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EVALUATION OF SELECTED RICE (*ORYZA SATIVA L.*) GENOTYPES FOR RATOONING POTENTIAL AND YIELD STABILITY ACROSS DIFFERENT ENVIRONMENTS

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ABSTRACT

Ratoon rice production offers an opportunity to increase rice productivity by utilizing the regrowth of harvested plants, thereby reducing production costs and shortening the cropping cycle. This study evaluated the ratooning potential and yield stability of five rice (*Oryza sativa* L.) genotypes across two environments in Niger State, Nigeria. Field experiments were conducted during the wet season at Badeggi and Edozhigi using a randomized complete block design with three replications. The genotypes evaluated were FARO 44, FARO 67, MADU YANKPA, WALUYE, and YANDA GWASHE. Data were collected on phenological, growth, and yield-related traits for both the main and ratoon crops and analyzed using analysis of variance, while treatment means were separated using Fisher's Least Significant Difference (LSD) test at the 5% probability level.

Significant ($P \leq 0.05$) genotypic differences were observed for most of the measured traits, indicating substantial genetic variability among the evaluated genotypes. Grain yield was consistently lower in the ratoon crop than in the main crop; however, the genotypes differed significantly in their ability to sustain productivity after harvest. FARO 67 produced the highest grain yield in both the main crop (3,207.20 kg ha^{-1}) and ratoon crop (822.25 kg ha^{-1}) and exhibited the greatest yield stability across environments. MADU YANKPA was the earliest flowering genotype, indicating its suitability for short-duration production systems. The significant genotype × environment interaction for grain yield demonstrated differential genotype responses across locations. Overall, FARO 67 combined superior grain yield, ratooning ability, and yield stability, making it a promising genotype for cultivation and for use in breeding programmed aimed at improving ratoon rice productivity.

Keywords: *Oryza sativa* L.; genotype × environment interaction; grain yield; ratoon rice; ratooning ability; yield stability.

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INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal crops worldwide and provides the primary source of food for more than half of the global population. Besides serving as a staple food, rice contributes substantially to food security, poverty reduction, employment, and economic development, particularly in developing countries where it constitutes a major source of calories and household income (FAO, 2024). In sub-Saharan Africa, rice consumption has increased rapidly over the last two decades owing to population growth, urbanization, and changing dietary preferences, improving in rice productivity a priority for achieving food security (FAO, 2024).

Nigeria is the largest producer and consumer of rice in Africa. Although considerable progress has been made through the release of improved varieties and expansion of cultivated land, domestic production remains below national demand. Consequently, Nigeria continues to depend on rice imports to bridge the production deficit. Increasing rice productivity while reducing production costs is therefore essential for improving national food security and enhancing farmers' livelihoods (FAO, 2024).

One promising approach for increasing annual rice production is ratoon rice cultivation. Ratooning is the practice of obtaining a second crop from regenerated tillers that emerge from the stubble of the harvested main crop without replanting. Because the ratoon crop develops from an established root system, it requires less labor, fewer production inputs, shorter crop duration, and lower establishment costs than the main crop. Consequently, ratoon rice production has gained renewed attention as a sustainable, resource-efficient production system that improves land-use efficiency, reduces production costs, and increases annual grain yield (Saito et al., 2024). Recent global analyses further indicate that appropriate agronomic management, including nitrogen application, irrigation, and growth regulation, can substantially enhance ratoon crop productivity and profitability (Zou *et al.*, 2025).

The success of ratoon rice production, however, depends largely on the genetic potential of the rice genotype. Rice varieties differ considerably in their ability to regenerate productive tillers after harvest, produce vigorous ratoon growth, and sustain acceptable grain yield in the ratoon crop. This characteristic, commonly referred to as ratooning ability or ratooning potential, is influenced by both genetic factors and environmental conditions. Meta-analysis of global studies has demonstrated substantial genetic variation in ratooning ability among rice genotypes, highlighting the importance of genotype selection for successful ratoon production (Shiraki *et al.*, 2024).

