq 0.05$) weight of 37.33g and 35.67g at 14 and 21 days after treatment. Additionally, 3 g of **Petiveria** leaf powder resulted in a significantly higher seed weight (30.67 g) compared to the control (27.67 g). This may be due to the presence of nimbin and Nimbidin compounds in neem leaf powder, which act as contact poisons to adult weevils and anti-feedants that reduce seed consumption by larvae. This finding is in line with Achio ***et al***. (2012 who reported that the mortality rate exceeds 70% in adult weevils when cowpea seeds were treated with neem leaf powder.

CONCLUSION AND RECOMMENDATIONS

From this study, it can be concluded that neem and **Petiveria** leaf powders are potent preservatives for cowpea. These botanicals can preserve the quality and quantity of cowpea. Application of 2 g Neem and 1 g of *Petiveria* leaf powders are the most effective botanical rate for effective control of cowpea weevils. Since neem trees and **Petiveria** shrubs are widely available in the study area, they are inexpensive, biodegradable, and safe for humans and livestock, making them a sustainable alternative to synthetic pesticides. Farmers should adopt the use of neem and **Petiveria** leaf powders for preserving cowpea in storage. This would help prevent the attendant dangers associated with the use of chemical preservatives, which are most common in our society today.

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ASSESSMENT OF CROP FARMERS' PATRONAGE AND PERCEPTION OF AGRICULTURAL PROGRAMMES OF SOLID FM RADIO IN SOUTHERN AGRICULTURAL ZONE OF NASARAWA STATE, NIGERIA

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ABSTRACT

The study was carried out to assess crop farmers' patronage and perceptions of the agricultural programmes of Solid FM Radio in the Southern Agricultural Zone of Nasarawa State, Nigeria. A total of 277 farmers were selected through a multi-staged sampling procedure. Data were collected using a structured questionnaire and analysed using descriptive statistics. The results of the analysis revealed that the majority of respondents were male (81.2 %), with a mean age of 40 years, had formal education (81.2 %), had a mean household size of 5 persons, and had a mean farming experience of 9 years. The majority (64.3 %) of the respondents had not accessed loan facilities, but had extension contacts (60.3 %). The majority of respondents (63.9%) belonged to one cooperative group or another, and all respondents owned a radio set or had access to one. The results further showed that all respondents were aware of Solid FM's popular agricultural programmes. While 83.4 % listen to 'Mu koma gona' (let's go back to farming), 84.8 % listen to Noman shinkafa jari (rice farming: a profitable venture). Most respondents (41.5 %) had been listening to Solid FM's agricultural programmes for 1-3 years. They were not regular listeners of 'mu koma gona' (71.1 %) and Noman shinkafa jari (71.8 %). Furthermore, the *majority (88.4 %) of respondents were delighted with the information they received from the agricultural programmes, and there was no significant association between the duration of listenership to agrarian programmes on the radio and satisfaction with them. The study recommended that the programmes be sustained and that the radio station do more to increase patronage.*

Key Words: Agricultural programmes, Crop Farmers, Patronage, Radio

INTRODUCTION

The dissemination of agricultural information through the media to educate farmers and increase their productivity and income cannot be overemphasissed. According to Duncan *et al.* (2024), mass media technologies are beneficial for empowering rural farmers by disseminating various forms of production information, which can directly advance farmers' social and economic lives and the broader development of agriculture. Similarly, Adejo *et al. (2016*) and Tijani *et al. (*2019) both asserted that, among the mass media, radio is the most effective at reaching rural areas. According to Omoghene *et al.* (2017), radio is one of the most appropriate media for agricultural communication because it spans distances and thus has immediate effects. It has been identified as the only mass medium with which the rural population is very familiar.

Abdul Aziz *et al.* (2013) observed that the introduction of radio broadcasting in Nigeria over the past century has brought about profound changes in society through Agricultural broadcasting. Various radio programme designs have been used to achieve the greatest reach among farmers. Farm broadcasting or "Farm Casting" refers to the whole system and structure within broadcasting institutions through which agricultural radio programmes are produced and disseminated to the general public, mainly as part of agrarian extension strategies. Olajide and Amusat (2012) report that farm broadcasting in Nigeria started in the 1960s through the regional government ministries of agriculture.

Many Nigerian radio stations now broadcast agricultural programmes to meet farmers' agricultural information needs. Most of these programmes are presented in different formats, predominantly in the local languages understood by the people. Nasarawa Broadcasting Service (NBS) Lafia is also among these stations. The NBS (Solid FM 97.1, as it is popularly called) was established in 1996 by the government of Nasarawa State, Nigeria, and was empowered to disseminate information for the purpose of informing, educating, and entertaining the people of the state.

In an effort to achieve its objectives in agriculture and to meet the information needs of farmers in Nasarawa State, NBS (Solid FM) designed two agricultural programmes: *Mu koma Gona* (let's go back to farming) and *Noman Shinkafa jari* (rice farming: a profitable venture). All the programmes are presented in Hausa. *Noman Shinkafa Jari,* sponsored by Radio Farm International (RFI); the other is produced and hosted by NBS Radio (Solid FM). The programmes cover various aspects of agriculture, including crop production, livestock, and fisheries; post-harvest handling practices; marketing strategies; environmental protection; prices of farm inputs; credit and loan facilities; weather forecasting; and climate change, among others.

Over the years, Solid FM has aired various agricultural programmes aimed at improving agricultural production, rural development, and farmers' livelihoods. Although the programmes are effective means of reaching farmers with agricultural information, their impact on farmers' output, income, and improved livelihoods has not been clearly evident. Moreover, there is a dearth of empirical studies on farmers' patronage and perceptions of Solid FM's agricultural programmes in the Southern Agricultural Zone of Nasarawa State; hence, it is not known whether crop farmers are actually listening to the programmes and adopting the technologies they promote. This leaves a gap that needs to be filled. Although previous studies (Abdulazzi and Ibrahim, 2024; Omoghene *et al*. 2017) have examined the patronage of radio agricultural programmes in Nigeria, no recent studies appear to have explicitly assessed crop farmers' patronage and perceptions of Solid FM Radio's agricultural programmes in the Southern Agricultural Zone of Nasarawa State. This gap underscores the purpose of the present study.

Objectives of the study

The broad objective of this study was to assess crop farmers' patronage and perception of agricultural programmes of Solid FM Radio in the Southern Agricultural Zone of Nasarawa State, Nigeria. The specific objectives were to;

1. described the socio-economic characteristics of the respondents
2. determined the respondents' awareness of the agricultural programmes of Solid FM Radio
3. determined the respondents' level of patronage of the agricultural programmes of Solid FM Radio in the study area

4. determine respondents' level of satisfaction with the agricultural programmes of Solid FM Radio.

Hypothesis

HO: There is no significant association between the duration of listening to agricultural programmes on solid FM and the level of satisfaction with the programmes.

METHODOLOGY

Study Area

The study was conducted in the Southern Agricultural Zone of Nasarawa State, Nigeria. The zone shares boundaries with Benue State to the South, Taraba State to the East, Plateau State to the Northeast, and Nasarawa Eggon Local Government Area to the North, and Nasarawa Local Government Area to the West. The area is located between latitudes 90.330N and 90.320E and covers a land area of 10,644 square kilometres (Nasarawa State Government, 2020), with a population of 811,020 people (National Population Commission, 2006). The study area is characterised by a period of rainy Season from May to October. The average rainfall is approximately 1750 mm, and the annual temperature range from 22.70 °C to 39.00 °C (Nasarawa State Government, 2020).

Agriculture is the dominant occupation in the area. Major crops grown in the study area include: yams, cassava, maize, rice, beni-seed, melon, groundnut, and tree crops such as mangoes, cashews, and oranges. The farmers also raise livestock, including cattle, sheep, goats, and poultry. The zone comprises five local government areas: Lafia, Obi, Awe, Keana, and Doma.

Population, Sample and Sampling Technique

The target population for this study comprised all the crop farmers in the Southern Agricultural zone who listened to Solid FM Radio. A multi-stage sampling technique was employed to obtain the sample size of 277 crop farmers from the 906 registered farmers. Stage 1 involved a random selection of three (3) Local Government Areas from the five Local Government Areas in the study area. Stage II was a random selection of three villages from each of the three selected Local Governments, making up a total of nine villages. Lastly, stage III involved the random selection of farmers from each village based on the list of 906 crop farmers obtained from the Nasarawa Agricultural Development Programme. The list was subjected to Yamane’s (1967) formula. This was to ensure proper selection and distribution of respondents accordingly.

The formula is presented in equation 1. According to the Yamane (1967) formula;

$n = N/1 + N(\alpha)^2$ to get the sample size n------------------ 1.

Where, n =desired sample size

N = population under study(906)

α = margin of error (0.05).

The working is summarised as follows:

$n = \frac{906}{1+906} \times 0.0025 =$

$\frac{906}{1+2.654} = n = \frac{906}{3.265}$

n=277.

Data Collection and Analysis

Primary data were collected using a structured questionnaire and analysed using both descriptive (frequency, percentage, mean) and inferential (chi-square) statistics.

RESULTS AND DISCUSSION

Socio-economic Characteristics of Respondents

The results of the analysis of socio-economic characteristics of respondents are presented in Table 1 and discussed as follows:

Age Distribution: The results revealed that the majority (52.0%) of respondents were aged 38 or older, with a mean age of 40 years. This implies that the majority of the respondents were still active and strong enough to participate actively in agricultural activities. This age range has been categorised as economically active, innovative, and productive. This finding is in agreement with Tafida and Sabiu (2021), who studied the utilisation of radio agricultural programmes among crop farmers in Kano State, Nigeria, and found that most crop farmers were active and well-positioned to utilise them.

Sex: The results showed that the majority (80.1%) of respondents were male, while only 19.9% were female. These results suggest that males were mainly engaged in farming activities in the study area, probably because farming is more physically demanding, traditional gender roles, and the fact that men have greater access to land and other farming inputs, as well as limited capital available to female farmers. The results also imply that male farmers listen to Solid FM Radio's agricultural programmes more than female farmers. This result corroborates the findings of Njoku and Ugboaja (2019) that radio-farmer agricultural programme listenership was dominated by male farmers in Imo State, Nigeria.

Level of Education: Table 1 further showed that the majority (33.9%) of respondents had secondary education, 31.8% had advanced education, 14.8% had primary education, and 19.5% had no formal education. This indicates that most respondents can read and write, and understanding and comprehending innovation on the radio will not be difficult. This result aligns with the study by Yakubu *et al.* (2019), who examined the effectiveness of radio agricultural programmes in Jibia Local Government Area of Katsina State, Nigeria, and revealed that the majority of farmers had received formal education. According to Omoghene *et al.* (2017), education was found to influence farmers' access to, comprehension of, and adoption of modern agricultural practices.

Household Size: The majority (39.0%) of respondents had a household size of 1-5 persons. The mean household size of the respondents was 5 persons. These results imply that the farmer in the area had a reasonably large household size. Reasons behind large family size could be attributed to the polygamous practices among the people and their dependency on family as a source of farm labour. It is expected that listening to agricultural programmes on the radio will be more popular among large farming households, especially if the programmes have the potential of raising productivity and household incomes. This finding aligns with the opinion of Tafida and Sabiu (2021) that crop farmers in Kano State, Nigeria, had high family responsibilities, which required them to utilise improved technologies aired on agricultural radio programmes.

Farming Experience: The majority (47.3%) of respondents had 1-10 years of farming experience. The mean years of farming experience in the area was 9 years. This implies that most farmers had extensive experience in crop production. The finding corroborates those of Adikwu (2022), who asserted that yam farmers in Benue State, Nigeria, who listened to Radio Benue agricultural programmes had considerable experience in yam farming.

Major Crops Cultivated: Table 1 shows the major crops grown by the respondents. The majority (37.7%) of the farmers grew rice, 35.8% grew maize, and 26.5% grew cassava. This could be attributed to government policies on homegrown rice and the rising demand for rice by Nigerians, as it is the major staple food for most Nigerians.

Farm Size: The result further revealed that the majority (90.3%) of the respondents had farm sizes of 1-5 hectares, 7.2% had 6-10 hectares, and 2.5% had more than 10 hectares. The mean farm size of the respondents was 3.4 hectares. The result indicates that farmers in the area were predominantly engaged in small-scale production. This could greatly affect their adoption of improved technologies from the radio. This finding is consistent with those of Tafida and Sabiu (2021), who reported that farmers in Kano State, Nigeria, were cultivating small farms of less than 5 hectares.

Extension Contact: Table 1 shows that 60.3% of respondents reported having extension contact, while 39.7% reported otherwise. Among respondents who had contact, 76.6% of the respondents, which constituted the majority, had contact with extension agents 1-2 times in the last 6 months. The overall mean extension contact was 2 visits in the previous 6 months. This implies that the farmers had very low extension contact. This could be due to an inadequate number of extension agents and a lack of logistical support, among other factors. These reasons had made it necessary to find other means to reach farmers with the required agricultural information. The Food and Agriculture Organization (FAO, 2023) described radio agricultural programmes as the most effective means of delivering reliable information to farmers. This result agrees with the findings of Njoku and Ugboaja (2019), who reported that farmers in Imo State, Nigeria, had very low extension contacts. According to Anag (2022), enhanced extension services could promote better-informed decision-making, improved farming techniques, and, ultimately, greater poverty reduction among staple crop farmers.

Access to Credit: The majority of respondents (64.3%) reported not having access to credit facilities, while 35.7% reported having access. These observations imply that accessing loans in the study area was difficult. The result further showed that for respondents who had access to credit, 57.1. % had accessed a loan of above ₦400,000. Access to Credits could facilitate farmers' acquisition and use of radio to increase their knowledge and adoption of new farming practices.

Membership of Cooperative Group: Table 1 shows that the majority (63.9%) of the respondents were members of cooperative societies, whereas 36.1% were not. The findings imply that most farmers had access to and benefited from the advantages offered by such groups. Being a member of cooperative societies gives farmers access to loans, farm inputs, and radios, and also helps them interact with one another on topics presented on the radio. Among cooperative society members, the majority (58.8%) had been members for 1 to 5 years. This indicates that the farmers have been members of the cooperative society long enough to enjoy the benefits. Njoku and Ugboaji (2019) reported that the majority (88.6%) of the farmers in Imo State, Nigeria, belonged to different cooperative organisations.

Access to Radio Set: Table 1 further revealed the respondents' ownership or access to a radio set. The results showed that all respondents had a radio or access to one. This indicates that farmers in the study area listen to the radio and have access to agricultural information. Farmers' radio set ownership is a crucial indicator of the information medium available and of farmers' exposure to radio agricultural programmes. The Food and Agriculture Organization (FAO, 2023) reported that the majority of farmers who listened to the Radio Benue agricultural programme owned their own radio sets.

.**Table 1: Socio-Economic Characteristics of Respondents**

Socio-economic variable	**Frequency**	**Percentage (%**	**Mean**
Age (years)			
18- 28	52	18.80	40.3 years
29-38	81	29.20	
Above 38	144	52.00	
Sex			
Male	222	80.10	
Female	55	19.90	
Level of education			
No-formal education	54	19.50	
Primary education	41	14.80	
Secondary education	94	33.90	
Tertiary education	88	31.80	
Household size (no. of persons)			
1-5	108	39.00	5 persons
6-10	104	37.50	
Above 10	65	23.50	
Farming experience (years)			
1-10	131	47.20	9,3 years
11-20	73	26.40	
Above 20	73	26. 40	
Major crops cultivated*			
Rice	231	83.40	
Maize	219	79.10	
Cassava	162	58.50	

Farm size (hectares)			
1-5	250	90.30	3.4 hectares
6-10	20	7.20	
Above 10	7	2.50	
Access to extension contact			
Yes	167	60.30	
No	110	39.70	
Number of extension contact (no. of visits received)	128	76.60	2 visits
1-2	14	8.400	
3-4	25	15.00	
Above 4			
Access to credit			
Yes	178	64.300	
No	99	35.700	
Amount of loan accessed (Naira)			
1,000-200,000	19	18.10	
200,001-400,000	20	24.80	
Above 400,000	60	57.10	
Membership of cooperative society			
Yes	177	63.90	
No	100	36.10	
Number of years of cooperative society membership (years)	104	58.80	
1-5	73	41.20	3 years
6-10			
Access to radio set			
Yes	277	100.00	

Source: Field survev. 2024

Awareness of Agricultural Programmes of Solid FM Radio

The results in Table 2 show respondents' awareness of 'Solid FM' Radio's agricultural programmes. All respondents indicated awareness of the agricultural programmes of Solid FM Radio, Mu koma Gona (let's go back to farming), and Noman Shinkafa Jari (Rice farming: a profitable venture). Respondents' awareness of the various agricultural programmes aired on the radio station reflects their popularity. Knowledge of a particular programme and its contents will develop listeners' interest, which could lead to its adoption. This corroborates the findings of Maurice *et al*. (2019) that farmers in Adamawa State were aware of various agricultural programmes aired on the radio stations.

Table 2: Awareness of Agricultural Programmes of Solid FM Radio by Respondents

Variable	Frequency	Percentage (%)
Respondents' awareness of agricultural programmes on Solid FM Radio.		
Mukoma Gona		
Yes	277	100.00
No	0	0.00
Noman Shikafa Jari		
Yes	277	100.00
No	0	0.00

Source: field survey, 2024

Patronage of Agricultural Programmes of Solid FM Radio by Respondents

The results of a patronage survey of Solid FM Radio's agricultural programmes revealed that all respondents listened to them, indicating that farmers in the study area had access to agricultural information. The result also showed that the respondents tuned in to both *Mukoma Gona* and *Noman Shinkafa Jari*, the agricultural programmes aired on Solid FM Radio. Specifically, 83.4% listened to *Mu koma gona* (Let's go back to farming) while 84.8% listened to Noman *shinka jari* (Rice farming: a profitable venture). This reflects the high popularity of these programmes among the respondents.

The majority (41.5%) of respondents had been listening to agricultural programmes for 1-3 years, 39% for 4-6 years, and 19.5% for more than 6 years. Implying that most of the respondents had listened to the farming programmes long enough to acquire some vital information necessary to improve production.

The results in Table 3 also revealed that the majority of the respondents — 71.1% and 71.8%, respectively — listened to *Mu koma gona* and *Noman Shinkafa Jari* agricultural programmes only occasionally, while 28.9% and 28.2%, respectively, reported regular listening to each of the agricultural programmes. This indicates very low patronage of the farming programmes. This could be a result of the wrong timing of the programmes, lack of time to listen, short time allotted to the programmes by the radio station, and the high cost of buying batteries, among others. Mtega (2018) noted in his study that the majority of farmers either did not listen to radio agricultural programmes or only tuned in occasionally. The study attributed it to farmers' lack of awareness, the wrong timing of the programmes, and the programme's short duration. Contrary to these findings, Abdulaziz and Ibrahim (2024) and Orifah *et al*. (2025) both found that farmers in Kaduna and Jigawa States, respectively, regularly listened to agricultural radio programmes and were consistently exposed to farming innovations.

Satisfaction with the Agricultural Programmes

The results on satisfaction with the agricultural programmes aired on Solid FM Radio revealed that the majority (88.4%) of the respondents were very satisfied with the information they received from the programmes, while 4.3%.% were not. This indicates that the agricultural programmes were supplying farmers with the information needed to increase production. This finding agrees with Antwi *et al*. (2022), who reported that the majority of farmers in Ghana were highly satisfied with the information they get from radio agricultural programme.

Table 3: Patronage of Agricultural Programmes on Solid FM Radio by Respondents

Variable	Frequency	Percentage(%)
Farmers who listened to Solid FM Radio agricultural programmes		
Yes	277	100.00
No	0	0.00
Agricultural programmes respondents listen to on Solid FM Radio		
Mukoma gona	231	83.40
Noman shinkafa jari	235	84.80
Duration of listening to radio agricultural programmes (years)		
1-3	115	41.50
4-6	108	39.00
Above 6 years	54	19.50
Frequency of listening to *Mukoma gona* programme		
Regularly (every week)		
Occasionally (once in several weeks)	47	20.30
	184	79.70
Frequency of listening to *Noman shinkafa jari* programme		
Regularly (every week)	61	26.00
Occasionally (once in several weeks)	174	74.00

Source: Field survey, 2024

Table 4: Distribution of Respondents based on Satisfaction with agricultural programmes of Solid FM Radio

Satisfaction	Frequency	Percentage
Very satisfied	245	88.40
Satisfied	20	7.30
Not satisfied	12	4.30

Source: Field Survey, 2024

Test of Hypothesis

The chi-square test result ($\chi 2$ = 8.07, df = 4, P = 0.089), as shown in Table 5, revealed no statistically significant association between the duration of listening to agricultural programmes and respondents' satisfaction levels. The null hypothesis was, therefore, not rejected. This implies that the length of time farmers have been listening to the programme does not necessarily determine how satisfied they are. This finding did not align with those of Duncan *et al*. (2024), who asserted that farmers with more radio exposure were more likely to listen to agricultural programmes on the radio and become satisfied with it.

Table 4: Association between Duration of Listening to Agricultural Programme and Satisfaction with the Programme.

Variables	χ^{2-}values	df	P -Value
Duration of listening to Agricultural Programs and satisfaction level.	8.07	4	0.890^{NS}

NS= Not Significant at 5%. df= Degree of Freedom, χ^2= Chi- Square

CONCLUSION AND RECOMMENDATIONS

The study revealed that the majority of the farmers were male, married, educated, in their active years, with a mean household size of 5 people, and experienced. The findings of this study also revealed that the majority of the farmers were aware of agricultural programmes aired on Solid FM Radio. However, despite this high level of awareness, the study found that listenership of the two popular agricultural programmes was irregular. This indicates low patronage of the popular agricultural programmes among the respondents. Interestingly, those who listened to the programmes expressed high levels of satisfaction, indicating that the content was relevant and met their agricultural information needs.

The observed gap between awareness and actual patronage may be attributed to factors such as the timing of the broadcast, competing daily activities, and socio-economic factors. Thus, the high satisfaction level suggests a strong potential for the programme to contribute positively if patronage is improved.

Therefore, the study recommended that, although awareness was high, a strategic publicity effort involving local extension officers, community leaders, and farmers-based organisations could help convert awareness into regular patronage. The high level of satisfaction among the farmers indicates they were getting the correct information from the agricultural programmes; therefore, the programmes should be sustained.

The radio station should take a deeper look into the reasons for low patronage. While awareness and satisfaction were established, the low patronage needs to be understood. This could involve research, looking at the time of presentation, duration/slots given to the programmes, format of presentation, language used, and quality of presentation, among others.

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INVESTIGATION OF RESPONSES TO WATER STRESS OF SELECTED MAIZE (*Zea mays* L.) ACCESSIONS FROM SOUTHERN GUINEA SAVANNAH OF NIGERIA

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ABSTRACT

The effects of different levels of water stress on several physiological traits were evaluated in the leaves of thirty maize genotypes (twenty landraces and ten check cultivars) at the vegetative stage of growth in a screen house. Samples were arranged in a completely randomized design with three replicates. Treatments included unstressed (100 % Field Capacity (FC)), moderately stressed (50 % FC), and severely stressed (25 % FC). The parameters determined include: Relative water content (RWC), total chlorophyll, and total soluble sugar contents. The results showed a significant ($p<0.05$) decrease in RWC of all maize genotypes, with an increase in the stress treatments. The thirty maize genotypes exhibited an RWC range of 79.77±0.26 % to 19.70±0.12 %, corresponding to the highest and lowest values, respectively, across all treatment *levels. The highest value of total chlorophyll content (4.57±0.15 mg g-1 FW) among all genotypes was recorded for TZM 1136 at 100% FC, while at 25% FC, the value decreased to 3.00±0.06 mg g-1 FW. The total soluble sugar content was significantly ($p<0.05$) influenced by the different treatments and genotypes. Except for a few genotypes, there was an increase in total soluble sugar contents with an increase in stress treatments. In conclusion, when compared with the check and control treatments, some of the landraces have shown appreciable adaptability to water stress. They can be further exploited for maize genetic improvement towards drought tolerance.*

Keywords: Investigation attributes; **Maize Landraces**; **Physiological Responses**; **Water stress**

INTRODUCTION

Drought is one of the major causes of reduced maize production worldwide, particularly in Sub-Saharan Africa (SSA) and Latin America, where production is largely rain-fed (Badu-Apraku *et al*., 2021). Drought conditions are projected to increase as a result of global warming and climate change (Sun *et al*., 2020). This can have a devastating effect on maize production, particularly in SSA, where more than half of the countries allocate over 50 % of their cereal area to maize production (Du and Xiong, 2024). The broad adoption of improved maize varieties by farmers and breeders is also an existential threat to maize production, because within the primary gene pool of maize and its wild relatives, there exists unexploited genetic diversity for novel traits and alleles in maize landraces that may have critical role in climate change adaptations, however, few agronomic data exist for such collections and this has limited the identification of novel drought tolerant maize varieties, as well as enhancing maize production in the face of drought condition (Nelimor *et al*., 2020). The conventional system of selecting for breeding drought-resistant traits in maize plants remains the most widely practiced in developing nations. This system is slow, time-consuming, laborious, and sometimes unpredictable (Sashi and Sapana, 2022); hence, there is a need for faster and more reliable approaches that can complement this effort.

Maize (Zea mays L.) is a cereal crop with over 50 different species existing in various colours, shapes, textures, and grains (Badu-Apraku *et al*., 2021). It is one of the most widely cultivated staple crops, profoundly affecting the livelihoods of people in Africa (Du and Xiong, 2024). Maize is grown on over 38 million hectares in sub-Saharan Africa (SSA), accounting for 35% of the total cereal area and 46% of cereal production between 2010 and 2020 (FAO, 2023). Maize production in the rain-fed agricultural regions of SSA is constrained by several abiotic factors, with drought being a significant limiting factor (Du and Xiong, 2024). Drought severely impairs plant growth and development, limiting the production and performance of crop plants (Abimbola and Oluwatosin, 2016). Drought conditions are projected to increase due to global warming and climate change (Sun *et al*., 2020), hence the need to find and implement adaptive strategies that can help sustain maize production in the face of drought conditions.

Drought tolerance is a complex trait, which includes interaction of morphological (earliness, reduced leaf area, leaf rolling, wax content, efficient rooting system, stability in yield and reduced tillering), physiological (reduced transpiration, high water-use efficiency, stomatal closure, and osmotic adjustment), and biochemical (accumulation of proline, polyamines, trehalose, increased nitrate reductase activity, increased storage of carbohydrates, and enhanced enzymatic and non-enzymatic antioxidant systems) parameters (Haraira *et al*., 2023). The physio-morphological responses, which include leaf wilting, a reduction in leaf area, leaf abscission, stimulation of root growth, and an increase in the production of abscisic acid (ABA), can improve the photosynthetic and water-use efficiencies, and hence the drought tolerance of plants (Aslam, 2015). The accumulation of different types of organic and inorganic solutes, in high concentrations in the cytosol, in response to water stress, is a physio-biochemical response that can lead to a decrease in the osmotic potential of a cell, thereby improving water uptake from drying soil, and maintaining cell turgor by way of osmotic adjustment (Aslam, 2015).
Therefore, the objective of this study was to evaluate the effect of water stress on specific physiological responses of maize landraces that contribute to drought resistance in plants.

MATERIALS AND METHODS

The study was carried out at the Screen House (average temperature of 26 oC (night) and 34 oC (day) and relative humidity of 48%) Unit of the Department of Crop Production Teaching and Research Farm, Gidan Kwano Campus, Federal University of Technology (FUT) Minna, Niger State, an area that lies in the Sudan Guinea Savannah of Nigeria (latitude 9.615', longitude 6.5478', and altitude 980 m), characterized by low rainfall (500-750mm per annum) and extended dry periods. Thirty maize accessions (20 landraces and 10 improved drought-tolerant maize varieties) were obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, and the Institute for Agricultural Research (IAR), Zaria. The improved varieties served as checks.

The soil used for the study was obtained from the FUT Minna Research Farm, located on the Gidan Kwano Campus. The soil sample was analyzed for pH, organic matter, organic carbon, nitrogen, and phosphorus contents, as well as the textural class, using standard conventional laboratory methods. The soil sample was sterilized by autoclaving at 110 °C for 10 minutes. Soil augers with core rings were used to carefully obtain topsoil from the field at the time of sampling. The weight of the core rings was noted. The core rings were covered at one end with a cheesecloth and immersed in water for 48 hours to obtain the saturation capacity of the soil. The weight of the core ring and moist soil was also noted. The moist soil was oven-dried for 24 hours until a constant weight was obtained. The weight of the oven-dried soil was also noted. The water holding capacity (WFC) of the soil was determined gravimetrically based on a saturation percentage model (Mbagwu and Mbah, 1998; Dinsa and Elias, 2021).

The experiment was laid out in a completely randomised design (CRD) with three replicates. Samples were well-watered for 2 weeks to establish growth. Treatment regimens included T1 (100% FC), T2 (50% FC), and T3 (25% WFC) for one month. Samples were collected at the end of the experimental duration in an ice pack and stored at -20 ^{o}C prior to analysis.

Determination of Relative Leaf Water Content (RWC)

A leaf cut was taken from the middle of the fully expanded leaf from all the experimental plants. The fresh weight was determined, and the leaf cut was floated on water for up to 48 hours. The turgid state was noted, and the leaf was subsequently oven-dried at ~70°C for 5 days, after which the dry weight was determined. The relative water content (RWC) of the leaf was calculated using the method described by Smart and Bingham (1979), as modified by Pieczynski *et al*. (2022).

$$\text{RWC} = \frac{(\text{Fresh weight} - \text{Dry weight})}{(\text{Turgid weight} - \text{Dry weight})} * 100$$

Determination of Total Chlorophyll Content

Total chlorophyll was estimated using the method described by Hiscox and Israelstam (1979) and Martina *et al*. (2015). 50 mg of the leaf material was extracted in 10 mL of dimethyl sulfoxide for 4 hours at 65 °C. The absorbance of the clear solvent was recorded at 663 nm and 645 nm. The total chlorophyll (Chl total) was calculated using Arnon's equation, and expressed as mg g-1 FW

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$$\text{Chl total (mg/g)} = [20.2\ (\text{A645}) + 8.02\ (\text{A663})] * \frac{V}{(100 * W)}$$

Determination of Total Soluble Sugar Content

Soluble sugar content was determined using the phenol-sulphuric acid method (Anjorin *et al*., 2016). 0.5 g of fresh leaf samples was homogenized with deionized water. The extracts were filtered and treated with 5% phenol and 98% sulphuric acid. The absorbance of the mixtures was read using a spectrophotometer at 485 nm. Contents of soluble sugar were expressed as mg g-1 FW.

Data were analysed using one-way ANOVA, and means were separated using Duncan's multiple range test at P < 0.05 with the statistical package STATISTICA 9.0.

RESULTS AND DISCUSSION

The Determination of Relative Water Content (RWC) values for thirty maize genotypes under different water stress treatments is shown in Table 2. The experimental data obtained showed that the 30 genotypes exhibited an RWC range of 79.77±0.26% to 19.70±0.12%, corresponding to the highest and lowest values, respectively, across all treatment levels. The highest RWCs were recorded at 100 % FC, while the lowest was at 25 % FC. A significant decrease in RWC ($p < 0.05$) was observed for all genotypes compared to the control, as the stress treatment increased.

Relative water content is the proportion of water in a leaf, expressed as the percentage of its maximum volumetric water capacity. It is widely accepted as a measure of plant water status in terms of the physiological consequence of cellular water deficit (Chowdhury *et al*., 2017. Abayneh, 2018). The decrease in RWC observed for all genotypes in relation to the control, as stress treatment increases, may be indicative of sensitivity to water stress. RWC of plants normally decreases during drought conditions, depending on the genotype and the level of stress (Effendi *et al*., 2019; Abayneh, 2018). At 100%, 50%, and 25% FC, the highest RWC among the improved varieties (checks) was observed in SAMMAZ 17 (79.77±0.26%, 70.27±0.09%, and 69.80±0.38%, respectively). The lowest RWC was recorded for SAMMAZ 32 (42.23±0.52%) at 100% FC, while at 50% and 25% FC, KAPAM 6 exhibited the lowest values (37.53±0.12% and 33.50±0.21%, respectively). Among the landraces, the highest RWC at all levels of treatments was recorded for TZM 219 (69.83±0.15 %, 66.33±0.50 %, and 52.83±0.26 % respectively), while the lowest RWC at 100 % FC was recorded for TZM 1482 (32.73±0.59 %). At 50% and 25% FCs, the lowest values were recorded for TZM 1488 (23.64±0.32 % and 19.70±0.12%, respectively). These findings are in agreement with those reported in bean mutant lines (P. vulgaris L.) (Masheva *et al*., 2022), honey bush (Cyclopia subternata) (Mahlare *et al*., 2023), local maize (Teixeira *et al*., 2021), and drought-tolerant maize lines (Martha *et al*., 2019). This genotypic variation in RWC may be attributed to differences in the ability of the varieties to absorb more water from the soil and/or the ability to control water loss through stomata. Normal values of RWC range between 98 % in fully turgid transpiring leaves to about 30-40 % in severely desiccated and dying leaves, depending on plant species. In most crop species, the typical leaf RWC at around initial wilting is about 60% to 70%, with exceptions. Based on the RWC at severe stress treatment, it can be inferred that all genotypes, except SAMMAZ 17, SAMMAZ 37, SAMMAZ 45, TZM 219, TZM 389, and TZM 1414, appear to be susceptible to drought at the vegetative stage of growth.

The effects of different levels of water stress on the chlorophyll contents of thirty maize genotypes are shown in Table 3. A significant ($p < 0.05$) decrease in total chlorophyll content, accompanied by an increase in stress treatments, was observed in all genotypes. The highest total chlorophyll contents among all genotypes were recorded at 100 % FC, while the lowest values were recorded at 25 % FC.

A decrease or unchanged chlorophyll level during drought stress has been reported in many plant species, depending on the duration and severity of the drought (Zulkarnaini *et al*., 2019). A decrease in total chlorophyll due to drought stress signifies a reduced capacity for light harvesting. The reduction in total chlorophyll content by the plant could be a strategy for avoiding the build-up of reactive oxygen species (ROS), as their production is primarily driven by excess energy absorption in the photosynthetic apparatus, leading to the degradation of the absorbing pigments (Yetik and Candogan, 2022). Among the improved varieties, KAPAM 6 exhibited the highest total chlorophyll content (4.53 ± 0.12 mg g-1 FW) at 100% FC. At 50 % FC, KAPAM 6 and OBASUPER 11 showed the highest chlorophyll values (3.90±0.02 and 3.90±0.06 mg g-1 FW, respectively). At 25 % FC, the highest value (3.30±0.06 mg g-1 FW) was recorded for KAPAM 6. The lowest value at 100% FC was shown by SAMMAZ 15 (3.13±0.09 mg g-1 FW), while at 50% and 25% FC, SAMMAZ 45 and OBA 98 exhibited the lowest values (3.10±0.06 and 1.93±0.09 mg g-1 FW, respectively). Among the landraces, TZM 1136 showed the highest values at 100 % and 50 % FCs (4.57±0.15 and 3.87±0.09 mg g-1 FW, respectively), while at 25 % FC, TZM 1136 and TZM 1129 showed the highest values (3.00±0.03 and 3.00±0.06 mg g-1 FW, respectively). The lowest value (3.39±0.10 mg g-1 FW) was recorded for TZM 154 at 100% FC. At 50% FC, TZM 389 showed the lowest value (2.90±0.0 mg g-1 FW), while at 25% FC, TZM 1414 exhibited the lowest value (1.73±0.03mg g-1 FW). These findings align with the results of Aref *et al*. (2014), who investigated the effect of water stress on the relative water and chlorophyll contents of Juniperus procera Hochst. Ex Endlicher. The authors reported a decrease in chlorophyll content with increasing water stress. Chlorophyll content was reduced to varying degrees in Avena species cultivars due to moisture stress at both the vegetative and flowering stages (Pandey *et al*., 2012). Water stress also significantly reduced the levels of chlorophyll a, chlorophyll b, total chlorophyll, and net photosynthesis in Oriental lily plants (Zhang *et al*., 2012). Generally, moisture stress causes a reduction in chlorophyll concentration in crops; however, the extent to which a particular crop tolerates a moisture deficit condition without being negatively affected is crop-dependent (Ehumadu *et al*., 2023)—the concentration of chlorophyll in cultivars that are stress-tolerant increases as compared to non-stress-tolerant cultivars. In Maize, chlorophyll loss due to water stress has been attributed to a reduction in the lamellar content of chlorophyll a/b-protein (Randall *et al*., 1979). Relative to the control treatments and in comparison with the checks, it can be deduced that TZM 1136, TZM 219, TZM 1129, TZM 1376, TZM 1389, TZM 1422, and TZM 1428, at severe stress treatment, retained total chlorophyll concentrations, indicating tolerance to water stress.

The effects of different levels of water stress on the total soluble sugar contents of thirty maize genotypes are revealed in Table 4. There was a significant ($p<0.05$) increase in the soluble sugar content observed for some genotypes, with an increase in the stress treatments relative to the controls, while in some, no significant ($p>0.05$) difference between the control and moderate stressed treatment, or between moderate stressed and severe stressed treatments.

Osmolytes and compatible solutes, such as soluble sugars (glucose, fructose, sucrose, etc.), are overproduced under osmotic stress, aiming to facilitate osmotic adjustment, which optimizes water potential, eliminates ROS, and safeguards cellular components and macromolecules from oxidative damage (Saad-Allah *et al*., 2022). Furthermore, soluble sugars act as signaling molecules that control gene expression in plants' stress responses (Maruyama *et al*., 2014). The results showed that some genotypes had a higher concentration of total soluble sugar in the unstressed treatment (control). In contrast, others had a moderate concentration at the moderately stressed treatment, and still others had a higher concentration at the severely stressed treatment. Among the improved varieties, KAPAM 6 exhibited the highest soluble sugar content at 100% and 50% FC (7.10 ± 0.12 and 6.77 ± 0.09 mg g-1 FW, respectively). At 25 % FC, SAMMAZ 45 showed the highest (6.77±0.09 mg g-1 FW) soluble sugar content. The lowest soluble sugar content (3.47±0.15 mg g-1 FW) at 100% FC, exhibited by the improved varieties, was observed in SAMMAZ 17. At 50% and 25% FC, SAMMAZ 15 recorded the lowest values (3.40±0.12 and 2.27±0.18 mg g-1 FW, respectively). Among the landraces at 100 % FC, TZM 1414 showed the highest (5.97±0.09 mg g-1 FW) total soluble sugar content, at 50 % FC, TZM 1428 and TZM 1389 showed the highest values (5.93±0.09 mg g-1 FW) that were not significantly ($p>0.05$) different, while at 25 % FC, TZM 1389 maintained the highest value of 6.17±0.09 mg g-1 FW.

The lowest values of 2.83±0.23 and 3.97±0.09 mg g-1 FW at 100% and 50% FC, respectively, were recorded for TZM 1422. In contrast, at 25% FC, the lowest value (2.80 ± 0.12 mg g-1 FW) was recorded for TZM 392. While several researchers have reported an increase in the accumulation of soluble sugars with increased water stress, which agrees with the responses of some genotypes in the present study, a significant ($p < 0.05$) decrease in total soluble sugar was recorded with increased severity of water stress for some genotypes. The different responses to the stress treatments shown by the genotypes could be a result of genotypic variation. Relative to the control treatments and the checks at severe stress treatments, it can be inferred that TZM 1389, TZM 1428, TZM 1129, TZM 1194, and TZM 1478 were able to maintain relatively high concentrations of total soluble sugar contents, which is an indication of tolerance response to water stress

Table 1: Physicochemical Properties of Soil Used for the Study

Parameters	Measured values
Textural class	Loamy sand
pH	6.8
Nitrogen (mg/kg)	2.9
Phosphorus (mg/kg)	7.2
Organic carbon (%)	7.8
Organic matter (%)	12.4
Clay (%)	2.8
Silt (%)	19.6
Sand (%)	77.6

Table 2: Relative Leaf Water Contents (%) of Maize Landraces and Drought Tolerant Varieties of Maize in Response to Water Stress

Genotypes	Treatments		
	T1	T2	T3
TZM 1422	52.67±0.08[a]	48.67±0.19[b]	41.50±0.15[c]
TZM 1488	42.38±0.98[c]	23.64±0.32[a]	19.70±0.12[b]
TZM 398	58.63±0.48[b]	52.50±0.12[c]	43.97±0.90[a]
TZM 1428	57.23±0.87[b]	51.70±0.15[c]	47.90±0.21[a]
TZM 1482	32.73±0.59[c]	29.83±0.39[b]	22.20±0.96[a]
TZM 154	48.97±0.81[b]	42.93±0.07[c]	35.33±0.10[a]
TZM 1136	56.80±0.82[a]	48.53±3.43[c]	38.87±0.37[b]
TZM 389	67.83±0.29[a]	61.63±0.15[b]	50.03±0.66[c]
TZM 1376	43.10±0.17[c]	38.57±0.15[b]	34.57±0.17[a]
TZM 1129	59.73±0.29[b]	54.27±0.09[a]	44.53±0.15[a]
TZM 1194	53.13±0.15[b]	41.80±0.15[a]	33.40±0.29[b]
TZM 1414	60.20±0.67[ab]	61.60±0.12[b]	49-03±0.21[a]
TZM 1478	46.97±0.38[a]	42.17±0.18[b]	38.57±0.15[c]
TZM 1149	69.80±0.12[c]	50.73±0.32[a]	23.43±0.12[b]
TZM 392	40.77±0.23[c]	38.43±0.75[b]	34.73±0.23[a]
TZM 1412	58.80±0.06[c]	53.77±0.26[b]	40.20±0.76[a]
TZM 155	40.33±0.09[c]	38.39±0.46[b]	34.53±0.18[a]
TZM 390	42.27±0.23[b]	41.87±0.45[b]	33.93±0.41[a]
TZM 219	69.83±0.15[a]	66.33±0.50[b]	52.83±0.26[c]
TZM 1389	31.43±0.09[a]	33.77±0.09[c]	32.10±0.15[b]
*SAMMAZ 45	70.23±0.09[b]	69.87±0.79[b]	57.20±0.23[a]
*SAMMAZ 11	57.54±0.18[a]	55.23±0.15[b]	45.07±0.47[c]
*SAMMAZ 37	67.53±0.92[b]	64.01±0.47[a]	63.23±0.67[a]
*KAPAM 6	40.06±0.02[b]	37.53±0.12[a]	33.50±0.21[c]
*SAMMAZ 40	67.83±0.19[c]	64.43±0.09[a]	55.47±0.12[b]
*SAMMAZ 17	79.77±0.26[a]	70.27±0.09[b]	69.80±0.38[b]
*SAMMAZ 15	47.53±0.18[a]	49.67±0.27[c]	38.37±0.09[b]
*OBASUPER 11	52.07±0.12[c]	49.23±0.23[b]	39.73±0.32[a]
*OBA 98	43.53±0.18[b]	42.87±0.19[a]	46.50±0.17[c]
*SAMMAZ 32	42.23±0.52[c]	38.47±0.12[b]	34.07±0.68[a]

Results are shown as mean ± standard error ($p<0.05$) of three replicate

KEY: T1 = 100 % FC, T2 = 50 % FC, T3 = 25 % FC, TZM Series= Landraces, * = Improved varieties (Checks)

Table 3: Total Chlorophyll Contents (mg g^{-1} FW) of Maize Landraces and Drought Tolerant Varieties of Maize in Response to Water Stress

Genotypes	Treatment		
	T1	T2	T3
TZM 1422	3.77±0.09[b]	3.56±0.23[b]	2.86±0.10[a]
TZM 1488	3.72±0.12[b]	3.39±0.09[b]	2.44±0.08[a]
TZM 398	3.56±0.17[c]	3.20±0.11[ab]	2.79±0.09[a]
TZM 1428	4.18±0.10[c]	3.75±0.06[b]	2.84±0.03[a]
TZM 1482	3.77±0.09[c]	3.35±0.08[b]	2.54±0.06[a]
TZM 154	3.39±0.10[b]	3.37±0.04[b]	2.01±0.08[a]
TZM 1136	**4.57±0.15[c]**	3.87±0.09[b]	3.00±0.03[a]
TZM 389	3.63±0.09[c]	2.90±0.06[b]	2.07±0.12[a]
TZM 1376	3.90±0.06[c]	3.70±0.06[b]	2.90±0.06[a]
TZM 1129	3.97±0.18[c]	3.57±0.07[b]	3.00±0.06[a]
TZM 1194	3.47±0.18[c]	3.07±0.03[b]	2.40±0.06[a]
TZM 1414	3.81±0.12[b]	3.80±0.06[b]	**1.73±0.03[a]**
TZM 1478	3.80±0.12[b]	3.57±0.03[b]	2.90±0.06[a]
TZM 1149	3.47±0.18[c]	3.07±0.03[b]	2.40±0.06[a]
TZM 392	4.03±0.12[c]	3.60±0.10[b]	2.57±0.03[a]
TZM 1412	3.87±0.09[c]	3.50±0.06[b]	2.67±0.09[a]
TZM 155	3.53±0.09[b]	3.40±0.06[b]	2.27±0.09[a]
TZM 390	4.23±0.12[c]	3.47±0.09[b]	2.73±0.09[a]
TZM 219	3.40±0.12[b]	3.67±0.09[b]	2.97±0.09[a]
TZM 1389	3.93±0.09[c]	3.33±0.09[b]	2.87±0.03[a]
*SAMMAZ 45	4.07±0.13[b]	3.10±0.06[a]	2.83±0.03[a]
*SAMMAZ 11	4.03±0.12[c]	3.60±0.12[b]	3.10±0.06[a]
*SAMMAZ 37	3.93±0.09[c]	3.23±0.07[b]	2.23±0.03[a]
*KAPAM 6	4.53±0.12[c]	3.90±0.02[b]	3.30±0.06[c]
*SAMMAZ 40	3.73±0.09[c]	3.37±0.07[b]	2.33±0.03[a]
*SAMMAZ 17	3.67±0.07[c]	3.07±0.03[b]	2.70±0.06[a]
*SAMMAZ 15	3.13±0.09[b]	3.43±0.03[c]	2.50±0.12[a]
*OBASUPER 11	4.37±0.09[c]	3.90±0.06[b]	3.13±0.09[a]
*OBA 98	4.00±0.06[b]	3.77±0.09[b]	1.93±0.09[a]
*SAMMAZ 32	3.97±0.12[c]	3.20±0.06[b]	2.87±0.03[a]

Results are shown as mean ± standard error ($p<0.05$) of three replicates

KEY: T1 = 100 % FC, T2 = 50 % FC, T3 = 25 % FC, TZM Series= Landraces, * = Improved varieties (Checks)

Table 4: Total Soluble Sugar Contents (mg g^{-1} FW) of Maize Landraces and Drought Tolerant Varieties of Maize in Response to Water Stress

Genotypes	Treatment		
	T1	T2	T3
TZM 1422	2.83±0.23[a]	3.97±0.09[b]	3.83±0.07[b]
TZM 1488	4.57±0.15[b]	4.53±0.15[b]	3.77±0.09[a]
TZM 398	4.70±0.12[c]	4.03±0.12[b]	3.60±0.06[b]
TZM 1428	5.57±0.15[a]	5.93±0.09[a]	6.00±0.36[a]
TZM 1482	5.90±0.12[b]	5.77±0.20[b]	4.80±0.06[a]
TZM 154	5.67±0.09[c]	5.20±0.12[b]	4.07±0.15[a]
TZM 1136	3.63±0.09[a]	5.27±0.09[b]	5.00±0.12[b]
TZM 389	5.33±0.09[c]	4.70±0.12[b]	3.07±0.12[a]
TZM 1376	4.17±0.12[a]	4.97±0.09[b]	5.57±0.12[c]
TZM 1129	4.13±0.18[a]	5.10±0.21[b]	5.60±0.12[b]
TZM 1194	4.33±0.18[a]	4.57±0.12[a]	5.60±0.12[b]
TZM 1414	5.97±0.09[c]	5.37±0.09[b]	3.63±0.15[a]
TZM 1478	4.83±0.09[a]	5.07±0.09[a]	5.60±0.12[b]
TZM 1149	4.93±0.12[a]	4.50±0.12[a]	4.93±0.15[a]
TZM 392	3.87±0.12[b]	4.53±0.15[c]	2.80±0.12[a]
TZM 1412	5.57±0.09[b]	5.90±0.06[c]	5.00±0.12[a]
TZM 155	4.90±0.12[a]	5.00±0.12[a]	5.63±0.09[b]
TZM 390	5.77±0.09[c]	4.90±0.12[b]	4.30±0.06[a]
TZM 219	4.63±0.07[a]	5.00±0.15[ab]	5.17±0.15[b]
TZM 1389	5.57±0.09[a]	5.93±0.09[b]	6.17±0.09[b]
*SAMMAZ 45	6.00±0.12[a]	6.47±0.09[b]	6.77±0.09[b]
*SAMMAZ 11	5.27±0.15[a]	5.60±0.12[a]	6.10±0.06[b]
*SAMMAZ 37	4.03±0.09[a]	4.57±0.07[b]	4.70±0.06[b]
*KAPAM 6	7.10±0.12[b]	6.77±0.09[b]	5.83±0.09[a]
*SAMMAZ 40	4.90±0.06[a]	5.13±0.09[a]	5.47±0.09[b]
*SAMMAZ 17	3.47±0.15[a]	3.70±0.12[a]	4.93±0.12[b]
*SAMMAZ 15	4.17±0.09[c]	3.40±0.12[b]	2.27±0.18[a]
*OBASUPER 11	4.90±0.10[b]	4.87±0.09[b]	3.97±0.09[a]
*OBA 98	5.00±0.23[b]	5.00±0.06[b]	4.23±0.09[a]
*SAMMAZ 32	6.90±0.12[c]	6.47±0.09[b]	4.70±0.12[a]

Results are shown as mean ± standard error ($p<0.05$) of three replicates

KEY: T1 = 100 % FC, T2 = 50 % FC, T3 = 25 % FC, TZM Series= Landraces, * = Improved varieties (Checks)

CONCLUSION AND RECOMMENDATION

The findings of this study suggest that most landraces (TZM 390, TZM 1149, TZM 1482, and TZM 1488), and improved varieties (KAPAM 6 and SAMMAZ 15), based on their RWC at severe water stress, are susceptible to drought stress. However, the ability of most landraces to maintain relatively higher chlorophyll and soluble sugar contents under severe stress treatment is an indication of a good response to water stress. It is recommended that these landraces and improved varieties be used for dry-season cultivation for increased maize production.

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QUALITY EVALUATION OF COUSCOUSANALOGUE PRODUCED FROM *ACHA*, SPENT LAYERMEAT AND TURMERIC FLOUR BLENDS

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ABSTRACT

This study evaluated the effects of incorporating spent layer meat and turmeric flour into Acha flour on the functional properties, proximate composition, mineral composition, and sensory characteristics of couscous. Acha flour was blended with spent layer meat flour 88:12) and turmeric flour at varying concentrations (0-12%). The results showed significant improvements in the functional properties, including bulk density (0.96-0.42 g/mL), water absorption capacity (1.25-2.95 g/mL), and oil absorption capacity (0.92-1.85 g/mL). The proximate composition of the couscous moisture, ash, crude fibre, crude protein, and crude fat increased from 4.69- 6.20, 3.80-5.44, 0.38-0.52, 8.82-13.14, 0.96-2.01 %, respectively; while the carbohydrate decreased from 81.21-72.58 % with an increase in the added turmeric powder. Also, the mineral composition: calcium, zinc, iron, magnesium and potassium increased from 0.96-2.02,0.46-1.18,0.02-0.16, 31.8-72.5, and 13.0-123.5 ppm, respectively. Generally, the couscous was acceptable (with a score of more than 5.0), but most preferred it with the addition of 2% turmeric flour. The study demonstrates the potential of acha, spent layer meat and turmeric flour blends in developing nutritious and acceptable couscous products.

Key words: Couscous, Quality evaluation, Spent layer meat, Turmeric flour.

INTRODUCTION

Cereal-based foods constitute a significant portion of the global diet, accounting for approximately 30–70% of daily energy intake (Nishida et al., 2004). Among these, pasta products such as couscous, noodles, and spaghetti are widely consumed due to their affordability, convenience, and sensory appeal (Cappa and Alamprese, 2017; Littardi et al., 2020; Tazrart et al., 2019). Couscous, in particular, is a traditional cereal-based food popular in Africa, Asia, and parts of Europe. It is typically produced using semolina or acha (Ayo et al., 2023). In Turkey, couscous is often made by coating bulgur granules with a mixture of semolina, wheat flour, eggs, and water or milk. Recognising its cultural significance and ancestral preparation techniques, couscous was inscribed in 2020 on UNESCO's list of Intangible Cultural Heritage (UNESCO, 2020). It is also commonly served during special events such as weddings, funerals, and religious festivals (Coskun, 2013).

Recent studies have explored enriching couscous with legume flours or other nutrient-dense ingredients to improve its nutritional profile (Ayo et al., 2023). Pasta products, including couscous, are ideal carriers for nutritional fortification due to their widespread acceptability and ease of processing (De Santis et al., 2020; Fradinho et al., 2020; Kowalczewski et al., 2019). With growing awareness of balanced diets, there is a demand for enriched, convenient foods that meet essential nutrient requirements, particularly protein.

Animal-based proteins, such as those from meat, milk, and eggs, are known for their high biological value and complete amino acid profiles (Hulya et al., 2015). Among them, chicken meat, particularly from spent layer meats (older laying birds), offers a promising source of protein due to its relatively low fat content, high protein concentration, and affordability compared to other meats (USDA, 2014). However, the highly perishable nature of chicken meat, driven by its high moisture and nutrient content, limits its use in shelf-stable products (Amit et al., 2017; Kim et al., 2019). Therefore, integrating chicken meat into processed foods, such as couscous, requires effective preservation strategies.

One promising approach to improving shelf life and nutritional value is the incorporation of natural antioxidants. Oxidative rancidity remains a significant challenge in meat-based products, resulting in flavour deterioration, discolouration, and reduced protein functionality (Ashish et al., 2020). Antioxidants, both synthetic and natural, have been shown to mitigate these effects. However, due to consumer concerns about synthetic additives, the food industry is increasingly exploring plant-based alternatives (Draszanowska et al., 2020; Lishianawati et al., 2022).

Turmeric (Curcuma longa L.), a rhizome in the ginger family, is widely recognised not only for its culinary applications but also for its potent antioxidant properties. Its bioactive compound, curcumin, is primarily responsible for its anti-inflammatory and anti-oxidative functions (Hewlings and Kalman, 2017; Pimentel et al., 2020). In meat and meat-based products, turmeric has demonstrated the potential to delay oxidative spoilage, thereby enhancing product shelf life (Mancini et al., 2015; Bae et al., 2019; De Carvalho et al., 2020). Acha (Digitaria exilis), also known as fonio, is a nutritious African cereal known for its digestibility and essential amino acid content. This study aimed to develop and evaluate the quality of couscous analogues made from blends of acha, spent layer meat flour, and turmeric flour.

MATERIALS AND METHODS

Source of Materials and Preparation

Acha was purchased from Jos Central Market in Jos, Plateau State. Spent layer meats were purchased from poultry farmers in Gboko, Benue State. Turmeric was purchased from the Gboko main market in Gboko Local Government, Benue State, Nigeria.

Acha flour was produced using the method described by Ayo (2007). Acha grains were winnowed to remove chaff and dust. Adhering dust and stones were removed by washing in water (sedimentation) using local calabashes. The washed and destoned grains were dried in a cabinet drier at 60°C to a moisture content of 12%. The dried grains were milled using an attrition milling machine (R175 Nigerian assembled) and the flour sieved to pass through a 0.4mm mesh size. The acha flour was packaged in air-tight containers for use.

The spent layer was slaughtered, deboned, and chopped into smaller sizes using a knife and a chopping board. Chopped meat was steamed for 35 minutes till the meat was thoroughly browned. This precooked meat was dried in a cabinet tray drier at 60 ºC for 9 hours and then milled in a blender (Kenwood BL335) into a powdery form. It was sieved to a particle size of 0.5mm and packed in polyethene material (Surender et al., 2019).

The turmeric rhizome was cleaned (hand picking of foreign materials), washed with portable, sliced and oven dried at a temperature of 60 0C for 24 h, milled in a blender (Kenwood BL335) into a powdery form, sieved to a particle size of 0.4 mm and packed in a polyethene material (Oladimeji et al., 2019).

Formulation of the flour blends

A preliminary sensory evaluation was done to select the best blend of acha and spent layer meat flour couscous. The most preferred sample, based on sensory evaluation, was one with 88% acha and 12% spent layer meat, which was then used to vary the inclusion of turmeric. Turmeric flour was substituted at varying concentrations (0, 2, 4, 6, 8, 10, 12%) into the standardised flour blend. The developed flour blends were used to prepare couscous, which was then subjected to sensory evaluation and other analyses.

Production of couscous

Couscous was produced from developed flour blends of acha-spent layer meat and turmeric flour using the modified Samia et al. (2017) method. The acha-spent layer meat-turmeric blend flour hydration was carried out with portable water. The flour was placed in a "guessâa" (pan). Water was added to the flour to achieve a semi-gel consistency. The gel was rolled for 15 min. After rolling and aggregating, the resulting couscous grains were sieved and sized with appropriate sieves. The mixture was sieved through a 2.9 mm sieve. The passage was sieved through another sieve (1.25 mm) to make couscous granules properly. The product was then sieved a third time (1.0 mm). At each rolling step, products were weighed to determine the couscous yield after rolling. The wet couscous was steam-precooked in a couscous cooker (strainer diameter 16 cm) containing 3 L of water that was brought to a boil at 100 °C and maintained at a boil for 8 min. The precooked couscous was passed through a local sieve (1.8 mm) and dried (for 48 h at 45 °C in an oven dryer).

Methods

Functional properties

Bulk density

Bulk density was determined as described by Onwuka (2005). A graduated cylinder flask (10mL) was weighed dry and gently oiled with the flour sample. The bottom of the cylinder was tapped gently on a laboratory bench several times. This continued until no further diminution of the test flour in the cylinder was observed after filling to the mark. The weight of the cylinder, including the flour, was measured and recorded.

$$\text{Bulk density } \left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{weight of sample (g)}}{\text{volume of sample after tappiing}} \qquad (1)$$

Water absorption capacity

The water absorption capacity was determined according to the method described by Akubor (2005). A 1-gram sample was mixed with 10mL of distilled water (specific gravity 0.904 kg/m^3) and allowed to stand at ambient temperature for 30 minutes. It was then centrifuged at 3,000 rpm for 30 minutes using a centrifuge model 800D (Hettich, Universal 11, Herford, Germany). Water absorption capacity was expressed as the percentage of water bound per gram of flour.

$$\text{Water absorption capacity} = \frac{\text{(weight of water absorped x density of water)}}{\text{(sample weight (g)}} \qquad (2)$$

Oil absorption capacity

Oil absorption capacity as determined using the method of Ukpabi and Ndimele (1990). One gram of the sample was weighed into pre-weighed 15mL centrifuge tubes and centrifuged at 300 rpm for 20 min. Immediately after centrifugation, the supernatant was carefully poured into a 10mL graduated cylinder, and the volume was recorded (v2). The oil absorption capacity (in millilitres of oil per gram of sampled material) was calculated.

$$\text{Oil Absorption capacity} = \frac{(\text{weight of oil absorbed (g)x density of water})}{(\text{sample weight})} \quad (3)$$

Oil absorption capacity was expressed as the grams of oil bound per gram of the sample on a dry basis, referred to as the swelling index. The method was used.

Swelling index and swelling capacity

The Swelling Index (SI) of the flour samples was determined using the method described by Ukpabi and Ndimele (1990). The sample was added up to the 10 mL mark in a pre-weighed 100 mL measuring cylinder. The cylinder was weighed again to obtain the sample weight. Distilled water was added up to the 50 mL mark and mixed thoroughly using a vortex mixer to homogenise the sample. The mixture was allowed to stand for 3 h. The swelling index was calculated

$$\text{Swelling index} = \frac{\text{Volume of sample after soaking} - \text{volume of sample before soaking}}{\text{weight of sample}} \quad (4)$$

The wet sediment obtained from the swelling index determination was used in calculating the swelling capacity (SC) using the following formula:

$$\text{swelling capacity} = \frac{\text{Weight of wet sediment X100}}{\text{weight of sample}} \quad (5)$$

Gelatinization temperature

A 10 % suspension of the flour sample was prepared in a test tube. The aqueous suspension was heated in a boiling water bath, with continuous stirring. The temperature was recorded 30 seconds after gelatinisation was visually observed, which corresponded to the gelatinisation temperature (Onwuka 2005).

Proximate Composition

The total carbohydrate content was estimated as the difference between 100 and the total sum of moisture, fat, protein, crude fibre and ash (AOAC, 2012).

$$\%Carbohydrate = 100 - (\%Moisture + \%Fat + \%Protein + \%Ash + \%CrudeFibre) \quad (6)$$

Mineral Content Determination

The AOAC (2012) wet ashing method was used. One gram of the dried powdered sample was digested with 10mL nitric acid and 5mL perchloric acid in a 100mL digestion flask and allowed to stand overnight in a fume cupboard. "The mixture was heated until the yellowish fume and white dense fume of nitric and perchloric acid, respectively, ceased. The contents were cooled and filtered through Whatman filter paper, transferred into sample bottles and made up to 100mL with deionised water. The iron, zinc, calcium, magnesium, and potassium content were analysed using an atomic absorption spectrophotometer.

Sensory evaluation

The 9-point Hedonic scale assessment and the pair comparison tests were used as described by Iwe (2002). A total of 25 untrained panellists from a cross-section of students and staff in the Department of Food Science and Technology at the University of Mkar, Gboko, Benue State, were selected based on their familiarity with couscous pasta. The panellists scored and coded couscous in terms of degree of taste, aroma, appearance, chewiness and general acceptability. The 9-point Hedonic scale used by the panellists for the evaluation ranged from 1-9, representing "disliked extremely "to "like extremely. The coded samples of couscous were served on clean, flat plates in an illuminated boardroom with fluorescent lighting at a time. Water was provided to each panellist for oral rinsing between tasting the samples.

Experimental Design and Statistical Analysis

The experimental design for the study was completely randomised. All the data obtained from this study were subjected to analysis of variance (ANOVA) using the Statistical Package for the Social Sciences (SPSS) software version 20. Significantly different means were separated using Duncan's Multiple Range Test (SPSS Statistics, version 20).

RESULTS AND DISCUSSION

Preliminary Investigations

Proximate composition of acha, spent layer meat and turmeric flour

The proximate compositions of acha, spent layer meat and turmeric flours are shown in Table 1. The moisture, crude protein, crude fat, ash, crude fibre, and carbohydrate content ranged from 5.63% to 9.29%, 8.05% to 72.3%, 1.99% to 12.27%, 2.21% to 6.16%, 1.61% to 7.08%, and 0.57% to 78.19%, respectively, for the Acha, spent layer meat, and turmeric flour. Spent layer meat flour had the highest protein content, with ash values of 72.93% and 6.16%, while turmeric flour had the highest fibre value at 7.08%, suggesting that they can be of importance in adding value to acha food products (couscous).

Selection of acceptable samples from acha, spent layer meat flour blends based on preliminary sensory evaluation. Couscous samples were prepared using acha flour and spent layer meat flour in the ratio of 100:0, 96:4, 92:8, 88:12, 84:16, 80:20 and 76:24. The couscous samples were assessed sensorially by a group of 25 panel members using 9 9-point Hedonic scale to select the best sample based on their taste, appearance, aroma, texture, and mouth feel. The average means scores for taste, appearance, and general acceptability of the produced couscous decreased from 6.06 – 4.44, 6.38 – 4.81, 6.31 – 5.38, respectively, while the aroma and chewiness ranged from 5.44 -6.69 and 5.88- 6.69, with an increase (4-24%) in the added turmeric powder. A couscous sample with 88% acha flour and 12% spent layer meat flour had the highest sensory score (Table 2). The effect of the added turmeric powder was significant ($p < 0.05$).

Table 1: Proximate Composition of *Acha*, Spent layer meatand Turmeric flour

Raw materials	Moisture (%)	Crude protein (%)	Crude fat (%)	Ash (%)	Crude fibre (%)	Carbohydrate (%)
Acha flour	$9.29^{a}\pm0.04$	$8.05^{c}\pm0.08$	$1.99^{c}\pm0.15$	2.21 ± 0.15	$2.27^{b}\pm0.06$	$76.19^{a}\pm0.02$
Spent LMF	$6.48^{b}\pm0.56$	$72.93^{a}\pm0.06$	$12.27^{a}\pm0.06$	6.16 ± 0.07	$1.61^{c}\pm0.30$	$0.57^{c}\pm0.32$
Turmeric flour	$5.63^{b}\pm0.57$	$8.76^{b}\pm0.04$	$5.80^{b}\pm0.11$	5.08 ± 0.03	$7.08^{a}\pm0.03$	$67.67^{b}\pm0.28$

*Values are means and standard deviation of triplicate determinations. Different Superscripts within the same column are significantly different at ($p<0.05$); Spent LMF: Spent layer meat flour

Table 2: Preliminary Sensory Evaluation of Couscous Produced from *Acha*-Spent layer meat flour Blends

***Acha*: spent Layer meat flour**	**Samples**	**Taste**	**Aroma**	**Appearance**	**Chewiness**	**General Acceptability**
100:0	T1	$7.06^{a}\pm0.93$	$6.94^{a}\pm1.24$	$7.00^{a}\pm1.21$	$7.13^{a}\pm0.96$	$7.50^{a}\pm0.\ 97$
96:4	T2	$6.06^{a}\pm1.44$	$5.44^{a}\pm1.83$	$6.38^{ab}\pm1.82$	$5.88^{b}\pm1.36$	$6.31^{abc}\pm1.25$
92:8	T3	$5.75^{abc}\pm2.18$	$6.13^{a}\pm1.89$	$6.75^{ab}\pm1.65$	$6.31^{ab}\pm1.74$	$6.38^{abc}\pm1.54$
88:12	T4	$6.31^{ab}\pm1.85$	$6.69^{a}\pm1.40$	$6.06^{abc}\pm2.05$	$6.69^{ab}\pm1.08$	$6.69^{ab}\pm1.30$
84:16	T5	$5.63^{bc}\pm1.99$	$5.94^{a}\pm2.14$	$5.56^{bc}\pm2.16$	$6.25^{ab}\pm1.18$	$6.13^{bc}\pm1.89$
80:20	T6	$5.06^{bc}\pm2.11$	$5.75^{a}\pm2.02$	$5.56^{bc}\pm1.63$	$6.06^{ab}\pm2.05$	$5.44^{bc}\pm1.99$
76:24	T7	$4.44^{c}\pm1.89$	$5.44^{a}\pm2.37$	$4.81^{c}\pm1.87$	$5.88^{b}\pm1.99$	$5.38^{c}\pm1.96$

*Values are means and standard deviation of triplicate determinations. Different Superscripts within the same column are significantly different at ($p<0.05$)

Functional Properties of **Acha**, Spent Layer Meat and Turmeric Flour Blends

The results of the functional properties of the flour blends are shown in Table 3. The parameters determined were bulk density, Water Absorption Capacity (WAC), Oil Absorption Capacity (OAC), gelatinisation temperature, swelling index and swelling capacity.

The bulk density, water absorption capacity, oil absorption capacity, gelatinisation temperature, swelling index and swelling capacity increased from 0.96-0.42, 1.25-2.95, 0.92-1.85 g/mL,63.5-75.0 oC, 0.17-1.15 g/mL and 111.36-182.45 (%), respectively. Sample A (100 % acha) had the highest bulk density, while sample G (88 % acha-spent layer meat and 12 % turmeric) had the lowest bulk density. Sample G (88% acha-spent layer meat and 12% turmeric) had the highest values for water absorption capacity, oil absorption capacity, gelatinisation temperature, swelling index, and swelling capacity. In comparison, sample A (100% acha-spent layer meat) showed the lowest values for water absorption capacity, oil absorption capacity, gelatinisation temperature, swelling index, and swelling capacity. The effect of adding turmeric powder was highly significant ($p < 0.05$) on the assessed functional parameters.

The bulk density recorded in this study ranged from 0.96 to 0.42 g/mL. The bulk density is the ratio of flour weight to volume in grams per millilitre of the flour blends. Samples A (100 % acha-spent layer meat) exhibited the highest bulk density of 0.96 g/mL, while sample G (88 % acha-spent layer meat and 12 % turmeric) had the lowest bulk density of 0.42 g/mL. There were significant differences ($p<0.05$) among the samples. This result agrees with Makanjuola et al. (2025), who observed a decrease in the bulk density (0.46-0.69 g/mL) of Tapioca fortified with turmeric. The results also agreed with values (0.56-0.71 g/mL) recorded by Eman and Asael (2017). A higher bulk density is required for greater ease of dispersion of flour, while a low bulk density is advantageous in the formation of complementary foods (Akpata and Akubor, 1999). Lower bulk density can indicate higher porosity and potentially greater water absorption capacity, which is beneficial for the texture and digestibility of the food.

There was a significant increase in the water absorption capacity of the flour blends. Sample A (100 % acha-spent layer meat) had the least value of 1.25 g/mL, while sample G (88 % acha, spent layer meat and 12 % turmeric) had the highest value of 2.95 g/mL. The water absorption capacity of the flour samples can be compared with the results reported by Ubbor et al. (2022) for flour blends of acha and wheat. WAC refers to the extent to which water can be bound per gram of flour and is vital for establishing product qualities such as the ability to retain moisture, starch retrogradation and staling. It indicates the product's ability to associate with water under conditions where water is limited, thereby improving its handling characteristics.

The oil absorption capacity of the flour blends increased significantly ($p < 0.05$) with an increase in the proportion of turmeric flour. Sample A (100 % acha-spent layer meat) had the least value of 0.92 g/mL, while sample G (88 % acha-spent layer meat and 12 % turmeric) had the highest value of 1.85 g/mL. This result agreed with the findings of Ubbor et al. (2022), who observed an increase in the OAC of flour blends of acha and wheat. The oil absorption mechanism involves the physical entrapment of oil by food components and the affinity of non-polar protein side chains for lipids. The WAC and OAC of food proteins depend on intrinsic factors, such as amino acid composition, protein conformation, and surface polarity. The ability of proteins in flour to bind with oil makes it useful in food systems where optimal oil adsorption is desired. This makes flour have more functional uses, enhancing flavour and mouthfeel when used in food preparations.

It was observed that the gelatinisation temperature increased significantly among all the samples from 63.5 °C in sample A (100 % acha-spent layer meat) to 75.0 0C sample G (88 % acha-spent layer meat and 12 % turmeric). This is slightly above the range reported by Ubbor et al. (2022) in acha: wheat flour blends. It is noted in the literature that flour with a high starch content requires a low temperature for gelatinisation to occur.

The swelling Index measures the amount of water-soluble solids per unit weight of the sample. There was an increase in the swelling index; sample A (100 % acha-spent layer meat) had the least value of 0.17 g/mL, while sample G (88 % acha-spent layer meat and 12 % turmeric) had the highest value of 1.15 g/mL.

Sample A was the only sample that showed a significant difference; for the other samples, there was no significant difference among them. In the literature, solubility is a measure of protein functionality, including denaturation and its potential applications (Adebowale et al., 2008). This is in contrast to Makanjuola et al. (2025), who observed a decrease in the swelling index with an increase in the proportion of turmeric powder in Tapioca.

Swelling capacity increased from 111.36 % in sample A (100 % acha-spent layer meat) to 182.45 % in sample G (88 % acha-spent layer meat and 12 % turmeric). There were significant differences among all the samples. Sample G (88 % acha-spent layer meat and 12 % turmeric) had the highest mean value, while sample A (100 % acha-spent layer meat) had the lowest mean value. The results indicate that the swelling capacity increased with the incorporation of turmeric flour. High swelling capacity has been reported as part of the criteria for a good quality product (Nlba et al., 2002). The swelling capacity of flours depends on the size of particles, the types of variety and the types of processing method.

Proximate Composition of Couscous Produced from Acha, Spent Layer Meat and Turmeric Flour Blends

The results of the proximate composition of couscous produced from acha-spent layer meat and turmeric proximate composition of couscous produced from acha-spent layer meat and turmeric flour blends are shown in Table 44. The moisture, ash, crude fibre, crude protein, crude fat, and carbohydrates ranged from 4.69% to 6.20%, 3.80% to 5.44%, 0.52% to 0.38%, 8.82% to 13.14%, 0.96% to 2.01%, and 81.21% to 72.58%, respectively. The effect of the added turmeric powder on the proximate composition was significant ($p<0.05$). The moisture content (4.69-6.20%) of acha-spent layer meat-turmeric flour blends in couscous is within the acceptable limit for couscous (<13.5%) (WFP, 2015). These low moisture levels suggest good storage stability and low microbial activity. Eman and Asael (2017) reported a higher moisture content of 9.1-9.6% in couscous made from Egyptian durum wheat flour fortified with inactive dried yeast and skim milk powder. Fatoumata et al. (2016) also reported crude fat and carbohydrate levels ranging from 4.69 to 6.20, 3.80 to 5.44, 0.52 to 0.38, 8.82 to 13.14, 0.96 to 2.01, and 81.21 to 72.58%, respectively.

Table 3: Functional Properties of *Acha*, Spent layer Meat and Turmeric Flour Blends

Samples	Bulk Density (g/mL)	WAC g/mL)	OAC g/mL)	Gelatinization Temprature. (^oC)	Swelling Index (mL/g)	Swelling Capacity (%)
A	$0.96^a \pm 0.02$	$1.25^c \pm 0.35$	$0.92^c \pm 0.11$	$63.5^f \pm 0.71$	$0.17^b \pm 0.24$	$111.36^g \pm 0.50$
B	$0.89^b \pm 0.01$	$1.82^{bc} \pm 0.25$	$0.98^c \pm 0.03$	$66.0^e \pm 1.41$	$0.80^a \pm 0.28$	$142.80^f \pm 0.28$
C	$0.84^c \pm 0.12$	$2.09^b \pm 0.13$	$1.10^c \pm 0.14$	$68.5^d \pm 0.71$	$0.91^a \pm 0.13$	$152.09^e \pm 0.13$
D	$0.79^d \pm 0.11$	$2.15^b \pm 0.21$	$1.15^{bc} \pm 0.21$	$70.5^c \pm 0.71$	$0.97^a \pm 0.04$	$165.81^d \pm 0.18$
E	$0.60^e \pm 0.00$	$2.27^b \pm 0.28$	$1.24^b \pm 0.34$	$72.5^b \pm 0.71$	$0.98^a \pm 0.03$	$162.64^c \pm 0.52$
F	$0.55^f \pm 0.01$	$2.86^a \pm 0.19$	$1.77^a \pm 0.34$	$74.0^{ab} \pm 0.00$	$1.03^a \pm 0.04$	$170.54^b \pm 0.65$
G	$0.42^g \pm 0.01$	$2.95^a \pm 0.06$	$1.85^a \pm 0.22$	$75.0^a \pm 0.00$	$1.15^a \pm 0.21$	$182.45^a \pm 0.64$

*Values are means and standard deviation of triplicate determinations.. Different Superscripts within the same column are significantly different at ($p<0.05$)
KEY:
Acha-spent layer meat flour contained 88 % *Acha* flour:12 % Spent layer meat flour
A Samples with 100 % *Acha* flour (control).
B Samples with 98 % *Acha*-spent layer meat flour and 2 % Turmeric flour
C Samples with 96 % *Acha*-spent layer meat flour and 4 % Turmeric flour
D Samples with 94 % *Acha*-spent layer meat flour and 6 % Turmeric flour
E Samples with 92 % *Acha*-spent layer meat flour and 8 % Turmeric flour
F Samples with 90 % *Acha*-spent layer meat flour and 10 % Turmeric flour
G Samples with 88 % *Acha*-spent layer meat flour and 12 % Turmeric flour
WAC-water absorption capacity, OAC- water absorption capacity

The effect of the added turmeric powder on the proximate composition is significant (p <). The moisture content (4.69-6.20%) of acha-spent layer meat-turmeric flour blends in couscous was within the acceptable limit for couscous (<13.5%) (WFP, 2015). These low moisture levels suggest good storage stability and low microbial activity. Eman and Asael (2017) reported a higher moisture content of 9.1-9.6% in couscous made from Egyptian durum wheat flour fortified with inactive dried yeast and skim milk powder. Fatoumata et al. (2016) also reported a higher moisture content of 10.63 to 11.22% in couscous based on three formulations of composite flours enriched with soybean.

The ash content (3.80-5.44%) of acha-spent layer meat-turmeric flour blends in couscous was above the range reported for composite flours enriched with soybean. The ash content (3.80-5.44 %) of acha-spent layer meat-turmeric flour blends couscous was above the range reported by Raihanatu et al.(2020), 1.89

to 3.16 % in a study on couscous produced from sprouted wheat fortified with soya bean (Glycine max (L.) Merr) and pumpkin (Cucurbita pepo) Seeds. Garsa (2016) also reported a low level (1.89 to 3.16%) in a study on couscous produced from sprouted wheat fortified with soybean (Glycine max (L.) Merr.) and pumpkin (Cucurbita pepo) Seeds. Garsa (2016) also reported a lower ash content of 0.94-1.99% in sesame-durum wheat flour blends for couscous. The increase in the ash content suggests that turmeric flour may contribute more micronutrients to couscous.

The crude fibre content (0.52-0.38 h content of 0.94-1.99%) in sesame-durum wheat flour blends for couscous. The increase in the ash content suggests that turmeric flour may contribute more micronutrients to couscous. The crude fibre content (0.52-0.38%) aligns with the values reported by Raihanatu et al. (2020), 0.24 to 2.68%, in a study on couscous produced from sprouted wheat fortified with soybean and pumpkin seeds. Agbar aligns with the values reported by Raihanatu et al. (2020), 0.24 to 2.68%, in a study on couscous produced from sprouted wheat fortified with soybean and pumpkin seeds. Agbara et al. (2020) reported a higher fibre content of 2.05 to 2.61% in a study on acha-semolina couscous as affected by pulse flour. Dietary fibre helps decrease the reported higher fibre content of 2.05 to 2.61% in a study on acha-semolina couscous, as affected by pulse flour. Dietary fibre helps to decrease the risk of cardiovascular diseases by reducing serum total and LDL cholesterol concentrations in adults and children (Sanchez, 2012). Dietary fibre promotes gastrointestinal function by building up important microflora, and acting as a prebiotic (substrate for beneficial microorganisms) (Costabile et al., 2010; Carvalho, 2010)

The crude protein content (8.82-13.14%) of couscous reduces the risk of cardiovascular diseases by lowering serum total and LDL cholesterol concentrations in adults and children (Sanchez, 2012). Dietary fibre promotes gastrointestinal function by building up important microflora, and acting as a prebiotic (substrate for beneficial microorganisms) (Costabile et al., 2010; Carvalho, 2010). The crude protein content (8.82-13.14%) of the couscous agreed with the findings of Agbara et al. (2020), who reported similar protein values of 6.74 to 11.12%. Eman and Asael (2017) recorded higher values of 17.46-22.60% in couscous made from Egyptian durum wheat flour fortified with inactive dried yeast, reporting similar protein values of 6.74-11.12%. Eman and Asael (2017) recorded higher values of 17.46-22.60% in couscous made from Egyptian durum wheat flour fortified with inactive dried yeast and skim milk powder. Protein and skimmed milk powder. Protein plays a crucial role in hormone regulation, enzyme production for digestion, maintaining fluid balance, and building and repairing body tissues.

The fat content of 0.96-2.01% aligns with that of Verma et al. (2014), who reported values of 1.39 to 3.89% in a study on the effects of replacing refined wheat flour with chicken meat on the physicochemical and sensory properties of noodles. It also aligns with Surender et al. (2019), who recorded a similar fat content of 0.92 to 3.89 % in a study on the development and evaluation of the quality of noodles enriched with chicken meat powder. Fat is a source of essential fatty acids, which the body cannot make itself. Fat helps give your body energy, protects your organs, supports cell growth, keeps cholesterol and blood pressure under control and helps your body absorb vital nutrients.

The carbohydrate content ranged from 81.21% to 72.58%. These results are consistent with previous studies, such as Eman and Asael (2017), who reported carbohydrate contents ranging from 72.29% to 84.59% in couscous made from Egyptian durum wheat flour fortified with inactive dried yeast and skim milk powder. Thi et al. (2024) reported a lower carbohydrate content of 65.8% to 66.0% in a study on the quality of cookies supplemented with various levels of turmeric by-product powder. Carbohydrates provide heat and energy for all forms of bodily activities. Deficiency can cause the body to convert proteins and body fat to produce the needed energy, thus leading to depletion of body tissues.

The fat content of 0.96-2.01% aligns with that of Verma et al. (2014), who reported values of 1.39 to 3.89% in a study on the effects of replacing refined wheat flour with chicken meat on the physicochemical and sensory properties of noodles. It also aligns with Surender et al. (2019), who recorded a similar fat content of 0.92 to 3.89 % in a study on the development and evaluation of the quality of noodles enriched with chicken meat powder. Fat is a source of essential fatty acids, which the body cannot make itself. Fat helps give your body energy, protects your organs, supports cell growth, keeps cholesterol and blood pressure under control and helps your body absorb vital nutrients.

The carbohydrate content ranged from 81.21% to 72.58%. These results are consistent with previous studies, such as Eman and Asael (2017), who reported carbohydrate contents in the range of 72.29% to 84.59% in couscous made from Egyptian durum wheat flour fortified with inactive dried yeast and skim milk powder. Thi et al. (2024) reported a lower carbohydrate content of 65.8% to 66.0% in a study on the quality of cookies supplemented with various levels of turmeric by-product powder. Carbohydrates provide heat and energy for all forms of bodily activities. A deficiency can cause the body to convert proteins and body fat to produce the needed energy, thus leading to the depletion of body tissues.

.**Table 4: Proximate Composition of Couscous Produced from *Acha*, Spent layer meat and Turmeric Flour Blends**

Samples	Moisture (%)	Ash (%)	Crude Fibre (%)	Crude Protein (%)	Crude Fat (%)	Carbohydrates (%)
A	$4.69^{b}\pm0.19$	$3.80^{d}\pm0.23$	$0.52^{a}\pm0.06$	$8.82^{d}\pm0.00$	$0.96^{e}\pm0.06$	$81.21^{a}\pm0.03$
B	$5.78^{a}\pm0.46$	$3.97^{d}\pm0.09$	$0.10^{e}\pm0.01$	$9.96^{c}\pm0.23$	$1.39^{d}\pm0.01$	$78.80^{b}\pm0.58$
C	$5.92^{a}\pm0.59$	$4.60^{c}\pm0.23$	$0.22^{d}\pm0.03$	$12.66^{b}\pm0.22$	$1.66^{c}\pm0.08$	$74.96^{c}\pm0.29$
D	$5.79^{a}\pm0.24$	$4.76^{bc}\pm0.23$	$0.28^{cd}\pm0.03$	$13.05^{ab}\pm0.13$	$1.81^{b}\pm0.01$	$74.32^{c}\pm0.31$
E	$6.18^{a}\pm0.22$	$5.15^{ab}\pm0.34$	$0.32^{bc}\pm0.06$	$13.46^{a}\pm0.00$	$1.92^{a}\pm0.01$	$72.98^{d}\pm0.07$
F	$6.09^{a}\pm0.18$	$5.34^{a}\pm0.09$	$0.36^{bc}\pm0.02$	$13.26^{a}\pm0.00$	$1.92^{a}\pm0.02$	$73.03^{d}\pm0.27$
G	$6.20^{a}\pm0.14$	$5.44^{a}\pm0.23$	$0.38^{b}\pm0.01$	$13.41^{a}\pm0.48$	$2.01^{a}\pm0.02$	$72.58^{d}\pm0.54$

*Values are means and standard deviation of triplicate determinations.. Different Superscripts within the same column are significantly different at ($p<0.05$)
KEY:

Acha-spent layer meat flour contained 88 % *Acha* flour: 12 % Spent layer meat flour
A Samples with 100 % *Acha*-spent layer meat flour (control).
B Samples with 98 % *Acha*-spent layer meat flour and 2 % Turmeric flour
C Samples with 96 % *Acha*-spent layer meat flour and 4 % Turmeric flour
D Samples with 94 % *Acha*-spent layer meat flour and 6 % Turmeric flour
E Samples with 92 % *Acha*-spent layer meat flour and 8 % Turmeric flour
F Samples with 90 % *Acha*-spent layer meat flour and 10 % Turmeric flour
G Samples with 88 % *Acha*-spent layer meat flour and 12 % Turmeric flour

Mineral Composition of Couscous Produced from Acha, Spent Layer Meat and Turmeric Flour Blends

The mineral composition of the study is presented in Table 5. The effect of the added turmeric powder on the mineral compositions of the couscous was significant ($p<0.05$). Ca, Zn, Fe, Mg and K contents of the produced couscous increased from 0.96-2.02, 0.46-1.18, 0.02-0.16, 31.8-72.5 and 13.0-123.5 ppm, respectively, with an increase (1-12%) in turmeric flour. The addition of turmeric flour had a significant effect ($p<0.05$) on all the assessed minerals. There was a significant difference ($p<0.05$) in the calcium content of the couscous samples (Table 5). The calcium content increased with the addition of turmeric flour. Sample G, which was made of 88% acha-spent layer meat flour and 12% turmeric flour, had the highest value (2.02 ppm). This indicates that the addition of turmeric flour increased the calcium content of the produced couscous. In comparison, sample A, with 100% acha-spent layer meat flour (control), had the lowest value (0.96 ppm). Calcium is an essential mineral required for maintaining muscle, heart, and digestive system health, as well as for building bones and supporting the synthesis and function of blood cells (Dinda, 2019).

In zinc sample A (100 % acha-spent layer meat) had the least value 0.46 (ppm), while sample G (88 % acha-spent layer meat flour and 12 % turmeric) had the highest value 1.18 (ppm); there were significant differences ($p<0.05$) among the samples. The Zinc content of the couscous increased with the inclusion of turmeric flour. Zinc is one of the nutritionally essential trace elements that the body requires in small quantities for a healthy life. The safe limit for Zn is 0.41–5 ppm (Kobia et al., 2016). The zinc content of the couscous samples is within the safe limits for zinc.

For iron, sample G (88 % acha-spent layer meat flour and 12 % turmeric) had the highest iron content, 0.16 (ppm), making it the best choice for those needing to boost their iron intake, such as individuals with anaemia or iron deficiency. Sample A (100% acha-spent layer meat) had the lowest value of 0.02 (ppm). There was an increase in the iron content as the inclusion of turmeric flour increased in the samples. The increase in iron content may be attributed to the rise in the proportion of turmeric flour. The body requires iron in small concentrations for normal growth, the proper functioning of the immune system, and DNA synthesis, among other functions (Ujowundu et al., 2014). The recommended levels of iron (Fe) concentration for human consumption are (4.49 ppm to 15.0 ppm) (Kobia et al., 2016).

The magnesium content showed an increasing trend with the addition of turmeric flour. It increased from 31.8 (ppm) in sample A (100% acha-spent layer meat) to 72.5ppm in sample G (88% acha-spent layer meat flour and 12 % Turmeric flour). There was a significant difference($p<0.05$) among the samples, which showed that turmeric flour increased the magnesium content of the produced couscous significantly ($p<0.05$), potentially contributing more significantly to daily intake. Magnesium is an essential mineral involved in various physiological functions, including bone health, cardiovascular function, and metabolic processes (Fatima et al., 2024). It plays a critical role in bone mineralisation and density, assists in regulating calcium and vitamin D levels, and helps prevent osteoporosis and bone fragility (Wang et al., 2025).

The potassium content increased from 13.0 ppm in sample A (100% acha-spent layer meat) to 123.5ppm in sample G (88% acha-spent layer meat and 12 % turmeric). There were significant differences ($p<0.05$) among the samples. Potassium is a systemic electrolyte and is essential in co-regulating ATP with sodium (Dinda,2019).

Blends

The sensory attributes of the produced couscous are shown in Table 6. The average means scores for taste, aroma, appearance, chewiness, and general acceptability of the couscous ranged from 7.18 to 4.36, 7.73 to 4.55, 7.45 to 5.00, 7.45 to 5.45, and 7.27 to 5.27 for samples A, B, C, D, E, F, and G, respectively. The effects of adding turmeric are generally significant, $p < 0.05$. The most preferred of the produced samples is the control, followed by sample B, which contained 98% acha-spent layer meat flour and 2% turmeric flour. The taste of couscous produced from acha-spent layer meat-turmeric flour blends showed a significant difference ($p<0.05$) among the samples. Sample A, with 100 % acha-spent layer meat flour (control), had the highest score (7.18±0.60), followed by sample B, whereas sample G, with 88 % acha-spent layer meat flour and 12 % Turmeric flour, had the

Table 5: Mineral Composition of Couscous Produced from *Acha*, Spent layer meat and Turmeric Flour Blends

Samples	Ca (ppm)	Zn(ppm)	Fe(ppm)	Mg(ppm)	K(ppm)
A	0.96^{d}±0.10	0.46^{e}±0.01	0.02^{c}±0.01	31.8^{e}±0.35	13.0^{f}±0.00
B	1.28^{cd}±0.08	0.66^{d}±0.00	0.07^{bc}±0.04	45.5^{d}±0.00	38.0^{e}±2.12
C	1.34^{cd}±0.04	0.73^{cd}±0.03	0.06^{bc}±0.03	46.0^{d}±0.71	77.5^{d}±0.71
D	1.67^{abc}±0.01	0.82^{c}±0.01	0.10^{ab}±0.00	51.0^{c}±0.00	91.0^{c}±3.54
E	1.59^{bc}±0.19	0.93^{b}±0.01	0.10^{ab}±0.01	52.0^{c}±0.00	95.8^{c}±5.30
F	1.83^{ab}±0.09	1.02^{b}±0.01	0.11^{ab}±0.01	62.5^{b}±0.71	111.8^{b}±2.47
G	2.02^{a}±0.09	1.18^{a}±0.12	0.16^{a}±0.05	72.5^{a}±0.71	123.5^{a}±0.71

*Values are means and standard deviation of triplicate determinations.. Different Superscripts within the same column are significantly different at ($p<0.05$)

KEY:

Acha-spent layer meat flour contained 88%*Acha* flour: 12 %Spent layer meat flour

A Samples with 100 % *Acha*-spent layer meat flour (control).

B Samples with 98 % *Acha*-spent layer meat flour and 2 % Turmeric flour

C Samples with 96 % *Acha*-spent layer meat flour and 4 % Turmeric flour

D Samples with 94 % *Acha*-spent layer meat flour and 6 % Turmeric flour

E Samples with 92 % *Acha*-spent layer meat flour and 8 % Turmeric flour

F Samples with 90 % *Acha*-spent layer meat flour and 10% Turmeric flour

G Samples with 88 % *Acha*-spent layer meat flour and 12 % Turmeric flour

Sensory Properties of Couscous Produced from Acha, Spent Layer Meat and Turmeric Flour

lowest score (4.36±1.91). There was a significant difference ($p<0.05$) among the samples.

There was a significant difference ($p < 0.05$) among the couscous samples in terms of aroma. The aroma scores of the couscous ranged from 7.73 ± 0.79 to 4.55 ± 1.75. Sample A had the highest scores in aroma, whereas the aroma scores of Sample G were the lowest. The appearance of different couscous samples showed a significant difference ($p<0.05$) among the samples. Sample B received the highest score (7.45 ± 0.99) while sample G had the lowest score (5.00 ± 1.14). Additionally, it was observed that the appearance scores increased at sample B and decreased with the addition of turmeric flour.