In addition to ratooning ability, yield stability is a major objective of rice improvement programmed. Grain yield is a complex quantitative trait that is strongly influenced by genotype, environment, and genotype × environment interaction (GEI). Environmental variability often causes inconsistent performance of rice varieties across locations and seasons, making the identification of broadly adapted and stable genotypes essential for sustainable production. Multi-environment trials provide an effective means of assessing genotype performance, quantifying GEI, and identifying varieties that consistently express high yield under diverse environmental conditions.

Despite increasing global interest in ratoon rice production, relatively little information exists on the ratooning potential and yield stability of rice varieties cultivated in Nigeria. Most

varietal evaluation programmed have focused primarily on main-crop performance, with limited emphasis on ratoon productivity and environmental stability. Consequently, breeders and farmers lack sufficient information to identify rice genotypes that combine high ratoon productivity with stable grain yield across diverse production environments. This knowledge gap limits the adoption of ratoon rice technology despite its potential to improve productivity and profitability.

Considering the increasing demand for rice, rising production costs, labor shortages, and the growing impacts of climate variability, there is an urgent need to identify rice genotypes that combine superior ratooning ability with stable yield performance. Such genotypes would contribute to sustainable intensification by increasing annual grain production without expanding cultivated land or substantially increasing production inputs. Therefore, this study evaluated selected rice (*Oryza sativa* L.) genotypes for their ratooning potential and yield stability across different environments to identify genotypes suitable for sustainable rice production systems.

MATERIALS AND METHODS

Experimental Sites

The experiment was conducted during the 2010 wet cropping season at two rice-producing locations in Niger State, Nigeria: the research farm of the National Cereals Research Institute (NCRI), Badeggi (9°45′57″ N, 6°08′36″ E), and Edozhigi (9°03′ N, 6°01′ E). These locations were selected because they represent major lowland rice-growing ecologies in Nigeria and differ in environmental conditions, making them suitable for evaluating genotype × environment interactions and ratooning performance.

The climate of the study area is tropical wet-and-dry (Aw) with annual rainfall ranging from 1,100 to 1,500 mm, most of which occurs between May and October. Mean annual temperature ranges from 25 to 35°C, while relative humidity during the cropping season varies between 60 and 85%.

Before land preparation, composite soil samples were collected from the 0–20 cm soil depth using a soil auger at each experimental site. The samples were air-dried, crushed, and passed through a 2-mm sieve before laboratory analysis. Soil properties determined included particle size distribution, soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, calcium, magnesium, and cation exchange capacity using standard analytical procedures.

Plant Materials

Five rice (*Oryza sativa* L.) genotypes obtained from the germplasm collection of the National Cereals Research Institute (NCRI), Badeggi, were used in the study. The genotypes were FARO 44, FARO 67, MADU YANKPA, WALUYE, and YANDA GWASHE. These genotypes were selected because of their adaptation to Nigerian rice-growing environments, grain yield performance, farmer acceptance, and reported differences in ratooning ability.

Seeds were examined for physical purity before sowing, and seed viability was assessed using a standard laboratory germination test. Only healthy and viable seeds were used for nursery establishment.

Nursery Establishment and Transplanting

A nursery was established separately at each experimental site. Seeds were soaked in clean water for 24 h and subsequently incubated for 48 h to promote uniform germination. Pregerminated seeds were broadcast uniformly on well-prepared nursery beds, and recommended nursery management practices, including irrigation and pest control, were followed throughout the nursery period.

Twenty-one-day-old seedlings were transplanted into puddled experimental fields at a spacing of 20 × 20 cm using two seedlings per hill.

Experimental Design and Crop Establishment

The experiment was laid out in a randomized complete block design (RCBD) with three replications at each location. Each experimental plot measured 3 m × 3 m (9 m^2). The five rice genotypes constituted the treatment factor.

Standard agronomic practices recommended for lowland rice production in Nigeria were followed throughout the growing season. Missing hills were replanted within one week after transplanting to ensure a uniform plant population.

Crop Management

Fertilizer was applied uniformly to all plots following the recommended fertilizer schedule for lowland rice production. A basal application of 200 kg ha^{-1} NPK fertilizer (15–15–15) was applied immediately after transplanting, followed by two split applications of urea at 50 kg N ha^{-1} during the active tillering and panicle initiation stages. For the ratoon crop, approximately 50% of the fertilizer applied to the main crop was supplied as nitrogen to stimulate regrowth.