There was a significant difference ($p < 0.05$) among the treatments in terms of chewiness. Sample A had the highest chewiness scores (7.45 ± 0.82), followed by sample B, while sample G had the lowest scores. There was a decrease in the general acceptability scores of the samples. There were significant differences ($p < 0.05$) among the samples in their general acceptability scores. However, samples A and B were significantly ($p>0.05$) the same, while samples C to G were also significantly ($p>0.05$) the same. Sample A received the highest scores, followed by Sample B, while Sample G had the lowest scores. Nur et al. (2016) reported a decrease in the appearance, aroma, taste, and overall acceptability of cookies prepared with fresh turmeric flower (Curcuma longa L.) extracts as a value-added functional ingredient. Wannee (2020) also recorded a decrease in the appearance (6.84-5.91 %), flavour (7.34 -7.18 %), taste (7.22-6.96 %) and general acceptability (7.13 - 6.81 %) values of the Beef Stick Product in a study on the sensory characteristics of three different levels of turmeric powder on beef stick product.

The findings suggest that acha, spent layer meat, and turmeric flour blends can be used to develop nutritious and acceptable couscous products, with optimal turmeric levels at around 2%. Consumers preferred couscous with a subtler turmeric flavour and aroma, as evident from the higher scores for sample B. Understanding consumer preference can help tailor product development and marketing strategies.

CONCLUSION

A relatively nutritious and acceptable couscous can be produced from acha-spent layer meat and turmeric powder. The most preferred product was one containing 2 % turmeric powder. The use of acha, a local food product, as an alternative to imported wheat flour in the production of couscous could reduce the production cost. Also, the use of spent layer meat in improving the nutrient composition of couscous has opened commercial marketing for the same.

Table 6: Sensory Properties of Couscous Produced from *Acha*, Spent layer meat and Turmeric Flour Blends

Samples	Taste	Aroma	Appearance	Chewiness	General Acceptability
A	$7.18^{a}\pm0.60$	$7.73^{a}\pm0.79$	$6.91^{a}\pm1.48$	$7.45^{a}\pm0.82$	$7.27^{a}\pm0.79$
B	$6.45^{ab}\pm1.13$	$6.36^{b}\pm0.81$	$7.45^{ab}\pm0.99$	$6.64^{ab}\pm0.81$	$6.82^{a}\pm1.08$
C	$5.45^{bc}\pm0.93$	$5.82^{bc}\pm1.08$	$6.00^{bc}\pm1.04$	$6.36^{ab}\pm1.50$	$5.73^{b}\pm0.79$
D	$5.09^{c}\pm1.14$	$5.09^{cd}\pm1.38$	$5.91^{bc}\pm1.70$	$6.18^{b}\pm1.08$	$5.64^{b}\pm1.36$
E	$5.09^{c}\pm1.30$	$4.64^{d}\pm1.57$	$5.91^{bc}\pm1.41$	$6.09^{b}\pm1.22$	$5.55^{b}\pm0.93$
F	$5.00^{c}\pm0.95$	$4.67^{d}\pm1.16$	$5.67^{c}\pm0.93$	$5.75^{b}\pm1.77$	$5.50^{b}\pm1.24$
G	$4.36^{c}\pm1.91$	$4.55^{d}\pm1.75$	$5.00^{c}\pm1.14$	$5.45^{b}\pm1.51$	$5.27^{b}\pm2.10$

Values are means and standard deviation of triplicate determinations.. Different Superscripts within the same column are significantly different at ($p<0.05$)
KEY: *Acha*-spent layer meat flour contained 88 % *Acha* flour: 12 % Spent layer meat flour
A Samples with 100 % *Acha*-spent layer meat flour (control).
B Samples with 98 % *Acha*-spent layer meat flour and 2 % Turmeric flour
C Samples with 96 % *Acha*-spent layer meat flour and 4 % Turmeric flour
D Samples with 94 % *Acha*-spent layer meat flour and 6 % Turmeric flour
E Samples with 92 % *Acha*-spent layer meat flour and 8 % Turmeric flour
F Samples with 90 % *Acha*-spent layer meat flour and 10 % Turmeric flour
G samples with 88 % *Acha*-spent layer meat flour and 12 % Turmeric flour

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FUNCTIONAL AND NUTRITIONAL PROPERTIES OF ACHA (*Digitaria exilis*), BAMBARA NUT *(Vigna subterranean)*, AND BEETROOT *(Vulgaris ruba)* FLOUR BLENDS AND PHYSICAL PROPERTIES OF THE BISCUITS

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ABSTRACT

This study evaluated the functional, nutritional, and sensory properties of biscuits produced from composite flours of acha (Digitaria exilis), Bambara groundnut (Vigna subterranea) and beetroot (Beta vulgaris). Composite flour blends were formulated by substituting the beetroot flour (0, 5, 10, 15, 20, 25%) into the acha-Bambara nut flour blend and used to produce biscuits. The blend flour was analysed for its functional properties, while the biscuits were analysed for their chemical (proximate, mineral, and vitamin) composition and sensory quality using standard methods. The water absorption and the forming capacity increased from 1.75 - 3.40 g/cm3 and 46.00 - 57.00 %, while the bulk density, swelling capacity and the oil absorption capacity decreased from 6.35 - 5.05, 4.15 - 3.75 g/cm3 and 2.75 – 1.40 mg/100g, respectively with increase in the percentage added beetroot powder (0 -25%). The fibre, ash and moisture content of the products increased from 2.60 to 2.95, 5.70 to 6.16 and 7.50 to 13.03 %, respectively, while the protein, fat and carbohydrate decreased from 14.20 to 13.05, 4.30 to 2.51 and 65.70 to 59.74 %, respectively, with an increase (0 -25 %) in added beetroot flour. The vitamin A and B content of biscuits made from different blends increased from 5.42 to 6.12 µg/100 g and from 48.84 to 71.23 µg/100 g, respectively, with the addition of beetroot flour. The phosphorus, potassium, sodium, and magnesium content of the flour blends increased from 162.54 to 276.47, 398.35 to 426.67, 98.63 to 169.67, and 143.45 to 195.67 mg/100g, respectively, with the addition of beetroot flour. The break strength and spread ratio decreased from 1210.0 to 767 g and increased from 7.10 to 7.60 with the addition of beetroot flour. Generally, all the blend products were accepted (8.42 to 6.63), but the most preferred was that of 100% wheat flour. The study confirmed that acceptable and nutritious biscuits can be produced from acha, Bambara nut and beetroot flour blends

Key Words: Functional property, Nutritional composition, Biscuits, acha (*Digitaria exilis*), Bambara nut (*Vigna subterranean),* beetroot (*Vulgaris ruba*)

INTRODUCTION

Biscuits may be regarded as a form of confectionery, dried to a very low moisture content, made from unleavened dough (Obi and Nwakalor, 2015). They are ready-to-eat, convenient and inexpensive food products, containing digestive and dietary principles of vital importance. The major ingredients for biscuit production are flour, fat, sugar, salt, and water, which are mixed with other minor ingredients, such as baking powder, skim milk, emulsifier, and sodium metabisulfite, to form a dough containing a gluten network (Oyedele et al., 2017). According to Nwakalor (2014), the dough is rested for a period and passed between rollers to make a sheet. These sheets, however, are transformed into an appetising product through the application of heat in the oven.

Biscuits are a popular product due to their low cost, ease of transportation, long shelf life, and nutritional properties, as biscuit provides significant amounts of carbohydrates, protein, and complex B vitamins (Fradique et al., 2013). It was found that moisture content ranging from 9.44 - 9.79 %, protein from 8.43 – 13 %, fat from 1.97 - 2.5 %, ash from 1.25 - 1.62 %, crude fiber from 7.14 - 11 %, carbohydrate from 62.44 - 71.39 %, magnesium from 86.30 - 136 mg/100g, calcium from 32.90 - 38 mg/100g, iron from 2.92 - 3.86 mg/100g (Olalekan et al., 2017). Biscuit is produced from imported wheat flour which are very expensive and also relatively low in other essential nutrient such as vitamin B, and minerals (like iron and magnesium), so there is need to research into locally cultivated cereal (acha) and other plant food (Bambara groundnut and beetroot) and were underutilized making them relatively cheaper hence reducing cost of producing biscuits.

Acha seeds are nutritious, containing 8.79 % protein and may be up to 11.89 % in some black acha samples (Isah et al., 2017). The grains are rich in amino acids: leucine (9.80 %), methionine (5.60 %), valine (5.80 %) and cysteine, which are vital to human health but deficient in today's major cereals (Jideani and Jideani 2011). According to Ayo et al. (2018), acha grains contain substantial minerals (mainly iron, calcium, and phosphorus) at approximately 5.00% dry matter. Acha seeds are rich in methionine and cystine, amino acids vital to human health that are deficient in most cereals (Omeire et al., 2014). Acha (Digitaria exilis), also known as fonio or hungry rice, is an annual crop indigenous to West Africa that is classified as an underutilised crop (Inyang et al., 2018). In Nigeria, it is widely cultivated and consumed in the Northern Areas. It can be consumed completely, milled into flour, processed into gruel, porridges, alcoholic and non-alcoholic beverages. They are a good source of magnesium, iron, and copper, but low in potassium, sodium, lead, and manganese compared to most cereals. They also contain 7.90% protein, 1.80% fat, 71.00% carbohydrate, and 6.80% fibre (Orisa and Udofia, 2019). The colour and size of the grain also classify Acha. Acha is one of the most nutritious of all grains. Its seed is rich in methionine and cystine, which are vital to human health, and these amino acids are deficient in major cereals such as wheat, rice, maize, sorghum, barley, and rye.

Bambara nut (Vigna subterranea) is a legume indigenous to Africa; it is cultivated in semi-arid regions of Africa. Bambara nut typically consists of 49–63.5% carbohydrates, 15–25% protein, 4.5–7.4% fat, 5.2–6.4% fibre, 3.2–4.4% ash, and 2% minerals (Murevanhema and Jideani, 2013). It has also been reported that Bambara nut is rich in essential amino acids, including leucine, isoleucine, lysine, methionine, phenylalanine, threonine, and valine. Despite these favourable nutritional properties, Bambara nut consumption is limited because it is regarded as difficult to cook with, and firewood scarcity poses serious problems in many regions (Mubaiwa et al., 2018).

Beetroot (Beta vulgaris ruba) is a crop belonging to the family Chenopodiaceae, and it is an excellent source of red and yellow pigments. It has been reported that red beetroot has a high concentration of betalain, which are used as food colourants and food additives (Kathiravan et al., 2015). Betalains impart attractive colours to food products and have been shown to confer free-radical scavenging and antioxidant activities. They can be eaten raw, boiled, steamed and roasted. Red beetroot is a rich source of minerals (manganese, sodium, potassium, magnesium, iron, copper). Beetroot contains a high amount of antioxidants, vitamins A and E (36 IU and 0.30 mg), fibre, and natural dyes. The macronutrients include: protein contents (13.57-15.83 %), ash content 1.02 - 3.18 %), dietary fibre (0.53 to 2.43%), fat (21.63 - 21.59 %) and energy (410.07 to 394.75 kcal/100 g) (Kohajdova et al., 2018; Singh et al., 2016). Beetroots are rich in other valuable compounds such as carotenoids (Abiodun et al., 2021), glycine betaine, saponins, betacyanins, folates, betanin, polyphenols and flavonoids (Chhikara et al., 2018).

Wheat flour is very expensive and also relatively low in other essential nutrients, such as vitamin B, and minerals (like iron and magnesium), so there is a need to research into locally cultivated cereal (acha) and other plant foods (Bambara groundnut and beetroot), which were underutilised, making them relatively cheaper, hence reducing the cost of producing biscuits. The objective was to determine the functional and nutritional composition of biscuits produced from blends of acha, Bambara nut, and beetroot flour.

MATERIALS AND METHODS

Materials

Acha (Digitaria exilis), Bambara groundnut (Vigna subterranea)(Plate 1), Beetroot (Vulgaris ruba)(Plate 2), sugar, baking powder, and baking fat were purchased from the new market, Wukari, Taraba State, Nigeria

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Plate 1: Pictorial view of Bambara ground nut purchased.

Plate 2: Pictorial view of Beetroot purchased with produced flour

Preparation of acha, Bambara groundnut and beetroot flour

Acha grains were manually cleaned, destoned (sedimentation in portable water), sun dried (for 6 h), milled (Kenwood model), sieved (14 mm), to produce acha flour (Mepba et al., 2021), and stored (32 -34 °C) for further use. Bambara groundnut seeds were dried under the sun (40 - 45 °C), dehulled, milled (Kenwood model), sieved (14 mm mesh sieve) to produce flour (Musah et al., 2021), stored in a Ziplock plastic bag and stored at room temperature (32 – 34 °C). Beetroot was washed, grated, dried (70 °C), milled (Kenwood model) and sieved (14 mm mesh sieve) to produce beetroot flour (Eke-Ejiofor et al., 2022).

Experimental Design

The bulk and principal flour used was a 90:10 mixtures of acha and Bambara groundnut, based on previous research (Ayo et al., 2016). The beetroot flour was substituted for the principal flour (acha) at 0, 5, 10, 15, 20, and 25% to produce respective flour blends used for the production of biscuits. Wheat flour (100%) was used as a control.

Biscuit Preparation

The method, as described by Ayo et al. (2018) with slight modifications, was used. The sugar (50 %) was beaten into fat (50 %) (Kenwood mixer). Mixed with acha-Bambara groundnut flour blends, baking powder (1.5%) and salt (1.5%) were slowly added to the fluffy sugar-fat mixture and blended until a uniform, smooth paste was obtained. The paste was rolled on a flat, oiled rolling board to form a uniform thickness of 0.4 cm using a wooden rolling pin. Circular biscuits of 4.0 cm diameter were cut (using a biscuit-cutter), placed on a greased baking tray and baked at 160ºC for 15 min (BCH- Rotary oven, Great Britain). The biscuit was allowed to cool down (to about 32º C) and hermetically sealed in a polyethene bag.

ANALYTICAL METHODS

Determination of functional properties of flour

Determination of bulk density: The loose bulk density was determined using the method outlined by Eltayeb et al. (2011). Five grams of the sample were placed into a 25 ml graduated cylinder, and its bottom was tapped on the laboratory bench until no further decrease in the sample's volume was observed. The observed volume of the sample was then recorded as the bulk density

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$$Bulk\ Density = \frac{weight\ of\ sample\ (g)}{\text{Volume of sample after tapping(ml)}} \qquad Eqn\ (i)$$

Determination of swelling capacity, foaming capacity, and oil and water absorption capacity: The swelling capacity, foaming capacity, and oil and water absorption capacity were determined as described by Coffman et al. (2012)

Chemical analysis of flour blend biscuit

Proximate composition: The proximate (moisture, crude protein, crude fibre, crude fat, ash, carbohydrate) composition of the flour blend biscuits was determined using the AOAC (2020) method.

Mineral and vitamin composition of flour blend biscuits

The Mineral (sodium and magnesium) and vitamin (Vit A and Vit B) composition of biscuits produced from acha, Bambara nut, and beetroot flour blends was determined using the AOAC (2020) method.

Sensory evaluation of the biscuit

The biscuit samples were assessed by the method described by Akubor et al. (2023). Twenty (20) panelists were randomly selected amongst the students of the Department of Food Science and Technology, Federal University Wukari, Nigeria, who were familiar with the quality attributes of biscuits. The samples were evaluated for appearance, flavour, taste, mouthfeel, and overall acceptability on a 9-point Hedonic scale (1 = dislike extremely and 9 = like extremely). The samples were presented to the panelists in clean glass tumblers. The order of presentation of the samples to the panelists was randomised. The evaluation was carried out in a sensory evaluation laboratory under controlled conditions of lighting and illumination.

Statistical analysis

Data were analysed using Analysis of Variance (ANOVA) in a completely randomised design with replicates, as implemented in the Statistical Package for the Social Sciences (SPSS) Version 16.00. Significant differences were separated using Duncan's Multiple Range Test (DMRT). Significance was accepted at $p<0.05$.

RESULTS AND DISCUSSION

Functional properties Acha, Bambara nut, and beetroot flour blends (g/ml)

The functional properties of flour blends are shown in Table 1. The water absorption and the forming capacity increased from 1.75 - 3.40 g/cm3 and 46.00 - 57.00 %, while the bulk density, swelling capacity and the oil absorption capacity decreased from 6.35 - 5.05, 4.15 - 3.75 and 2.75 – 1.40 cm3/100mg, respectively, with an increase in the percentage added beetroot powder (0 -25 %).

The results indicate significant ($p \leq 0.05$) variations among the samples, suggesting that the incorporation of Acha, Bambara nut, and beetroot flours influences these functional properties differently. The decrease in the bulk density could be due to a relative decrease in the particle size of the added beetroot flour. Bulk density reflects the particle packing efficiency, which in turn affects dough handling and the texture of the final product (Ayo et al., 2016). The decrease in swelling capacity with a sample containing 95% Acha-Bambara nut flour blend and 5% beetroot flour (4.35 g/ml), showing the highest value, suggests superior starch gelatinisation, which enhances dough expansion during baking (Singh et al., 2007). The findings align with those of Oladele and Aina (2007), who observed that higher swelling capacity in composite flours improves biscuit texture by promoting better dough rise and a more desirable crumb structure.

The increase in the water absorption capacity could be attributed to the higher fibre or protein content from Bambara nut or beetroot flour (Kaur et al., 2011). Increased WAC enhances dough cohesiveness and moisture retention, extending product freshness. Kaur et al. (2011) reported similar trends, noting that WAC increases with elevated protein and fibre content due to their hydrophilic nature.

The effects on the oil absorption capacity indicate better fat-binding ability, which could enhance the richness and palatability of biscuits (Adebowale et al., 2005). Variations in OAC may be due to differences in protein hydrophobicity and fibre content, as hydrophobic protein regions bind lipids more effectively (Adebowale et al., 2005). The increase in the foaming capacity, a good potential for dairy and confectionery foods, could likely be due to protein-polysaccharide interactions enhancing foam stability (Mune Mune et al., 2018).

Table.1 Functional properties Biscuits from Acha, Bambara nut, and beetroot flour blends (g/ml)

Sample Code	Bulk density (g/cm^3	Swelling capacity g/ml)	Water absorption Capacity cm^3/100mg	Oil absorption capacity cm^3/100mg	Foaming capacity (%)
A	6.35^{ab}±0.21	4.15^{bc}±0.01	1.75^{e}±0.01	2.75^{a}±0.35	46.00^{d}±1.41
B	6.05^{b}±0.07	4.05^{c}±0.01	2.15^{d}±0.21	2.10^{b}±0.14	51.50^{cd}±0.71
C	6.35^{ab}±0.21	3.85^{d}±0.01	2.45^{cd}±0.01	2.45^{ab}±0.01	50.50^{c}±0.70
D	6.50^{a}±0.14	4.35^{a}±0.01	2.35^{cd}±0.01	2.10^{bc}±0.14	51.00^{cd}±1.41
E	6.15^{ab}±0.01	4.25^{ab}±0.01	2.60^{bc}±0.14	2.05^{bc}±0.07	52.00^{cd}±1.41
F	6.05^{b}±0.01	4.05^{c}±0.01	2.80^{b}±0.14	1.80^{cd}±0.14	53.50^{bc}±0.71
G	5.40^{a}±0.14	3.85^{d}±0.01	2.90^{b}±0.14	1.55^{de}±0.07	55.50^{ab}±0.71
H	5.05^{b}±0.21	3.75^{d}±0.02	3.40^{a}±0.14	1.40^{e}±0.14	57.50^{a}±0.71

Means within each column not followed by the same superscript are significantly different ($P \leq 0.05$) from each other using Duncan's multiple range test.
Note: The bulk and principal flour (Sample C) used was 90:10 of acha and Bambara groundnut, based upon former research (Ayo *et al*., 2016)
Key: Sample A= 100 % Wheat flour; Sample B= 100 % Acha flour; Sample C= 100 % Acha - Bambara nut flour blend; Sample D= 9 5 % Acha-Bambara nut flour blend and 5 % Beet root flour; Sample E= 90 % Acha-Bambara nut flour blend and 10 % Beet root flour, Sample F= 85 % Acha-Bambara nut flour blend and 15 % Beet root flour, Sample G= 80 % Acha-Bambara nut flour blend and 20 % Beet root flour, Sample H= 75 % Acha-Bambara nut flour blend and 25 % Beet root flour

Chemical Composition of Flour Blend Biscuits

Proximate Composition of flour blend biscuits: The proximate composition of the flour blends showed significant nutritional variations as influenced by the blending ratios and inherent properties of the individual components. The results highlight key trends in macronutrient distribution, which have important implications for food fortification and dietary applications. The fibre, ash and moisture content of the products increased from 2.60 to 2.95, 5.70 to 6.16 and 7.50 to 13.03 %, respectively, while the protein, fat and carbohydrate decreased from 14.20 to 13.05, 4.30 to 2.51 and 65.70 to 59.74 %, respectively, with an increase (0 -25 %) in added beetroot flour. The relative decrease in protein and fat content of the blend biscuit could be due to the low content of these ingredients in the added beetroot flour. The decrease in fat content, which could be attributed to the relatively low natural fat content of Bambara nuts (6–8%) (Hillocks *et al.,* 2012), may lower the energy content but reduce the tendency for oxidative rancidity, thereby improving the storage stability of the product. Lower-fat blends may be preferable for weight management and cardiovascular health (Mozaffarian *et al*., 2011). The increase in fibre content could be attributed to the high fibre content in beetroot flour (Chawla *et al.*, 2016). The relatively high fibre content of the blend product could be an advantage in fortification and enhancing dietary fibre, which may aid in improving gut health and reducing the risks of obesity and diabetes. The increase

in ash content with the addition of beetroot suggests it to be a valuable, mineral-rich food source, addressing micronutrient deficiencies in populations at risk of mineral deficiencies (e.g., iron-deficiency anaemia) (Bailey *et al*., 2015). The increase in the moisture content could be attributed to beetroot's **hygroscopic nature,** which absorbs and retains water (Adeleke and Babalola, 2020). While moisture impacts could negatively affect shelf stability, proper drying and storage techniques could mitigate microbial spoilage, ensuring product longevity (Labuza and Hyman, 1998).

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Mineral composition of flour blend biscuits: The phosphorus, potassium, sodium, and magnesium content of the flour blends increased from 162.54 to 276.47, 398.35 to 426.67, 98.63 to 169.67 and 143.45 to 195.67 mg/100g, respectively, with an increase in the added beetroot flour shown in Table 3. The relative increase in these minerals could be attributed to the addition of beetroot, which has been confirmed to be rich in these minerals (Jideani and Akingbala, 2011; Mazahib *et al.,* 2013; Wruss *et al.,* 2015).

Sodium is critical for maintaining fluid balance and nerve function, but its intake must be moderated to prevent hypertension (Strazzullo and Leclercq, 2014). The observed values of sodium are lower than those in processed foods but comparable to those in whole-food-based blends, indicating that these formulations could be beneficial for individuals monitoring their sodium intake. Magnesium plays a key role in muscle relaxation, oxidative stress reduction, and enzymatic reactions (Nielsen, 2018).

Proximate composition from Acha, Bambara nut, and beetroot flour blends

Table 2 Proximate composition from Acha, Bambara nut, and beetroot flour blends (%)

Sample Code	Crude Protein (%)	Crude Fiber (%)	Fat (%)	Ash (%)	Moisture content (%)	Carbohydrate (%)
A	$10.02^{h}±0.01$	$0.16^{h}±0.01$	$2.69^{e}±0.04$	$0.76^{h}±0.05$	$3.54^{h}±0.01$	$82.81^{a}±0.08$
B	$13.95^{c}±0.00$	$2.20^{g}±0.00$	$3.61^{b}±0.01$	$4.95^{g}±0.00$	$7.00^{g}±0.00$	$68.29^{b}±0.01$
C	$14.20^{a}±0.00$	$2.60^{e}±0.00$	$4.30^{a}±0.00$	$5.70^{f}±0.00$	$7.50^{f}±0.00$	$65.70^{c}±0.00$
D	$14.00^{b}±0.00$	$2.51^{f}±0.01$	$3.01^{c}±0.01$	$5.81^{e}±0.01$	$14.03^{a}±0.00$	$65.47^{c}±0.66$
E	$13.91^{d}±0.01$	$2.73^{d}±0.01$	$2.90^{d}±0.01$	$5.98^{d}±0.01$	$13.92^{b}±0.00$	$62.60^{d}±0.33$
F	$13.05^{e}±0.01$	$2.95^{c}±0.00$	$2.51^{f}±0.01$	$6.16^{c}±0.01$	$13.07^{c}±0.00$	$59.74^{e}±0.02$
G	$12.25^{f}±0.01$	$2.97^{b}±0.00$	$2.01^{g}±0.01$	$7.14^{b}±0.00$	$12.27^{d}±0.00$	$59.34^{ef}±0.01$
H	$12.01^{g}±0.01$	$3.00^{a}±0.00$	$1.93^{h}±0.01$	$8.13^{a}±0.00$	$12.01^{e}±0.00$	$58.95^{f}±0.01$

*Means within each column not followed by the same superscript are significantly different ($P \leq 0.05$) from each other using Duncan multiple range test.

Note: Note: The bulk and principal flour (Sample C) used was 90:10 of acha and Bambara groundnut based upon former research (Ayo *et al*., 2016)

** Key: Sample A= 100 % Wheat flour; Sample B= 100 % Acha flour; Sample C= 100 % Acha - Bambara nut flour blend; Sample D= 9 5 % Acha-Bambara nut flour blend and 5 % Beet root flour; Sample E= 90 % Acha-Bambara nut flour blend and 10 % Beet root flour, Sample F= 85 % Acha-Bambara nut flour blend and 15 % Beet root flour, Sample G= 80 % Acha-Bambara nut flour blend and 20 % Beet root flour, Sample H= 75 % Acha-Bambara nut flour blend and 25 % Beet root flour

Table 3 Mineral composition from Acha, Bambara nut, and beetroot flour blends (mg/100g)

Sample Code	Phosphorus (P)	Potassium (K)	Sodium (Na)	Magnesium (Mg)
A	$123.53^{h}\pm0.01$	$360.50^{h}\pm0.01$	$312.22^{a}\pm0.01$	$137.52^{g}\pm0.02$
B	$126.66^{g}\pm0.01$	$376.27^{g}\pm0.02$	$60.18^{h}\pm0.01$	$86.26^{h}\pm0.01$
C	$162.54^{f}\pm0.01$	$398.35^{f}\pm0.02$	$98.63^{g}\pm0.02$	$143.45^{f}\pm0.00$
D	$212.36^{e}\pm0.02$	$401.45^{e}\pm0.00$	$126.67^{f}\pm0.01$	$166.25^{e}\pm0.00$
E	$218.96^{d}\pm0.02$	$410.86^{d}\pm0.01$	$129.57^{e}\pm0.02$	$169.30^{d}\pm0.01$
F	$225.56^{c}\pm0.01$	$415.26^{c}\pm0.01$	$132.47^{d}\pm0.02$	$172.35^{c}\pm0.02$
G	$251.01^{b}\pm0.01$	$420.96^{b}\pm0.01$	$151.07^{c}\pm0.02$	$184.01^{b}\pm0.02$
H	$276.47^{a}\pm0.02$	$426.67^{a}\pm0.02$	$169.67^{b}\pm0.03$	$195.67^{a}\pm0.02$

The data values are mean ± standard deviation of the mineral composition. Means within each column not followed by the same superscript are significantly different ($p \leq 0.05$) from each other using Duncan multiple range test.

Note: Note: The bulk and principal flour (Sample C) used was 90:10 of acha and Bambara groundnut based upon former research (Ayo *et al*., 2016)

Key: Sample A= 100 % Wheat flour; Sample B= 100 % Acha flour; Sample C= 100 % Acha - Bambara nut flour blend; Sample D= 9 5 % Acha-Bambara nut flour blend and 5 % Beet root flour; Sample E= 90 % Acha-Bambara nut flour blend and 10 % Beet root flour, Sample F= 85 % Acha-Bambara nut flour blend and 15 % Beet root flour, Sample G= 80 % Acha-Bambara nut flour blend and 20 % Beet root flour, Sample H= 75 % Acha-Bambara nut flour blend and 25 % Beet root flour

Vitamin composition of flour blend biscuits:

The vitamin A and B6 content of biscuits made from different blends increased from 5.42 to 6.12 and from 48.84 to 71.23 µg/100 g (Table 4) with the addition of beetroot flour. Beetroot contains significant amounts of provitamin A carotenoids, which could be converted into retinol (active vitamin A) in the body (Jones and Abu, 2019). The higher vitamin B levels in flour blend biscuits proved the potential of beetroot in food (Adebowale et al., 2016; Oyeyinka et al., 2018).

Table 4: Vitamin composition of the Biscuits from Acha, Bambara nut, and beedroot flour blends (ug/100g)

Sample Code	Vitamin A	Vitamin B_6
A	$1.63^{g}\pm0.28$	$0.61^{h}\pm0.04$
B	$4.59^{cd}\pm0.03$	$65.49^{d}\pm0.01$
C	$5.42^{b}\pm0.01$	$48.84^{b}\pm0.01$
D	$3.28^{f}\pm0.02$	$51.70^{g}\pm0.00$
E	$4.17^{f}\pm0.02$	$59.67^{f}\pm0.02$
F	$4.45^{e}\pm0.02$	$64.55^{e}\pm0.01$
G	$4.75^{c}\pm0.04$	$66.44^{c}\pm0.01$
H	$6.12^{a}\pm0.01$	$71.25^{a}\pm0.02$

Means within each column not followed by the same superscript are significantly ($P \leq 0.05$) different from each other using Duncan multiple range test. Note: The bulk and principal flour (Sample C) used was 90:10 of acha and Bambara groundnut based upon former research (Ayo *et al*., 2016)

Key: Sample A= 100 % Wheat flour; Sample B= 100 % Acha flour; Sample C= 100 % Acha - Bambara nut flour blend; Sample D= 9 5 % Acha-Bambara nut flour blend and 5 % Beet root flour; Sample E= 90 % Acha-Bambara nut flour blend and 10 % Beet root flour, Sample F= 85 % Acha-Bambara nut flour blend and 15 % Beet root flour, Sample G= 80 % Acha-Bambara nut flour blend and 20 % Beet root flour, Sample H= 75 % Acha-Bambara nut flour blend and 25 % Beet root flour

Physical quality of flour blend biscuits:

The break strength and spread ratio decreased from 1210.0 to 767 g and increased from 7.10 to 7.60 with an increase in the added beetroot flour (Table 5). Biscuit weight is primarily determined by moisture retention, dough density, and ingredient composition (Manley, 2011). The differences observed here suggest variations in dough hydration or baking conditions, with heavier biscuits likely retaining more moisture or containing denser flour matrices (Pareyt and Delcour, 2008).

a.Wheat(100%) b. Acha(100%) c. Acha/Bnut (90/10) d.Acha-bnut/bert(95/5)

e.Acha-Bnut/Bert (90/10) f. Acha-Bnut/Bert(85/15) g. Acha-Bnut/Bert(80/20)h.Acha-Bnut/Bert(75/25)

Bnut= Bambara nut

Plate 3: Pictorial view of the biscuit samples produced

Break strength, a measure of resistance to fracture, was highest in 100 % Wheat flour (3250.50 N) and lowest in 80 % Acha-Bambara nut flour blend and 20% Beet root flour (776.50 N) and 75 %Acha-Bambara nut flour and 20 % Beet root flour (767.50 N). This parameter reflects textural hardness, influenced by gluten development, fat/sugar ratios, and baking time/temperature (Sahin and Sumnu, 2006). The results suggest that Sample A had a more rigid structure, possibly due to the use of high-protein flour or lower fat content, while G and H were more tender, likely because of their higher fat or sugar content.

The spread ratio, which measures dough expansion, was highest in 100% Wheat flour (7.70), 100 % Acha flour (7.60), and 80 % Acha-Bambara nut flour blend and 20% Beet root flour (7.60) and lowest in 95 % Acha-Bambara nut flour and 5 % Beet root flour (6.80). Spread is governed by sugar dissolution, fat lubrication, and leavening efficiency (Jacob and Leelavathi, 2007). Greater spread is linked to enhanced sugar melting (which increases dough fluidity) and optimal fat distribution (Baltsavias *et al.*, 1999)

Table 5: Physical properties of the flour blend biscuits

Sample Code	Weight (g)	Break strength (N)	Spread ratio (%)
A	$9.89^{a}\pm0.01$	$3250.50^{a}\pm0.71$	$7.70^{a}\pm0.14$
B	$9.51^{c}\pm0.07$	$2070.50^{b}\pm0.71$	$7.60^{a}\pm0.14$
C	$9.50^{c}\pm0.08$	$1260.00^{c}\pm7.07$	$7.10^{bc}\pm0.14$
D	$9.83^{a}\pm0.01$	$1710.00^{d}\pm0.00$	$6.80^{c}\pm0.14$
E	$9.83^{a}\pm0.01$	$955.00^{e}\pm7.07$	$7.10^{bc}\pm0.14$
F	$9.63^{b}\pm0.01$	$917.50^{f}\pm3.54$	$7.25^{b}\pm0.07$
G	$8.74^{d}\pm0.01$	$776.50^{g}\pm4.95$	$7.25^{b}\pm0.07$
H	$8.21^{e}\pm0.01$	$767.50^{g}\pm3.54$	$7.60^{a}\pm0.14$

Means within each column not followed by the same superscript are significantly different ($p \leq 0.05$) from each other using Duncan multiple range test.

Note: The bulk and principal flour(Sample C) used was 90:10 of acha and Bambara groundnut based upon former research (Ayo *et al*., 2016)

Key: Sample A= 100 % Wheat flour; Sample B= 100 % Acha flour; Sample C= 100 % Acha - Bambara nut flour blend; Sample D= 9 5 % Acha-Bambara nut flour blend and 5 % Beet root flour; Sample E= 90 % Acha-Bambara nut flour blend and 10 % Beet root flour, Sample F= 85 % Acha-Bambara nut flour blend and 15 % Beet root flour, Sample G= 80 % Acha-Bambara nut flour blend and 20 % Beet root flour, Sample H= 75 % Acha-Bambara nut flour blend and 25 % Beet root flour

Sensory quality of flour blend biscuits

The average means of appearance, aroma, taste, texture, and overall acceptability decreased from 8.37 to 6.21, 8.21 to 6.31, 7.95 to 5.85, 7.89 to 6.37, and 8.42 to 6.63, respectively, with an increase in the added beetroot flour (Table 6). The low standard deviation (0.37–0.63) suggests high consistency in the panellists' ratings, reinforcing their preference. This can be attributed to an optimal flour blend ratio, which enhances palatability. Similar findings were reported by Oluwajuyitan *et al.* (2021), who noted that balanced composite flour blends enhance the sensory properties of baked goods.

The decline in texture scores (7.89–8.11) may be related to the increased fibrous content from Bambara nut or beetroot, as noted by Adeleke and Babalola (2020) in their studies on legume-enriched bakery products. The lower scores in Samples E (90 % Acha-Bambara nut flour blend and 10 % Beet root flour)–H (75 % Acha and Bambara nut flour and 20% Beet root flour) align with findings by Obadina *et al*. (2017), who reported that legume flours can introduce beany or bitter notes, while beetroot may impart an earthy taste that not all consumer's favor. The relatively softer texture, with higher average scores in the control sample (100% Wheat flour and 100% acha flour), may result from acha's fine particle size, as highlighted by Oyeyinka *et al.* (2019). Generally, all the blend products were accepted (8.42 to 6.63), but the most preferred was that of 100% wheat flour.

Table 6: Sensory evaluation of the Biscuits from Acha, Bambara nut, and beetroot flour blends

Sample Code	Appearance	Aroma	Taste	Texture	Overall acceptability
A	$8.84^{a}±0.37$	$8.79^{a}±0.54$	$8.79^{a}±0.63$	$8.68^{a}±0.58$	$8.79^{a}±0.54$
B	$8.32^{ab}±1.44$	$8.11^{ab}±0.57$	$7.95^{b}±0.91$	$8.11^{ab}±0.57$	$8.26^{ab}±0.65$
C	$8.37^{ab}±0.60$	$8.21^{ab}±0.71$	$7.95^{b}±0.85$	$7.89^{bc}±0.65$	$8.42^{a}±0.69$
D	$7.53^{bc}±0.96$	$7.95^{b}±0.78$	$7.58^{bc}±1.12$	$7.47^{bcd}±1.07$	$7.68^{bc}±0.82$
E	$7.26^{cd}±0.99$	$7.21^{c}±1.03$	$7.21^{bcd}±1.13$	$7.42^{bcd}±0.84$	$7.47^{c}±1.07$
F	$7.10^{cde}±1.56$	$7.00^{cd}±1.10$	$6.84^{cd}±1.11$	$7.11^{cde}±1.15$	$7.42^{c}±1.07$
G	$6.47^{de}±1.84$	$6.58^{cd}±1.50$	$6.68^{de}±1.38$	$6.68^{de}±1.57$	$6.68^{d}±1.37$
H	$6.21^{e}±2.29$	$6.31^{d}±1.78$	$5.95^{e}±1.87$	$6.37^{e}±1.95$	$6.63^{d}±1.57$

The data values are mean ± standard deviation of the sensory evaluation. Means within a column not followed by the same superscript are significantly different ($P \leq 0.05$).

Note: The bulk and principal flour (Sample C) used was 90:10 of acha and Bambara groundnut based upon former research (Ayo *et al*., 2016)

Key: Sample A= 100 % Wheat flour; Sample B= 100 % Acha flour; Sample C= 100 % Acha - Bambara nut flour blend; Sample D= 9 5 % Acha-Bambara nut flour blend and 5 % Beet root flour; Sample E= 90 % Acha-Bambara nut flour blend and 10 % Beet root flour, Sample F= 85 % Acha-Bambara nut flour blend and 15 % Beet root flour, Sample G= 80 % Acha-Bambara nut flour blend and 20 % Beet root flour, Sample H= 75 % Acha-Bambara nut flour blend and 25 % Beet root flour

CONCLUSION

This study has shown that nutritious and acceptable biscuits can be produced from blends of acha, Bambara nut, and Beetroot flour. The addition of beetroot flour significantly improved the ash, fibre, and mineral content (phosphorus, sodium, and magnesium), as well as the sensory quality of the product. Although all the flour blend products were accepted, the most preferred is that of 100% wheat, which compares favourably with blend samples containing 5-10% beetroot flour. However, the sample containing 100% Acha-Bambara nut has the highest crude protein content (14.20%), indicating that Bambara nut fortification could improve the protein content more effectively. Acha and Bambara nut and beetroot flour blends can present a viable and sustainable alternative to wheat flour, offering enhanced nutrition and functional benefits.

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COMPARATIVE EVALUATION OF *IN VITRO* FERMENTATION AND METHANE PRODUCTION OF *BRACHIARIA*, NAPIER, AND *DIGITARIA* GRASSES

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ABSTRACT

Forages are the foundation of ruminant nutrition, critically influencing productivity and environmental sustainability. This study evaluated the nutritional composition and predicted in vitro fermentation characteristics of three widely cultivated tropical grasses—Brachiaria, Napier (Pennisetum purpureum), and Digitaria—to assess their suitability for ruminant feeding and environmental impact. Samples were harvested at a uniform vegetative stage and analysed for proximate composition and fibre fractions. Using established predictive models, we estimated Dry Matter Digestibility (DMD), fermentation kinetics, volatile fatty acid production, and methane yield. Results revealed significant ($p < 0.05$) differences among the species. Brachiaria demonstrated superior fermentability, with the highest DMD (70%), the lowest fibre fractions (NDF 62.40%; ADF 37.80%), and a moderate methane yield (0.13 mL CH_4/g DMD). Digitaria exhibited an intermediate nutritional profile but the most rapid fermentation rate ($t_{1/2}$ = 13.50 h), indicating faster microbial degradation. Despite a high crude protein content (26.90%), Napier grass exhibited lower digestibility (60%) and the highest methane intensity (0.15 mL CH_4/g DMD), which was associated with its elevated fibre content (NDF 48.30%; ADF 47.30%). The findings underscore that fibre composition is a primary determinant of fermentation efficiency and methane emissions. We conclude that Brachiaria and Digitaria are promising forages for enhancing productivity and mitigating enteric methane production, whereas Napier grass requires targeted management strategies to achieve these benefits. Selection of tropical grasses based on these criteria is essential for developing climate-smart, sustainable livestock production systems.

Keywords: Dry matter digestibility, Fibre composition, In-vitro fermentation, Methane emissions, Tropical forages, Sustainable livestock

INTRODUCTION

Forages form the foundation of ruminant feeding systems and remain indispensable in both intensive and extensive livestock production (Sanderson and Liebig, 2020). They supply the bulk of the nutrients required for animal maintenance, growth, reproduction, and milk or meat yield. In many low- and middle-income countries, where concentrate feeds are often prohibitively expensive or unavailable, forages serve as the primary feed resource (Balehegn *et al.*, 2020). Their role extends beyond animal nutrition, as they also contribute to soil fertility, erosion control, and the broader sustainability of mixed crop–livestock systems (Ahuchaogu, 2022; Ogbu and Ilo, 2021). Nevertheless, the nutritional value of forages is highly heterogeneous. It is shaped by intrinsic factors such as species and genotype, as well as external influences including soil fertility, climate, management practices, and particularly the stage of maturity at harvest. As plants advance in maturity, structural carbohydrates accumulate, lignification intensifies, and protein concentration declines, leading to reduced digestibility and diminished voluntary intake (Osuga *et al.,* 2020).

In tropical regions, forage production is dominated by warm-season (C4) grasses, among which *Brachiaria*, *Pennisetum purpureum* (commonly known as Napier grass), and *Digitaria* species are prominent. These grasses are favoured for their vigorous growth, high yield potential, and resilience under low-input conditions. However, their chemical composition often presents nutritional challenges. Elevated concentrations of Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) depress digestibility and slow rumen turnover, constraining energy extraction from the diet. Greater methane (CH_4) emissions accompany this inefficiency in ruminal fermentation. Methane not only represents a loss of dietary energy—estimated at 2–12 % of gross energy intake in ruminants—but also contributes significantly to global greenhouse gas emissions, with a warming potential about 28 times higher than that of carbon dioxide over a century-long timescale. Consequently, strategies that reduce enteric methane production while sustaining animal performance are at the centre of efforts to develop more sustainable livestock systems (Seketeme *et al.*, 2022).

Within this context, differences among tropical grasses are increasingly attracting attention. *Brachiaria* species have been noted for their relatively favourable balance of crude protein and fibre, with some accessions showing promising potential for moderating methane output compared to other tropical grasses. Their adaptability and positive effects on soil health have further cemented their importance in tropical livestock systems. Napier grass, in contrast, is the most widely cultivated forage across sub-Saharan Africa and parts of Asia due to its exceptional biomass productivity and suitability for cut-and-carry feeding. Its limitation, however, lies in its high fibre fractions, which tend to accumulate rapidly with maturity, reducing its digestibility and feeding value. *Digitaria* species, though less extensively studied, occupy an intermediate position: their nutritional profile suggests a balance between yield and quality, making them promising candidates for more detailed evaluation. Preliminary findings indicate that some *Digitaria* ecotypes may offer improved digestibility and reduced methane emissions compared to more fibrous grasses, although robust comparative studies are still scarce (Jayasinghe *et al.*, 2022).

Comparative assessments of these grasses are essential not only to guide on-farm forage choices but also to inform broader policy and research agendas aimed at reducing the environmental footprint of livestock production. Understanding their relative fermentation efficiency, dry matter digestibility, and methane emission potential provides a scientific basis for recommending species or management practices that enhance both productivity and sustainability. Against this backdrop, the present study was designed to evaluate *Brachiaria*, Napier, and *Digitaria* under comparable conditions, to identify their relative strengths and limitations for ruminant feeding and their implications for climate-smart livestock systems.

MATERIALS AND METHODS

Sample collection and preparation

Fresh forage samples of *Brachiaria*, *Pennisetum purpureum* (Napier grass), and *Digitaria* spp. were harvested from experimental plots at uniform vegetative stages to minimise variability due to maturity. Approximately 500 g of fresh material was collected per replicate from at least five randomly selected points within each plot to obtain a representative composite sample. Samples were immediately placed in airtight polyethene bags and transported to the laboratory to minimise moisture loss and oxidation. Upon arrival, the samples were washed to remove soil, debris, and other extraneous materials. They were then chopped into 2–3 cm segments, oven-dried at 60 °C for 72 h to constant weight, and ground to pass through a 1 mm screen using a Wiley mill. Ground samples were stored in airtight containers at room temperature until they were analysed. Three independent replicates were prepared for each forage species to ensure reproducibility.

Chemical composition analysis

Proximate analysis followed AOAC (2019) standard methods: Moisture content (method 934.01) by oven-drying, Crude Protein (CP) (method 954.01) by Kjeldahl nitrogen determination (N × 6.25), Crude Fibre (CF) (method 978.10), Ether Extract (EE) (method 920.39) via Soxhlet extraction, and ash content (method 942.05) by incineration at 550 °C were used for analysis. Fibre fractions were determined using the Van Soest detergent analysis system (Van Soest *et al*., 1991). NDF and ADF were measured using an ANKOM fibre analyser and reported inclusive of residual ash. These compositional parameters provided the input data for fermentation modelling.

Predicted *in vitro* fermentation

The *in vitro* fermentation characteristics of each forage were estimated using compositional data and established predictive models. The Menke and Steingass (1988) gas production model was applied to simulate: DMD %, cumulative gas production (mL/200 mg DM), Volatile Fatty Acid (VFA) concentrations (mmol/L), methane production (mL and mL/g DMD), and fermentation kinetics, including potential gas production (a + b), rate constant (c), and half-time to asymptote ($t_{1/2}$), based on the Ørskov and McDonald (1979) exponential model. All simulations assumed standard ruminal conditions: 39 °C, anaerobic environment, and buffered medium. Parameters were calculated for three independent replicates per forage species, and mean values were used for comparisons.

Experimental design and statistical analysis

The study employed a Completely Randomised Design (CRD) with three forage species as treatments and three replicates per species. Data from chemical composition and predicted fermentation outcomes were tested for normality using the Shapiro–Wilk test. One-way analysis of variance (ANOVA) was performed to detect significant differences among forage species. Where significant effects were observed ($p < 0.05$), means were separated using Tukey's honestly significant difference (HSD) test. All statistical analyses were conducted using R software version 4.3.0 (R Core Team, 2023). Data were presented as means ± Standard Error of the Mean (SEM), and graphical illustrations of gas production kinetics and methane estimates were generated using the ggplot2 package in R.

RESULTS AND DISCUSSION

Chemical composition of forages

The proximate composition and fibre fractions of the three tropical grasses are presented in Table 1. Significant ($p < 0.05$) differences were observed among the species. *Brachiaria* contained the highest crude protein (CP, 11.60%), followed by *Digitaria* (10.20%) and Napier grass (8.70%). Napier grass had the highest fibre content, with NDF exceeding 70% and ADF above 45%, whereas *Brachiaria* exhibited the lowest fibre fractions (NDF 62.40%; ADF 37.80%). Ether extract and ash contents did not differ significantly ($p > 0.05$) among the grasses.

Table 1. Proximate composition and fibre fractions of *Brachiaria*, Napier, and *Digitaria* (g/100 g DM)

Parameter (%)	*Brachiaria*	Napier Grass	*Digitaria*	SEM	*p-value*
Dry matter	91.20	90.60	91.00	0.18	0.212
Crude protein	11.60^{a}	8.70^{c}	10.20^{b}	0.23	0.031
Crude fibre	28.50^{b}	33.10^{a}	29.40^{b}	0.47	0.044
Ether extract	2.90	2.70	2.80	0.09	0.317
Ash	9.80	9.20	9.50	0.21	0.288
NDF	62.40^{c}	70.10^{a}	66.70^{b}	0.65	0.026
ADF	37.80^{c}	45.20^{a}	41.60^{b}	0.58	0.033

Superscripts (a–c) indicate significant differences along the rows ($p < 0.05$).

Predicted fermentation characteristics

Predicted in vitro fermentation outcomes are shown in Table 2. Brachiaria exhibited the highest dry matter digestibility (DMD, 67.40 %) and cumulative gas production (42.60 mL/200 mg DM), while Napier grass showed the lowest digestibility (59.10 %) and gas production (36.20 mL/200 mg DM). Digitaria ranked intermediate for most parameters. Methane production followed a similar trend: Napier grass produced the greatest methane volume (6.80 mL/200 mg DM; 18.60 mL/g DMD), while Brachiaria produced significantly lower values ($p < 0.05$) (4.90 mL/200 mg DM; 12.10 mL/g DMD). Digitaria again showed intermediate values (5.70 mL/200 mg DM; 14.80 mL/g DMD).

Table 2. Predicted fermentation outcomes of *Brachiaria*, Napier, and *Digitaria*

Parameter	Brachiaria	Napier Grass	Digitaria	SEM	p-value
DMD (%)	67.40[a]	59.10[c]	63.20[b]	0.64	0.018
Gas production (mL/200 mg DM)	42.60[a]	36.20[c]	39.80[b]	0.71	0.041
VFA concentration (mmol/L)	88.40[a]	75.60[c]	81.90[b]	1.02	0.022
Methane (mL/200 mg DM)	4.90[c]	6.80[a]	5.70[b]	0.12	0.027
Methane (mL/g DMD)	12.10[c]	18.60[a]	14.80[b]	0.33	0.035
Gas potential (a + b, mL)	48.50[a]	41.70[c]	45.30[b]	0.89	0.039
Rate constant (c, h^{-1})	0.076[a]	0.062[c]	0.069[b]	0.002	0.029
Half-time ($t½$, h)	9.10[c]	11.20[a]	10.00[b]	0.23	0.033

Fermentation kinetics curves

Gas production kinetics are illustrated in Figure 1. Brachiaria exhibited a faster rate of fermentation and higher asymptotic gas production compared to Napier grass, which displayed a delayed fermentation curve and a lower plateau. Digitaria demonstrated intermediate kinetics, confirming its moderate nutritive quality.

The present study highlights distinct differences in chemical composition, predicted fermentation efficiency, and methane emission potential among Brachiaria, Napier, and Digitaria grasses. These variations are consistent with known physiological and structural characteristics of tropical C4 grasses (Gemeda and Hassen, 2014).

Nutritional quality and fermentation efficiency

Brachiaria exhibited the highest crude protein content combined with the lowest fibre fractions (NDF and ADF), which translated to superior dry matter digestibility and cumulative gas production. The inverse relationship between structural carbohydrates and fermentability aligns with prior findings, which indicate that high NDF and ADF concentrations impede rumen microbial access to cell contents, slowing fermentation kinetics (Van Soest et al., 1991; Jung et al., 2020). The enhanced gas production observed for Brachiaria reflects its higher availability of soluble carbohydrates, which serve as rapid substrates for rumen microbes, thereby improving fermentation efficiency.

Digitaria presented intermediate protein and fibre levels, resulting in moderate digestibility and gas production, but demonstrated the fastest fermentation rate ($t_{1/2}$ = 13.5 h). This suggests that, while its total fermentable substrate may be slightly lower than *Brachiaria*, microbial degradation occurs more rapidly, which could support higher intake rates under grazing or cut-and-carry systems (Hernández-Miranda *et al*., 2023).

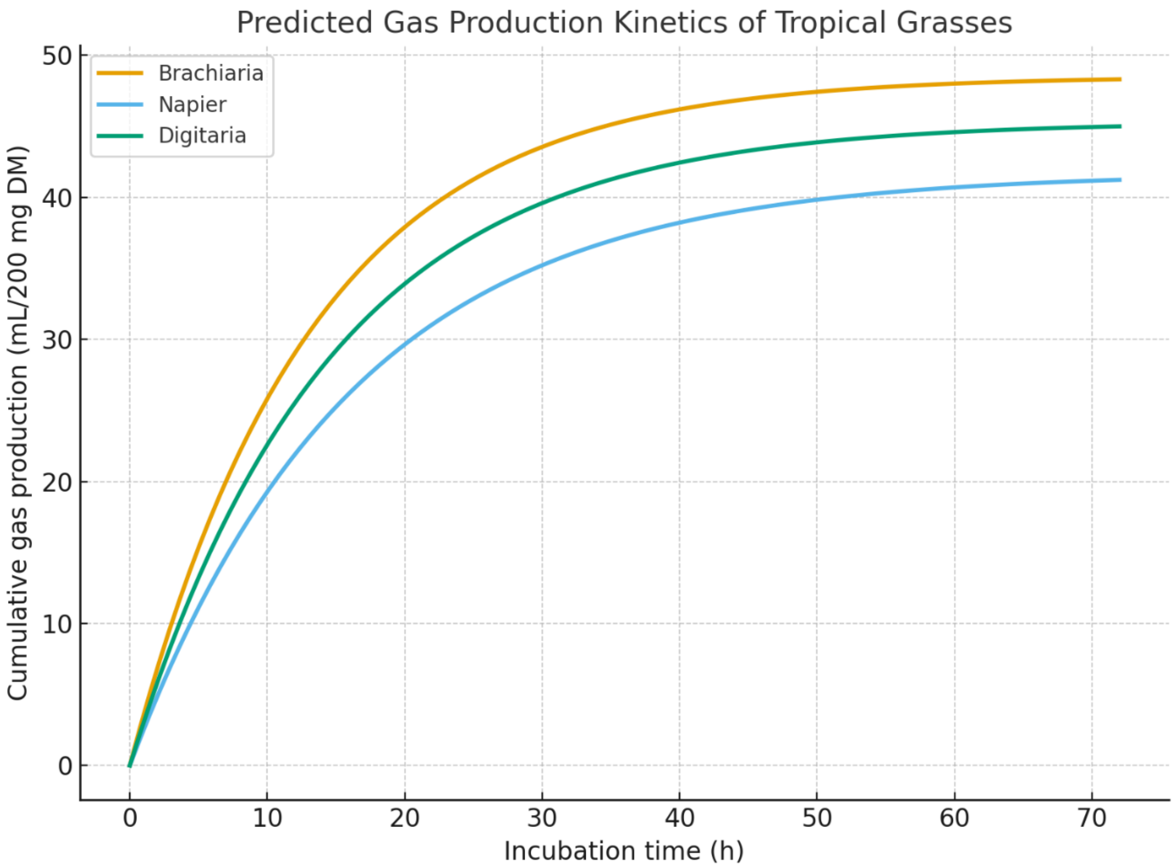

Figure 1. Predicted gas production kinetics of *Brachiaria*, Napier, and *Digitaria*
X-axis: Incubation time (h), **Y-axis:** Cumulative gas production (mL/200 mg DM), **Curves:** *Brachiaria* (green), *Napier* (red), *Digitaria* (blue).

Napier grass, despite its relatively high crude protein, had the highest NDF and ADF fractions. This aligns with previous observations that high structural fibre reduces rumen degradability and limits total energy extraction (Patra, 2014; Mwangi *et al*., 2024). Consequently, predicted digestibility and gas production were lowest, underscoring the importance of fibre quality over protein content alone in determining fermentation efficiency.

Methane emission

Potential methane production per unit of degraded matter followed the inverse trend of digestibility, with Napier emitting the most (0.15 mL CH_4/g DMD) and *Brachiaria* the least (0.13 mL CH_4/g DMD). This finding is consistent with the literature, which indicates that a high fibre content, particularly lignified NDF, promotes hydrogen availability for methanogenesis, thereby increasing methane yield (Gerber *et al*., 2013; Jung *et al*., 2020). *Brachiaria*'s lower fibre content and higher digestibility reduced the residence time of substrates in the rumen, limiting hydrogen accumulation and subsequent methane formation. *Digitaria*'s intermediate methane intensity further confirms the role of fibre composition in modulating enteric methane production.

These findings for sustainable livestock production suggest that selecting forage species is a crucial strategy for balancing productivity with environmental sustainability. *Brachiaria.* The results showed that supporting high digestibility and lower methane emissions offers an effective means to enhance feed efficiency while mitigating greenhouse gas output. *Digitaria*, with rapid fermentation kinetics, could complement *Brachiaria* in mixed pasture systems, particularly in scenarios where feed intake and rapid rumen turnover are prioritised. Napier grass, although widely cultivated for biomass yield, may require management interventions such as early harvesting, mechanical processing, or supplementation with low-fibre forages to optimise fermentability and reduce methane emissions (Silva *et al*., 2023).

The stage of forage maturity strongly influences fibre accumulation, digestibility, and methane emissions. Harvesting *Brachiaria* and *Digitaria* at early vegetative stages can maximise protein content, minimise lignification, and optimise fermentation outcomes (Hernández-Miranda *et al*., 2023; Silva *et al*., 2023). Napier grass may require more careful timing or supplementation to offset fibre-related limitations. These strategies align with climate-smart livestock practices that emphasise the dual goals of productivity and environmental stewardship. While *in vitro* predictions provide valuable insights, *in vivo* studies are necessary to validate these results under realistic feeding conditions. Future research should explore animal performance, voluntary intake, and methane emissions across different forage mixtures and harvest intervals. Additionally, breeding or selecting low-fibre, high-digestibility cultivars could further enhance the sustainability of tropical livestock systems.

In conclusion, this study confirms that forage fibre content is the primary driver of ruminal methane emissions. *Brachiaria* and *Digitaria* emerged as superior forages for simultaneously boosting productivity and reducing environmental impact. In contrast, Napier grass requires strategic management—such as specific harvesting times or supplementation—to realise its full potential and mitigate its higher methane yield.

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EFFECTS OF NEEM SEEDS SYNTHESIZED SILVER NANOPARTICLES AND GAMMA-IRRADIATION ON CERTAIN MORPHOLOGICAL TRAITS IN SELECTED ACCESSIONS OF PIGEON PEAS [*CAJANUS CAJAN* (L.) MILLSP]

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ABSTRACT

Cajanus cajan (L.) Millsp is an essential and nutritious crop plant in Nigeria. This study investigated the combined effects of gamma irradiation and bio-synthesized silver nanoparticles on selected agro-morphological traits of pigeon peas. It is based on this background that two accessions of pigeon peas (NGB05522 and NGB05543) were obtained from the National Centre for Genetic Resources Conservation and Biotechnology, Ibadan. The seeds were irradiated using a gamma irradiation source (Cirus Cobalt- 60 Teletherapy) at various levels. Before sowing, the seeds were primed with different concentrations of biosynthesized Silver Nanoparticles (AgNPs) from neem seeds. The results showed that the combined effects of gamma irradiation and biosynthesized AgNPs stimulate both plant height and the number of leaves per plant. At 12 Weeks after Sowing (WAS), the highest plant height in NGB05543 (115.80cm) was obtained in seeds treated with 400 gray and 100 ppm AgNPs; the value was significantly different ($p < 0.05$) from all the other treatments. In NGB05522, the highest plant height at 12WAS (143.00cm) was observed with 100 gray and 50 ppm AgNPs; this value was significantly different from all the other treatments. In NGB05543, 100 Gray and 100 ppm consistently produced the highest number of leaves throughout the periods under study (36 at 4WAS, 60 at 6WAS, 117 at 8WAS, 210 at

10WAS, and 894 at 12WAS); these values were significantly different ($p<0.05$) from all the other values. It is therefore concluded that gamma irradiation of pigeon pea seeds primed with AgNPs increased plant height and the number of leaves in pigeon peas.

Keywords: Improvement, Silver Nanoparticles, Gamma Irradiation, Plant Height, Leaves

INTRODUCTION

Pigeon pea [Cajanus cajan (L.) Millsp] is one of the most important food legume crops of both tropics and subtropics. Pigeon pea is a drought-tolerant plant and exhibits a large variation in physiological maturity. It primarily grows under marginal and high-risk conditions, but yields are generally poor. Rural communities primarily sow it in low-input, wet locations. The seeds of pigeon peas are enriched with vitamin B, protein, carotene, and ascorbic acid, which is better than other indigenous legumes. Pigeon pea (Cajanus cajan L. Millsp.) is an important grain legume grown in Nigeria. It primarily grows in marginal and poor soil conditions, but yields are generally low (Saxena et al., 2018). The seeds of pigeon peas are enriched with vitamin B, protein, carotene, and ascorbic acid, which is better than other indigenous legumes. There has been an increasing demand for healthy, protein-rich foods and critical minerals over the years. Soybeans and cowpeas, which serve as alternatives to animal protein, have become so expensive and unaffordable to the average Nigerian, hence aggravating the threat to food security.

Despite the nutritional importance of pigeon peas, its detrimental traits, such as a long cooking time (requiring a high cost of cooking energy), have led to low cultivation of the crop and reduced its consumer demand. Due to this, the crop has been branded as an "orphan crop" in many parts of Sub-Saharan Africa, including Nigeria. Mutation has been an essential tool in evolution, and at one time, it was considered the chief source of origin of new species. Mutation has been a crucial tool in evolution, and at one time, it was considered the primary source of new species. Plant breeders over across countries have adopted various strategies for crop improvement, like hybridization, selection, and mutation in pulse crops for generating variability and designing genotypes with desirable traits (Jaganathan et al., 2018). Mutagenesis is a phenomenon in which biological, chemical, or physical stimuli elicit abrupt heritable changes in plant contents that are not mediated by genetic dispersion or integration (Roychowdhury and Tah, 2013). Ionizing radiation has been observed to be useful in improving the overall traits in pigeon pea, including some preferred changes in functional properties of the seed (Bamidele and Akanbi, 2013).

Nanotechnology has permeated several disciplines over the last two decades, including medicine, environmental science, drug development, and biotechnology. To breed pigeon pea varieties with unique genetic architecture and improved agromorphological traits, there is a need to explore the use of mutation breeding through irradiation with gamma rays, as well as priming the irradiated seeds with silver nanoparticles. Nanotechnology has permeated several disciplines over the last two decades, including medicine, environmental science, drug development, and biotechnology (Niharika et al., 2016). Therefore, the objective of this research was to evaluate the effect of gamma irradiation and silver nanoparticles on genetic architecture and the reduction in cooking times of pigeon peas.

METHODOLOGY

Source of Research Materials

Pigeon pea (Cajanus cajan (L.) Millsp.) genotypes (NGB05543 and NGB05522) were obtained from the National Centre for Genetic Resources Conservation and Biotechnology (NACGRAB), Ibadan. Irradiation of the seeds was carried out at the Radiology and Oncology Department, Ahmadu Bello University Teaching Hospital, Shika, Zaria, using a gamma irradiation source (Cirus Cobalt- 60 Teletherapy) from Atomex. The Atomtex is a self-calibrated radiation source with an ambient dose equivalent of 50 nSv – 10 Sv/h. The leakage-free Cobalt-60 machine is a 229.061 TBq (6190.84Ci) model.

Treatment of Pigeon Pea Seeds with Gamma Radiation

The dried seeds of the pigeon pea [Cajanus cajan (L.) Millsp] were subjected to various doses of gamma rays (control 0,100, 200 and 400 Gy) obtained from a Cobalt-60 (60CO) source with a measured dose rate of 124.5 Gy/min for 8 hours 52 minutes.

Source of Neem Seeds

Fresh and healthy seeds of Neem (Azadirachta indica) were collected from the biological garden at the Federal University of Technology, Minna. The seeds were rinsed thoroughly first under running tap water, followed by deionized water to remove all the dust and unwanted particles. The seeds were then cut into small pieces and dried at room temperature (Niharika et al., 2016).

Preparation of Seed Extracts

Ten grams of the ground seeds were transferred into a 250 ml beaker containing 100 ml of deionized water and stirred on a magnetic stirrer at 80 °C for 20 minutes. The extracts were filtered twice through Whatman filter paper and refrigerated at 4 °C in Erlenmeyer flasks for further experiments. At every step of the experiment, sterile conditions were maintained to ensure effectiveness and accuracy in the results (Niharika et al., 2016).

Biosynthesis of Silver Nanoparticles

A 1 mM aqueous solution of silver nitrate (AgNO3) was prepared in a 250 ml Erlenmeyer flask, and 10% leaf extract was added for the reduction of Ag+ ions. The complete mixture was kept on a magnetic stirrer at 30 oC. Time and colour changes were recorded, along with periodic sampling and scanning using a UV-

Visible (UV-Vis) spectrophotometer. Suitable controls were maintained throughout the experimental conditions. The Complete reduction of Ag+ ions was confirmed by the change in colour from light or faint to yellowish colloidal brown. The colloidal solution was then left aside for 24 hours to allow for complete bio-reduction, as indicated by UV-Vis spectrophotometric scanning. The solution was sealed and stored properly for further use. The formation of silver nanoparticles will be further confirmed by different spectrophotometric analyses (Niharika et al., 2016).

Seed Treatments

The biosynthesized silver nanoparticles were dissolved at different concentrations (0, 25, 50, 75, and 100 ppm) in deionized water. Irradiated pigeon pea seeds were subjected to priming by soaking in a silver nanoparticle solution for approximately 2 hours. The treated seeds were then dried in the shade before planting (Khalaki et al., 2016).

Field Laid out and Experimental Design

The experiment was arranged in a randomized complete block design with five replicates; seeds of four genotype lines were sown alongside their respective controls. Two seeds were sown per hole, and then thinned to one after five weeks. The inter- and intra-row spacing was 40 × 25 cm. The treatments includes CONTROLS (for both NGB05543 and NGB05522), W1 (100G/25ppm), W2 200G/25ppm, W3 400G/25PPM, W4 100G/50ppm, W7 100G/100ppm, W8 200G/100ppm, W9 400G/100ppm, 400G/25ppm, 100G/50ppm, 200G/50ppm, 100G/100ppm, R3 400G/25ppm, R4 100G/50ppm, R5 200G/50ppm, R7 100G/100ppm, R8 200G/100ppm, and R9 400G/100ppm

Data Collection

During the planting phase, data on plant height and the number of leaves per plant were collected using techniques recommended by ICRISAT and IBPGR (1993). The plant height was recorded at 4 weeks after sowing (WAS) to 12 WAS. The length of the shoots (from the base of the stem to the terminal bud) of four randomly selected plants from each treatment, as well as the control, was measured using a meter rule. The number of leaves per plant was taken by directly counting all the leaves attached to the plants from 4 to 12 WAS.

Data Analyses

Quantitative data on plant height and the number of leaves per plant, obtained at various weeks after sowing, were pooled for analysis. Analysis of variance (ANOVA) was used to determine the level of significance among the treatments, and means were separated using Duncan's Multiple Range Test (DMRT) where necessary. All values were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

The effects of gamma irradiation on pigeon pea seeds primed with silver nanoparticles (AgNPs) are presented in Table 1. The results revealed significant differences ($P < 0.05$) in plant height and the number of leaves per plant throughout the experiment periods. At 4 weeks after sowing (WAS), the highest plant height in the white seed-coated pigeon pea (NGB05543) was observed with 400 gray and 100 ppm AgNPs (20.70 cm); this value was significantly higher than that of all other treatments (Table 1). Similarly, in the red seed-coated pigeon pea (NGB05522), the highest plant height at 4 WAS (25.00 cm) was due to 200 gray and 50 ppm AgNPs treatment; this value was significantly different from all the other treatments, including the controls. At 6 WAS, the highest plant height (36.00 cm) was obtained in NGB05543 treated with 100 Gray gamma rays and 100 ppm AgNPs. Meanwhile, in NGB05522, the highest plant height at 8 WAS (36.00 cm) was due to 200 Gray gamma irradiation and primed with 50 ppm AgNPs. A similar trend was obtained in all the weeks; the treated seeds produced higher plant heights than their controls (Table 1). At 12 WAS, the highest plant height in NGB05543 (115.80 cm) was obtained in seeds treated with 400 gray and 100 ppm AgNPs. In NGB05522, the highest plant height at 12 WAS (143.00 cm) was due to 100 gray and 50 ppm AgNPs (Table 1).

The results obtained for the number of leaves per plant for both pigeon accessions indicated that gamma irradiation and AgNPs enhanced leaf production. In NGB05543, 100 Gray and 100 ppm consistently produced the highest plant heights throughout the periods under study (36 at 4 WAS, 60 at 6 WAS, 117 at 8 WAS, 210 at 10 WAS, and 894 at 12 WAS); these values were significantly different from all the other values (Table 1). In NGB05522, 200G/50PPM consistently produced the highest number of leaves per plant at 4 WAS (27), 8 WAS (84), and 12 WAS (790); these values were significantly different from all the other values (Table 2). Meanwhile, the 100G/50PPM produced the highest number of leaves per plant at 6 WAS (50); however, this value was significantly different from all the other treatments.

Table 1: Combined Effects of Gamma Irradiation and Biosynthesized AgNPs on Plant Height of Selected Pigeon Peas Accessions

Treatments	PH (cm) 4 WAS	PH (cm) 6 WAS	PH (cm) 8 WAS	PH (cm) 10 WAS	PH (cm) 12 WAS
NGB05543 (WHITE SEED COAT)					
CONTROL	15.40^{cd}	22.94^{bc}	42.94^{bcd}	59.40^{a}	101.68^{b}
W1 100G/25ppm	16.90^{d}	35.10^{d}	55.60^{de}	75.00^{b}	109.80^{c}
W2 200G/25ppm	13.64^{bc}	18.46^{ab}	35.14^{ab}	62.14^{a}	100.86^{b}
W3 400G/25ppm	11.76^{ab}	26.26^{c}	45.26^{bcd}	71.00^{ab}	107.76^{c}
W4 100G/50ppm	14.00^{bcd}	16.00^{a}	29.00^{a}	55.00^{a}	85.00^{a}
W7 100G/100ppm	11.00^{ab}	36.00^{d}	65.00^{e}	74.00^{b}	108.00^{c}
W8 200G/100ppm	9.14^{a}	16.48^{a}	39.68^{abc}	69.68^{ab}	108.48^{c}
W9 400G/100ppm	20.70^{e}	27.40^{c}	51.60^{cd}	76.40^{b}	115.80^{d}
Standard Errors	0.63	1.34	2.20	2.13	2.21
NGB05522 (RED SEED COAT)					
CONTROL	14.40^{b}	21.60^{ab}	40.00^{a}	61.20^{a}	106.40^{a}
R3 400G/25ppm	17.20^{b}	29.60^{bc}	57.00^{bc}	83.00^{c}	130.00^{c}
R4 100G/50ppm	19.50^{b}	33.00^{c}	59.00^{bc}	85.00^{c}	143.00^{d}
R5 200G/50ppm	25.00^{c}	36.00^{c}	70.00^{c}	85.00^{c}	122.00^{bc}
R7 100G/100ppm	6.00^{a}	17.00^{a}	43.00^{a}	71.00^{ab}	100.00^{a}
R8 200G/100ppm	14.00^{b}	22.50^{ab}	48.00^{ab}	74.00^{bc}	108.00^{a}
R9 400G/100ppm	15.60^{b}	23.90^{ab}	49.00^{ab}	75.00^{bc}	117.40^{b}
Standard Errors	1.12	1.40	2.24	1.91	2.62

Values followed by the same letter(s) do not statistically differ at $p<0.05$, tested with DMRT

N.B: PH is Plant Height, WAS is Week after Sowing, NGB (NACGRAB). PPM (Part per Million)

Table 2: Combined Effects of Gamma Irradiation and Biosynthesized AgNPs on Number of Leaves per Plant of Selected Pigeon Peas Accessions

Treatments	NL 4 WAS	NL 6 WAS	NL 8 WAS	NL 10 WAS	NL 12 WAS
CONTROL	14.34ab	25.34ab	59.58bc	96.66a	379.20bc
W1 (100 g / 25 ppm)	26.60d	39.00c	82.60c	164.00bc	573.00c
W2 (200 g / 25 ppm)	18.88bc	21.20a	31.12a	66.32a	150.40a
W3 (400 g / 25 ppm)	22.50cd	34.76bc	52.26ab	123.50ab	360.76bc
W4 (100 g / 50 ppm)	13.00ab	22.00a	29.00a	72.00a	207.00a
W7 (100 g / 100 ppm)	36.00e	60.00d	117.00d	210.00c	894.00d
W8 (200 g / 100 ppm)	10.14a	20.26a	45.66ab	82.94a	142.38a
W9 (400 g / 100 ppm)	20.00bc	34.00bc	80.80c	161.80bc	530.80c
Standard Error	1.47	2.30	5.17	9.78	44.76
Treatments	NL 4 WAS	NL 6 WAS	NL 8 WAS	NL 10 WAS	NL 12 WAS
CONTROL	18.00bc	24.40b	44.80ab	88.40a	366.00a
R3 (400 g / 25 ppm)	17.60bc	31.80bc	64.60bc	119.60ab	454.00ab
R4 (100 g / 50 ppm)	10.00ab	50.00d	72.00c	193.00d	627.00c
R5 (200 g / 50 ppm)	27.00d	37.00c	84.00c	190.00d	790.00d
R7 (100 g / 100 ppm)	5.00a	14.00a	31.00a	194.00d	504.00abc
R8 (200 g / 100 ppm)	15.00bc	27.00b	68.00bc	149.00c	528.00bc
R9 (400 g / 100 ppm)	19.40c	24.20b	67.60bc	134.80b	478.20ab
Standard Error	1.47	2.04	3.83	8.99	27.06

Values followed by the same letter(s) do not statistically differ at $p<0.05$, tested with DMRT
N.B: NL is Number of Leaves

The study has established that gamma irradiation is a potent physical mutagen in inducing variation among pigeon pea accessions. Muhammad et al. (2018) suggested that gamma rays are a potent mutagen, causing variation in the population of crop plants, with effects that can be either stimulatory or inhibitory. In most of the parameters taken, stimulatory effects were established. This observation could be due to the enhancement of certain hormone activities in the crop by AgNPs. It could also be as a result of the interaction of the nanoparticles with the plant hormone (auxin), which is responsible for cell elongation, especially at the tips of a plant. This finding aligns with Latif et al. (2017), who demonstrated that foliar application with various concentrations of silver nanoparticles enhanced the growth parameters of wheat plants. The 50 to 100 ppm of AgNPs could have modulated and reduced the inhibitory effects of the gamma rays in the crop. Najafi and Jamei (2014) found a significant increase in plant height and root fresh weight in mung beans in response to 50 ppm AgNPs. Nanoparticles have been reported to enhance total chlorophyll contents in some plants. Mazhar et al. (2022) reported that seed priming of canola plants with 75 ppm of calcium oxide nanoparticles increased the total chlorophyll content by 28.9% and the number of leaves by 16%. A probable increase in the chlorophyll contents of pigeon pea, coupled with the stimulatory effect of gamma irradiation, could have led to the positive increases in the plant height and number of leaves per plant.

CONCLUSION

In conclusion, gamma irradiation of pigeon pea seeds primed with silver Nanoparticles increased plant height and the number of leaves per plant. Where 400 Gray at 100 ppm and 100 Gray at 100 ppm tend to be the optimum dose in NGB05543 (White Coated seeds) that enhanced plant height and number of leaves per plant respectively, in NGB05522 (Red Coated seeds) the optimum doses tend to be 100 Gray at 50 ppm (for plant height) and 200 Gray at 50 ppm for number of leaves per plant.

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EFFECTS OF EXIT ORIFICE DIAMETER, SPRAY PRESSURE, AND SPRAY HEIGHT ON THE SPRAY CHARACTERISTICS OF AN AGRICULTURAL SWIRL NOZZLE

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ABSTRACT

This study investigated the impact of exit orifice diameter, spray pressure, and spray height on the spray characteristics of an agricultural swirl nozzle, utilizing image processing to identify optimal nozzle design and operating conditions that enhance atomization efficiency and improve spray performance. The research evaluated the effects of four orifice diameters (1, 2, 3, and 4 mm), four spray pressures (100, 150, 200, and 250 kPa), and three spray heights (40, 60, and 80 cm) on average droplet size, spray angle, and spray uniformity. The Nikon 750 JP, equipped with a 24.3-megapixel sensor, was used to capture spray patterns under varying operating conditions. Python-based algorithms were employed to analyze the spray patterns and quantify droplet distribution. The images processed reveal that Orifice diameters of 1 mm and 2 mm produce relatively smaller droplets (0.1295 mm and 0.0523 mm, respectively), while orifice diameters of

3 mm and 4 mm generate larger droplets (0.1569 mm and 0.1347 mm, respectively). Spray angle increases with increasing orifice diameter, from 10.59° at 1 mm to 42.07° at 4 mm. Spray uniformity improves as the orifice diameter increases from 1 mm to 3 mmm but drops slightly at 4 mm. Increase in spray pressure tends to decrease droplet size. The largest droplets were observed at 40 cm (0.1909 mm), with size decreasing significantly at 60 cm (0.1104 mm) and 80 cm (0.0529 mm). Spray height primarily influenced droplet size, with 60 cm being the optimal spray height, resulting in the most uniform spray coverage. Beyond 60 cm, uniformity declines, suggesting reduced precision at greater heights. These findings provide valuable insights for optimizing nozzle design and operating conditions to enhance spray performance and efficiency in agricultural applications.

Keywords: Agricultural swirl nozzle, Exit orifice diameter, Spray height, Spray pressure

INTRODUCTION

Accurate and efficient spray-delivery systems are vital for ensuring effective application of pesticides and nutrients while minimizing environmental impact and resource waste (Rahimi *et al*., 2024). Among the various components influencing spray performance, the design and operational parameters of spray nozzles are critical (Hosamani and Krishnamurthy, 2020). Swirl nozzles, which introduce a tangential flow to generate a hollow cone spray pattern, have gained popularity due to their ability to produce uniform droplet distribution and cover larger surface areas (Gao *et al*., 2011). One of the most influential design factors is the exit orifice diameter, which directly affects the velocity and volume flow rate of the spray. Similarly, spray pressure determines the energy available for atomization, which in turn impacts droplet size and spray dispersion. Additionally, the spray height, which is the vertical distance between the nozzle and the target, affects the travel time and dispersion of droplets, thereby influencing coverage uniformity and drift potential (Chen *et al*., 2020). Despite existing studies on nozzle performance, there is a limited comprehensive analysis of the interactive effects of these three parameters: exit orifice diameter, spray pressure, and spray height, particularly in the context of swirl nozzles adapted for agricultural use. This study aims to fill this gap by experimentally evaluating how variations in these parameters influence key spray characteristics, including droplet size, spray angle, and uniformity. The outcomes are expected to guide farmers, agricultural engineers, and policymakers in selecting and optimizing spraying systems for efficient and sustainable field applications.

Agricultural spray nozzles are critical components in pesticide application, influencing spray coverage, droplet size distribution, and drift potential. Recent experimental studies have focused on pressure swirl nozzles, which produce hollow cone sprays with fine atomization. Xue *et al.* (2023) investigated full-cone pressure swirl nozzles, analyzing droplet size, velocity, and liquid volume flux under varying Reynolds numbers, demonstrating the sensitivity of spray characteristics to operating conditions. Similarly, Han *et al.* (2024) conducted detailed experimental studies on pressure-swirl nozzles, focusing on flow rates and pressure drops relevant to industrial applications, which provided insights into the atomization mechanisms and spray morphology. Zhang *et al.* (2017) further investigated the effects of nozzle diameter and injection pressure on spray angle and morphology, confirming that nozzle geometry has a significant impact on spray behavior.

In the context of agricultural applications, Harikant *et al.* (2023) reviewed adjustable flow and rotating spray nozzles, emphasizing their potential to enhance spray uniformity and reduce drift through controlled fluid dynamics and spray motion. Their work highlights the importance of innovative nozzle designs in overcoming the limitations of conventional nozzles, enabling precise and efficient spraying. Optimization studies, such as those by Kumar *et al.* (2020), have evaluated nozzle characteristics, including pressure and height, to improve discharge rate, spray angle, and uniformity across different sprayer types. Their findings indicate that operating parameters have a significant influence on spray performance and that specific combinations of pressure and nozzle height yield optimal results for various sprayers. Çetin *et al.* (2019) conducted a study on the determination of spray angle and flow uniformity of spray nozzles with diverse hydraulic spray nozzles at different spray pressures with the aid of image processing operations based on the indices of spray images, which were obtained with a digital camera to verify spray patterns and spray angles using different image processing software for analysis. The study found that the pattern of spray captured using the image processing method was homogeneous, with uniformity of flow achieved through the line-profile method. Their study concluded that the pressures of spray had a significant impact on spray angles, with $p < 0.05$ for all spray nozzles.

MATERIALS AND METHODS

Experimental material and setup

The experimental setup incorporated several essential components to ensure precise data collection and analysis. A Nikon 750 JP camera, featuring a 24.3-megapixel resolution, was used to capture high-resolution images with excellent detail and dynamic range. The camera is capable of continuous shooting at a rate of up to 6.5 frames per second, making it suitable for documenting rapid spray events. To ensure image stability and eliminate motion blur during capture, the camera was mounted on a tripod stand, which provided a secure and steady base throughout the experimental process. A custom-designed test rig was utilized to support the experimental evaluation of the swirl nozzles. This rig provided controlled testing conditions, enabling the accurate assessment of nozzle performance. Water was used as the testing fluid in this study, chosen for its consistency, availability, and suitability for evaluating the atomization and spray characteristics of agricultural nozzles under controlled laboratory conditions (Ou et al., 2024).

Description of swirl nozzle

The swirl nozzle (Figure 1) consists of the nozzle body or sleeve. This swirl element is a cylindrical plug that has a helical liquid passage groove mounted on it, the orifice disk with a nozzle exit orifice, the hexagonal nut acting as a securing cap for the orifice disk, a swirl chamber, a pair of tapered roller bearings, a rubber gasket seal, and an end cap at the other end of the nozzle. The nozzle was connected to a supply line through the tangential inlet port. The securing cap of the nozzle holds the exit orifice securely in place. The securing cap features a hexagonal body and a screw thread on the interior part, facilitating easy removal and installation of the orifice plate with the use of a specially fabricated open-end wrench (flat spanner). One ball bearing is located on the upper nozzle body, while the second bearing is located in the lower nozzle body. This arrangement enables the cantilevered swirl element to rotate freely within the upper nozzle body when actuated by the inflowing pressurized liquid stream entering the nozzle through the tangential inlet port.

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Experimental Procedure

The experiment was conducted in a controlled laboratory environment to observe and analyze the behavior of the spray pattern. A Nikon D750 DSLR camera was used for high-speed image capture to determine the key spray characteristics, including droplet size, spray angle, and uniformity through image processing techniques. The camera was securely mounted on a tripod stand and configured with a high shutter speed of up to 1/14,000 seconds to accurately freeze and document the motion of the spray. To ensure optimal visibility and image clarity, appropriate lighting was provided using a combination of artificial light sources. The collected images were transferred to a personal computer for image analysis using Python source code to determine droplet sizes, spray angle, and spray uniformity.

Experimental Design and Statistical Analysis

The study considered three independent variables: nozzle exit orifice diameter at four levels (1, 2, 3, and 4 mm), operating pressure at four levels (100, 150, 200, and 250 kPa), and spraying height at three levels (40, 60, and 80 cm) randomized using Optimal design of design expert (Version 13). The data obtained from the experiment were analysed using the Statistical Package for the Social Sciences (SPSS) software. The Duncan multiple range test was used to separate the means of spray characteristics and mean plot were used to identify the relationships between nozzle exit orifice diameter, operating pressure, and spraying height, as well as their effects on spray characteristics.

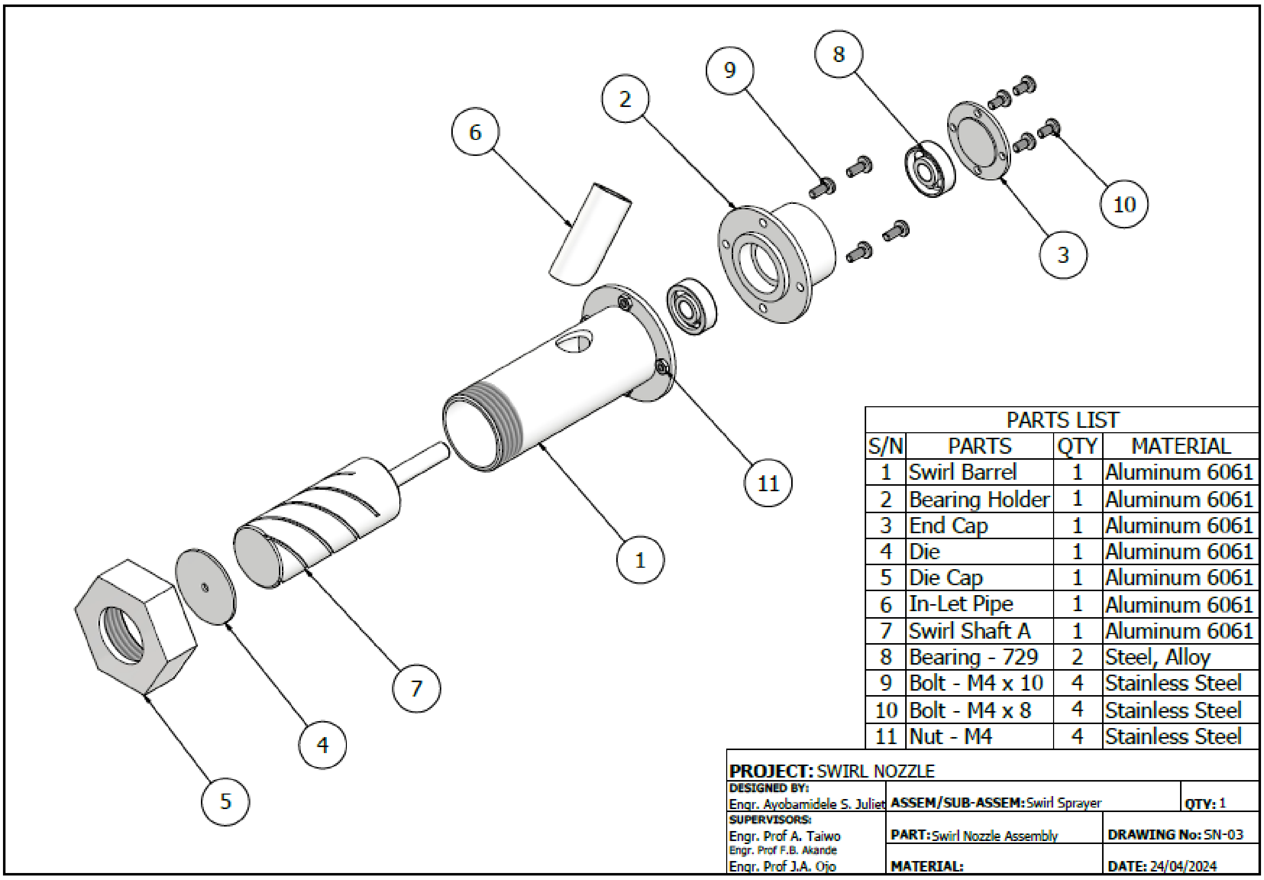

Figure 1: Exploded diagram of the Swirl Nozzle

RESULTS AND DISCUSSION

Result of Spray Characteristics

The results of spray characteristics arranged using Duncan Multiple Range (DMR) method is presented in Table 1. From the table of results, it is shown that orifice diameter has the most significant impact on both spray angle and spray uniformity, with larger diameters producing wider spray angles and more uniform spray patterns. While spray pressure tends to improve spray uniformity slightly, it has no significant effect on droplet size or spray angle. The spray height exhibits a trend in which droplet size decreases as height increases, and spray uniformity peaks at an intermediate height of 60 cm; however, these differences are not statistically significant. Overall, larger orifices consistently yield wider spray angles and improved uniformity, while droplet size remains relatively unchanged. Higher spray pressure enhances uniformity but has a limited influence on droplet size and spray angle within the tested range. Additionally, a spray height of 60 cm provides the best balance between spray angle and uniformity, whereas increasing height generally leads to smaller droplet sizes. These findings align with the study by Santosh et al. (2023), which reported that droplet size decreases with increasing pressure, spray uniformity improves with higher pressure, and spray angle varies according to nozzle height. Figure 2 shows spray images taken at different height, orifice diameter, and spray pressure combinations

Table 1: Result of spray characteristics arranged using DMR method

	Average droplet size	Spray angle	Spray uniformity
Orifice diameter			
1	0.0544^{a}	21.1120^{a}	2.5900^{a}
2	0.0371^{a}	30.8750^{ab}	6.1000^{b}
3	0.0547^{a}	39.4050^{b}	6.9625^{b}
4	0.0526^{a}	52.9925^{c}	5.8125^{b}
Spray pressure			
100	0.0532^{a}	33.1725^{a}	3.2250^{a}
150	0.0488^{a}	33.7920^{a}	4.9600^{a}
200	0.0513^{a}	36.4350^{a}	6.2250^{a}
250	0.0470^{a}	37.8150^{a}	6.4625^{a}
Spray height			
40	0.0688^{a}	32.4317^{a}	4.3167^{a}
60	0.0449^{a}	38.6050^{a}	6.3333^{a}
80	0.0335^{a}	34.4860^{a}	4.9100^{a}

Means with the same letter(s) are not significantly different from each other. ($p \leq 0.005$)

Figure 2: Spraying pattern of the nozzle at different heights

Effect of Orifice Diameter on Spray Characteristics

A. Average droplet size

The graph in Figure 3 highlights that an orifice diameter of 2 mm is optimal for achieving the smallest average droplet size, which is advantageous in applications requiring fine misting or uniform coverage. This observation aligns with the findings of Karabey and Tanış (2024), who noted that intermediate orifice diameters typically produce more favorable droplet size distributions compared to very small or large diameters.

Figure 3: Effect of orifice diameter on average droplet size

B. Spray angle

Figure 4 shows that as the orifice diameter increased, the spray angle became wider steadily and consistently, indicating a strong and direct relationship between these variables. Therefore, in practical applications, selecting a nozzle with a larger orifice diameter will result in a broader spray pattern. This observation is consistent with the findings of Zheng et al. (2020), who also reported that increasing orifice diameter contributes to a wider spray angle and enhanced spray uniformity.

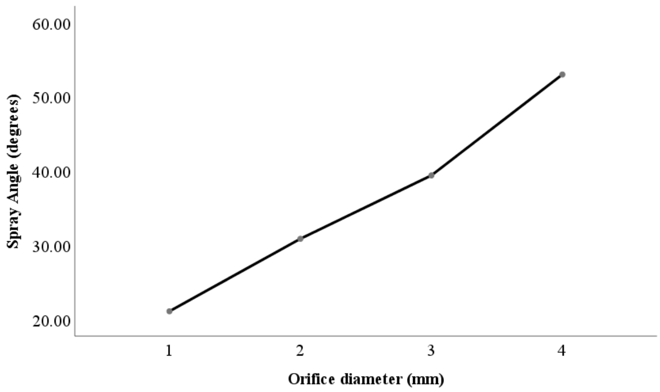

Figure 4: Effect of orifice diameter on spray angle

C. Spray uniformity

The graph in Figure 5 illustrates the relationship between orifice diameter and spray uniformity, where uniformity is expressed as a percentage. As orifice diameter increases from 1 mm to 3 mm, spray uniformity improves steadily, reaching a peak at 3 mm. This trend indicates a decrease in the coefficient of variation (CV), signifying more consistent droplet distribution and reduced variability across the spray pattern. However, at 4 mm, a slight decline in spray uniformity is observed, implying a modest increase in CV. This suggests that beyond a specific orifice diameter, the spray pattern becomes less uniform—possibly due to the formation of coarser droplets, weakened swirl intensity, or increased turbulence, which may disrupt even coverage. These observations are consistent with the findings of Chen et al. (2020) and Boel et al. (2020), who reported that increasing orifice diameter generally enhances spray distribution and cone angle up to an optimal point, after which uniformity plateaus or declines due to destabilization of the spray cone and droplet coalescence. Therefore, an orifice diameter of 3 mm appears to offer the best balance between flow rate and uniform coverage, as reflected by the lowest CV and highest spray uniformity in this study.