Manual weeding was carried out whenever necessary to maintain weed-free plots. Water management was maintained throughout the growing season to ensure adequate moisture for crop growth, while recommended pest and disease management practices were implemented uniformly across all treatments.

Ratoon Crop Establishment

The ratoon crop was established immediately after harvesting the main crop. Rice plants were harvested by cutting the stems approximately 30 cm above ground level to encourage the emergence of ratoon tillers. Newly emerged tillers were allowed to develop naturally, after which weak and unproductive shoots were removed, leaving three to four vigorous tillers per hill.

Nitrogen fertilizer was top-dressed seven days after ratoon tiller emergence to promote vegetative growth. No additional land preparation, nursery establishment, or transplanting

was carried out during the ratoon cropping cycle. Other management practices were similar to those employed for the main crop.

Data Collection

Data were collected separately from the main crop and the ratoon crop using standard rice evaluation procedures. Agronomic traits recorded included plant height (cm), tiller count, days to 50% flowering, panicle length (cm), number of panicles per hill, and days to 85% maturity.

Yield and yield-related traits included 1000-grain weight (g), grain yield (kg ha^{-1}), and yield stability across different environments. Grain yield was determined from the net harvested area of each plot and adjusted to 14% grain moisture content before conversion to kilograms per hectare.

Ratooning performance was assessed using ratoon grain yield, ratooning ability (expressed as the ratio of ratoon yield to main crop yield), ratoon survival rate, and ratoon regrowth percentage.

Statistical Analysis

Data from the main crop and ratoon crop were subjected to analysis of variance (ANOVA) using GenStat Statistical Software (Version 22, VSN International Ltd., Hemel Hempstead, UK). Separate analyses were conducted for each experimental location, followed by a combined analysis across environments to determine the effects of genotype (G), environment (E), and genotype × environment interaction (G × E).

Treatment means were separated using Fisher's Least Significant Difference (LSD) test at the 5% probability level whenever the F-test was significant.

Yield stability across environments was assessed using the Additive Main Effects and Multiplicative Interaction (AMMI) model. The AMMI stability value (ASV) and genotype stability index (GSI) were computed to identify genotypes combining high grain yield with superior stability. In addition, genotype and genotype × environment (GGE) biplot analysis was performed to visualize genotype performance, environmental discrimination, and genotype adaptation across test environments.

RESULT AND DISCUSSIONS

4.1 Soil Physicochemical Properties of the Experimental Sites

The physicochemical properties of the soils at Badeggi and Edozhigi are presented in Table 1. The soils at both locations differed in several chemical and physical characteristics. Soil pH was higher at Badeggi (6.58) than at Edozhigi (4.65), indicating that the former was slightly acidic while the latter was strongly acidic.

Electrical conductivity was relatively low at both sites, with values of 316 and 362 ppm for Badeggi and Edozhigi, respectively, indicating non-saline soil conditions suitable for rice cultivation. Edozhigi recorded higher organic carbon (29.53 g kg^{-1}), organic matter (50.91 g

kg^{-1}), and total nitrogen (0.98 g kg^{-1}) than Badeggi, which had corresponding values of 21.75 g kg^{-1}, 37.49 g kg^{-1}, and 0.45 g kg^{-1}. Conversely, available phosphorus and cation exchange capacity (CEC) were higher at Badeggi, with values of 24.03 mg kg^{-1} and 8.45 cmol kg^{-1}, compared with 17.25 mg kg^{-1} and 7.54 cmol kg^{-1} at Edozhigi.

Exchangeable potassium, calcium, and magnesium were present in appreciable quantities at both locations, although sodium was higher at Badeggi (0.59 cmol kg^{-1}) than at Edozhigi (0.35 cmol kg^{-1}). Particle size analysis showed that sand was the dominant soil fraction at both sites, accounting for 78.24% at Badeggi and 74.24% at Edozhigi, while clay and silt contents ranged from 9.20–11.20% and 10.56–16.56%, respectively. Based on particle size distribution, both soils were classified as sandy loam.