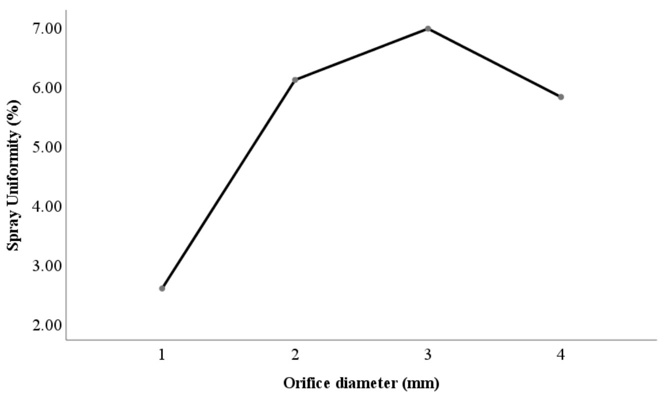

Figure 5: Effect of orifice diameter on spray angle

3.3 Effect of Spray Pressure on Spray Characteristics

A. Average droplet size

The graph shown in Figure 6 indicates that spray pressure has a variable effect on the average droplet size. Generally, increasing spray pressure tends to reduce droplet size, consistent with the principle that higher pressures promote finer atomization. However, the observed increase in droplet size at 200 kPa suggests that other factors, such as nozzle dynamics or fluid properties, may influence droplet formation at certain pressure levels. This pattern aligns with the findings of Anacleto *et al.* (2021), who reported that while higher spray pressures usually result in finer droplets, intermediate pressures can sometimes produce variable outcomes depending on the nozzle type and liquid characteristics.

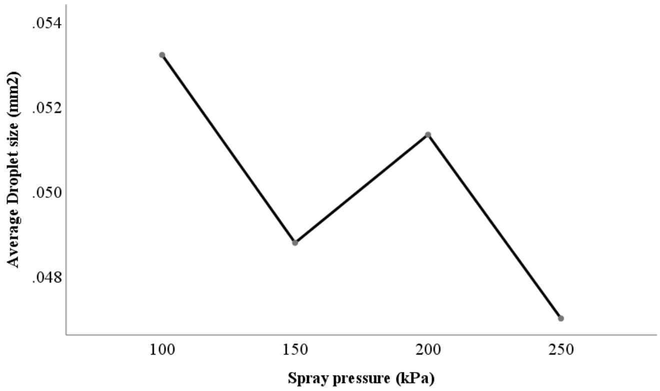

Figure 6: Effect of orifice diameter on spray angle

B. Spray angle

The graph in Figure 7 shows that increasing spray pressure resulted in a broader spray angle. This finding aligns with Santosh et al. (2023), who reported that higher spray pressure results in a broader spray angle, thereby improving coverage in agricultural spraying systems.

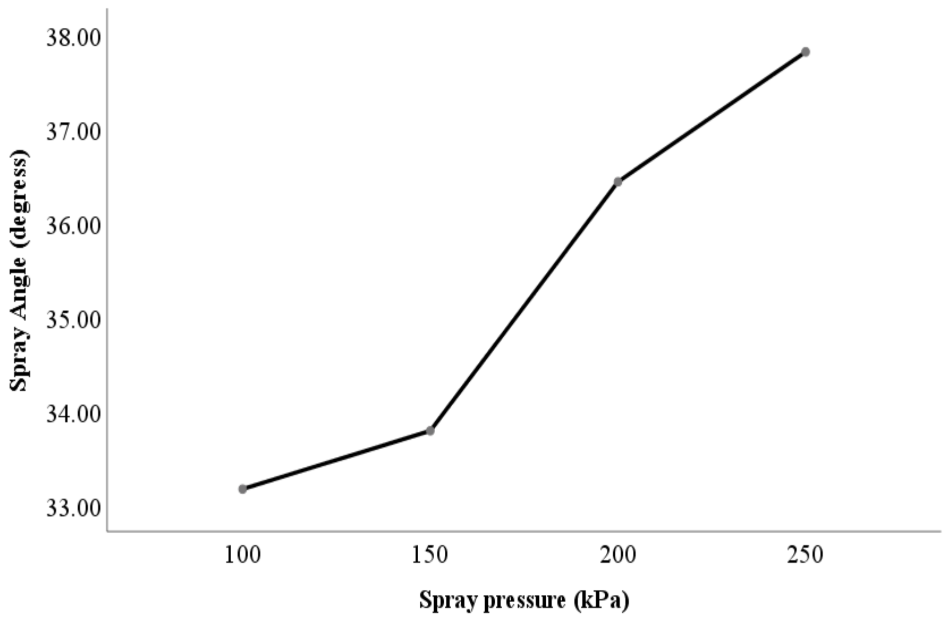

Figure 7: Effect of orifice diameter on spray angle

C. Spray uniformity

The graph in Figure 8 demonstrates the effect of spray pressure on spray uniformity. As pressure increased from 100 kPa to 250 kPa, spray uniformity consistently improved, indicating a steady reduction in the coefficient of variation (CV). This implies that higher pressures promote more uniform droplet distribution, likely due to enhanced atomization and better spray cone formation. Contrary to earlier assumptions of an optimal pressure, the graph does not show a decline beyond 200 kPa; instead, 250 kPa yields the highest spray uniformity, corresponding to the lowest CV observed in this study. This suggests that under the tested conditions, higher pressure enhances droplet breakup and uniformity of distribution, without reaching the point of over-atomization or turbulence-induced variability. These results align with those of Kole and Singh (2021), who noted that increasing spray pressure generally reduces CV, thereby enhancing spray consistency up to an operationally safe upper limit. Furthermore, the consistent improvement observed supports the findings of Lavernia et al. (2024), who highlighted that optimized pressure levels minimize drift potential and maximize chemical deposition efficiency. The results however, further emphasize the importance of selecting appropriate spray pressures to achieve high spray uniformity with minimal CV, thereby enhancing application precision, minimizing chemical waste, and supporting adequate crop coverage.

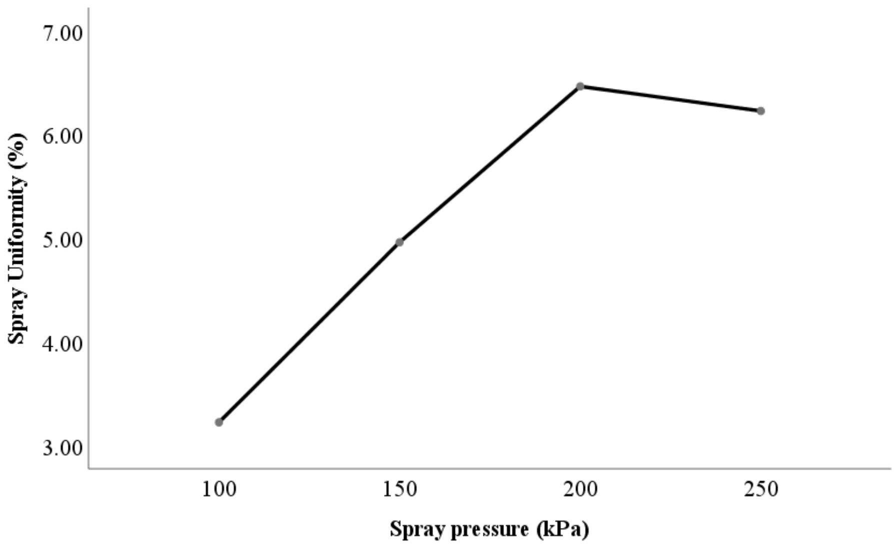

Figure 8: Effect of orifice diameter on spray angle

3.4 Effect of Spray Height on Spray Characteristics

A. Average size distribution

The average drop size as a function of spray height is presented in Figure 9. At lower heights, 40 cm, droplets had a shorter distance to travel and therefore experienced minimal breakup from air resistance or turbulence, resulting in larger droplet sizes. As the spray height increased, droplets travelled a longer path through the air, encountering greater resistance and fragmentation, which promoted droplet breakup and yields finer droplets. The smallest droplets were observed at a height of 80 cm, indicating that higher spray heights enhance atomization. This observation aligns with the findings of Tesfaye et al. (2016), who reported that increasing nozzle height significantly reduces droplet size, especially for hollow-cone and flat-fan nozzles.

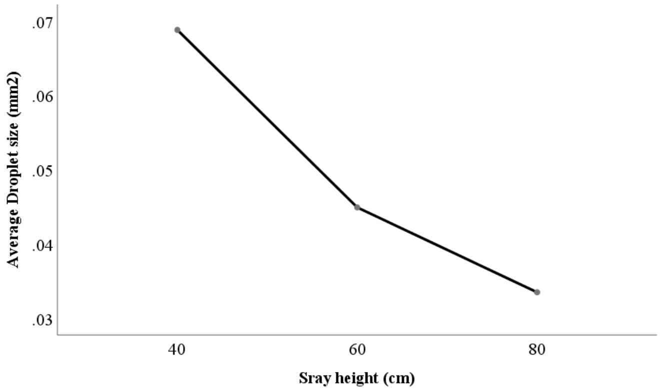

Figure 9: Effect of orifice diameter on spray angle

B. Spray angle

As shown in Figure 10, spray angle increased with height up to an optimal point at 60 cm, after which it began to decline. This suggests that 60 cm is the most efficient height for achieving the widest spray dispersion. Such behavior indicates the presence of an optimal spray height, around 60 cm, that maximizes lateral dispersion and coverage, which is crucial for achieving effective application uniformity. These findings align with those of Santosh et al. (2023), who found that spray height significantly influences spray angle and coverage, with medium heights providing the most effective dispersion.

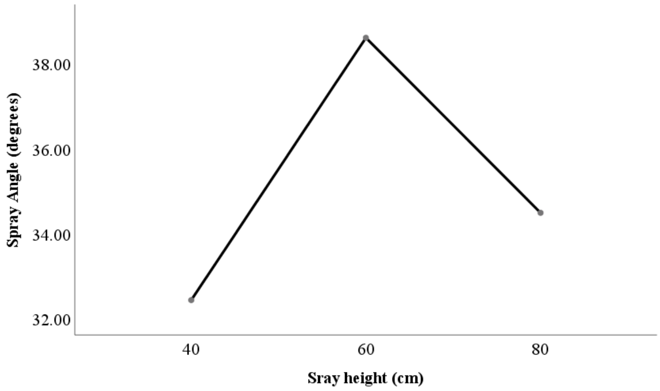

Figure 10: Effect of orifice diameter on spray angle

C. Spray uniformity

The graph in Figure 11 depicts that spray height has a significant effect on spray uniformity, with 60 cm emerging as the optimal height for achieving the most consistent spray distribution. This corresponds to the lowest coefficient of variation (CV) among the tested heights, indicating minimal variation in droplet deposition and a more uniform spray pattern. At lower heights (40 cm), the CV is relatively higher, implying reduced uniformity due to restricted spray dispersion and possible overlap or pooling. Conversely, at higher heights (80 cm), CV increases again, reflecting greater inconsistency in droplet distribution likely caused by increased drift, air resistance, or turbulence that disrupts uniform coverage. These findings align with Pan et al. (2016), who reported that excessive nozzle height introduces drift and coverage irregularities, and Singh et al. (2024), who found that drone sprayers achieved optimal uniformity at intermediate hover heights, with poorer performance at both lower and higher altitudes due to airflow and spray pattern disturbances. In summary, maintaining a spray height around 60 cm results in the lowest CV and thus the most uniform coverage, highlighting the importance of height control in precision spraying systems.

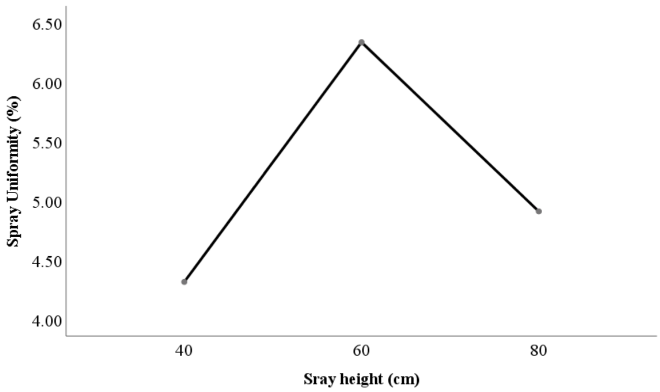

Figure 11: Effect of orifice diameter on spray angle

4.0 CONCLUSION

This study has been able to relate the effects of exit orifice diameter, spray pressure, and spraying height on agricultural spray characteristics (droplet size, spray angle, and uniformity). Among the parameters examined, orifice diameter mainly affects spray angle and uniformity, with larger diameters generally enhancing spray coverage. However, an optimal orifice size was identified, beyond which further increases yielded diminishing or negative effects on uniformity. Spray pressure demonstrated a moderate effect, primarily improving spray uniformity with minimal influence on droplet size and spray angle. Invariably, 200 kPa is the optimal pressure for achieving a balance between spray uniformity and spray droplet size.

Meanwhile, spray height had a nuanced impact, with 60 cm identified as the optimal height for maximizing spray angle and uniformity, while also promoting finer droplet formation at greater heights. The proper selection and combination of orifice size, operating pressure, and spraying height are essential for achieving efficient, uniform, and targeted application of pesticides or fertilizers. Careful calibration of these factors to suit specific crop requirements and environmental conditions can significantly enhance resource use efficiency, crop protection, and sustainability in modern agricultural practices.

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APPLICATION OF *Bacillus safensis* LAU 13 METABOLITE FOR THE CONTROL OF GROWTH AND AFLATOXIN PRODUCTION BY *Aspergillus flavus* ON STORED MAIZE GRAINS

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ABSTRACT

The uncontrolled rise in the use of synthetic chemicals for post-harvest preservation of farm produce has resulted in ecological deterioration and contamination of crop products with harmful chemical residues. Thus, the use of bioactive materials as a substitute for common synthetic chemicals in controlling post-harvest microbial contamination of crops has gained tremendous attention due to their eco-friendliness, cost-effectiveness, and sustainability. This study aims to evaluate the antifungal effect of Bacillus safensis LAU13 metabolites (METOX) for the control of Aspergillus species growth and aflatoxin production on stored maize grains. The METOX was produced by Bacillus safensis LAU 13 during a three-day submerged fermentation cultivation. Characterisation of METOX by gas chromatography-mass spectrometry (GC-MS) revealed the presence of bioactive compounds, predominantly aldehyde derivatives, 4-Dodecen-1-al (13.5%) and Octanal,3,7-dimethyl (13%). The METOX exhibited a potent inhibitory effect against the aflatoxin-producing strains of A. flavus and A. niger isolated from stored maize grains, as it induced 62% and 16% fungal growth inhibition against the isolated strains of A. flavus *and A. niger, respectively. Hence, the results obtained herein suggest that the METOX produced by B. safensis LAU 13 has promising applications as a bioactive material for the sustainable control of aflatoxin-producing fungal species in stored grains.*

Keywords: *Bacillus safensis, Aspergillus species,* aflatoxin, METOX, eco-friendly

INTRODUCTION

Aflatoxins are one of the types of mycotoxins produced primarily by Aspergillus species (Peles et al., 2019). They are highly toxic, carcinogenic food poison that mainly causes pathological dysfunction of the liver, kidneys, gastrointestinal tract, immune and reproductive systems in both humans and livestock (Peles et al., 2019). Contaminations by aflatoxins have been reported in various food and feed products, including groundnuts, millet, sesame seeds, maize, wheat, rice, spices, and cocoa, due to fungal infections during pre- and post-harvest conditions (Mahato et al., 2019). Aflatoxin contamination of food crops poses a serious health threat to humans and livestock. Additionally, it incurs a significant global economic burden, as it is responsible for the annual destruction of a substantial quantity of the world's food crops. Aflatoxins significantly limit the development of international trade due to strict regulations in high-value markets. Several cases of liver cancer incidences in Sub-Saharan Africa have been attributed to dietary aflatoxin exposure. Conventionally, physical and chemical methods are used to control post-harvest aflatoxin contamination; however, limitations such as the presence of residues of synthetic fungicides in food and the environment, the emergence of resistant strains, and the development of secondary pests necessitate the development of better and sustainable alternative approaches. In recent times, biocontrol of mycotoxins and phytopathogens using microbial metabolites as well as the use of biogenic nanoparticles are receiving tremendous research interest and have been recommended as a suitable alternative to the traditional physical and chemical approaches owing to their biocompatibility, cost-effectiveness and eco-friendliness (Lagogianni and Tsitsigiannis, 2019; Lateef et al., 2024).

Maize is a staple food for more than 1.2 billion people in sub-Saharan Africa (SSA) and Latin America, and it is the most important cereal crop in SSA (IITA, 2020). It is a versatile crop that is not only consumed domestically but also used industrially by confectionery and animal feed producers, flour mills, breweries, and bakeries (Sadiq et al., 2020). The global production of maize averages 785 million tons; the United States of America is the largest producer, accounting for 42%. Africa produces 6.5% of its goods and imports 28% from countries outside the continent. Additionally, Africa accounts for 30% of global maize consumption. Africa as a whole use 95% of its maize, compared to other world regions, which typically use most of their maize as animal feed (IITA, 2020). In Nigeria, maize accounts for between 60% and 65% of poultry feed constituents, and approximately 6.5% is used by brewing companies.

In comparison, 13% is used for the manufacturing of industrial flours, cornflakes, and other confectionery products (IITA, 2020). The quality of maize products depends on agronomic practices and climatic conditions (Sadiq et al., 2020), and unfortunately, it is one of the most susceptible crops to aflatoxin contamination, thereby causing significant food safety issues and hindering exportation (Foley, 2019). In fact, due to high aflatoxin content, maize and other related food items were denied from developing countries like Nigeria (Sadiq et al., 2020).

Bacillus safensis is a Gram-positive, mesophilic, spore-forming, aerobic and chemo-heterotrophic bacterium (Lateef et al., 2015). It is a rod-shaped, motile bacterium with high tolerance to salt, heavy metals, and ultraviolet and gamma radiation (Satomi et al., 2006). B. safensis LAU 13 is a non-pathogenic bacterium whose mutant and wild strains' enzymes and hydrolysates have demonstrated potent multifunctional activities, ranging from keratin waste management, destaining of blood-stained fabric, dehairing of animal hide, biofertilizer and very remarkable application in nanobiotechnology (Lateef et al., 2015; Adelere and Lateef, 2016; Adelere and Lateef, 2023a, b). Investigation into its potential for preventing and controlling mycotoxins in food grains is likely to open a new vista of research in the area of food safety. Therefore, this study investigates the antifungal effect of its metabolites (METOX) for the control of growth and aflatoxin production by Aspergillus flavus and Aspergillus niger on stored maize grains.

MATERIALS AND METHODS

Collection of Maize Grains

The maize grain sample was purchased from Kure Ultramodern Market, Minna, in a clean plastic container and kept under ambient conditions in the Microbiology Laboratory of Federal University of Technology, Minna, until further use.

Source of Bacterial Isolate

Bacillus safensis LAU 13 was obtained from the culture collection of the Department of Microbiology, Federal University of Technology, Minna. It was subcultured on a fresh nutrient agar plate and stored on an agar slant for further use.

Production of *B. safensis* LAU 13 METOX

The production of METOX was carried out by inoculating 1 mL of a 24 h-old *B. safensis* LAU 13 inoculum into 19 mL of nutrient broth in 100 mL flasks and incubating at 37 °C and 100 rpm for 3 days. After the incubation period, the flask contents were centrifuged in a refrigerated centrifuge (10,000 rpm, 15 min, 4 °C) to obtain supernatant (Lateef *et al*., 2015). The supernatant was collected, freeze-dried, and stored at 4 °C until required for use. This served as METOX.

Isolation of *Aspergillus species* from Stored Maize Grains

Stored maize grains were ground into powder form using an electric blender, and 1 g of the powder was suspended in 9 ml of sterile distilled water and serially diluted. An Aliquot of 0.5 ml of 10-4 dilution was plated out on Saboraud Dextrose Agar (SDA) using the pour plate technique. The plate was incubated at ambient conditions (27 ± 2°C) for 48 h. Thereafter, distinct colonies were sub-cultured on fresh SDA plates to obtain pure cultures, which were stored on agar slants for further use (Abd El-Aziz *et al.*, 2021).

Identification of Fungal Isolates Obtained from Stored Maize Grains

Macroscopic features of the isolates, including colony growth, colour, texture, and conidia, will be observed after 3 days of incubation. The slide culture was prepared for microscopic examination. The 18 × 18 mm cover slip was placed gently at a 45° angle on the inoculated SDA. Upon fungus sporulation, the cover slip was gently removed and placed on the microscope slide. A drop of lacto-fuchsin was added, and a small coverslip was placed on top. Another drop of lactofuchsin was placed on top of the small cover slip before completing the assembly with a 22 × 22 mm cover slip. The microscopic features, such as conidiophores, vesicles, metulae, philiades, conidium shape, and texture, were observed under a basic biological light microscope (BA 210, 100x objective) using immersion oil (Okayo *et al.*, 2020).

Quantification of Aflatoxins on Stored Maize Grains

Aflatoxins were quantified using the AOAC method (AOAC 999.07, 20th edition, 2016), where a 50g powder form of the maize sample was dispersed into a 1-litre capacity solvent-resistant blender jar. 200 ml of 60% acetonitrile was added, and the mixture was mixed at high speed for 2 minutes. This was centrifuged at 4000 rpm for 10 minutes. The filtrate obtained was diluted with 22 ml of phosphate-buffered saline (PBS). The diluted filtrate was passed through the column at a flow rate of 2 ml. The column was washed with 20 mL of PBS, and air was blown through it to remove residual liquid. The toxin was eluted at a flow rate of 1 drop per second using acidified methanol (acetic acid: methanol (2:98 v/v)). Then, 100 microlitres of this was injected into the HPLC system.

Characterisation of METOX

This was achieved using Gas Chromatography-Mass Spectrometry (GC-MS) analysis to identify the biomolecules that comprise the product. The METOX was prepared by extracting its compounds using methanol, followed by filtration to remove any particulate matter, before being injected into the GC-MS instrument. Peaks were matched to compounds based on their molecular weights and retention times.

Antifungal Activity of METOX Against the Aflatoxin-Producing *A. flavus* and *A. niger*

This was carried out using the cup disc technique, where 1 mL of METOX was introduced into SDA media before solidification. A 6mm hole was punched into the agar with a sterile cork borer, as explained by Dasari *et al.* (2014), and a mycelial mass of 6mm was placed into the hole. The percentage of fungal growth inhibition was calculated relative to the control.

$$\text{Percentage (\%) growth inhibition} = \frac{\text{Diameter of control} - \text{Diameter of test}}{\text{Diameter of control}} \times 100$$

Data Analysis

The data obtained in this study were analyzed using SPSS (version 25). Results were expressed as mean inhibition (%) ± standard deviation, and differences among treatment means were evaluated using one-way ANOVA at a 5% significance level ($p < 0.05$), followed by Duncan's multiple range test.

RESULTS AND DISCUSSION

METOX Production

The cultivation of *B. safensis* LAU 13 in nutrient broth resulted in very profuse growth after three days of incubation (Fig. 1). The freeze-dried supernatant, regarded as METOX, is a yellow solid pellet (Fig. 2). *Bacillus* spp. have remarkable biosynthetic potential. Some of their metabolites have demonstrated tremendous applications as therapeutic agents, food preservatives, and plant-pathogen control agents (Iqbal *et al*., 2023). Moreover, several strains of *B. safensis* have been found to produce metabolites that can be harnessed industrially for diverse biotechnological applications (Adelere and Lateef, 2016).

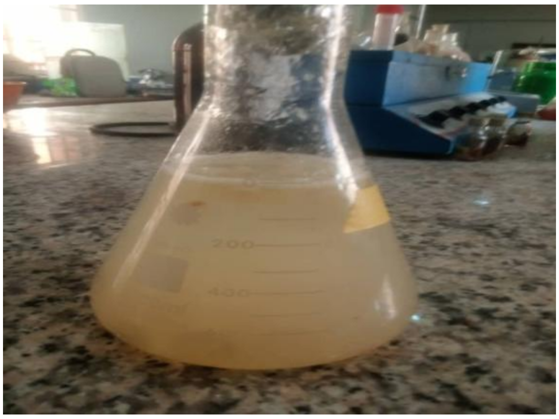

Fig. 1: Cell Suspension of *B. safensis* after cultivation for three days in nutrient broth

Fig. 2: Freeze-dried cell-free extract of the *B. safensis*

GC-MS Characterization of METOX

The result of analysis of METOX is shown in GC-MS chromatogram in Fig. 3. The analysis revealed the presence several bioactive compounds in the METOX. Aldehydes, including 4-Dodecen-1-al (13.5%) and Octanal (13%), were the most abundant, while the likes of monoterpenes, phenols, and fatty acids were detected in low quantity (Table 1). The result obtained herein correlate with the study of Koilybayeva *et al*. (2023) that reported the production of 69 volatile organic compounds by five *Bacillus* species. The authors affirmed that all the five species were found to share different chemical classes of volatile organic components, which have a variety of pharmacological applications. The remarkable metabolic capacity and adaptive biochemistry of *Bacillus* species might be responsible for the production these diverse volatile organic compounds making them a promising organisms for commercial, pharmaceutical and biotechnological applications.

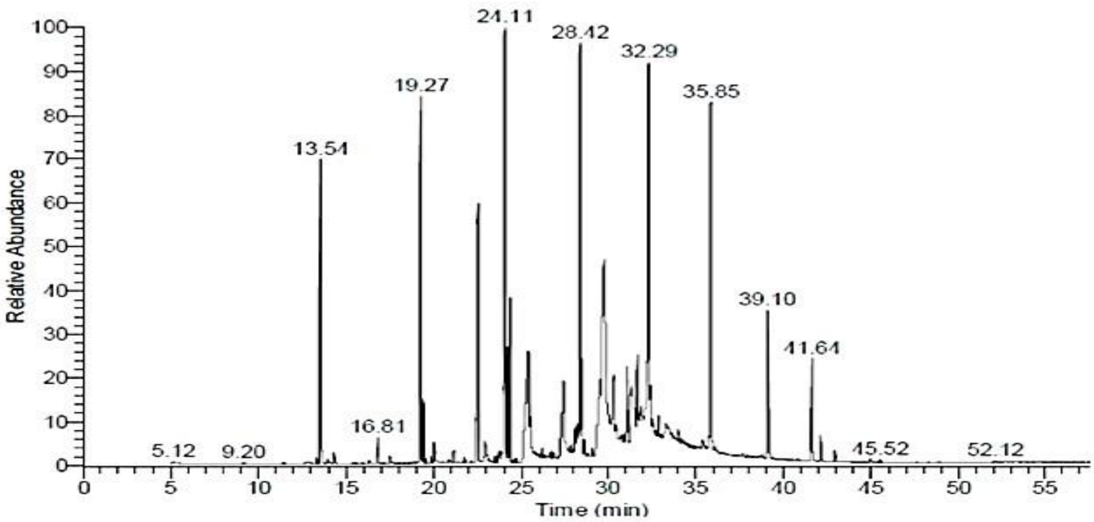

Fig. 3: GC-MS Chromatogram of *Bacillus safensis* LAU 13 metabolite (METOX)

Fungal Identification

Aflatoxin-producing strains of A. flavus and A. niger were isolated from stored maize grains. The A. flavus appeared greenish and velvety with a powdery surface on the SDA plate. The colonies are dense with a granular appearance and slightly raised. At the same time, the A. niger strain has a woolly texture, black in appearance and are more granular (Fig. 4). Microscopically, the Aspergillus flavus strain shows rough, radiating conidia attached to vesicles with Aspergillus niger exhibiting large, smooth conidial heads with dense arrangement of conidia (Fig. 5). Contamination of maize grains by aflatoxin-producing fungal species have been reported by authors. For instance, Dadzie et al. (2019) isolated aflatoxin-producing strains of A. flavus, A. niger, Rhizopus sp., Penicillium sp., and Fusarium sp. as the major fungal contaminants on stored maize grains. The authors affirmed that Aspergillus flavus was the most predominant contaminant among the isolated fungal species.

Table 1: Chemical Composition of *Bacillus safensis* LAU 13 Metabolites (METOX)

Compound Groups	Identified Compounds	Molecular Weight	Molecular Formula	Retention Time	Peak Area %
Monoterpene Derivatives	L-(−)-Menthol	156	$C_{10}H_{20}O$	13.29	1
	Decitol,1,2:4,5:9,10-trianhydro	178	$C_{10}H_{10}O_3$	13.53	5.84
Cyclic Ketone Derivatives	Tert-Butyl-p-benzoquinone	164	$C_{10}H_{12}O_2$	14.3	0.5
	2,5-Cyclohexadiene-1,4-dione	220	$C_{14}H_{20}O_2$	21.17	0.8
	7-Ethyl-4,6-heptadecandione	296	$C_{19}H_{36}O_2$	30.42	1
	Cyclopentadecanone, 2-methyl	238	$C_{16}H_{30}O$	30.76	1.2
Alkaloid Derivatives	1-Amino-7-methylpyrrolo[1,2a]pyrazine	147	$C_8H_9N_3$	17.47	0.5
	Glycozolicine [5-methoxy-3-methylcarbazole]	211	$C_{14}H_{13}NO$	24.35	2.87
Alkane Derivatives	Pentanenitrile, 4-methyl	97	$C_6H_{11}N$	19.26	6.79
	Tetradecane	198	$C_{14}H_{30}$	19.42	0.8
	Octadecane	254	$C_{18}H_{38}$	24.19	1.22
	Tridecane, 3-methylene	196	$C_{14}H_{28}$	28.21	0.7
	(cis)-2-nonadecene	266	$C_{19}H_{38}$	32.29	10.52
	10-Heneicosene (c,t)	294	$C_{21}H_{42}$	32.53	1.5
	Cyclopentane, 1,2-dibutyl	182	$C_{13}H_{26}$	35.84	7
	Cyclotetracosane	336	$C_{24}H_{48}$	42.12	0.5
Phenol Derivatives	Phenol,2,4-bis(1,1-dimethylethyl)	206	$C_{14}H_{22}O$	22.49	7.5
	1,4-Benzenediol,2-(1,1-dimethylethyl)	166	$C_{10}H_{14}O_2$	23.74	0.6
Fatty Acids	Dodecanoic acid	200	$C_{12}H_{24}O_2$	22.96	0.55
	Tridecanoic acid	214	$C_{13}H_{26}O_2$	25.44	2.7
	Tetradecanoic acid	228	$C_{14}H_{28}O_2$	27.45	2.52
	9-Octadecenoic acid (Z)	282	$C_{18}H_{34}O_2$	28.11	0.8
	Hexadecanoic acid	256	$C_{16}H_{32}O_2$	25.54	0.7
	9,12-Octadecadienoic acid (Z,Z)	280	$C_{18}H_{32}O_2$	35.35	0.6
	9-Hexadecenoic acid	254	$C_{16}H_{30}O_2$	31.87	0.4
Aromatic Derivatives	1-methoxymethyl-4-methylnaphthalene	186	$C1_3H_{14}O$	19.84	0.4
Aldehyde Derivatives	4-Dodecen-1-al	182	$C_{12}H_{22}O$	24.09	13.5
	Octanal, 3,7-dimethyl	156	$C_{10}H_{20}O$	28.38	13
Alcohols	1-Tetradecanol	214	$C_{14}H_{30}O$	26.76	0.6

	n-Tetracosanol-1	354	$C_{24}H_{50}O$	39.1	2.5
Carboxylic Acids Ester Derivatives	Sebacic acid, 2,6-dimethoxyphenyltridecyl ester	520	$C_{31}H_{52}O_6$	31.68	1.5
	Glutaric acid, di-(−)-menthyl ester	408	$C_{25}H_{44}O_4$	42.93	0.9
Alkene Derivatives	1-Octadecene	252	$C_{18}H_{36}$	28.64	0.5
	10-Methyl-E−11-tridecen-1-ol-propionate	268	$C_{17}H_{32}O_2$	29.06	0.4

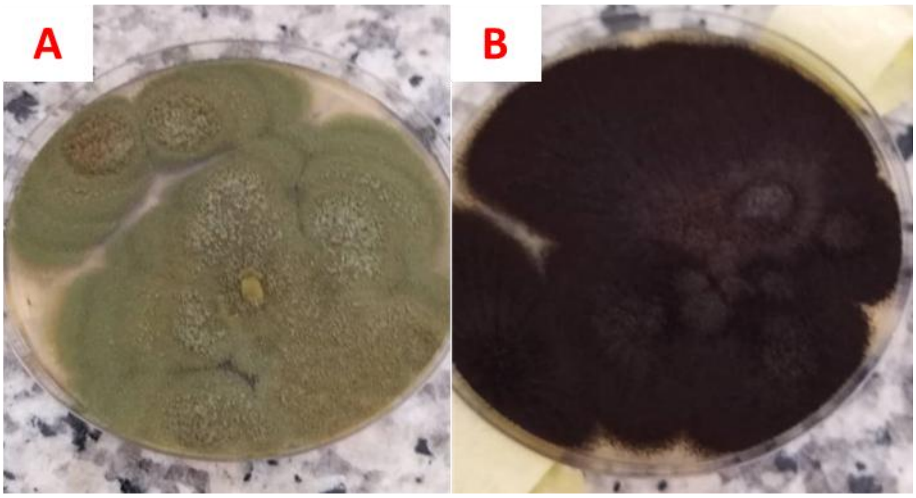

Fig. 4: Colonial morphologies of aflatoxin-producing strains of *Aspergillus* isolated from stored maize grains: *Aspergillus flavus* (A) and *Aspergillus niger* (B)

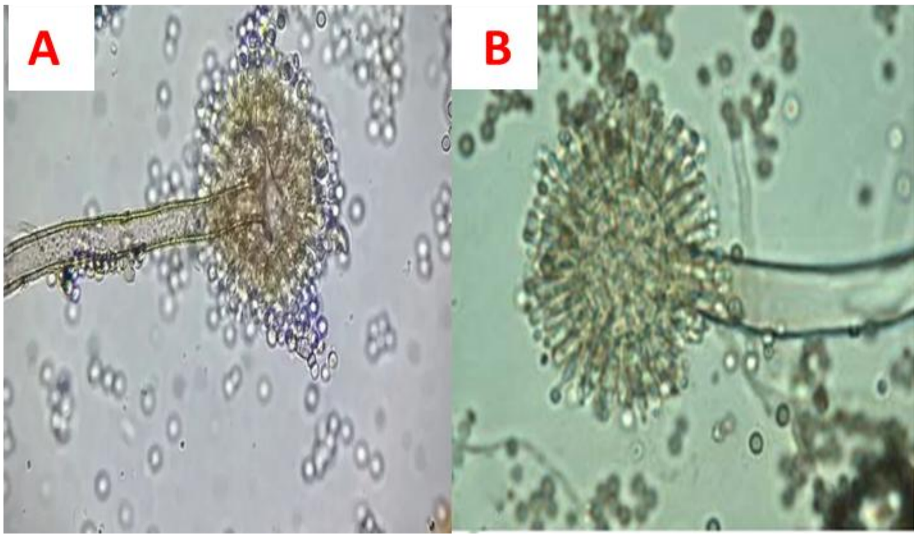

Fig. 5: Microscopic morphologies of aflatoxin-producing strains of *Aspergillus* isolated from stored maize grains: *Aspergillus flavus* (A) and *Aspergillus niger* (B)

Aflatoxin Quantification

Fig. 6 is the chromatogram of varieties of aflatoxins detected in the stored maize grains. Aflatoxin B1 was found to be most predominant with a concentration of 204.39 ng/mL, exceeding permissible limits for human consumption. The amount of aflatoxin obtained in this study falls within the range of values of aflatoxin (23-945 ng/g) reported in stored maize grains by Dadzie *et al*. (2019). Moreover, Perrone *et al*. (2014) reported high levels of aflatoxins in maize grains collected from open markets in Ghana and Nigeria. Due to the toxic and health-threatening nature of aflatoxin, it is therefore very pertinent to devise means of attenuating the activity of aflatoxin-producing organisms in our stored food items.

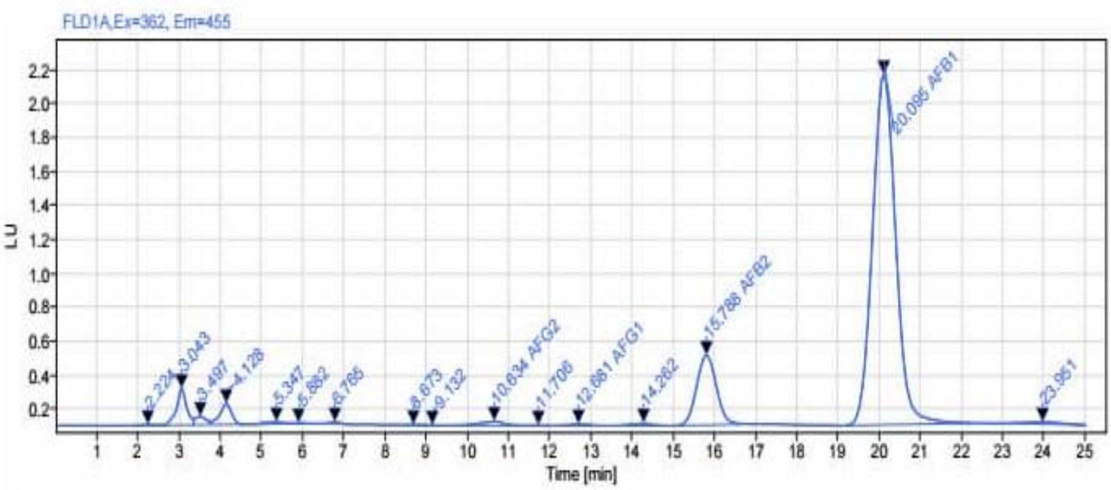

Fig. 6: HPLC Chromatogram of Aflatoxins in Stored Maize Grain

Antifungal Activity

METOX demonstrated significant antifungal activity against *A. flavus* (61.50% inhibition) and *A. niger* (16 % inhibition) (Fig. 7). Statistical analysis confirmed a significant difference ($p < 0.05$) in growth inhibition between the two fungi (Table 2). Many bacteria exhibit antifungal activity, producing substances or using other mechanisms to inhibit fungal growth. These mechanisms include the production of antifungal compounds, the activity of lytic enzymes, and competitive growth for nutrients. Bacteria, such as *Bacillus* species, are known for their antifungal properties, producing substances like lipopeptides and other compounds that effectively inhibit fungal growth. Bharose and Gajera (2018) reported that a metabolite produced by Bacillus species exhibited desirable antifungal activity against an aflatoxin-producing strain of Aspergillus flavus. Similarly, Siahmoshteh et al. (2018) reported potent antifungal activities demonstrated by particular species of Bacillus against Aspergillus parasiticus. The Bacillus species were able to suppress A. parasiticus growth (up to 92%) and aflatoxin production (up to 100%). Most recently, Abdel-Nasser et al. (2024) reported the production of bioactive metabolites obtained from Bacillus cereus DSM 31T, which exhibited strong antifungal capabilities against an aflatoxin-producing strain of A. Flavus. The authors affirmed that the bioactive metabolites displayed antifungal efficiency against A. flavus growth and caused morphological alterations in fungal conidiophores and conidiospores. Also, data obtained indicated that the metabolites reduced aflatoxin B1 production by 99.98%. The results report herein indicate that Bacillus species metabolites could be harnessed as biological control agents to control aflatoxin contamination in crops and agricultural commodities.

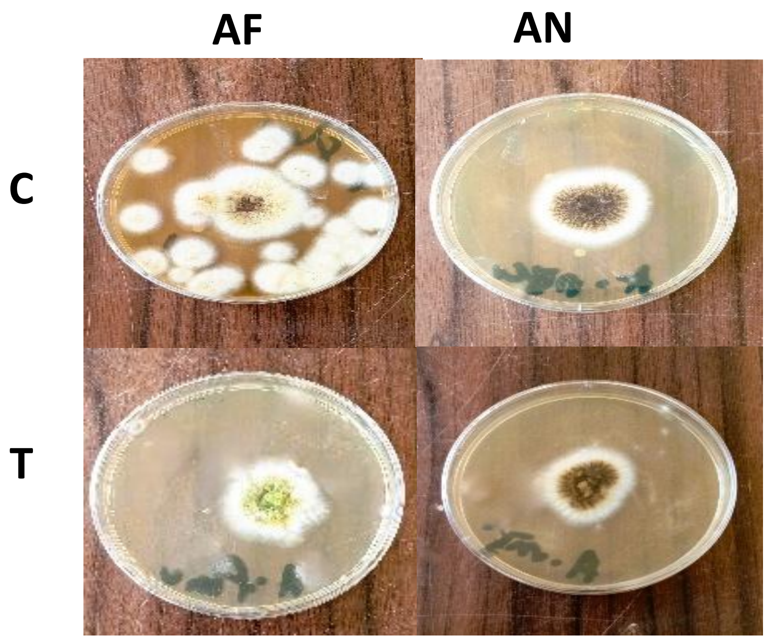

Fig. 7: Inhibitory effect of METOX on mycelial growth of *A. flavus* (AF) *and A. niger* (AN). The control is C (treatment without METOX) and T represents test (treatment with METOX

Table 2: Antifungal Activity of METOX Against A. flavus and A. niger

Fungal Species	Mean Inhibition (%) ± SD	Degree of freedom (between, within)	F-value	p-value	Significance
Aspergillus flavus	61.50 ± 5.20	(1,4)	122.36	0.0005	Yes ($p < 0.05$)
Aspergillus niger	16.00 ± 3.50				

Values are expressed as mean inhibition (%) ± standard deviation of three replicates

CONCLUSION

This study established the production of antifungal metabolite (METOX) by *B. safensis* LAU 13 during 3 days of cultivation through submerged fermentation. The metabolite was rich in bioactive compounds predominantly aldehyde derivatives, 4-Dodecen-1-al (13.5%) and Octanal,3,7-dimethyl (13%). The METOX exhibited potent inhibitory effect against the aflatoxin-producing strains of *A. flavus and A. niger* isolated from stored maize grains as it induced 62% and 16% fungal growth inhibition against the isolated strains of *A. flavus and A. niger*, respectively. Hence, the result obtained herein suggests that the METOX produced by *B. safensis* LAU 13 has promising application as a bioactive agent for sustainable control of the growth of aflatoxin-producing fungal species in stored grains.

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ASSESSMENT OF FACTORS INFLUENCING ADOPTION OF IMPROVED AGRO-FORESTRY TECHNOLOGIES AMONG SMALL-SCALE FARMERS IN NASARAWA STATE, NIGERIA

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ABSTRACT

This study assessed the factors influencing the adoption of improved agroforestry technologies among small-scale farmers in Nasarawa State, Nigeria. Data were collected from 111 registered agroforestry farmers using structured questionnaires and analysed using descriptive statistics, Likert-scale analysis, and multiple linear regression. Results showed that 77.3 % of the respondents were male, 91.8 % were married, and the mean age was 41.7 years. The most commonly adopted agroforestry technologies were boundary planting (mean = 4.0), shelterbelt/home gardening (mean = 3.6), alley cropping (mean = 3.3), and alley farming (mean = 3.1), while biomass transfer (mean = 1.9) and woodlots (mean = 2.9) had the lowest adoption. Benefits cited by respondents included increased income (80.9 %), firewood (49.1 %), erosion control (44.5 %), and provision of staking materials (39.1 %). Regression analysis revealed that extension contact ($\beta = 2.232$, $p < 0.01$) and farm size ($\beta = 0.194$, had significant $p < 0.05$) positive influences on adoption, whereas education ($\beta = -0.256$, $p < 0.05$) had a significant negative effect. The study concludes that agroforestry adoption is higher for practices that offer immediate benefits and are supported by extension services. Strengthening extension delivery, providing access to inputs, and promoting awareness are recommended to enhance the adoption of agroforestry technologies in the region.

Keywords: Adoption, agro-forestry, assessment, factors, improved, influencing, technologies

INTRODUCTION

Agriculture has historically been the foundation of Nigeria's economy, supporting the livelihoods of a significant segment of the population, especially smallholder farmers. However, various environmental challenges such as deforestation, land degradation, and the impacts of climate change continue to threaten food security and rural development. In response, sustainable practices like agroforestry, an approach that integrates trees with crops and/or livestock on the same land, are gaining relevance. Agroforestry not only improves agricultural output but also promotes environmental conservation and enhances the socio-economic conditions of rural communities (Boni *et al*., 2022). Adoption refers to the consistent use of an innovation once it is introduced (Orisakwe and Agomuo, 2011), and is often considered the most rational course of action (Abay *et al*., 2016; Garba, 2013). Technology, in this context, involves the systematic application of scientific knowledge for practical purposes (Orisakwe and Agomuo, 2011).

Agroforestry systems integrate trees and shrubs with crops and/or livestock in a deliberate, sustainable manner (Orisakwe and Agomuo, 2011). These systems support biodiversity, improve soil health, generate income, and strengthen food security by integrating woody perennials with farming activities (Olujobi, 2018). Agroforestry is a globally recognised practice, known for its role in combating deforestation, hunger, and poverty (Mulukh *et al*., 2017; Olujobi, 2018). It serves as a sustainable land-use model that boosts production while conserving ecosystems and mitigating climate change through carbon sequestration (Akinwalere, 2017).

Agroforestry is a dynamic and ecologically driven system with social, economic, and environmental benefits. It involves integrating trees into farmland or rangeland settings, contributing to long-term sustainability (Ishola *et al*., 2020; Awe *et al*., 2021; Ogunkalu *et al*., 2017). Nawaz *et al*. (2016) define agroforestry as a land-use strategy in which woody species are intentionally combined with crops and/or animals to foster ecological and economic interactions. The practice is now acknowledged as a distinct scientific discipline. According to Sangeetha *et al*. (2016) and Naibi (2013), agroforestry is a sustainable and culturally appropriate system that boosts soil fertility and resource conservation. It can take either sequential (e.g., improved fallows) or simultaneous (e.g., alley cropping) forms, with at least 18 major practices documented

(Akosim *et al*., 2020). Gillian (2010) characterises agroforestry as a resource management tool that enhances and diversifies production systems. Similarly, Akosim *et al*. (2020) define it as the purposeful integration of trees into farming systems for both ecological and economic gains. Agroforestry technologies encompass a wide range of practices that combine elements of agriculture, forestry, horticulture, and animal husbandry. These practices help mitigate production risks while increasing output. Traditionally, indigenous mixed cropping systems were used by farmers to reduce uncertainty (Amonum, 2009). Due to their complexity, agroforestry systems are often classified based on structure, function, and ecological distribution. The primary categories include agrisilviculture (trees and crops), silvopastoral (trees and livestock), and agrosilvopastoral (trees, crops, and livestock). Additional components include apiculture, aquaculture, and multipurpose tree lots.

Despite the availability of these technologies, their adoption remains low due to weak linkages between research and extension services, as well as mismatches between technologies and farmers' socio-economic realities (Orisakwe and Agomuo, 2011). Farmers are less likely to embrace innovations that do not align with their specific needs or conditions. Agroforestry practices can be classified as either farm-based (such as woodlots and intercropping) or forest-based (such as collection of food and gum) (Peter *et al*., 2019). These systems improve household income through diverse outputs (Ibrahim *et al*., 2019). Trees commonly used in agroforestry, such as mango, cashew, citrus, guava, and native species like *Parkia biglobosa*, *Vitellaria paradoxa*, and *Azadirachta indica*, are critical for maintaining land productivity. Improved agroforestry systems include agrisilviculture, silvopastoral systems, agrosilvopastoral systems, and multipurpose tree plantations (Amonum *et al*., 2009). Measuring adoption often involves assigning numerical values to reflect farmers' decisions and behaviour.

Improved agroforestry technologies such as alley farming, shelterbelts, windbreaks, home gardens, fodder banks, biomass transfer, improved fallows, trees on farmland, and woodlots offer numerous advantages. These include sustainable land management, increased resilience to climate shocks, enhanced crop yields, poverty reduction, income generation, food security, improved soil fertility, and overall environmental conservation. Yet, despite these benefits, the adoption of such technologies remains relatively low. This limited adoption is often due to a lack of comprehensive understanding of the various factors influencing farmers' decisions. These factors may include socio-economic, cultural, educational, and institutional variables. This study aimed to investigate these influencing factors to understand better what encourages or hinders the uptake of agroforestry technologies. The findings will provide valuable insights for designing effective policies and extension strategies that promote widespread adoption. Ultimately, the goal is to enhance agricultural productivity and environmental sustainability in Nasarawa State. The study thus seeks to bridge a critical knowledge gap in agroforestry adoption. The broad objective of the study was to assess the adoption of improved agroforestry technologies among small-scale farmers in FCT and Nasarawa State, Nigeria. The specific objectives were to:

i Describe the socio-economic characteristics of agroforestry small-scale farmers in Nasarawa State.

ii Assess farmers' awareness of improved agroforestry technologies in the study area.

iii Assess the level of adoption of improved agroforestry technologies by the respondents.

iv Identify the perceived benefits of adopting agroforestry technologies by the respondents, and

v. Determine the factors influencing farmers' adoption of enhanced agroforestry technologies in the study area.

MATERIALS AND METHODS

Study Area

The study was conducted in Nasarawa State, North Central Nigeria. Nasarawa State is located at latitudes 7° and 90 N and longitudes 80° and 320 E. Nasarawa State was created from the former Plateau State in 1996 and is located in Nigeria's North Central region. The state has a land mass of about 27,117 km2 (Nasarawa State Government, 2022). The state has a tropical climate typical of its location. It has a mean temperature range from 25 °C in October to about 36 °C in March, while rainfall varies from 1373 mm in some places to 1450 mm in others (NADP, 2021). The state is divided into three Agricultural Zones (Southern, Central and Western). Agriculture forms the foundation of the state's overall development thrust, with farming as the main occupation of the people in the area (NADP, 2014). The major crops grown in the zone include maize, yams, groundnuts, rice, sesame, sorghum, millets and cowpea. Other crops produced within the area include cassava, melon, sweet potato, okra, and tree crops such as mango, cashew and shea trees (NADP, 2021). The major ethnic groups in the area include Afo, Egbira, Mada, Nyankpa, Eggon, Gwandara, Rindre, and Migili, among many others.

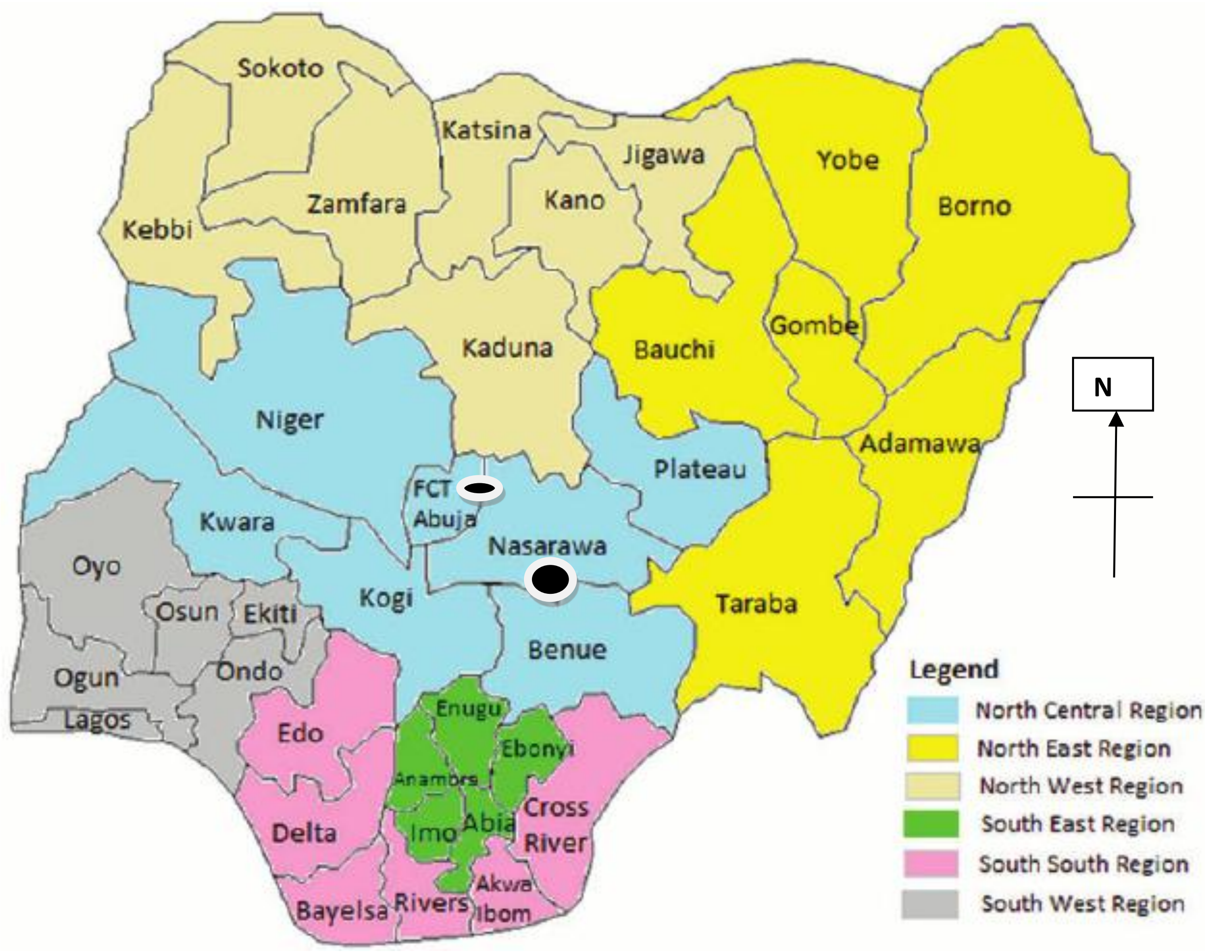

Figure 1: Map of Nigeria showing study area

Source: Map data @ Google Imagery (2018).

Key

Nasarawa State

Population and Sampling Procedure

The population for this study comprised 222 registered small-scale agroforestry farmers in Nasarawa State, as documented by the Ministry of Environment and Natural Resources (2024). A multi-stage sampling technique was employed to select respondents. In the first stage, five Local Government Areas (LGAs) were purposively selected based on their active engagement in agroforestry practices: Awe, Nasarawa, Karu, Wamba, and Toto. In the second stage, two communities notable for agroforestry activities were purposively selected from each of the five LGAs: Awe town and Tunga (Awe LGA); Nasarawa town and Laminga (Nasarawa LGA); Karshi and Uke (Karu LGA); Mama and Jida (Wamba LGA); and Toto town and Gadabuke (Toto LGA).

In the third stage, 50 per cent of the registered small-scale agroforestry farmers in each of the 10 selected communities were selected using simple random sampling, yielding a total sample of 110 respondents.

Method of Data Collection

Primary data were collected using structured questionnaires administered to selected agroforestry farmers in the study areas. The data covered socioeconomic characteristics, types of agroforestry technologies practised, sources of information, levels of adoption, and challenges faced in adopting these technologies—trained enumerators assisted in administering the questionnaires.

Method of Data Analysis

The collected data were subjected to simple descriptive statistics, such as frequency distributions, Percentages, and means, to describe the socioeconomic characteristics of agroforestry farmers (objective i) and to identify the perceived benefits of adopting agroforestry technologies by the respondents (objective iv). A five-point Likert scale was used to ascertain the level of awareness of improved agroforestry technologies among farmers (objective ii) as well as the level of adoption of improved agroforestry technologies among farmers (objective iii). Binary logit regression was used to examine the effects of selected socioeconomic variables on farmers' adoption of improved agroforestry technologies (objective iv).

Five-Point Likert Scale

The respondents' awareness and adoption of improved agroforestry technologies were assessed using a five-point Likert scale. This scale measures attitudes, preferences, and subjective responses by gauging the degree of agreement with specific items (Likert, 1932).

Level of Awareness of Improved Agroforestry Technologies

A five-point Likert-type scale was used to measure respondents' level of awareness of improved agroforestry technologies in the study area. Respondents were asked to specify the degree of agreement with statements regarding their awareness of improved agroforestry technologies using a 5-point Likert scale of fully aware (FA) =5, aware (A) =4, undecided (U) =3, not fully aware (NFA) =2 and not aware (NA) =1. Weights of 5, 4, 3, 2, and 1 were assigned to each response. A weighted mean of ≥ 3 means aware, whereas any weighted mean of < 3 means not aware. For each response, a weighted average is obtained as follows:

$$\overline{X} = \sum Fi\ (Ai)$$

$$5 + 4 + 3 + 2 + 1/5$$

Where,

Fi = frequency of respondents who agreed with a particular rating

Ai = value assigned to each rating

N = sample size

∑ = summation

FA = fully aware

A = aware

U = undecided

NFA = not fully aware

NA = Not aware

Level of Adoption of Improved Agro-Forestry Technologies

Similarly, a five-point Likert-type scale was used to measure the level of adoption of improved agro-forestry technologies among respondents in the study area. Respondents were asked to specify the degree of agreement with statements regarding the level of adoption of improved agro-forestry technologies using a 5-point Likert scale of fully adopted (FA) =5, adopted (A) =4, undecided (U) =3, not fully adopted (NFA) =2 and not adopted (NA) =1. Weights of 5, 4, 3, 2, and 1 were assigned to each response. A weighted mean of ≥ 3 means adopted, whereas any weighted mean of < 3 means not adopted. For each response, a weighted average is obtained as follows:

$\overline{X} = \sum Fi\ (Ai)$

5 + 4+ 3 + 2 + 1/5

Where,

Fi = frequency of respondents who agreed with a particular rating

Ai = value assigned to each rating

N = sample size

∑ = summation

FA = fully adopted

A = adopted

U = undecided

NFA = not fully adopted

NA = Not adopted

The weighted means were further analysed to evaluate the relationship between the level of adoption (dependent variable) and other independent variables. The weighted score served as the dependent variable (Y) in the regression analysis.

Decision:

For this study, adoption status was classified using the equal interval method, i.e.

Divide the full scale range (1–5) into 3 equal parts:

Range = 5.00 −1.00 = 4.00

Interval width = 4.00/3 = 1.33

Thus,

- Low Adoption: 1.00 – 2.33
- Moderate Adoption: 2.34 – 3.67
- High Adoption: 3.68 – 5.00

Multiple Linear Regression model is stated as follow:

$Y= a+ \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6+ \beta_7X_7 + \beta B_8X_8 + \beta_9X_9 + \beta_{10}X_{10} + e$

Where:

Y= cumulative mean adoption score per respondent

a= Constant term

β_1 β_2---- β_{10} = Regression coefficients

The independent variables specified are the determinant factors influencing the adoption of agro-forestry technologies and are defined below:

X_1 = Gender (Dummy: 1=male, 0=female)

X_2 = Age (years)

X_3 = Household size (number of dependent persons)

X_4 = Education (years spent in formal education)

X_5 = Marital Status (Married =1, single =0)

X_6 = Farming experience (years)

X_7 = Extension contact (yes =1, No = 0)

X_8 = Amount of credit obtained (in naira)

X_9 = Farm size (Ha)

X_{10} = Total annual income (amount in naira)

E = error term

RESULTS AND DISCUSSION

Socio-economic Characteristics of Respondents

Age**:** The socio-economic characteristics of respondents, as shown in Table 1, indicated a mean age of 41.7 years for agroforestry farmers. Most respondents were over 38 years (68.2 %), indicating that they are within productive age brackets and constitute a viable labour force. Age is crucial in influencing the adoption of improved agroforestry technologies, aligning with findings by Ibrahim *et al*. (2019), who reported a similar mean age (40.9 years) in New Bussa, Nigeria.

Sex: About 77.3 % of respondents were male. This suggests male dominance in agroforestry activities, possibly due to the physical nature of the work and land ownership patterns that favour men. This agrees with Ishola *et al*. (2020), who noted male predominance in farming due to labour demands.

Marital Status*:* A large proportion of respondents were married (91.8%). Married individuals may engage in agroforestry to support their families. Single farmers, though fewer in number, may benefit from independent decision-making and skill development. Ibrahim *et al*. (2019) similarly found that 66.7% of farmers were married and argued that married farmers tend to be more rational in decision-making.

Household Size*:* About 44.5% had households of 6–10 persons. The mean household size was 9 persons. Larger households imply greater family labour availability but may also increase household expenses. Obadimu *et al*. (2020) also found that the majority of farmers had 6–10 household members, suggesting access to family labour.

Educational Qualification: The respondents' educational status indicates that 46.4 % had primary education, 24.5 % secondary education, and 29.1 % tertiary education. Education enhances farmers' ability to adopt and manage improved technologies. Ishola *et al*. (2020) similarly reported that 91.67 % of respondents were educated, facilitating the adoption of innovations.

Farming Experience*:* Most (85.5 %) of the farmers had 1–10 years of agroforestry experience. Experience fosters better adoption of sustainable practices, resource use efficiency, and resilience. This aligns with Ishola *et al*. (2020), who found that 76.67% had over six years of experience.

Cooperative Membership*:* Majority (90.9 %) belonged to cooperatives, with many of them having 1–10 years of membership. Cooperatives support members with collective input procurement, credit access, and market linkage. This reflects an awareness of the benefits of group participation.

Extension Contact*:* About 71.8% had contact with extension agents. Most had 1–2 contacts during the last season. Despite this, the overall frequency of extension visits was low, limiting access to training and the dissemination of innovation. Extension support is critical for improving farmers' knowledge and technology uptake.

Access to Loan*:* About 71.8% of agroforestry farmers had access to credit. This suggests relatively good access to financial services, which can enhance technology adoption and farm productivity. The sources of loans included cooperative societies (31.8%), friends (20.0%), neighbours (10.0%), and banks (10.0%). These findings indicate that cooperative societies and informal sources, such as friends, were the primary sources of credit for agroforestry farmers in the study area. Access to loans is critical for investing in improved seeds, equipment, agrochemicals, and other farm inputs and technologies, thereby enhancing productivity and efficiency. It also enables farm expansion and adoption of improved agroforestry practices.

Regarding the loan amounts accessed, 35.5 % accessed between ₦1,000 and ₦200,000; 19.1 % accessed between ₦201,000 and ₦400,000; and 17.3 % accessed over ₦400,000. The average loan accessed was ₦295,636.36. This amount is considered low, which may limit farmers' ability to invest in modern agroforestry technologies.

Method of land acquisition*:* In the aspect of land acquisition, 90.0 % of respondents used family land, 12.7 % used purchased land, and 3.6 % used gifted land. This shows that family land was the predominant mode of land acquisition in the study area. Access to land is crucial as it supports not only food production and economic returns but also environmental sustainability and social well-being.

Farm size: In terms of land size, 89.1 % farmed on 1–5 hectares, while 10.9 % farmed on 6–10 hectares. The average landholding was 3.4 hectares, indicating that the majority of agroforestry farmers are smallholders. Limited land size may constrain diversification and the full adoption of agroforestry practices, which require integrating trees, crops, and sometimes livestock. Smallholders may also struggle to access capital and markets, further limiting their productivity.

Boni *et al*. (2022) reported a mean agroforestry farm size of 2.71 hectares, attributing this to persistent rural poverty in Nigeria.

Annual Income: The income distribution showed that 49.1% of agroforestry farmers earned above ₦1,000,000 annually**,** 35.5 % earned between ₦501,000 and ₦1,000,000**,** and 15.5 % earned between ₦1,000 and ₦500,000**.** The average annual income was ₦1,384,545.45. Generally, the findings indicate that agroforestry farming provides a sustainable source of income for practitioners in both areas, likely supported by the adoption of improved agroforestry technologies.

Table 1: Socio-economic Characteristics of Agro-Forestry Farmers in Nasarawa State

Variable	Frequency	Percentage	Mean
Sex			
Male	85	77.3	
Female	25	22.7	
Age (years)			
18-28	4	3.6	
29-38	31	28.2	
Above 38	75	68.2	41.7
Marital status			
Single	9	8.2	
Married	101	91.8	
Household size			
1-5	35	31.8	
6-10	49	44.5	
Above 10	26	23.7	9
Level of education			
Primary education	51	46.4	
Secondary education	27	24.5	
Tertiary education	32	29.1	
Farming experience			
1-10	94	85.5	
11-20	16	14.5	7.7
Access to loan			
Yes	79	71.8	
No	31	28.2	
Source of loan			
No access to loan	31	28.2	
Neighbours	11	10.0	
Friends	22	20.0	
Cooperative societies	35	31.8	
Banks	11	10.0	
Amount of loan accessed (Naira)			
No access to loan	31	28.2	

1,000-200,000	39	35.5	
201,000-400,000	21	19.1	
Above 400,000	19	17.3	295, 636.36
Membership of cooperative society			
Yes	100	90.9	
No	10	9.1	
Extension contact			
Yes	79	71.8	
No	31	28.2	
Number of visits received			
No extension visits	31	28.2	
1-5	77	70.0	
6-10	2	1.8	
Above 10	0	0.0	
Method of land acquisition			
Farm on family land	92	83.7	
Farm on purchased land	14	12.7	
Gifted land	4	3.6	
Farm size (hectares)			
1-5	98	89.1	
6-10	12	10.9	3.4
Total annual income			
1,000-500,000	17	15.5	
501,000-1,000,000	39	35.5	
Above 1,000,000	54	49.0	1, 384, 545.45

Source: Field survey, 2024

Awareness of Improved Agroforestry Technologies in Nasarawa State

Table 2 presents the level of awareness of improved agroforestry technologies among the respondents. The responses were measured using a five-point Likert scale ranging from Fully Aware (5) to Not Aware (1). The mean scores for each technology were computed, and a score of 3.0 and above was considered an indication of awareness. Of the ten agroforestry technologies listed, six had mean scores of 3.0 or higher, suggesting that respondents were generally aware of these practices. In contrast, the remaining four had mean scores below 3.0, indicating low levels of awareness. Among the assessed technologies, Multipurpose Trees on Cropland recorded the highest mean score of 3.9, indicating that most respondents were aware of this practice. This high awareness could be attributed to the visibility and usefulness of such trees in providing shade, improving soil fertility, serving as sources of firewood, and contributing to overall farm productivity. Alley Farming also showed a high level of awareness, with a mean score of 3.6. This may be linked to its integration into existing farming systems and its benefits in reducing erosion and maintaining soil structure. Alley-Cropping (Hedgerow Intercropping) had a mean score of 3.4, indicating that the practice is relatively well known among the respondents. The similarity between alley farming and alley-cropping could explain this level of awareness. Taungya Farming and Boundary Planting both recorded mean scores of 3.3, reflecting moderate awareness. The Taungya system is likely known for its historical use in combining forestry and food crop production. At the same time, boundary planting is appreciated for its role in land demarcation, wind protection, and the provision of fodder or wood. Improved Fallows also recorded a mean score of 3.1, suggesting some familiarity, likely due to its role in restoring natural soil fertility.

On the other hand, Fodder Bank had a mean score of 2.9, indicating low awareness despite its importance in livestock feed management. This may be due to the predominance of crop farming over livestock among the respondents or inadequate extension services targeting this practice. Shelterbelt/Windbreak and Home Gardening was at the threshold with a mean score of 3.0, suggesting moderate awareness. Its slightly higher score may be due to its relevance in areas prone to strong winds and its benefits for home food security. The least known technologies were Woodlots and Biomass Transfer, with mean scores of 2.4 and 2.1, respectively. The low level of awareness of woodlots might be due to issues related to land ownership or the long-term nature of returns from such investments, which may not appeal to smallholder farmers. Biomass transfer, which recorded the lowest mean, may be poorly understood or perceived as complex and labour-intensive, especially where there are limited practical demonstrations or support services.

In summary, the findings reveal that awareness was generally high for agroforestry practices that are directly beneficial, easy to integrate into existing systems, or offer immediate economic returns. However, awareness was low for practices that require technical knowledge, long-term investment, or are less familiar within the local context. This underscores the need for targeted extension interventions, awareness campaigns, and practical demonstrations to promote the adoption of underutilised but beneficial agroforestry technologies.

Table 2: Awareness of Improved Agro-Forestry Technologies by the Respondents

Improved Agro-forestry Technology	FA (5)	A (4)	U (3)	FNA (2)	NA (1)	Sum	Mean
Alley farming	155	196	9	22	16	398	3.6*
Alley-cropping	120	208	15	18	20	381	3.4*
Shelter belt/wind break/home gardening	95	156	21	36	27	335	3.0*
Multipurpose trees on cropland	165	236	9	16	7	433	3.9*
Fodder bank	55	144	33	66	19	317	2.9
Improved fallows	105	132	27	50	22	336	3.1
Taungya farming	120	156	21	50	15	362	3.3*
Boundary planting	135	152	12	44	19	362	3.3*
Biomass transfer	30	44	39	88	36	237	2.1
Woodlots	45	68	18	110	23	264	2.4

FA=fully aware, A=aware, U=Undecided, FNA=fully not aware, NA=not aware

NOTE: *means Aware

Level of Adoption of Improved Agroforestry Technologies by the Respondents

Table 3 presents data on the adoption levels of various improved agroforestry technologies among respondents. The adoption levels were assessed using a five-point scale ranging from Fully Adopted (5) to Not Adopted (1). The total score for each technology was computed, and mean scores were used to determine the level of adoption. A mean score of 3.0 and above indicates that a technology has been adopted, while a mean score below 3.0 suggests low or no adoption.

From the data, it is evident that only 4 of the 10 agroforestry technologies assessed were adopted by the respondents, as they recorded mean scores of 3.0 or higher. These are Boundary Planting (4.0), Shelterbelt/Windbreak and Home Gardening (3.6), Alley-Cropping (3.3), and Alley Farming (3.1).

Boundary Planting recorded the highest level of adoption with a mean score of 4.0. This suggests that respondents are not only aware of this practice but also actively implementing it, likely due to its multiple benefits, including farm boundary demarcation, fuelwood provision, and wind protection. Similarly, Shelterbelt/Windbreak and Home Gardening, with a mean of 3.6, were highly adopted. This may be attributed to its immediate visible benefits in controlling wind erosion and supporting household nutrition and income through home gardening.

Alley-Cropping (Hedgerow Intercropping) and Alley Farming also recorded adoption, with mean scores of 3.3 and 3.1, respectively. Their moderate levels of adoption could be linked to their compatibility with existing cropping systems, benefits in soil fertility improvement, and availability of technical knowledge or demonstration through extension services.

In contrast, the remaining six agroforestry technologies had mean scores below the adoption threshold, indicating low adoption among respondents. For example, Multipurpose Trees on Cropland, which had the highest awareness level in Table 2, recorded a low adoption mean of 2.6. This suggests a gap between awareness and actual implementation, possibly due to constraints such as a lack of planting materials, land tenure issues, or long gestation periods for the benefits of trees.
Similarly, Improved Fallows, Fodder Banks, and Taungya Farming recorded mean scores of 2.6, 2.4, and 2.4, respectively, reflecting limited adoption. These practices, while beneficial, may require more labour, land, or time before benefits are realised, which could discourage their adoption among resource-constrained farmers.

Woodlots, with a mean score of 2.9, came close to the adoption threshold but still fall into the low-adoption category. The low adoption may stem from the same reasons noted for multipurpose trees, such as limited land access and the long-term commitment required to establish woodlots.
Biomass Transfer had the lowest adoption level, with a mean score of 1.9. This may reflect a lack of awareness or understanding of the technology, as well as challenges associated with its labour intensity and the need for technical knowledge or external support.

In summary, the data show that adoption is highest for agroforestry technologies that are easy to integrate, offer immediate benefits, or are supported by extension services. However, there is a clear gap between awareness and adoption of several beneficial technologies, indicating the need for targeted interventions, such as farmer training, input provision, and the promotion of practical demonstrations to enhance adoption.

Table 3. Level of Adoption of Improved Agro-Forestry Technologies

Improved Agro-forestry Technology	FA(5)	A(4)	U(3)	FNA(2)	NA(1)	Sum	Mean
Alley farming	115	152	9	40	26	342	3.1*
Alley-cropping	105	200	15	18	25	363	3.3*
Shelter belt/wind break/home gardening	145	184	21	36	10	396	3.6*
Multipurpose trees on cropland	80	88	33	66	28	295	2.6
Fodder bank	45	68	18	110	23	264	2.4
Improved fallows	75	84	33	66	30	288	2.6
Taunya farming	55	84	21	82	30	272	2.4
Boundary planting	185	232	12	8	7	444	4.0*
Biomass transfer	15	32	39	88	42	216	1.9
Woodlots	55	144	33	66	19	317	2.9

FA=fully adopted, A=adopted, U=Undecided, FNA=fully not adopted, NA=not adopted

NOTE: *means Adopted

Benefits of Adopting Improved Agro-Forestry Technologies

The results of the benefits of adopting improved agroforestry technologies by respondents, as presented in Table 4, showed that respondents benefited in areas of increase in income (80.9%), firewood (49.1%), erosion control (44.5%), staking materials (39.1%) and shelter (20.0%). This means that adopting improved agroforestry technologies offers many benefits to agroforestry farmers in the study area. The study revealed that farmers either plant agroforestry trees for income, fuelwood, and erosion control. The result also aligns with Mukundente's (2021) finding that these trees are planted for various uses, including fuelwood (18%), income (22%), and soil erosion (14%). The study found that farmers plant trees for additional benefits, such as stakes for crops, firewood, improved soil, reduced crop failure, and control of weeds and pests.

Factors Influencing the Adoption of Improved Agroforestry Technologies

Table 5 presents the results of a multiple regression analysis showing the influence of selected socio-economic and institutional variables on respondents' adoption of improved agroforestry technologies in Nasarawa State. The explanatory variables considered include sex, age, marital status, household size, level of education, agroforestry farming experience, loan amount, extension contact, farm size, and total annual income. The regression model's intercept (constant) is significant with a t-value of 9.537, indicating a solid baseline adoption level when all explanatory variables are held constant. Among the independent variables, three were statistically significant, indicating a meaningful influence on the adoption of improved agroforestry technologies. These are:

Table 4. Benefits of Adopting Improved Agro-Forestry Technologies

Benefits of Agroforestry	Frequency	Percentage
Source of income	89	80.9
Provision of staking materials	43	39.1
Control erosion	49	44.5
Climate regulation	19	17.3
Increase soil fertility	21	19.6
Weed control	17	15.5
Fire wood	54	49.1
Provision of shelter	22	20.0

Multiple responses

Extension contact(β=2.232): This variable showed a highly significant positive influence at the 1% level. The strong effect suggests that frequent interaction with extension agents significantly enhances the adoption of improved agroforestry practices. This implies that extension services play a critical role in disseminating knowledge, demonstrating best practices, and encouraging farmers to adopt innovations. Paul *et al*. (2015) reported that extension visits influenced the adoption of agroforestry technologies in Nigeria. This shows that an extension visit is a determinant of agricultural innovation adoption. The extension contact was significant at the 1 per cent level. The results revealed that an increase of 1 unit in the number of extension visits will increase the probability of adoption. This is because access to extension education exposes farmers to different farming techniques and systems, including agroforestry information, and enhances their decision-making regarding adoption.

Level of Education (β = -0.256): This variable had a significant negative effect at the 5% level. This suggests that higher levels of formal education among respondents may not necessarily lead to increased adoption of agroforestry technologies. It could be that more educated individuals in the study area are less involved in farming or more inclined towards non-farm occupations, thereby reducing their likelihood of adopting agroforestry practices.

Farm Size (β = 0.194): Farm size also had a positive and significant influence at the 5% level. This implies that farmers with larger landholdings are more likely to adopt improved agroforestry technologies. Larger farms offer greater flexibility in integrating trees with crops and livestock, making it easier for these farmers to experiment with and benefit from agroforestry systems. This is in line with the findings of Awe *et al.* (2021) who reported that farm size had positively and significantly related to adoption of agroforestry technologies, which implies that the larger the farm size, the higher the likelihood of a farmer to adopt agroforestry technologies, since the farmers will have enough land to accommodate both their tree and arable crops for optimal benefits.

Other variables, such as sex, age, marital status, household size, agroforestry farming experience, loan amount, and total annual income, were not statistically significant, indicating that these factors did not have a strong influence on the adoption of agroforestry technologies in this study. Although factors like farming experience and loan amount may intuitively support adoption, their effects were statistically weak in this case.

Table 5: Factors Influencing the Adoption of Improved Agro-Forestry Technologies

Explanatory variable	β- value	Str error	t-value
(Constant)	1.917	.201	9.537
Sex	.074	.235	.313
Age	.001	.012	.092
Marital status	.218	.368	.592
Household size	.005	.021	.231
Level of education	-.256	.125	-2.053**
Agro-forestry farming experience	.038	.029	1.297
Amount of loan	1.978E-7	.000	.815
Extension contact	2.232	.226	9.894***
Farm size	.194	.093	2.089**
Total annual income	-2.251E-7	.000	-1.451

In summary, the findings highlight the critical importance of extension services and farm size in promoting the adoption of improved agroforestry technologies in Nasarawa State. The unexpected negative influence of education suggests that more targeted sensitisation is needed among educated farmers. The lack of significance for most socio-economic factors suggests that institutional and structural supports, such as land access and technical guidance, may be more influential than demographic characteristics alone.

Conclusion

The study concludes that, despite high awareness, the adoption of improved agroforestry technologies among small-scale farmers in Nasarawa State remains limited, with only a few practices widely adopted. Key factors influencing adoption include extension contact and farm size, highlighting the need for targeted institutional support to bridge the gap between awareness and implementation for sustainable rural development.

The study recommends strengthening extension services through ICT integration and capacity building, alongside policy backed by input subsidies and distribution systems to improve farmers' access. Awareness campaigns and demonstration plots should be institutionalised, with educated farmers engaged as role models. Legislative reforms to enhance land tenure security are essential to encourage long-term agroforestry investment. Farmer cooperatives should be supported with credit, collective procurement, and market access, while proven high-impact agroforestry practices should be scaled up through public–private partnerships and extension-led demonstration farms.

Declaration of Conflict of Interest

The authors declare no conflict of interest.

Data Availability

Data are available upon request from the first author or corresponding author or any of the other authors

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QUALITY EVALUATION OF BISCUIT PRODUCED FROM RICE *(Oryza sativa)*, DEFATTED SESAME *(Sesamum indicum)*, AND CARROTS *(Daucus carota)* FLOUR BLENDS

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ABSTRACT

Biscuits are a popular food product consumed by a wide range of consumers as breakfast items and snacks due to their pleasant, diverse flavours, relatively long shelf life, and low cost. The use of wheat flour, an imported, low-nutrient commodity, as the main ingredient in its production has raised concerns about its potential to cause gluten-related disorders and nutritional deficiencies, underscoring the need for a cost-effective, gluten-free, and nutrient-rich alternative for biscuit production. Hence, the study was aimed at producing biscuits from composite flour formulated from rice, defatted sesame seed, and carrots flour blend, with varying proportions of rice, defatted sesame seed, and carrots (100 % wheat, 100 % rice, 92:5:3, 87:10:3, 82:15:3, 89:5:6, 86:5:9, and 83:5:12, respectively). The functional, physical, proximate properties, mineral content, and sensory attributes of the biscuit blends were determined using standard analytical methods. The results of the functional properties varied significantly at p≤ 0.05. Oil absorption decreased from 50.50 to 38.70 with an increase in defatted sesame, while an increase in carrot content resulted in a decrease in bulk density from 0.46 to 0.41. Length and spread ratio increased while height, *weight ratio, and break strength increased, with the mean score of 2.45 to 2.65cm, 11.85-12.50, and 1939.85-2478.50g with the increase of defatted sesame in the sample. The moisture content decreased from 0.96-0.10 while ash content increased from 1.71 to 2.15 in the 82:15:3. However, crude protein and crude fiber increased 7.45-12.70 and 5.02-6.32% lipid exhibited an increase with an increase in defatted sesame content from 13.63-14.61 and 12.11-13.69. The mineral content increased with increasing defatted sesame. Calcium, potassium, and Phosphorus content increased from 3.05-4.12, 9.21-10.75, and 4.10-4.21mg, while the phosphorus level increased from 3.92-4.06mg|100 g. Sensory attributes increased across all attributes, with samples containing 82:15:3 exhibiting the highest protein and acceptability. The increased protein, fiber, and essential minerals in the blend could improve the nutrient intake of consumers and promote their well-being.*

Keywords: Biscuit, Carrots, Defatted sesame, Rice and Quality evaluation

INTRODUCTION

Biscuits are a popular food product consumed by a wide range of consumers as breakfast items and snacks due to their diverse flavours, long shelf life, and low cost (Javaria *et al.*, 2017). The major ingredients are typically wheat flour, sucrose, and fat, making biscuits a rather energy-dense cereal food (Sozer *et al*., 2014). Altering the ratios of non-wheat flours and adding various nutritional ingredients may improve the quality and shelf life of biscuits (Ahmed *et al*., 2012). All biscuits can be nutritious, contributing valuable amounts of iron, calcium, protein, calories, fibre, and some B vitamins to our diet and daily food requirements if made from composite flours. Composite flour has the added advantage of enhancing the nutritional value of biscuits and other bakery products, especially when cereals are blended with legumes or tubers (Tyagi *et al*., 2007). Rice (*Oryza sativa*) is the seed of the grass species. As a cereal grain, it is the most widely consumed staple food worldwide, especially in Nigeria. It is an agricultural commodity with the third-highest worldwide production, after maize, according to FAO (2010). Rice is the most important grain in terms of human nutrition and calorie intake, providing more than one-fifth of the calories consumed worldwide by humans. Its flour is a good substitute for wheat flour, which irritates the digestive systems of those who are gluten intolerant. Rice flour is also used as a thickening agent and for making rice bread (Hosking, 2017). The nutritional composition of white rice, as documented by Das *et al.* (2020), shows that rice contains 4.43 g of crude protein, 0.39 g of fat, 0.56 g of fibre, and 53.2 g of carbohydrate.

Sesame (*Sesamum indicum*) is an oilseed legume rich in protein and essential amino acids (Idowu *et al*., 2021). It is categorised as an underutilised oilseed, particularly for protein extraction and food formulation. Sesame is a rich source of most inorganic nutrients; it is also consumed for its medicinal properties. Sesame seeds are rich in protein compared to other seed proteins because of the higher essential amino acid content. Sesame protein is more nutritious compared to all the other oilseed proteins (Pathak *et al*., 2014; Idowu *et al*., 2021). Defatted sesame flour contains protein (55.70 %), ash (9.83 %), and crude fibre (1.64 %), total carbohydrate (29.40 %), and is high in sulfur-containing amino acids (El-adawy*et al*., 2021).

Carrots (*Daucus carota*) are among the most nutritious vegetables consumed worldwide, both raw and processed. Carrots are inexpensive and highly nutritious, as they contain appreciable amounts of vitamins B1, B2, B6, and B12, as well as being rich in carotene (Manjunatha *et al*., 2003) and fibre. In recent years, the consumption of carrots and related products has increased steadily due to recognition of the antioxidant and anticancer activities of beta-carotene, a precursor of vitamin A (Kotecha *et al*., 1998; Speizer *et al*., 1999). Carrots can be consumed raw, processed, or fortified in a variety of food products. Carrots are a staple of the human diet and can be eaten fresh, cooked into various dishes, or processed into puree, juice, or dehydrated. However, carrots are a seasonal product, and their quality can be significantly degraded by the loss of their bioactive compounds after harvest.

The high cost of wheat in Nigeria has significantly increased biscuit production costs, making it challenging for bakers to maintain profitability while providing affordable products to consumers. Furthermore, the complicated health concerns associated with wheat usage, such as gluten-related disorders and nutritional deficiencies, highlight the need for a cost-effective, gluten-free, and nutrient-rich alternative in biscuit production. The biscuit's nutritional content is relatively low and requires fortification. The study aimed to evaluate the quality of biscuits produced from a combination of rice, defatted sesame seed, and carrot flour.

MATERIALS AND METHODS

Source of Materials and Preparation

The materials used in the experiment are rice (*Oryza sativa*), defatted sesame (*Sesamum indicum*), and carrots (*Daucus carota*). The other ingredients included: margarine (Blue Band), sugar (Dangote), baking powder (Royal Baking Powder), salt (NASCO Ltd. salt), and water, which were purchased at Lafia Modern Market.

The method described by Okpala and Egwu (2015) was used to produce rice flour. The rice grains were sorted manually to remove extraneous materials. The rice was washed with potable water, sun-dried, and milled using a hammer mill, then passed through a 60 µm mesh sieve. Flour was stored in an airtight plastic container at room temperature (32–38 °C) until needed.

The method described by Chinma (2018) was used to produce defatted sesame seed flour. Sesame seeds were cleaned, sorted, washed, and dried at 60°C for 30 min. After cooling, the seeds were milled, oil was extracted, and the defatted sesame seed flour was air-dried for 1 h.

The carrots were peeled, sliced, and dried to an almost brittle consistency at 400 °C in a cabinet dryer (5 h to reduce the moisture content to 8%). The dried, brittle carrot was then milled into flour using a stainless steel milling machine. The flour was sieved through a 0.25µm sieve, packed into a cellophane bag, and stored for further analysis (Adegunwa *et al*., 2014).

Production of Flour Blends for Biscuits

The blends were thoroughly mixed in a Kenwood blender to achieve uniformity. The salt and baking powder were added and mixed. Another separate mixing bowl was used to combine the butter, sugar, and egg till the mixture became creamy. The creamy mixture was poured into the flour and mixed thoroughly. Water was added and mixed to obtain the dough. The dough was cut into sizes (3.0cm diameter, 0.1cm thickness) and baked at 180 °C for 15 minutes. The cookies were removed, cooled, and then packaged in airtight containers.

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Composite Flour Formulation

Table 1: Recipe of biscuit produced from Rice, defatted sesame, and carrot flour (%)

Materials	Samples							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Wheat Flour (%)	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rice Flour (%)	0.00	100.00	92.00	87.00	82.00	89.00	86.00	83.00
Defatted Sesame Flour (%)	0.00	0.00	5.00	10.00	15.00	5.00	5.00	5.00
Carrot Flour (%)	0.00	0.00	3.00	3.00	3.00	6.00	9.00	12.00
Sugar (g)	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Baking fat (g)	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Baking powder (g)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Salt (g)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Water (ml)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

Key:
R. S. C
A 100:0:0 Wheat Flour, B 100 :0: rice, C 92:5:3, D 87:10:3, E 82:15:3, F 89:5:6, G 86:5:9
H 83:5:12, R= Rice Flour, S = Sesame, C = Carrot Flour

Functional Properties

Water Absorption Capacity (WAC)

Water absorption capacity is an index of the amount of water retained within a food matrix under certain conditions. It usually refers to entrapped water, but includes bound water and hydrodynamic water, and depends upon the condition of determination. This was determined using the procedure described by Adebowale *et al*. (2012). Approximately 10mL of distilled water was added to 1.0g of each flour sample. The suspension was stirred using a magnetic stirrer for 3 minutes. The suspension was transferred into centrifuge tubes and centrifuged at 3,500 rpm for 30 min. The supernatant obtained was measured using a 10ml measuring cylinder. The density of the water was assumed to be 1g/mL. The water absorbed by the sample was calculated as the difference between the initial water used and the volume of the supernatant obtained after centrifugation. The result was expressed as a percentage of water absorbed by the blends on a percentage by weight basis.

Swelling capacity

The swelling capacity was determined by the method described by Okaka and Potter (1977). A graduated cylinder (100 mL) was filled with the sample to the 10 mL mark. Distilled water was added to achieve a total volume of 50 mL. The top of the graduated cylinder was tightly covered, and the contents were mixed by inverting the cylinder. The suspension was inverted again after 2 minutes and left to stand for an additional 8 minutes. The volume occupied by the sample was taken after the 8th minute.

Oil absorption capacity

The oil absorption capacity was also determined using the method described by Sosulski *et al.* (1976). One gram of sample mixed with 10 mL of soybean oil (Sp. Gravity: 0.9092) and allowed to stand at ambient temperature 30$\pm$2 0C) for 30 min, then centrifuged for 30 min at 300 rpm or 2000 ×g. Oil absorption was examined as the percentage of oil bound per gram of flour.

Bulk density

The volume of 100 g of the flour was measured in a measuring cylinder (250 mL) after tapping the cylinder on a wooden plank until no visible decrease in volume was noticed, and based on the weight and volume, the apparent (bulk) density was calculated (Jones *et al.,* 2000).

Physical Properties

Physical properties (weight, volume, spread ratio, break strength) were determined as described by Ayo *et al.* (2019). The weight and diameter of the baked biscuit were determined by weighing on a weighing balance and measuring with a calibrated ruler. The thickness was measured according to the AOAC (2012) method. Three rows of five well-formed biscuits were made, and their heights were measured. Also, the same were arranged horizontally edge-to-edge, and the sum diameter was measured. The spread ratio was calculated as the diameter divided by the height.

For break strength, a biscuit of known thickness (0.4cm) was placed between two parallel wooden bars (3.0cm apart). Weights were added to the biscuit until the biscuit snapped. The least weight that caused the breaking of the biscuit was regarded as the breaking strength of the biscuit.

Proximate Composition

The proximate composition (moisture, fat, fibre, protein, ash, and carbohydrate) of the blend biscuits was determined using the AOAC (2012) method as adopted by Paul *et al.* (2024).

Sensory Evaluation

Sensory quality attributes, including taste, flavour, texture, crust appearance, crumb colour, and overall acceptability of the biscuit samples, were evaluated by (20) panellists comprising students and staff members of the Department of Nutrition and Dietetics, Faculty of Agriculture, Shabu-Lafia campus, Nasarawa State University, Keffi, Nigeria. The panellists were instructed to score the coded samples based on a 9-point Hedonic scale, ranging from 9 (liked extremely) to 1 (disliked extremely) (Mishra *et al.,* 2015).

Data Analysis

All experiments were carried out in triplicate. The data obtained were subjected to one-way analysis of variance (ANOVA), and Duncan's Multiple Range Test was conducted to separate the means. These analyses were performed using the Statistical Package for the Social Sciences (SPSS version 16.0). The significance level was set at 5%.

RESULTS AND DISCUSSION

Functional Properties of Biscuits Produced from Rice, Defatted Sesame Seed, and Carrot Flour Blends

The results of functional properties are shown in Table 2. The functional properties varied significantly at ($p < 0.05$) for all parameters assessed. The oil absorption, water absorption, bulk density, foam capacity, and swelling capacity of the produced flour blend biscuits ranged from 38.70 – 50.50 cm3/100g, 185.50 -119.50 cm3/100g, 0.44 - 0.46 g/cm3, 30.50 - 70.50 cm3/100g and 145.80 -166.25 cm3/100g, respectively, with increase in the added defatted sesame (5-15 %). Also, the same assessed parameters ranged from 21.70 - 61.75 cm^3/100g, 193.50 - 24.50 cm3/100g, 0.41 - 0.42g/cm^3, 39.50 - 49.50 cm3/100g, 183.02 - 193.00 cm3/100g, respectively, with an increase (6-12 %) in added carrot flour. The 100% wheat-flour product had the lowest values for all assessed functional properties.

The observed decrease in oil absorption capacity could be beneficial for reducing the overall fat content of foods, which is crucial for managing cholesterol levels. Research by Mozaffarian (2016) suggests that high-fat diets rich in saturated fats can elevate LDL cholesterol, a risk factor for cardiovascular diseases. By lowering the oil absorption, the food blend becomes healthier, thereby reducing the risk of conditions such as atherosclerosis and coronary artery disease (Mozaffarian, 2016). The increase in high water absorption capacity could aid in digestion and enhance stool bulk, preventing constipation (Tiwari *et al.,* 2020). Foods with high water retention also have a lower caloric density, which contributes to weight management and the prevention of obesity (Tiwari *et al.,* 2020).

The low bulk density observed could be an added value. Lower bulk density is associated with lighter foods, which are easier to digest and can support individuals with low energy requirements or those following calorie-restricted diets. According to Singh *et al*. (2016), low bulk density also allows for nutrient-dense foods that are more efficient in meeting dietary needs without contributing to excessiveness.

The swelling capacity significantly increased from 245 g/mL to 193.00 g/mL in the 83:5:12 blend. Foods with high swelling capacity tend to promote satiety, helping to regulate appetite and reduce overeating (Kaur *et al.*, 2019). This is particularly important in weight management, as it can prevent excessive caloric intake and contribute to long-term weight control strategies (Kaur *et al.*, 2019).

Table 2: Functional Properties of Biscuits Produced from Rice, Defatted Sesame Seed, and Carrot Flour Blends

Sample R:S:C	Oil Absorption (%)	Water Absorption Capacity (%)	Bulk Density (g/cm^3)	Form Capacity (%)	Swelling Capacity (%)
*100%	66.90^b±0.42	56.50^h±0.71	0.79^a±0.00	20.50^g±0.71	78.75^h±0.35
100% rice	71.15^a±0.35	100.50^g±0.71	0.43^c±0.00	19.50^h±0.71	85.95^{h}g0.35
92:5:3	50.50^d±0.70	119.50^f±0.71	0.46^b±0.01	30.50^f±0.71	145.80^f±0.42
87:10:3	44.6^e±0.56	132.50^e±0.71	0.44^b±0.05	50.5^b±0.71	156.02^e±0.46
82:15:3	38.70^g±0.42	185.50^d±0.71	0.44^b±0.01	70.50^a±0.71	166.25^d±0.49
89:5:6	21.70^h±0.42	193.50^c±0.71	0.42^c±0.00	39.50^e±0.71	183.02^c±0.31
86:5:9	41.72^f±0.39	209^b±0.71	0.41^d±0.00	44.5^d±0.71	188.02^b±0.31
83:5:12	61.75^c±0.35	224.50^a±0.71	0.41^d±0.00	49.50^c±0.71	193.00^a±0.28

* 100 % wheat flour. R = Rice, S= Sesame, C=Carrot. Values are mean ± standard deviation of duplicate determinations. Mean values in the same column followed by different superscript letters are significantly (p< 0.05) different

Physical Properties of Biscuits Produced from Rice, Defatted Sesame Seed, and Carrot Flour Blend Biscuits

Table 3 represents the results of the physical properties of the samples, which showed that the spread ratio and break strength increased with the addition of sesame (5-15 %) and the values ranged from 10.90 - 11.70 and 1939.85 - 2121.60 g respectively and also 11.88 - 12.97 and 2314.11-2478.50 g with increase in added carrot (6.12 %), respectively. The 100 % wheat had the lowest spread ratio (6.15) and the highest break strength (2,522.45 g). The physical properties of biscuits, such as length, height, spread ratio, weight ratio, and break strength ratio, provide information on the food product's structural integrity and palatability. The increase in the spread ratio and break strength of the produced flour blend biscuits is significant (p<0.05) and acceptable. These properties can influence the food's texture, making it more appealing and easier to handle during preparation. According to Zhang *et al.* (2018), the improved spreadability and structural integrity of complementary foods contribute to consumer acceptability, which is crucial for promoting the consumption of nutrient-rich foods.

Table 3: Physical Properties of Biscuits Produced from Rice, Defatted Sesame Seed, and Carrot Flour Blend Biscuits.

Sample R:S:C	Length(cm^3)	Width(cm^3)	Height (cm^3	Weight Ratio(g)	Break Strength Ratio
*100%	22.40^g±0.14	3.55^a±0.07	6.15^h±0.07	13.90^a±0.14	2522.45^a±4.03
100% rice	22.40^g±0.14	2.15^g±0.07	10.60^g±0.14	11.70^g±0.14	1825.25^h±3.89
92:5:3	22.10^f±0.14	2.45^e±0.07	10.90^f±0.14	11.85^f±0.07	1939.85^g±3.89
87:10:3	22.30^e±0.14	2.40^f±0.07	11.46^e±0.14	11.93^e±0.11	1998.98^f±4.00
82:15:3	22.50^d±0.14	2.45^e±0.07	11.70^d±0.14	12.10^d±0.14	2121.60^e±4.10
89:5:6	22.60^c±0.14	2.46^d±0.07	11.88^c±0.14	12.20^c±0.14	2314.11^d±0.82
86:5:9	22.65^b±0.14	2.55^c±0.07	12.80^b±0.14	12.35^b±0.14	2365.05^c±3.39
83:5:12	22.70^a±0.14	2.65^b±0.07	12.97^a±0.14	12.50^{ab}±0.14	2478.50^b±3.82

* 100% wheat flour. R = Rice, S= Sesame, C=Carrot. Values are mean ± standard deviation of duplicate determinations. Mean values within the same column followed by different superscript letters are significantly ($p < 0.05$) different

Chemical Composition of Biscuits Produced from Rice, Defatted Sesame Seed, and Carrot Flour Blend Biscuits.

Proximate properties of biscuits produced from rice, defatted sesame seed, and carrot flour blends.

The proximate properties of the biscuits produced from rice, defatted sesame, and carrots are summarized in Table 4. The crude protein, crude lipid, ash, and crude fibre increased from 7.45 % to 9.64 %, 13.63 % to 14.61 %, 1.71 % to 2.15 %, and 5.02 % to 5.43 %, respectively, with increasing levels of added defatted sesame paste (5-15%). However, the protein, lipid, and ash content decreased from 7.31 % to 6.79 %, 2.21 % to 2.00 %, and 1.51 % to 1.45 %, respectively, with a sharp increase in the fiber content (from 5.89 % to 6.32%) accompanying the addition of carrot flour (from 6 % to 12 %). This research aligns with the findings of Paul *et al.* (2024), which revealed that the addition of defatted sesame increased the amounts of crude protein, crude fibre, ash, and mineral content in complementary food. Moreover, the defatted flour has relatively good foaming, water absorption, and emulsification properties; however, it has reduced oil absorption and bulk density due to its high protein content. The decrease in the moisture content is within the acceptable level for stored food. A low moisture content is advantageous for the shelf life and microbial stability of the product, as it reduces the risk of spoilage. According to Beyene *et al.* *(*2018), foods with lower moisture content are less susceptible to microbial growth, making them more suitable for long-term storage and reducing the risk of foodborne illnesses.

The increase in protein content could be due to the high protein content in the defatted sesame. Protein is a critical nutrient for growth, immune function, and tissue repair. The increased protein content in the enriched blends will support better nutritional outcomes, especially in children and pregnant women, who have higher protein requirements (Micha *et al.,* 2017). Protein-rich diets also play a key role in muscle development and the maintenance of lean body mass, making this food blend suitable for all age groups. The crude fiber content increased from 5.01 % to 6.32 % in the 83:5:12 blend. Dietary fiber is crucial for maintaining digestive health, as it supports regular bowel movements and helps prevent constipation (Anderson *et al.*, 2016). A higher fiber content also helps regulate blood sugar levels and lower cholesterol, contributing to the prevention of cardiovascular diseases and type 2 diabetes (Anderson *et al*., 2016).

The relative increase in lipid content is vital for providing essential fatty acids and facilitating the absorption of fat-soluble vitamins such as A, D, E, and K (Kris-Etherton *et al*., 2020). The relatively low carbohydrate content is still within the acceptable level. This may indicate a shift towards higher-protein and lipid formulations, which are beneficial for products targeting specific dietary needs, such as those with higher protein content (Khan *et al.,* 2016). Carbohydrates provide quick energy but should be balanced with proteins and fats for a well-rounded diet. The increase in energy content from 389.86 kcal to 486.43 kcal suggests that the formulations become more energy-dense as the R:S ratio changes. A higher energy density can be beneficial for individuals requiring increased caloric intake, such as athletes or those with higher metabolic demands (FAO, 2022). However, attention should be paid to the overall macronutrient balance to ensure that energy is derived from a variety of sources (Oloyede *et al*., 2021).

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Table 4: Proximate Properties of Biscuit Produced from Rice, Defatted Sesame Seed, and Carrot Flour Blend

Sample R:S:C	Moisture (%)	Crude protein (%)	Crude lipid (%)	Ash (%)	Crude fiber (%)	Carbohydrate (%)	Energy (kcal)
*100%	$14.01^{a}\pm0.01$	$10.61^{a}\pm0.01$	$1.91^{f}\pm0.01$	$1.41^{f}\pm0.01$	$10.51^{a}\pm0.01$	$82.59^{b}\pm0.02$	$389.86^{g}\pm0.08$
100%	$7.49^{b}\pm0.01$	$7.31^{e}\pm0.01$	$2.21^{e}\pm0.01$	$1.06^{g}\pm0.01$	$4.01^{g}\pm0.01$	$85.97^{a}\pm0.04$	$292.85^{h}\pm0.06$
92:5:3	$0.96^{c}\pm0.00$	$7.45^{d}\pm0.01$	$13.63^{b}\pm0.01$	$1.71^{c}\pm0.01$	$5.02^{f}\pm0.01$	$81.29^{c}\pm0.02$	$477.53^{d}\pm0.04$
87:10:3	$0.74^{d}\pm0.00$	$8.54^{c}\pm0.01$	$14.12^{ab}\pm0.01$	$1.92^{b}\pm0.01$	$5.22^{e}\pm0.01$	$79.10^{f}\pm0.01$	$477.03^{e}\pm0.04$
82:15:3	$0.59^{e}\pm0.00$	$9.64^{b}\pm0.01$	$14.61^{a}\pm0.01$	$2.15^{a}\pm0.01$	$5.43^{e}\pm0.01$	$78.47^{g}\pm0.04$	$483.76^{b}\pm0.08$
89:5:6	$0.52^{f}\pm0.00$	$7.3^{ed}\pm0.01$	2.22d±0.01	$1.51^{e}\pm0.01$	$5.89^{d}\pm0.01$	$82.14^{d}\pm0.02$	$475.94^{f}\pm0.06$
86:5:9	$0.35^{g}\pm0.00$	$7.00^{f}\pm0.01$	$2.10^{c}\pm0.01$	$1.62^{d}\pm0.01$	$6.11^{c}\pm0.01$	$80.09^{e}\pm0.01$	$481.04^{c}\pm0.05$
83:5:12	$0.10^{h}\pm0.00$	$6.79^{g}\pm0.01$	$2.00^{b}\pm0.01$	$1.72^{c}\pm0.01$	$6.32^{b}\pm0.01$	$78.13^{h}\pm0.03$	$486.43^{a}\pm0.04$

* 100% wheat flour. R = Rice, S= Sesame, C=Carrot. Values are mean ± standard deviation of duplicate determinations. Mean values in the same column followed by different superscript letters are significantly ($p< 0.05$). different

Table 5: Mineral Composition of Biscuits Produced from Rice, Defatted Sesame Seed, and Carrot Flour

*100% wheat flour. R = Rice, S= Sesame, C=Carrot. Values are mean ± standard deviation of duplicate determinations. Mean values in the same column followed by different superscript letters are significantly ($p < 0.05$) different.

The mineral content of the biscuits produced from Rice, defatted sesame, and carrots is summarized in Table 4. The calcium, potassium, and phosphorus content of the produced biscuits increased from 3.05 to 4.13, 9.21 to 11.79, and 4.10 to 4.21 mg/100 g, respectively, with increasing defatted sesame addition (5-15%). Additionally, the addition of carrot flour (6-12%) increased the calcium, potassium, and phosphorus levels from 3.28 to 4.12, 9.43 to 10.75, and 3.92 to 4.06 mg/100 g, respectively. The relative increase in the assessed minerals could be due to the substantial levels of these minerals in the added defatted sesame and carrot. Considering calcium intake from complementary foods in children, the amount is vital for improving bone development, muscle contraction, and the proper functioning of the cardiovascular system (Paul *et al.*, 2024). Potassium is crucial for maintaining normal fluid balance, nerve transmission, and muscle contractions (Grillo *et al.*, 2019). It also helps lower blood pressure, reducing the risk of hypertension and stroke (Grillo *et al.*, 2019). Phosphorus is a critical component of bones, teeth, and cellular energy production. It also plays a role in DNA synthesis and repair (Murray *et al*., 2018), making it an essential nutrient for growth and cell regeneration.

Sensory Quality of Biscuits Produced from Rice, Defatted Sesame Seed, and Carrot Flour Blend

Sample R:S:C	Calcium (mg/kg)	Potassium (mg/kg)	Phosphorus (mg/kg)
* 100%	1.93^{g}±0.01	0.36^{f}±0.01	1.72^{e}±0.01
100% rice	2.49^{f}±0.01	4.78^{e}±0.01	2.91^{d}±0.01
92:5:3	3.05^{e}±0.01	9.21^{d}±0.01	4.10^{b}±0.01
87:10:3	3.59^{c}±0.01	10.50^{b}±0.01	4.11^{b}±0.01
82:15:3	4.13^{a}±0.01	11.79^{a}±0.01	4.21^{a}±0.01
89:5:6	3.28^{d}±0.01	9.43^{d}±0.01	3.92^{c}±0.01
86:5:9	3.70^{b}±0.01	10.09^{b}±0.01	3.96^{c}±0.01
83:5:12	4.12^{a}±0.01	10.75^{b}±0.01	4.06^{c}±0.01

The sensory attributes of biscuits produced from rice, defatted sesame, and carrots are presented in Table 6. The average means score for the taste, aroma, appearance, mouth feel, and overall acceptability ranged from 7.73-8.65, 7.55-9.60, 7.30-8.40, 7.53-9.65, 7.35-8.90, and 8.07-8.90, respectively, with an increase in added defatted sesame (5-15 %) and carrot flour (6-12 %). Generally, all the products have very high average scores. Taste scores increased from 7.73 to 8.65 in the enriched blends. The improved taste is due to the addition of S and C, making the food more palatable and enhancing consumer satisfaction, which is crucial for ensuring adherence to a nutrient-rich diet (Meilgaard *et al.*, 2015). The taste and aroma improved significantly, with the highest scores of 9.60 and 8.40 in the 83:5:12 blend. These sensory attributes are essential for consumer appeal and can influence the perceived quality of the food (Meilgaard *et al.*, 2015).

The overall acceptability of the enriched blend was high at 8.90, indicating that the addition of S and C not only improved the nutritional quality but also the sensory attributes, making the blend more likely to be consumed and integrated into daily diets.

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Table 6: Sensory Quality of Biscuits Produced from Rice, Defatted Sesame Seed, and Carrot Flour

Sample R:S:C	Taste	Aroma	Appearance	Mouth feel	Overall acceptability
* 100%	$8.20^{d}\pm0.89$	$7.70^{b}\pm0.80$	$7.80^{e}\pm1.32$	$7.50^{bc}\pm1.00$	$8.40^{c}\pm0.82$
100% Rice	$7.25^{f}\pm1.29$	$6.90^{c}\pm1.54$	$7.45^{f}\pm1.15$	$7.20^{d}\pm1.24$	$7.75^{d}\pm0.91$
92:5:3	$7.73^{e}\pm0.09$	$7.30^{bc}\pm1.19$	$7.53^{d}\pm1.24$	$7.35^{c}\pm1.12$	$8.07^{c}\pm0.87$
87:10:3	$7.80^{e}\pm1.17$	$7.65^{b}\pm1.66$	$7.62^{d}\pm2.04$	$7.75^{b}\pm1.33$	$8.65^{ab}\pm1.27$
82:15:3	$7.86^{e}\pm0.63$	$7.78^{b}\pm1.42$	$7.76^{d}\pm1.64$	$7.95^{b}\pm1.22$	$8.78^{ab}\pm1.40$
89:5:6	$8.35^{c}\pm1.16$	$7.85^{b}\pm1.79$	$7.89^{c}\pm1.54$	$8.20^{ab}\pm1.91$	$8.85^{b}\pm1.53$
86:5:9	$8.55^{b}\pm1.50$	$7.95^{b}\pm1.61$	$8.40^{b}\pm1.82$	$8.75^{a}\pm1.86$	$8.88^{a}\pm1.37$
83:5:12	$8.65^{a}\pm1.88$	$8.40^{a}\pm2.19$	$9.65^{a}\pm1.95$	$8.90^{a}\pm1.79$	$8.90^{a}\pm1.59$

* 100% wheat flour. R = Rice, S= Sesame, C=Carrot. Values are mean ± standard deviation of duplicate determinations. Mean values within the same column followed by different superscript letters are significantly ($p< 0.05$) different

CONCLUSION

The study has shown that acceptable biscuits with relatively improved nutritional value can be produced from blends of rice, defatted sesame, and carrot flour. The most preferred and acceptable flour blend biscuit is one containing 83 % rice, 5 % defatted sesame, and 12 % carrot flour. The findings highlight the potential of these enriched complementary blends to enhance the nutritional status of diverse populations, particularly those at risk of malnutrition, including children, pregnant women, and the elderly. The increased protein, fiber, and essential minerals in the blends can contribute to better health outcomes by addressing common nutrient deficiencies and promoting overall well-being. The study has shown that acceptable biscuits with relatively improved nutritional value can be produced from blends of rice, defatted sesame, and carrot flour. The most preferred and acceptable flour blend biscuit is one containing 83 % rice, 5 % defatted sesame, and 12 % carrot flour. The findings highlight the potential of these enriched complementary blends to enhance the nutritional status of diverse populations, particularly those at risk of malnutrition, including children, pregnant women, and the elderly. The increased protein, fiber, and essential minerals in the blends can contribute to better health outcomes by addressing common nutrient deficiencies and promoting overall well-being.

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HAEMATOLOGY AND SERUM BIOCHEMICAL RESPONSE OF WEST AFRICAN DWARF GOATS FED DIFFERENT GRASSES SUPPLEMENTED WITH PALM KERNEL CAKE AND CASSAVA PEELS

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ABSTRACT

This study was conducted to investigate the haematological and serum biochemical responses of West African Dwarf (WAD) goats to diets comprising different grass species supplemented with palm kernel cake (PKC) and cassava peels. Sixteen growing WAD goats were randomly allocated to four dietary treatments in a completely randomised design: T1 (Guinea grass only), T2 (Brachiaria Mulato II + PKC + cassava peels), T3 (Congo grass + PKC + cassava peels), and T4 (Guinea grass + PKC + cassava peels). Haematological and serum biochemical parameters of goats were measured to assess animal health and physiological response to experimental diets. Results indicated significant variation in packed cell volume (PCV), haemoglobin (Hb), white blood cell (WBC) count, and platelet count, with T4 yielding the highest WBC and platelet values, suggesting an improved immune status. Serum biochemical analysis revealed that T2 had significantly higher glucose, albumin, ALT, cholesterol, and ALP levels, indicating enhanced metabolic and liver function. In contrast, creatinine levels were highest in the control (T1), potentially reflecting lower protein utilisation. The findings indicate that the inclusion of PKC and cassava peels as feed supplements, particularly with Mulato II and Congo grass, can have a

positive influence on health indicators in WAD goats. The findings of this study provide evidence supporting the use of PKC and cassava peels as agro-industrial by-products in small ruminant feeding to reduce costs and enhance animal produc
Keywords: **West African Dwarf goats, Haematology, Serum biochemical indices, Palm kernel cake, Cassava peels, Forage supplementation**

INTRODUCTION

Nigeria has recognised the significance of ruminant production in livestock output (Aruwayo *et al*., 2015). Ruminants significantly contribute to Nigeria's livestock production and have distinct advantages over other livestock, including essential roles in the daily lives of rural households (Aruwayo *et al*., 2015). He further stated that in order of significance, small ruminants are primarily raised for their meat, milk, skin, and wool. Many developing nations rely heavily on goats (*Capra aegagrus hircus*) for their livestock economy. In 2014, the FAO estimated that there were 1,050 million goats in the world, with approximately 300 species identified. Goats have been domesticated worldwide for their meat, hides, milk, and hair. Bornu red, Kano brown, Bauchi type, and West African dwarfs are the main domestic goat breeds raised in Nigeria. The eastern and southern regions of the country are home to West African dwarfs raised for their meat, while the northern region is home to the others raised for their milk and meat.

Additionally, the West African dwarfs produce meat that tastes better than any other meat (FAO, 2008). The use of locally available feed sources aligns with the principles of sustainable agriculture by promoting resource efficiency and minimising feed cost (Ekeocha *et al.*, 2023). According to Aganga *et al.* (2005), supplementation of forages with concentrates is necessary to optimise production outcomes in small ruminants. The biofuel business produces palm kernel (*Elaeis guineensis*) cake (PKC), a by-product that is regularly available all year round when palm oil fruit oil is extracted. Palm kernel cake (PKC) is an excellent supplement for improving goats' diets because of its low cost. PKC will make ruminant production more economical and cost-effective by reducing the cost of feed for livestock. Forages such as grasses (*Digitaria debilis*, *Brachiaria ruziziensis*, *Panicum maximum, Mulato II*, etc.) are the primary source of feeds for ruminants to meet their nutritional requirements, either for maintenance or production (Dandara *et al.*, 2023a; Dandara *et al.*, 2023b; Bacorro *et al.*, 2025; Dandara *et al.*, 2025).

Natural pastures in Nigeria are generally high in fibre, low in protein and energy, and yet they form the primary source of animal feed in the country (FAO, 2019; Dandara *et al.*, 2023). These resources are overutilised to the extent that they fail to meet even the basic maintenance requirements of indigenous animals, especially when the dry season persists for extended periods. Forages have always provided the basis upon which ruminant nutrition is built (Dandara *et al.*, 2025). Ruminants can utilise a wide range of feed resources, but the bulk of their feed comes from forages; hence, they are primarily considered as forage consumers. In the tropics, the natural pasture, which supplies the bulk of ruminants' feed, becomes dry and of low nutritive value during the dry season, leading to a marked decrease in voluntary intake and digestibility. Over the years, remarkable improvements in forage cell wall digestibility have been achieved through forage breeding programs and agronomic advances. The plant becomes coarser and less digestible over time, with significant changes in key nutritional parameters. To maintain high forage quality, it is recommended that harvesting of forage grasses at early stages be practised, as the plant will have higher protein, lower fibre, and better overall digestibility at this stage (Dandara *et al.*, 2013a; Dandara *et al.*, 2025). The increasing cost and competition for conventional livestock feeds, such as maise and soybean meals, necessitate the exploration of alternative feed resources that are cost-effective and locally available (FAO, 2019). Therefore, there is a need for farmers to transition into pasture production to meet the nutritional requirements of their ruminant animals at a minimal cost compared to conventional feedstuffs. Jonah *et al.* (2024) studied the haematological parameters of West African Dwarf goats fed a mixture of cassava peels with groundnut husk supplement and reported improved haematological indices in goats fed a diet containing 50% Guinea grass and 27% cassava sievate. Ogunbosoye *et al.* (2022) reported that PKC and cassava peels improve protein metabolism and liver enzyme regulation. Blood indices are important indicators of farm animals' physiological performance, as they have shown the relationship between nutrition and health status of the animals (Jiwuba *et al.*, 2016). Hence, this study was designed to evaluate serum biochemical indices and haematological parameters of West African dwarf growing goats fed selected agro-industrial waste (PKC and cassava peels) with hay of different grasses.

METHODOLOGY

Experimental Area

The experiment was conducted at the Teaching and Research Farm of the Federal University Oye Ekiti, located on the Ikole Campus in Ikole Local Government Area, Ekiti State, Nigeria. Ekiti State lies between latitudes 7°15′ and 8°51′ North and longitudes 4°51′ and 5°45′ East of the Greenwich Meridian, situated just north of the Equator (NPC, 2006). The entire Ikole Local Government Area is located within the tropical rainforest zone of southwestern Nigeria. Its coordinates are approximately latitude 7°–8°15′ North and longitude 4°5′ East (Wikipedia, 2025).

Experimental Animals and Design

Sixteen growing West African Dwarf Goats were used in this research. The animals were purchased from Ikole market, Ekiti state. The animals were acclimatised for seven (7) days before the commencement of the study. The animals were randomly allocated to four (4) treatments (T1, T2, T3 and T4), with four goats per treatment in a Completely Randomised Design (CRD). Each treatment was replicated four times with one goat per replicate.

Harvesting and processing experimental diets

The forages were harvested from the pasture research plots of the university farm. Guinea grass, Mulato II and Congo grass forages were cut at 2cm above the ground level at pre-flowering stage, chopped at 3 cm long and wilted for 2-3hours in the sun and air dried under shade for four to five days by spreading on a concrete floor and turning thoroughly to facilitate uniform drying for saving storage to prevent bleaching and loss of nutrients. The hay was packed into different sacks and then stored. Cassava peels and palm kernel cake were purchased from garri and palm oil processing factories within the Ikole Local Government Area.

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Table 1: Experimental diets formulation

Diet/10kg	T1 (%)	T2 (%)	T3 (%)	T4 (%)
Guinea grass	100	-	-	60
Mulato II	-	60	-	-
Congo grass	-	-	60	-
Palm kernel cake (PKC)	-	20	20	20
Cassava peels	-	20	20	20
Total (%)	**100**	**100**	**100**	**100**

T1=Guinea grass only), T2= Mulato II + Palm kernel cake + cassava peels, T3= Congo grass +Palm kernel cake + cassava peels, T4= Guinea grass +Palm kernel cake + cassava peels

Haematological and biochemical analysis

Blood samples were collected at the end of the feeding trial. A new hypodermic needle and syringe (for each animal to avoid cross-contamination) were used to collect a 10 mL blood sample via the jugular vein from three randomly selected goats from each treatment. The blood samples were then discharged into a sterile plain bottle (5 mL) and an EDTA bottle (5 mL). For haematological analyses, blood samples were collected in vacutainers containing EDTA as an anticoagulant. For the serum biochemical analysis, blood samples were collected into vacutainers without anticoagulants, and serum was separated by centrifugation at 750 *g* for 15 min and stored in a freezer at -20 °C until use. Haematological analyses, packed cell volume PCV by the microcentrifuge method, haemoglobin, red blood cell count, white blood cell count, platelet count, lymphocytes, heterophils, monocytes, and eosinophils were analysed. For differential leukocyte counts, blood smears were prepared and stained with Giemsa (Jain, 1986). The total protein was measured by the Biuret method, albumin by the bromcresol green method, total globulin by the difference of total protein and albumin, and cholesterol by a modified Abell-Kendall/Levey-Brodie (A-K) method. Triglyceride was measured by the enzymatic procedure of McGowan *et al.* (1983), glucose by the glucose oxidase method, AST and ALT activities by the colourimetric method of Reitman and Frankel, LDH by the Sigma colourimetric (Cabaud-Wroblewski) method, and ALP by the modified method of Bowers and McComb.

Data Analysis

Data on haematology and serum biochemistry were analysed using a General Linear Model (GLM) with Type III Analysis of Variance (ANOVA) (SAS, 2010). Differences among means were separated using Tukey's honest significant difference (HSD).

RESULTS AND DISCUSSION

Haematology of West African Dwarf Goats (WAD) Fed Guinea grass, Mulato II and Congo grass Supplemented with Palm Kernel Cake and Cassava Peels

The results of haematology are presented in Table 1, which shows that there were significant differences in some haematological parameters, including packed cell volume (PCV), haemoglobin (Hb), white blood cell (WBC) count, and Platelet Count. The experimental animals were fed Guinea grass only in Treatment 1(control), Mulato II supplemented with Cassava peels and Palm Kernel Cake (T2), Congo grass supplemented with Cassava peels and Palm Kernel Cake (T3), and Guinea grass supplemented with Cassava peels and Palm Kernel Cake (T4). In terms of PCV (%), treatment 1 (Guinea grass fed only) recorded the highest value of 27.0, while in HB, treatments 1, 2, and 3 shared similar significant values of 9.5, 8.8, and 8.2, respectively. Furthermore, the result showed that treatment 4 showed the highest significant values in WBC and platelets. However, there were no significant differences in Lymphocytes, heterophils, monocytes and eosinophils among the experimental treatments. Ajayi *et al.* (2021) and Ezenwa *et al.* (2023) linked higher WBC with improved immune function in supplemented ruminants. There was no significant difference ($P < 0.05$) in lymphocytes, heterophils, or eosinophils, indicating no immune suppression across treatments. Red blood cell counts (RBC) between 7.75-13.82 x 10^6/mm^3 have been observed in goats fed similar diets, indicating healthy erythropoiesis (Falola and Olufayo (2024); Jonah *et al.*, 2024), and the values observed in the current study fall between the range there by indicating healthy erythropoiesis in the experimental animals in all the treatments. Falola and Olufayo (2024) and Jonah *et al.* (2024) further revealed that a White blood cell count (WBC) ranging from 9.78 to 13.48 x 10^3/mm^3 suggests a healthy immune system. Jonah *et al.* (2024) studied the haematological parameters of West African Dwarf goats fed a mixture of cassava sievate with groundnut husk supplement and reported improved haematological indices in goats fed a diet containing 50% Guinea grass and 27% cassava peels.

This showed that cassava peels supplementation improves haematological indices as observed in this study. Both the reported literature and the current studies demonstrate that West African Dwarf goats can tolerate diets supplemented with palm kernel cake and cassava peels, with haematological parameters within normal ranges.

Table 1: Haematology of West African Dwarf Goats Fed Guinea grass, Mulato II and Congo grass Supplemented with Palm Kernel Cake and Cassava Peels.

Parameters	Treatments				*P-value*	SEM
	T1	T2	T3	T4		
PCV (%)	27.0^{a}	26.0^{ab}	24.0^{c}	25.0^{bc}	0.031	0.289
HB (g/dL)	9.5^{a}	8.8^{a}	8.2^{a}	6.4^{b}	0.013	0.252
RBC ($\times 10^6/\mu L$)	3.64	4.21	3.82	3.12	0.519	0.250
WBC ($\times 10^3/\mu L$)	15600^{c}	16800^{b}	14400^{d}	18100^{a}	0.001	55.902
PLATELET ($\times 10^3/\mu L$)	130000^{b}	117000^{c}	128000^{b}	182000^{a}	0.004	763.763
LYM (%)	60.0	60.0	54.0	53.0	0.326	1.627
HET (%)	26.0	30.0	33.0	33.0	0.345	1.465
MON (%)	3.0	3.0	3.0	3.0	1.000	0.289
EOS (%)	4.0	5.0	4.0	6.0	0.112	0.289

Means on the same row with different superscripts were significantly (P<0.05) different.
PCV=Parked cell volume, HB=Hemoglobin, RBC=Red blood cell count, WBC=White blood cell count, PLATELET=Platelet count, LYM=Lymphocytes, HET=Heterophils, MON=Monocytes, EOS=Eosinophils
T1=Guinea grass only), T2= Mulato II + Palm kernel cake + cassava peels, T3= Congo grass +Palm kernel cake + cassava peels, T4= Guinea grass +Palm kernel cake + cassava peels, SEM=Standard error of mean.

Serum Biochemistry of West African Dwarf Goats Fed Guinea grass, Mulato II and Congo grass Supplemented with Palm Kernel Cake and Cassava Peels

The results of the serum biochemistry are presented in Table 2. The result revealed that there was significant difference (P<0.05) in the serum biochemistry which treatment 2 recorded the highest significant values in glucose (Gluc), alanine aminotransferase (ALT), albumin (ALB), cholesterol (CHOL), UREA and alkaline phosphatase (ALP) as 196.7, 21.3, 1.1, 158.0, 4.5 and 108 respectively. There was a statistical similarity between treatments A and B in terms of ALT and CHOL; furthermore, treatments 1 and 3 showed a similarity in high-density lipoprotein (HDL). However, treatment 1 recorded the highest significant difference in creatinine and low-density lipoprotein (LDL), at 1.0 and 30.4, respectively. There was no significant difference (P > 0.05) between all treatments in terms of total protein (TP) and globulin (GLOB). The values are optimal, indicating a well-functioning liver and metabolic status, as revealed by Gabriel *et al.* (2023) and Jonah *et al.* (2024). Creatinine was higher in T1 (1.0 mg/dl), possibly due to lower protein intake and metabolic inefficiency. There was no significant difference (P > 0.05) in total protein and globulin across all treatments. The results of this study aligned with the findings of Ogunbosoye *et al.* (2022), who reported that PKC and cassava peels improve protein metabolism and liver enzyme regulation. Another survey by Adebisi *et al.* (2023) reported enhanced serum metabolites in West African Dwarf rams fed *Panicum maximum* supplemented with *Cajanus cajan* foliage hay.

Table 2. Serum biochemistry of West African Dwarf Goats Fed Guinea grass, Mulato II and Congo grass Supplemented with Palm Kernel Cake and Cassava Peels.

Parameters	Treatments				*P-value*	SEM
	T1	T2	T3	T4		
Glucose (mg/dL)	180.0^{ab}	196.7^{a}	170.0^{b}	174.0^{b}	0.058	3.008
Aspartate (U/L)	172.0	184.0	175.0	184.0	0.157	2.051
ALT (U/L)	22.0^{a}	21.3^{a}	18.0^{b}	19.0^{b}	0.002	0.264
Total protein (g/dL)	5.1	4.3	3.8	4.0	0.449	0.289
Albumin (g/dL)	1.0^{ab}	1.1^{a}	0.8^{c}	0.9^{bc}	0.014	0.025
Cholesterol (mg/dL)	159.0^{a}	158.0^{a}	140.0^{b}	150.0^{ab}	0.037	2.051
Globulin (g/dL)	4.2	4.0	3.8	3.6	0.894	0.289
Urea (mg/dL)	4.0^{ab}	4.5^{a}	3.1^{ab}	2.15^{b}	0.083	0.289
ALP (U/L)	94.0^{c}	108^{a}	98.0^{b}	28.0^{d}	0.001	0.289
Creatinine (mg/dL)	1.0^{a}	0.8^{b}	0.6^{c}	0.6^{c}	0.003	0.022
HDL (mg/dL)	23.0^{a}	19.0^{c}	24.0^{a}	21.0^{b}	0.001	0.289
LDL (mg/dL)	30.4^{a}	28.1^{b}	27.2^{b}	26.3^{b}	0.005	0.289

Means on the same row with different superscripts were significantly (P<0.05) different.
ALT=Alanine aminotransferase, UREA=Blood urea nitrogen, ALP=Alkaline phosphatase, HDL=High density lipoprotein, LDL= Low density lipoprotein, T1=Guinea grass only), T2= Mulato II + Palm kernel cake + cassava peels, T3= Congo grass +Palm kernel cake + cassava peels, T4= Guinea grass +Palm kernel cake + cassava peels, SEM=Standard error of mean.

CONCLUSION AND RECOMMENDATION

Feeding West African Dwarf goats with Mulato II, Congo grass, and Guinea grass, supplemented with palm kernel cake and cassava peels, significantly improved haematological indices and serum biochemical parameters, which reflect an enhanced immune response and protein metabolism. The use of PKC and cassava peels as alternative feed resources offers a cost-effective and nutritionally viable strategy for improving the health and productivity of WAD goats. Such interventions hold significant potential for promoting sustainable small ruminant production systems in Nigeria. Farmers should be encouraged to supplement goat feed with grasses like Mulato II or Congo, or guinea, with diets containing palm kernel cake and cassava peels to improve their health status. Research on optimal feed combinations and farmer training in sustainable practices could also be prioritised. This approach enhances nutrition while reducing reliance on expensive feeds. Adopting these strategies will boost productivity and support resilient goat farming systems

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PERCEIVED BENEFITS AND CONSTRAINTS OF URBAN TREE PLANTING IN MINNA, NIGER STATE, NIGERIA

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ABSTRACT

This study assesses the environmental benefits of tree species in Minna, the capital of Niger State, Nigeria. A total of 100 questionnaires were randomly administered across four purposely selected towns within two major local government areas (LGAs): Bosso and Chanchaga. The chosen towns were Tunga and Maitumbi in Bosso LGA, and Tudun Wada and Sabon Gari in Chanchaga LGA. Twenty-five questionnaires were distributed across age and sex in each town, with 92 retrieved for analysis. Data were analysed using descriptive statistics, including frequency distribution tables and percentages. Results indicated that the majority of respondents (45.7%) were aged 21–30 years, with 56.5% male and 43.5% female. Identified tree species include Azadirachta indica, Mangifera indica, Terminalia catappa, Moringa oleifera, and Parkia biglobosa, among others. Preferred characteristics include fast growth (28.1%), deep rooting *systems (23.4%), and aesthetic value (20.3%). Key benefits include erosion control (18.2%), recreation (16.8%), and aesthetic enhancement (15.4%). Constraints include high maintenance costs (18.1%), pest and disease harbouring (16.7%), and litter production (16.7%). Urban tree planting is recommended as a strategy to mitigate ecological challenges, with a call for greater public sensitisation to address environmental hazards driven by urbanisation and industrialisation.*

Keywords: tree species, environment, benefits, constraints, characteristics

INTRODUCTION

Urban forestry is a critical strategy for addressing the multifaceted challenges of urbanisation, particularly in rapidly urbanising regions like Niger State, Nigeria, where high temperatures and seasonal variations exacerbate environmental stress (Babalola, 2010). Urban trees provide ecosystem services, including microclimate regulation, air purification, noise reduction, biodiversity conservation, and aesthetic enhancement (Jiang, 2003). In Minna, the capital of Niger State, trees are planted to mitigate heat, reduce evaporation from water bodies, and enhance urban landscapes, aligning with global trends that recognise urban green spaces as vital for sustainable development (Roy *et al.,* 2012). Trees also provide provisioning services, such as shade, fruit, fuelwood, and non-timber forest products, supporting local livelihoods and environmental resilience (Adenle *et al*., 2020).

The importance of urban trees extends to global environmental functions, such as carbon sequestration and mitigation of urban heat island effects (Nowak *et al*., 2013). In Nigeria, rapid urbanisation has intensified the need for urban forestry to address erosion, flooding, and air pollution (Agbelade *et al*., 2016). Studies in North-western Nigeria, such as Zaria, highlight the carbon storage potential of urban trees, with species like *Azadirachta indica* and *Mangifera indica* contributing significantly (Dangulla *et al*., 2021). However, urban forestry faces challenges, including inadequate policy frameworks, limited public awareness, and high maintenance costs (Popoola, 2018). In semi-arid regions like Niger State, climatic conditions and resource limitations exacerbate these issues (Moussa, 2019).

Globally, urban trees improve mental health, reduce stress, and enhance property values (Houlden *et al*., 2018). In African contexts, studies in Lagos and Ibadan show that urban trees provide provisioning and cultural services but are unevenly distributed, reflecting socio-economic inequalities (Adeyemi and Shackleton, 2024a). In Niger State, urban forestry initiatives, such as schoolyard tree planting, emphasise educational and climate resilience benefits (Adamou, 2025). Therefore, the objectives of the study were to assess urban forestry development in Minna, identify prevalent tree species, evaluate their benefits and constraints, and provide recommendations for sustainable management.

METHODOLOGY

The study was conducted in Minna, the capital of Niger State, Nigeria, encompassing Bosso and Chanchaga LGAs. Niger State is located between latitudes 8°20'N and 11°30'N and longitudes 3°30'E and 7°20'E, sharing boundaries with Kaduna, Kebbi, Zamfara, Kogi, Kwara, and the Federal Capital Territory. The mean annual temperature ranges from 24°C to 28°C, with rainfall lasting 150–180 days annually, ranging from 1200 mm to 1600 mm. Relative humidity ranged from 20% to 50% during the dry season. The vegetation is characterised as Guinea savanna, with a mix of grasses, shrubs, and trees (Adenle *et al.,* 2020).

Primary data were collected using structured questionnaires distributed among residents of the selected communities. A reconnaissance survey identified areas with high concentrations of urban trees, guiding the selection of study sites.

A multi-stage sampling technique was employed. Two LGAs (Bosso and Chanchaga) were purposively selected based on urban tree prevalence. Two towns per LGA were chosen: Tunga and Maitumbi (Bosso), and Tudun Wada and Sabon Gari (Chanchaga). A total of 100 questionnaires were randomly distributed, with 25 per town, stratified across age and sex. Ninety-two questionnaires were retrieved for analysis.

Data were analysed using descriptive statistics, including frequency distribution tables and percentages, to summarise socio-economic characteristics, tree species, benefits, and constraints.

RESULTS

Socio-Economic Characteristics

The socio-economic profile of respondents influences their preferences for urban tree planting. Table 1 presents the characteristics of the sampled population. It shows that 45.7% of respondents were aged 21–30 years, indicating an economically active population. Males comprised 56.5%, suggesting greater involvement in tree planting. Education levels were high, with 54.3% having secondary education and 21.7% having tertiary education. Married respondents dominated (67.4%).

Table 1: Socio-Economic Characteristics of Sampled Respondents

Variable	Frequency	Percentage(%)
	Gender	
Male	52	56.5
Female	40	43.5
	Age	
10 – 20	5	5.4
21 – 30	42	45.7
31 – 40	28	30.4
41 – 50	13	14.1
50 - above	4	4.3
	Education	
Primary	14	15.2
Secondary	50	54.3
Tertiary	20	21.7
No formal education	8	8.7
	Marital Status	
Married	62	67.4
Single	24	26.1
Widow	4	4.3
Divorced	2	2.2
Total	92	100.0

Environmental Tree Species and Their Families

A variety of tree species were identified in Minna, including both planted and naturally occurring trees. Table 2 lists the major species and their families and indicates that Azadirachta indica (9.5%) and Mangifera indica (8.2%) were the most common species, likely due to their fast growth and fruit production (Adeyemi and Shackleton, 2024a). Other prevalent species include Terminalia catappa (7.8%) and Moringa oleifera (7.4%), valued for shade and medicinal uses (Faleyimu, 2014).

Characteristics of Identified Urban Tree Species

Respondents' preferences for tree species were influenced by specific characteristics, as shown in Table 3. Fast growth (28.1%) and deep rooting systems (23.4%) were the most valued characteristics, supporting the preference for species like Azadirachta indica and Gmelina arborea (Faleyimu, 2014). Aesthetic value (20.3%) was also significant, reflecting the cultural importance of trees in urban settings (Adeyemi and Shackleton, 2024b).

Table 2: Identified Tree Species in the Study Area and Their Families

Tree Species	Family	Percentage (%)
Azadirachta indica	Meliaceae	9.5
Mangifera indica	Anacardiaceae	8.2
Terminalia catappa	Combretaceae	7.8
Moringa oleifera	Moringaceae	7.4
Parkia biglobosa	Mimosaceae	6.9
Gmelina arborea	Verbenaceae	6.5
Psidium guajava	Myrtaceae	6.1
Anacardium occidentale	Anacardiaceae	5.8
Adansonia digitate	Malvaceae	5.3
Citrus sinensis	Rutaceae	5.0
Vitellaria paradoxa	Sapotaceae	4.7
Delonix regia	Fabaceae	4.3
Tamarindus indica	Fabaceae	4.0
Carica papaya	Caricaceae	3.7
Ficus sycomorus	Moraceae	3.3
Khaya senegalensis	Meliaceae	3.0
Polyalthia longifolia	Annonaceae	2.8
Borassus aethiopum	Arecaceae	2.5
Persea Americana	Lauraceae	2.3
Gliricidia sepium	Fabaceae	2.0
Eucalyptus camaldulensis	Myrtaceae	1.7
Casuarina equisetifolia	Casuarinaceae	1.5
Balanites aegyptiaca	Zygophyllaceae	1.2
Total	260	100.0

Table 3: Characteristics of Tree Species in the Study Area

Characteristic Exhibited	Frequency	Percentage (%)
Fast growing	36	28.1
Rooting system	30	23.4
Aesthetic characteristics	26	20.3
Coppicing ability	18	14.1
Large crown size	14	10.9
Evergreen ability	10	7.8
Total	128	100.0

Benefits Derived from Urban Tree Species

Urban trees provide multiple ecosystem services, as illustrated in Figure 1. Erosion control (18.2%) and recreation (16.8%) were the most cited benefits, aligning with Kaduna's findings (Ogunkalu *et al.*, 2015). Trees like Mangifera indica and Parkia biglobosa provide fruits and seeds, while Terminalia catappa enhances aesthetics (Rouchiche, 2009).

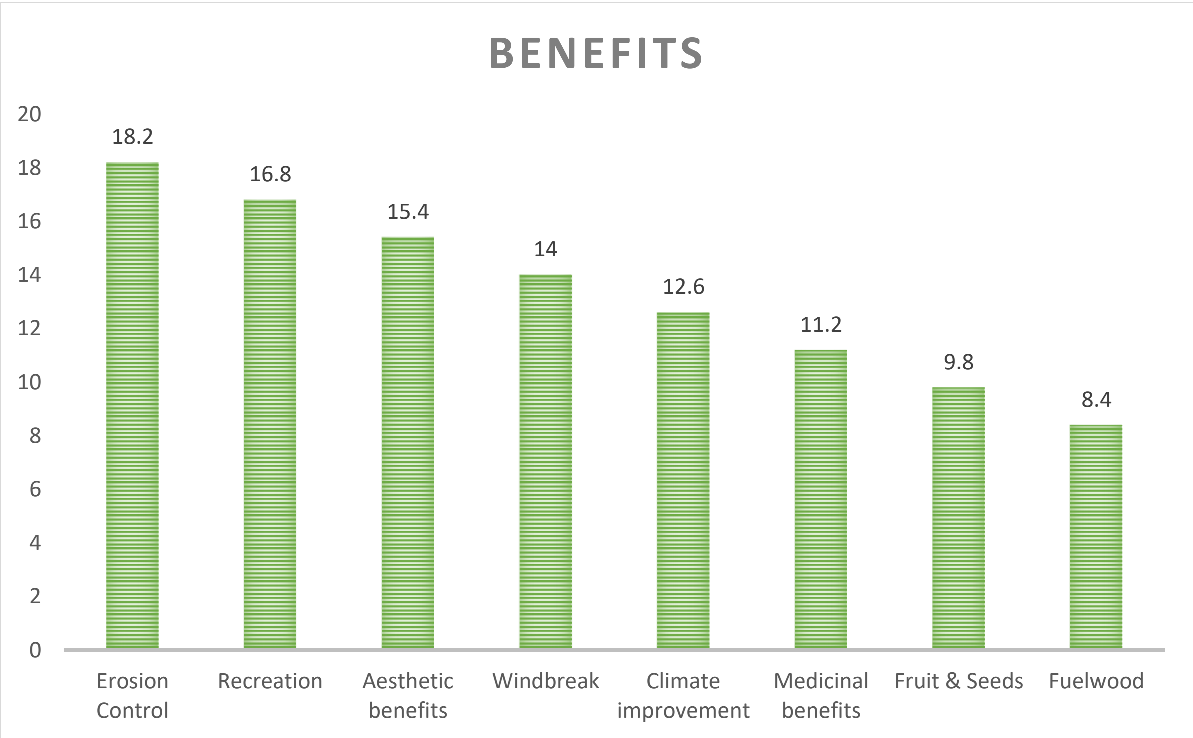

Figure 12: Distribution of Perceived Benefits of Urban Trees

Constraints of Urban Trees

Table 4 highlights the constraints associated with urban trees in Minna. High maintenance costs (18.1%) and pest/disease issues (16.7%) were the primary constraints, consistent with findings in other Nigerian cities (Popoola, 2018). Litter production (16.7%) was also a significant concern, particularly in densely populated areas.

Table 4: Identified Constraints Associated with Urban Trees

Constraints	Frequency	Percentage (%)
Expensive to maintain	30	18.1
Harbors pests and diseases	28	16.7
Litter constitutes dirt	28	16.7
Seasonal variation (weather)	25	15.1
Harbors dangerous animals	22	13.3
Constitutes threat later in life	18	10.8
Serves as hideout for thieves	15	9.0
Difficult to get desired species	10	6.0
Total	100.0	166

DISCUSSION

The findings from this study highlight the critical role of urban trees in enhancing environmental quality and urban livability in Minna, Niger State. The demographic profile of respondents, dominated by young adults aged 21–30 and individuals with secondary and tertiary education, points to a potentially responsive and informed population that can be actively engaged in future urban forestry initiatives. This aligns with Agbelade *et al*. (2016), who emphasised the importance of demographic and educational factors.

The dominance of species such as *Azadirachta indica*, *Mangifera indica*, and *Terminalia catappa* suggests a preference for trees that provide multiple ecosystem services, including shade, fruit yield, aesthetic appeal, and rapid growth. These species have been widely acknowledged in Nigerian urban forestry studies (Dangulla *et al*., 2021) for their resilience, economic value, and capacity to thrive in tropical urban conditions. Respondents' emphasis on desirable characteristics such as fast growth (28.1%) and deep-rooting systems (23.4%) further underlines the functional priorities of urban dwellers, especially in regions prone to erosion and flooding. These preferences align with previous findings by Faleyimu (2014), who reported that urban populations in southwestern Nigeria prioritised trees with physical traits that provide both ecological stability and rapid greening. The benefits derived from urban trees in this study, ranging from erosion control and recreation to aesthetic and nutritional values, highlight the multi-dimensional utility of urban forestry in developing contexts. Similar patterns have been observed in studies across Africa, including Lagos and Ibadan (Adeyemi and Shackleton, 2024b), where urban trees were found to support food security, temperature regulation, and social cohesion.

However, the study also revealed several constraints to urban tree sustainability in Minna, notably high maintenance costs (18.1%), pest and disease incidence (16.7%), and litter production (16.7%). These constraints are typical of unmanaged urban green spaces and are corroborated by findings in Akure and Kaduna (Popoola, 2018; Ogunkalu *et al*., 2015). They point to the need for targeted interventions such as selecting low-maintenance species and promoting biological pest control.

Seasonal variation (15.1%) was also identified as a constraint, reflecting the vulnerability of urban vegetation to climatic extremes in semi-arid regions such as Niger State. As emphasised by Moussa *et al*. (2019), this challenge requires selecting drought-tolerant native species and integrating tree watering schemes during dry spells to ensure survival and continuity. In addition, socio-political factors, including limited government investment and weak enforcement of urban greening policies, may compound the physical constraints reported by respondents. Strengthening municipal frameworks, incentivising community participation, and integrating urban forestry into broader land-use planning are therefore essential for overcoming these barriers.

Overall, the study underscores the dual nature of urban forestry in Minna as both an opportunity for environmental enhancement and a domain requiring strategic planning and investment. Public awareness campaigns, participatory tree-planting programs, and integration of indigenous knowledge could further enhance tree survival, reduce conflict, and promote sustainable urban environments.

CONCLUSION

Urban tree planting in Minna is a viable strategy to mitigate ecological challenges such as erosion, heat, and flooding, exacerbated by rapid urbanisation. The study identified diverse tree species, with *Azadirachta indica* and *Mangifera indica* being the most prevalent due to their fast growth and multiple benefits. However, constraints like maintenance costs and pest issues hinder adoption. To enhance urban forestry, establish shelterbelts in erosion-prone areas, intensify public sensitisation about the ecological and economic benefits of urban trees, and promote low-maintenance, native species to reduce costs and pest risks.

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SHORT COMMUNICATION

SUITABILITY OF YAM FLOUR FOR ON-FARM FLOATING FEED PRODUCTION

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ABSTRACT

Fish feed is a critical component in aquaculture, accounting for 60-80% of operational costs, particularly for small-scale farmers in Nigeria. This study explored the incorporation of yam flour as a replacement for wheat flour in the production of on-farm floating fish feeds. Five feeds were formulated and compounded at 30 % and 40 % crude proteins at varying replacement levels of wheat flour with yam flour designated as feed 1 (25 %YF/75 %WF), feed 2 (50 %YF/50 %WF), feed 3 (75 %YF/25 %WF), feed 4 (100 %YF), and feed 5 (100 %WF.). Ten pellets were randomly selected and tested for buoyancy for 60 minutes. The data obtained were analysed using descriptive statistics, with a bar chart. The results showed that the combination of 25% yam flour and 75% wheat flour gave 100% flotation for 60 minutes. This combination is recommended for on-farm floating feed production.

Keywords: Replacement, pellet, buoyancy

INTRODUCTION

Extruded fish feed has many vital uses in the aquaculture sector, including its high physical and nutritional value (Sørensen, 2012). Complete fish feed diets must contain nutrients; the main nutrients are protein, starch, fat, and crude fibre. Among nutrients, starch provides energy for fish and also serves as a floater to facilitate the expansion of the feed (Sørensen *et al.,* 2010). Fish is regarded as an excellent source of dietary protein, vitamins, fats and minerals that are important to the human diet for the maintenance of good health, it is also responsible for about 55 % of protein intake sources in worldwide (FAO, 2022), fish is a viable source of income and food to a large populace in developing nations such as Nigeria (Abiodun, 2003). The majority of fish farmers in Nigeria are small-holder semi-intensive (Adekola, 2001). As the aquaculture sector continues to grow, demand for formulated feeds and protein is increasing (Hua *et al.,* 2019). High-quality feeds are too expensive; they also accounted for 60-80% of production costs (Fu, 2005; Sá *et al.,* 2007; Orire and Sadiku, 2014). To achieve the maximum yield of fish, feed requires appropriate ingredients and processing techniques (Tiamiyu and Solomon, 2012). Different qualities of fish feed, including pellet shape, size, water-absorption quality, density, softness or stability, and floating time, may affect feed quality. Yam flour has the important features of gelatinization and non-crystallization (Colonna *et al*., 1984; Gomez and Aguilera, 1984; Chevanan *et al.,* 2007). They act as a binder, playing an important role in both floating and sinking fish feed (Orire *et al.*, 2010; Solomon *et al.*, 2011). The minimum requirements of yam flour for sinking and floating feed are 18% to 22% and 5% to 11%, respectively (Riaz, 1997). Pellets absorb water, becoming soft, but must maintain their shape for 2 hours until the fish consumes them.

Therefore, this research was carried out to assess the suitability of yam flour for on-farm floating feed production, and to investigate the replacement level of wheat flour with yam flour that produces the best feed buoyancy.

MATERIALS AND METHODS

Experimental Materials

The materials used in this experiment include fish meal, wheat flour, baker's yeast, yam flour, a plastic spoon, bowls, warm water, a sensitive weighing scale, and hand-pelleting machines.

Experimental Site

The research was carried out at the Department of Water Resources, Aquaculture and Fisheries Technology Laboratory, located at the School of Agriculture and Agricultural Technology, Federal University of Technology, Minna, Niger State.

Source of Feed Stuffs

Yam tubers, wheat flour, vegetable oil, and baker's yeast were purchased from Kure Ultra-Modern market, Minna, Niger State, while fish meal was purchased from the fish meal store in Minna.

Processing of Yam Flour

Two kg of tubers of the variety *Discorea rotundata* (white yam) were washed with portable water, peeled, washed, cut into smaller chips (150g), and parboiled at 50 °C. The parboiled samples were soaked in portable water for 12 h and then dried under the sun for 5 days. The dried yam chips were milled into flour, sieved using 0.25 0.25-micrometer sieve, and were subjected to analysis (Orire *et al*., 2010)

Proximate Analysis

Proximate analysis for crude protein, moisture, lipids, and ash content was carried out for both ingredients and pelleted feeds according to the AOAC (1980) method in the Water Resources Aquaculture and Fisheries Technology Laboratory (Table 1).

Feed Preparation and formulation.

The Pearson Square method was used to formulate eight feeds containing 30% and 40% crude protein (Salihu and Orire, 2020). They were compounded by the addition of a proportion part mix of yam flour, wheat flour, fish meal, and baker's yeast at 5% for all the feeds. Yam flour was used to replace wheat flour at 0%, 25%, 50%, 75% and 100% for 30% and 40% crude protein feeds (Tables 2 and 3).

Warm water at 60°C was added to the feedstuffs to produce a semi-solid dough, which was then pelleted using a pelleting machine. The sun-dried pellets were kept in a sealed plastic container for later buoyancy analysis (Adekunle *et al*., 2014).

Feed Buoyancy Test

The floating ability of pellets was evaluated for 1 hour. Five pellets were randomly selected, placed in a 250ml beaker with 150ml of fresh water, and the degree of floatation was recorded every 5 minutes for 1 hour (Orire *et al*., 2012).

Statistical Analysis

The results were subjected to descriptive statistics using a bar chart to determine significant differences among the mean treatments.

Table 1: Proximate Compositions of the Feed Ingredients

Feed Stuffs	Crude Protein (%)	Moisture (%)	Ash (%)	Crude Lipid (%)
Fish meal	59.06	5.99	7.88	16.15
Wheat flour	14.44	7.33	1.45	3.19
Yam Flour	4.38	3.95	1.10	2.60
Yeast	40.69	3.33	2.10	0.60
Palm Oil	12.25	8.98	1.45	2.10

Table 2: Formulated Feeds at 30% Crude Protein Level Containing Varying Replacement of Wheat Flour with Yam Flour

Feedstuff (%)	Feed 1 (100WF)	Feed 2 (25%YF 75%WF)	Feed 3 (50%YF 50%WF)	Feed 4 (75%YM 25%WF)	Feed 5 (100%YF)
Fishmeal	56.62	56.62	56.62	56.62	56.62
Wheat flour	33.38	24.54	16.69	8.84	0.00
Yeast	5.00	5.00	5.00	5.00	5.00
Yam flour	0.00	8.84	16.69	24.54	33.38
Vitamin-mineral premix	5.00	5.00	5.00	5.00	5.00
Total	100	100	100	100	100

Table 3: Formulated Feeds at 40% Crude Protein Level at Varying Replacement Levels of Wheat Flour with Yam Flour

Feedstuff (%)	Feed1 (100WF)	Feed2 (25%YF 75%WF)	Feed3 (50%YF 50%WF)	Feed4 (75%YM 25%WF)	Feed5 (100%YF)
Fishmeal	38.43	38.43	38.43	38.43	38.43
Wheat flour	51.57	41.92	24.28	9.65	0.00
Yeast	5.00	5.00	5.00	5.00	5.00
Yam flour	0.00	9.65	27.28	41.92	51.57
Vitamin-mineral premix	5.00	5.00	5.00	5.00	5.00
Total	100	100	100	100	100

RESULTS

Figure 1 indicates the floatability test for 30% crude protein feeds with varying replacement levels of wheat flour with yam flour. As shown in Figure 1, 100% wheat-flour-based feed and 25% WF/75% WF feed both achieved 100% floatability for 60 minutes. Feed with 75%YF/25%WF had an 80% floatation rate for 60 minutes, while the 50%YF/50%WF replacement level exhibited 50% floatability for 60 minutes. The 100% YF-based feed gave a 20% floatation percentage for 35 minutes.

Figure 2: indicates the floatability test for 40% crude protein feeds at varying replacement of wheat flour with yam flour. The feed containing 25%YF/75%WF maintained 80% floatability for 60 minutes, while 50%YF/50%WF maintained 40% floatability for 60 minutes. Moreover, at 75%YF/25%WF, the performance dropped to 20% for 60 minutes. However, 100% WF-based pellets gave 100% floatability for over 60 minutes.

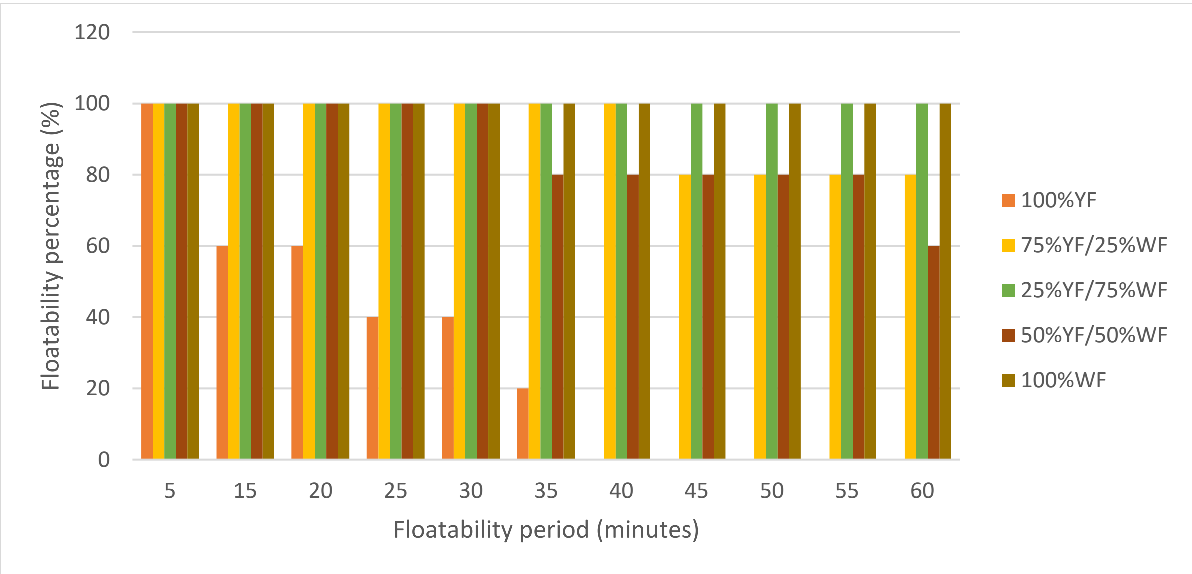

Figure 1: Floatability Performance for 30% Crude Protein Feed at Varying Replacement Level of Wheat Flour with Yam Flour

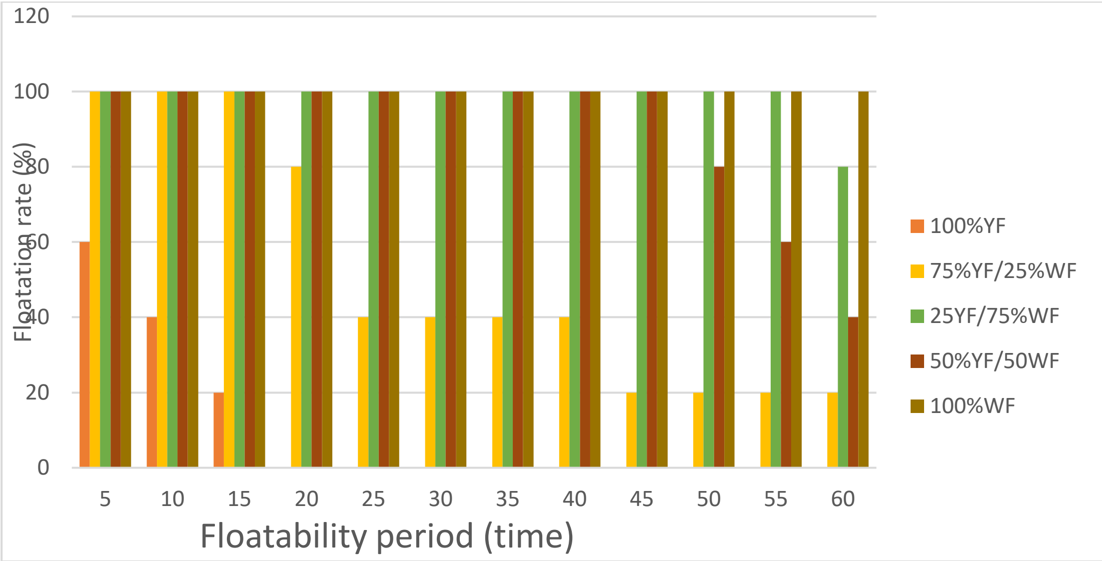

Figure 2: Floatability Performance for 40% Crude Protein Feed at Varying Replacement Level of Wheat Flour with Yam Flour

DISCUSSION

The results of the experiment showed that floatability tests for 30% and 40% crude protein feeds, at varying replacement levels of yam and wheat flour, are promising for on-farm floating feed. Pellets containing a high percentage of yam flour had lower floatation percentages than wheat-based feeds. Wheat flour has moderate to high buoyancy due to its gluten content (Akintoye *et al.*, 2020). This property holds the ingredients together, thereby contributing to pellet buoyancy. The 25% YF/75% WF feed gave the best flotation for 30% and 40% crude protein feeds. The pellets maintained 100% floatability for 60 minutes with 30% crude protein and for 55 minutes with 40% crude protein; however, the decrease i.12n floatation rate observed with 40% crude protein could be due to a higher protein density. This agrees with the work of Salihu and Orire (2020), who reported high floatability with feed of a lower crude protein level. For the 50% YF/50 WF feed, flotation performance declined gradually to 100% across all treatments, irrespective of oil protein level. The 75% YF/25% WF also indicates a reduced flotation percentage of up to 20%. Yam flour-based floating feed at 100% inclusion level performed poorly despite being a starchy product, but its non-glutinous nature could be responsible for poor floatation. The feed absorbed water quickly and sank faster during the buoyancy test. The high water-absorption capacity of yam flour can cause the pellets to become waterlogged and sink more rapidly. The 100 % floatability was maintained in 100 % wheat-based diets throughout the study periods, and the 30% and 40% crude protein diets were attributed to the pellets' water stability. This finding is consistent with the report by Fashina *et al.* (2019), which found that better feed stability was achieved with gelatinized wheat binders. Thus, combining yam flour at 25% and 75% with wheat flour achieves a high feed floatability. Higher inclusion of yam flour, up to 75%, can cause the feed to absorb water quickly and sink.

CONCLUSION

The yam flour on its own may not contribute significantly to the production of buoyant feed unless it is combined with wheat flour at a 25 % replacement level.

RECOMMENDATION

It is therefore recommended that the yam-to-wheat-flour ratio be optimized at a ratio 25 %:75 % beyond which there will be reduced pellet floatation.

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SHORT COMMUNICATION

FACTORS INFLUENCING MAIZE FARMERS' PARTICIPATION IN ANCHOR BORROWERS' PROGRAMME IN FUNTUA AND DANJA LOCAL GOVERNMENT AREAS OF KATSINA STATE

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ABSTRACT

The study examined the factors influencing maize farmers' participation in the Anchor Borrowers' programme (ABP) in Funtua and Danja Local Government Areas of Katsina State, Nigeria. Data were collected using a purposive and random sampling technique. The data were collected during the 2022 maize farming season using a structured questionnaire and analyzed using descriptive statistics and a Tobit regression model. The results showed that sex, household size, cooperative society, extension contact, farm size, and input cost significantly ($p<0.05$) influenced the level of maize farmers' participation in the programme. 46 % had moderate ease of access to fertilizer and improved seed varieties, while access to agrochemicals and market linkages was low. However, maize farmers' credit repayment rates are generally low, with over 86 % of farmers reporting low repayment rates. The likelihood index ratio indicated that the specified factors in the model explained 67 % of the total variation in participation. Farmers were constrained by inadequate finance and poor disbursement timing. The government should continue to support

the programme, address the challenges it faces, and expand its reach to more farmers, while also addressing the identified challenges to encourage participation in ABP..
Keywords: Maize farmers, participation, Anchor Borrowers' Programme.

INTRODUCTION

Maize (*Zea mays* L.), also known as corn, is one of the world's major crops. In Nigeria, maize is cultivated across the country, especially in Northern Nigeria. It is the fourth most consumed cereal after sorghum, millet, and rice, and a valuable source of carbohydrates, protein, vitamin B, iron, and other minerals (Girei *et al*., 2018). Globally, according to the United States Department of Agriculture (USDA), (2022), it was estimated that the total world production of maize was 1,161.86 Million Metric Tons (MMT), against the 1,216.8 MMT estimated in 2021 with a decrease of 55 MMT, In Nigeria, about 12 MMT of maize were produced from 4.8 million hectares, making Nigeria the second highest producer in Africa (FAO, 2022). According to the Mundi Index, maize consumption in Nigeria in 2022 stood at 12.7 MMT. The United States Department of Agriculture's grain report also revealed that Nigeria's midyear maize production in 2023 was 12 MMT, a 0.5 percent increase from the 11.5 MMT forecast in 2019. Yields are still low (i.e., 2.9 MT/ha) in the Nigerian savannas compared to those obtainable in other parts of the world (Osabohien ***et al***., 2020)**.**

Over the years, Poor economic conditions continue to impair rural households' living standards. In areas where rising population and non-agricultural uses compete for land, the returns to land in terms of output have been declining (Girei *et al.* 2018). Given the importance of maize to Nigeria, efforts are continually made to increase yields per unit area and expand areas where it can be grown to meet the demand for maize from a growing population, for both food and industrial use. A larger proportion of farmers in Nigeria are smallholder farmers who earn their livelihoods through production on small plots of land. For these households, access to inputs and improved production methods is quite critical to their livelihoods. A maize farmer's livelihood may depend on the availability and access to inputs such as seed, agrochemicals, fertilizer, agricultural tools, and cash for labour needed for maize production. Since independence, the governments of Nigeria have formulated numerous programmes and strategies to promote the growth and development of agriculture. These measures included the setting up of large-scale mechanized farms by the State and Federal Government, the introduction of schemes such as the River Basin Development Authority (RBRDA), National Accelerated Food Production Programme (NAFPP), Operation Feed the Nation (OFN), Green Revolution Programme (GRP), and Directorate of Food, Road, and Rural Infrastructure (DFRRI). National Fadama Development Project (NFDP), National Economic Empowerment Development Strategy (NEEDS), Agricultural Transformation Agenda (ATA), Special Programme for Food Security (SPFS), and National Poverty Eradication Programme (NAPEP). All these were aimed at improving agricultural production, increasing crop output, enhancing the living standards of rural people, and ensuring food security.

The Anchor Borrowers' Programme (ABP) was initiated in 2016 to complement other agricultural programmes in Nigeria. ABP aimed to provide farm inputs to smallholder farmers through loans to produce major agricultural commodities across the country, such as maize, wheat, cotton, roots and tubers, sugarcane, and tree crops, among others (CBN, 2016). For administrative convenience, these farmers are organized into groups/cooperatives of 5 to 20 people, and they are given inputs in the form of seed and fertilizer loans in kind. It is largely driven and coordinated by the private sector (primarily among private financial institutions: Deposit Money Banks, Development Finance Institutions, and Microfinance Banks). The Anchor (private large-scale integrated processors) have agreed to off-take the produce at agreed prices or as may be reviewed, and finally input suppliers (CBN, 2016). In view of this, the study investigated the level of participation and the factors affecting participation in the Anchor Borrowers programme by Funtua and Danja LGA Maize farmers.

METHODOLOGY

The study was conducted in Funtua and Danja Local Government Areas of Katsina State, Nigeria. Both Local Government Areas are among the major maize-producing areas in Katsina State. Funtua Local Government lies between Latitude 11'25N and 11034'N, and Longitudes 7016'E and 7022'E. It covers an estimated land area of 448 square kilometres and has a population of 225,156 people (NPC, 2006), with a population growth rate of 3.7%, projected to reach 402,400 in 2023.

Danja Local Government Area of Katsina State, in the Northern Guinea Savanna agroecological zone of Nigeria. The zone lies between Latitude 11o2'N and 11o1'N, Longitudes 7o30 and 7o40E. It covers an estimated land area of 504.7 square kilometres and has a population of 125,481 (NPC, 2006), with a population growth rate of 3.7%, and a population projection of 224,300 in 2023. The State is predominantly Hausa-speaking communities, and they practice the Islamic religion, with huge populations in and around the towns of Funtua, Bakori, Danja, and Dandume. The Hausa are culturally and historically closest to other Sahelian ethnic groups.

Occupationally, the people of Katsina State are farmers and traders, thereby making food and cash crops flourish and grow in abundance. The most common food staples consist of sorghum, millet, rice, and maize, which are ground into flour for a variety of dishes. The economic activity in Funtua and Danja LGAs is agriculture, and small-scale farmers undertake the bulk of agricultural production.

Primary data were collected using a structured questionnaire and a personal interview. A reconnaissance survey was conducted to locate villages with intensive maize production and Anchor Borrowers Programme activities. Purposive sampling was used to select two Local Government Areas in the State, and maize farmers were identified with the assistance of the Katsina State Agricultural Development Agency (KTARDA) and extension agents in the zone. A simple random sampling technique was used to select 10% of the participating farmers' sample frame, yielding a sample of 271. In comparison, 10% of the total population of non-participating maize farmers were also randomly selected to form a sample of 234, bringing the total sample to 505 participating and non-participating maize farmers to ensure equal chances of selection and interview. Descriptive statistics and the Tobit regression model were used for the analysis.

TOBIT REGRESSION MODEL

This was used to estimate the factors affecting maize farmers' participation in ABP. The regression model was expressed as:

$Yi = f(X_i, \beta) + e_i$

$Yi = \beta_0 + \beta i Xi + Ui > 0$……………………………………………………………..1

$Yi = 0$ if $\beta_0 + \beta iXi+Ui \leq 0$

$Yi = \beta_0 + \beta_1+ \beta_2X_1+\beta_3+X_2+ \beta_4X_3+ \beta_5X_4 + \beta_6X_5+ \beta_7X_6+ \beta_8X_7+\beta_9X_8 + \beta_{10}+X_9+ X_{10}$.....2

Where:

Y = Level of farmers participation (Using index of participation i.e level of accessibility each farmers has divided by the total number of the items).

β_0 = constant

β_1 - β_{10} = Regression coefficients

X_1= Age of the farmer (in years)

X_2 = Sex of the farmer (Male = 1, Female = 2)

X_3 = Marital status (Married = 1, otherwise 0)

X_6 = Educational level (years of schooling)

X_5 = Household size (Number of Individual)

X_7 = Farming experience (years)

X_8 = Membership of association (years spent)

X_9 = Extension contact (number of extension visits)

X_{10} = Access to credit (actual amount received in naira)

U = error term

RESULTS AND DISCUSSION

The results of the level of maize farmers' participation in the Anchor Borrowers' programme indicated that less than half of the farmers have moderate access to fertilizer and improved seed, with about 46% and 48%, respectively. It further revealed that maize farmers' access to agrochemicals is limited: 45% use some form of agrochemical, while 49% have limited market linkages for their produce. However, maize farmers' credit repayment rates are generally low, with over 86% of farmers reporting low repayment rates. However, Ajibola *et al*. (2020) observed that participation in the ABP was low, with only 44% of respondents participating. This finding is at variance with those of Adebayo e*t al.* (2021), who reported that participation was relatively high, with approximately 60% of maize farmers participating in the programme.

In examining the factors influencing participation in ABP in the study areas, the sigma values for the participants were statistically significant at the 1 % level. The chi-square value indicated overall model significance at the 1 % level ($p < 0.01$), suggesting good explanatory power for the specified model's variation. A pseudo-R^2 value of 0.66 indicates that the model explains 66% of the variation in programme participation. The result revealed that of the six variables included in the tobit regression model, sex, household size, cooperative society, extension contact, farm size, and input cost are statistically significant factors that influence the level of maize farmers' participation in the programme.

Table 1: Distribution of farmers based on their level of access in the programme intervention

ABP programme activities	Low		Medium		High		Mean score	Remarks
	Freq.	%	Freq.	%	Freq.	%		
Fertilizers	113	41.7	125	46.1	33	12.2	0.42	Moderate
Improved seed	108	39.9	129	47.6	34	12.5	0.43	Moderate
Agro chemical	122	45	118	43.5	31	11.4	0.411	Low
Access to market	133	49.1	113	41.7	25	9.2	0.391	Low
Repayment of credit	235	86.7	0	0	36	13.3	0.276	Low
Grand Mean score							0.386	

Note: Index: Low (0.00-0.40), medium (0.41- 0.60), high (0.61-1.00)

The coefficient for sex was positive and significant at 10 %, indicating that male farmers participate more than female farmers due to their inability to meet the landholding requirement of 1-2 hectares, as well as cultural norms and traditions that keep women in seclusion (pudda). The marginal effect (0.0587 %) indicates that, with other variables kept constant, the probability of maize farmer participation in ABP will increase by 0.05 % with a unit change in sex. Household size was found to be negative and significant at 5 % level of probability. This implies that the larger the household size, the less the participation in ABP. Households with higher incomes appear less likely to participate in the development programme; those with more labour are more likely to participate (Ngugi *et al*., 2003). Similarly, the coefficient for extension contact showed a positive and significant relationship with the probability of farmers' participation in ABP at the 5% level. There was a positive and significant (1 %) relationship between membership in a cooperative society and farmers' participation in ABP. This implies that cooperatives could offer their members financial assistance and capacity-building to take part in opportunities that enhance their livelihoods.

Farm size was positively and significantly associated with 5 %. This reveals that farmers with large farms are more likely to participate in ABP than those with small farm land. However, Audu (2018) observed that larger farms require higher crop yields. There was a negative relationship between input costs and farmers' participation in ABP, which was significant at the 5% level. This implies that any increase in input costs will reduce farmers' involvement in ABP. This finding aligns with Adebayo, Salisu, and Awolabi (2021), who found that the cost of inputs supplied by the ABP remained too high for maize farmers to participate actively.

Table 2: The coefficient of socio-economic and institutional Factors affecting the level of farmers' participation in ABP

Variable	Coefficient	Standard error	T-value	Marginal effects
Constant	0.5898	0.0960	6.141	
Sex	0.0587*	0.0306	1.920	0.0587
Age	-0.0004	0.0018	-0.242	-0.0004
Marital status	-0.0149	0.0276	-0.540	-0.0149
Education	-0.0046	0.0077	-0.605	-0.0046
Household size	-0.0059**	0.0026	-2.270	-0.0059
Farming experience	0.0006	0.0017	0.336	0.0006
Cooperative society	0.1200***	0.0322	3.728	0.1200
Extension contact	0.0748**	0.0328	2.277	0.0748
Farm size	0.0311**	0.0127	2.455	0.0311
Amount of credit received	0.0366	0.0367	0.997	0.0366
Input cost	-0.0307*	0.0166	-1.848	-0.0307
Sigma squared	0.0355***	0.0031		
Log likelihood	67.63			
LR $chi^2(11)$	35.69			
Prob > chi^2	0.000			
Pseudo R^2	0.657			

*Note: ***, ** and * significant at 1 %, 5 % and 10 % levels of probability*

CONCLUSION AND RECOMMENDATIONS

The overall level of participation in ABP in the study areas was impressive, as the programme intervention showed that participating farmers had moderate access to fertilizer and improved seed. In contrast, access to agrochemicals, market linkages, and repayment rates was low. It was found that sex, household size, cooperative society, extension contact, farm size, and input cost were the factors that significantly influence the level of farmers' participation in the ABP programme in the study area.

Extension workers should educate farmers on the significance of forming and strengthening farmer groups, as these collectively enhance participation in the Anchor Borrowers' Programme (ABP). The study highlights that cooperative societies positively impact the level of farmer involvement in the ABP, underscoring the role of farmer groups in facilitating access to vital information, inputs, and markets.

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DEVELOPMENT OF SUBMERGENCE TOLERANCE RICE FROM SEGREGATING POPULATION OF CROSSES OF SWARNA *SUB-2* GENE WITH TWO MAJOR COMMERCIAL RICE VARIETIES IN NIGERIA

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ABSTRACT

Flooding remains one of the most significant challenges in rice cultivation in Nigeria; therefore, the experiment aimed to develop flood-tolerant rice varieties from crosses between flood-tolerant rice and high-yielding susceptible cultivars. Three parents were used in the cross combination of FAROs 44 and 57, with Swarna Sub-2 as the male parent. The crosses were performed to generate F1 hybrids, which were selfed to produce the F2 generation. The F2 were evaluated in a randomised complete block design in three replications. Parameters such as plant height, tiller count, and percentage survival were recorded. Results showed highly significant differences among the treatments. Plant height increased after submergence, but tiller count decreased in most progenies and the parents. Heritability values ranged from 29% (Plant height before submergence) to 71% tiller count after submergence. The percentage survival after submergence varied from 36.37% (FARO 57) to 69.70% (FARO 44 X Swarna sub-2). The progeny FARO 44 X Swarna sub-2 could be a better option for flood tolerance in flood-prone areas.

Keywords: Flooding, Rice, Submergence, Tolerance

INTRODUCTION

Rice (*Oryza sativa* L.) has become a strategic commodity across most African countries (AfricaRice, 2020). Driven by changing food preferences in both urban and rural areas and compounded by high population growth rates, rice consumption in the Sahel and sub-Saharan Africa (SSA) increased by 5.6% per annum between 2009 and 2012, a rate more than double the population growth rate (AfricaRice, 2020). Rice is a staple food for billions of people worldwide, including in Nigeria, where over half of the population depends on it as a primary source of food (Mayowa *et al*., 2025). In 2008, world rice production was 661 million tons from 155.7 million ha (PWC, 2017). Of these, Asian farmers produced about 600 million tons, representing more than 90% of global rice production. India and China together accounted for 341 million tons, with India producing 148 million. A recent report indicates that in 2023, Nigeria's milled rice production was estimated at 5.2 million metric tons (Mayowa *et al.*, 2025)

Rainfed lowland rice production, which accounts for more than 70% of total rice area in Nigeria, is prone to recurrent flooding caused by heavy rainfall or the overflow of nearby rivers. This often leads to yield losses ranging from 10% to total crop loss (Bashir *et al.*, 2018). In 2012, when Nigeria experienced the worst flooding in 40 years, floods reduced rice production by about 22% (UNDRR, 2017). Flooding is expected to be increasingly problematic under global warming, as studies by AfricaRice on future rice climates projected massive increases in overall precipitation in north and northwest Nigeria (Africa Rice, 2017). Most rice varieties can get severely damaged or killed within a week of severe flooding. Depending on the intensity of flooding, it can reduce yield or prolong the growth duration, and in extreme cases, it can cause total crop loss. The only possible solution to this problem is the use of flood-tolerant varieties.

The available flood-tolerant rice varieties (FARO 66 and 67) in Nigeria are less adopted by Nigerian farmers due to low yields, limited tolerance (< 10 days), and grain quality (NCRI, 2020). The parental lines (FARO 52 and 60) used to develop the varieties contributed to the adoption rate, as they are not major farmers' varieties. The 2020 survey conducted by NCRI revealed the extent of farmers' requests for submergence varieties with the characteristics of FARO 44 and FARO 57 (Most Preferred commercial Rice Varieties in Nigeria). Improving the ability of two rice plants to survive under flooding conditions by studying the genetics underlying the mechanism remains a major constraint for sustainable local rice production in unstable environments undergoing climate change (NCRI, 2017). Previous studies have reported the successful development of submergence-tolerant varieties by introgressing the Sub1 locus (Oladosu *et al.*, 2020). However, in all the studies, background parentage has shown a significant influence on the nature of the progeny and its characteristic features. Thus, it is important to develop more submergence-tolerant varieties using major farmers' cultivars as parents. Therefore, this research aimed to develop fixed lines of flood-tolerant genotypes suitable for flood-prone areas. This will enhance yield levels in farmers' fields and improve food security.

MATERIALS AND METHODS

Study location. The study was conducted at the National Cereals Research Institute (NCRI) in the Badeggi rice field. NCRI Badeggi lies within latitude N09o 04.238′ and longitude E 006o 06.638′. NCRI receives an average annual rainfall of about 1184mm, with temperatures ranging from 25.9 to 31.1 ^{0}C and a relative humidity of about 77 % (Ehirim, 2023)

Sources of Experimental Materials

The parent materials used for the study were three *Oryza sativa* lines, of which one is a donor parent line (Swarna Sub-2), already developed as tolerant to submergence, and the other two are susceptible parents to submergence (FARO 44 and 57). These two susceptible parents are commercially released and highly cultivated in Nigeria. The materials were collected from the NCRI breeding Unit in Badeggi.

The F1 hybrids were developed by crossing Swarna Sub-2, a donor parent, with two commercially released varieties, FARO 44 and FARO 57, in 2024. The F1 was advanced to F2. The progenies of F2 were evaluated under submerged conditions for 14 days of flooding after transplanting, when the plants were 21 days old, in the year 2025.

Experimental design and layout

The trial was carried out in a randomised complete block design with three replications. The three parents were planted alongside the F2 test entries, replicated three times. Each entry was planted in a 1-metre row, with plants spaced 20 cm apart.

Screening of the Crosses under Submergence Conditions

The crops were raised in a nursery bed and transplanted after 21 days. Each stand was planted with a single seedling**.** Submergence screening was performed under controlled conditions, with flooding to a depth of 1.0 meters for 14 days. The crops were de-submerged, and plant survival was scored after 20 days of recovery, as described by Pamplona *et al.* (2007).

Data Collection.

The following data were collected

i. Percentage Survival of the Test Entries = $\frac{Number\ of\ Seedling\ Survived}{Number\ of\ Seedling\ Transplanted} \times 100$

ii. Percentage Survival of the Resistant Entries = $\frac{Number\ of\ Seedling\ Survived}{Number\ of\ Seedling\ Transplanted} \times 100$

iii. Plant height (cm): The length from ground level to the tip of the longest panicle was measured at maturity.

iv. Number of tillers per plant: The number of tillers per plant was counted for each genotype at maturity. All the tillers were counted for both before and after submergence.

Crosses and their numbering

T1= FARO 44 X Swarna sub-2

T2= FARO 57 x Swarna sub2

T3= FARO 44 X Swarna sub-2

T4= FARO 57 x Swarna sub2

T5= FARO 44 X Swarna sub-2

T6= FARO 57 x Swarna sub2

T7= FARO 44 X Swarna sub-2

T8= FARO 57 x Swarna sub2

T9= FARO 44 X Swarna sub-2

T10= FARO 57 x Swarna sub2

T11= FARO 44

T12= Swarna sub 2

T13= FARO 57

Data analysis

Phenotypic and Genotypic Coefficient of Variation

The formula suggested by Singh and Chaudhary (1985) was followed for the computation of the Phenotypic and Genotypic coefficients of Variation among the generations.

Genotypic coefficient of variation (GCV) = $\frac{\sqrt{\sigma_g^{2}}}{\overline{X}} \times 100$

Phenotypic coefficient of variation (PCV) = $\frac{\sqrt{\sigma_{ph}^{2}}}{\overline{X}} \times 100$

Where:

σ_g^{2} = Genotypic variance

σ_{ph}^{2} = Phenotypic variance

$\overline{X}$ = Mean

RESULTS

Table 1 shows the results of plant and tiller count before and after submergence. There were significant differences among the treatments for both plant height and tiller count. Plant height before submergence showed that T11 was the tallest, followed by T1, and was significantly taller than the other three treatments. Height after submergence also showed significant differences, with T11 being the tallest and differing significantly from the others, except T2 and T4. There was a progressive increase in height after submergence. Tiller count before submergence showed significant differences, with T12 having the highest number of tillers, followed by T9 and T2, which were significantly different from the others. Tiller count after submergence also showed significant differences among the treatments, with T7 having the highest number of tillers and being significantly equal to T3, T5, and T9.

Table 1: Plant height (cm) and tiller count before and after submergence of rice at Badeggi

Treatment	Plant height before submergence (cm)	Plant height after submergence (cm)	Tiller count before submergence	Tiller count after submergence
T1	61.47a	83.62bc	6.83h	8.97cd
T2	56.17bc	87.37ab	10.42abc	9.00cd
T3	61.02ab	84.59bc	8.58efg	9.68abc
T4	60.90ab	86.97ab	9.90bcd	9.30bc
T5	57.75abc	75.60d	9.25cdef	9.68abc
T6	54.89c	84.21bc	8.38fg	9.70abc
T7	58.10abc	75.96d	9.83bcde	10.70a
T8	57.23abc	85.42bc	8.67defg	8.20d
T9	58.83abc	83.47bc	10.63ab	10.15ab
T10	49.80d	86.02bc	10.07bc	9.52bc
T11	61.62a	91.33a	8.80defg	9.25bcd
T12	59.66abc	81.76c	11.60a	6.50e
T13	57.82abc	65.25e	7.80gh	6.50e
Mean	58.10	82.43	9.29	9.01
SE±	2.41	2.38	0.61	0.51
CV	5.08	3.53	8.04	6.99
Sig Level	**	***	***	***

Means with the same letters are significantly the same at $P < 0.05$, LSD

Table 2 shows the effect of submergence on plant height and tiller number. Plant height increased progressively as plants increased under water. However, the tiller count decreased after submergence. The change in plant height (After - Before) is statistically significant for all 13 treatments ($P< 0.05$). The positive Mean Difference indicates that plant height increased after the submergence period in all treatments, suggesting that growth occurred through elongation in the submerged condition. The change in tiller count (After - Before) is statistically significant only for treatments T1, T11, and T12.

Table 2: T-test comparison of plant height and tiller number before and after submergence

Treatment	Trait	Mean Difference	t-statistic	p-value	Significant (alpha=0.05)
T1	Plant Height	22.1500	8.5832	0.0133	Yes
T1	Tillers	2.1333	4.7571	0.0415	Yes
T2	Plant Height	31.2050	17.2259	0.0034	Yes
T2	Tillers	-1.4167	-1.3567	0.3077	No
T3	Plant Height	23.5667	25.5310	0.0015	Yes
T3	Tillers	1.1000	1.5466	0.2620	No
T4	Plant Height	26.0700	12.1533	0.0067	Yes
T4	Tillers	-0.6000	-0.6694	0.5722	No
T5	Plant Height	17.8500	5.7972	0.0285	Yes
T5	Tillers	0.4333	1.1855	0.3576	No
T6	Plant Height	29.3200	18.7252	0.0028	Yes
T6	Tillers	1.3167	2.1144	0.1688	No
T7	Plant Height	17.8600	4.8375	0.0402	Yes
T7	Tillers	0.8667	0.8810	0.4713	No
T8	Plant Height	28.1867	11.9996	0.0069	Yes
T8	Tillers	-0.4667	-0.6793	0.5670	No
T9	Plant Height	24.6400	14.1391	0.0050	Yes
T9	Tillers	-0.4833	-0.7804	0.5169	No
T10	Plant Height	36.2167	13.1614	0.0057	Yes
T10	Tillers	-0.5500	-0.4795	0.6789	No
T11	Plant Height	29.7100	25.4173	0.0015	Yes
T11	Tillers	0.4500	5.1962	0.0351	Yes
T12	Plant Height	22.1000	439.0820	0.0000	Yes
T12	Tillers	-5.1000	-8.3843	0.0139	Yes
T13	Plant Height	7.4300	49.3872	0.0004	Yes
T13	Tillers	-1.3000	-1.7321	0.2254	No

Result of Table 3 indicates that plant height before Submergence (PH bf S) had a much higher environmental variance (14.14) than Genotypic Variance (5.87), Plant Height after Submergence (PH af S) showed a significantly higher genotypic variance (42.33) compared to Environmental Variance (8.12), Tillers (Before and after Submergence) both tiller traits showed Genotypic Variance notably higher than environmental variance, similar to plant height after submergence.

The traits Plant Height After Submergence (PH af S), Tillers Before Submergence (TIL bf S), and Tillers After Submergence (TIL af S) all showed high heritability and high or moderate GAM.

Table 3: Genotypic variances for plant height and tiller count before and after submergence

Trait	Mean	Genotypic Variance	Environmental Variance	Phenotypic Variance	H^2	GCV (%)	PCV (%)	Genetic Advance (GA)	GAM (%)
PH bf S	58.10	5.87	14.14	20.01	0.29	4.17	7.70	2.70	4.65
PH af S	82.43	42.33	8.12	50.46	0.84	7.89	8.62	12.28	14.89
TIL bf S	9.29	1.48	0.53	2.01	0.74	13.09	15.27	2.15	23.13
TIL af S	9.01	1.41	0.57	1.98	0.71	13.17	15.62	2.06	22.89

Table 4 presents the results for plants that survived after submergence for 14 days. The result shows highly significant differences among the test entries. The progeny T9 had the highest survival percentage (69.70%) and was only significantly different from T5. The least surviving plant is T13 (36.37%), which is FARO 57.

Table 4: Percentage survival of rice plants after 14 days of submergence

Treatment	Survival count	Survival percentage
T1	34.00bc	61.80bc
T2	32.67bcd	59.43bcd
T3	32.33cd	58.80cd
T4	28.00ef	50.90ef
T5	36.33ab	66.07ab
T6	29.33de	53.33de
T7	34.00bc	61.83bc
T8	32.33cd	58.77cd
T9	38.33a	69.70a
T10	30.33cde	55.17cde
T11	24.67f	44.87f
T12	29.00de	52.70de
T13	20.00g	36.37g
Mean	30.87	56.13
SE±	1.97	3.39
CV	7.41	7.39
Sig. level	***	***

Means with different letter in a column are significantly different at $P < 0.05$

DISCUSSION

Flooding of rice fields has been one of the most devastating environmental factors affecting rice production and yield. Genetic variances were observed among the entries scored. This indicates the progenies' ability to respond differently to submergence. The plant's height increased in most progenies and the parents; this might be due to plant elongation under flood stress. Rice plants escape from a flooded condition by elongating their internodes. Similar results were reported by Ja'a far *et al.* (2025), who found that stem elongation occurs in most varieties when exposed to submergence for 14 days. The authors also noted that the escape strategy involves elongation of the stem as found in IR 64. The number of tillers decreased sharply after submergence and varied among the test progenies. They showed some segregation and genetic variation among the progenies. Percentage survival was moderate in some progenies and very low in the susceptible parents. This indicates that tolerant genes might have been transferred to the progenies. Ehirim *et al.* (2023) observed survival rates ranging from 0% to 100% in crosses between Swarna-sub1 and commercial varieties in Nigeria. Among all the mitigating measures, developing tolerant rice varieties has been prioritised as a sustainable strategy that can reduce the impact of the submergence problem in the major rice production areas of the country

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