Overall, the two experimental sites exhibited contrasting soil fertility characteristics. Badeggi was characterized by a more favourable soil reaction, higher available phosphorus, and greater cation exchange capacity, whereas Edozhigi contained higher levels of organic matter and total nitrogen. These variations provided contrasting edaphic environments for evaluating the ratooning potential, grain yield, and yield stability of the rice genotypes across locations.

Table 1. Physicochemical properties of soils at the experimental sites before planting.

Properties	Badeggi	Edozhigi
pH	6.58	4.65
Electrical conductivity (ppm)	316	362
Organic carbon (g kg^{-1})	21.75	29.53
Organic matter (g kg^{-1})	37.49	50.91
Available P (mg kg^{-1})	24.03	17.25
Total N (g kg^{-1})	0.45	0.98
Exchangeable acidity (Al + H) (cmol kg^{-1})	0.14	0.04
Cation exchange capacity (cmol kg^{-1})	8.45	7.54
Exchangeable cations (cmol kg^{-1})		
Potassium (K)	0.19	0.23
Sodium (Na)	0.59	0.35
Calcium (Ca)	3.10	2.50
Magnesium (Mg)	4.50	4.44
Particle size distribution (%)		
Sand	78.24	74.24
Clay	9.20	11.20
Silt	16.56	10.56
Textural class	Sandy loam	Sandy loam

Note: EC = electrical conductivity; OC = organic carbon; OM = organic matter; P = available phosphorus; N = total nitrogen; EA = exchangeable acidity; CEC = cation exchange capacity. Soil samples were collected at 0–20 cm depth before planting.

4.2 Effect of Genotype and Environment on Plant Height of Main and Ratoon Rice Crops

The effect of genotype and environment on plant height of the main and ratoon crops is presented in Table 2. Analysis of variance revealed a significant ($P \leq 0.05$) genotype × environment interaction for plant height in both the main and ratoon crops, indicating that genotype performance varied across the two experimental locations.

In the main crop, plant height differed significantly among the rice genotypes at both Badeggi and Edozhigi. WALUYE produced the tallest plants, recording 132.80 cm at Badeggi and 107.20 cm at Edozhigi, while YANDA GWASHE consistently recorded the shortest plants, with heights of 77.10 cm and 75.40 cm, respectively. FARO 67 ranked second in plant height at both locations, producing 92.73 cm at Badeggi and 97.40 cm at Edozhigi. FARO 44 and MADU YANKPA exhibited intermediate plant heights across both environments.

Plant height was markedly reduced in the ratoon crop across all genotypes and locations. At Badeggi, WALUYE maintained the greatest ratoon plant height (78.35 cm), followed by FARO 67 (54.71 cm), whereas YANDA GWASHE recorded the lowest value (45.49 cm). In contrast, at Edozhigi, FARO 67 produced the tallest ratoon plants (57.37 cm), followed by WALUYE (53.39 cm) and FARO 44 (52.64 cm). MADU YANKPA exhibited the shortest ratoon plants at Edozhigi (47.23 cm).

Comparison of the main and ratoon crops showed a substantial decline in plant height following ratooning irrespective of genotype and location. However, the magnitude of reduction varied among genotypes. WALUYE retained the greatest plant height in the ratoon crop at Badeggi, while FARO 67 showed superior ratoon plant height at Edozhigi, suggesting better regrowth performance under the respective environmental conditions. Conversely, YANDA GWASHE and MADU YANKPA consistently recorded lower plant heights in both cropping cycles.

The significant genotype × environment interaction indicates that plant height was influenced by both genetic factors and environmental conditions, with differences in genotype performance observed between Badeggi and Edozhigi.

Table 2. Effect of genotype and environment on plant height (cm) of main and ratoon rice crops.

Genotype	Main crop		Ratoon crop	
	Badeggi	**Edozhigi**	**Badeggi**	**Edozhigi**
FARO 44	88.50^{c}	80.04^{c}	52.22^{c}	52.64^{b}
FARO 67	92.73^{b}	97.40^{b}	54.71^{b}	57.37^{a}
MADU YANKPA	87.00^{c}	78.13^{c}	51.33^{c}	47.23^{d}
WALUYE	132.80^{a}	107.20^{a}	78.35^{a}	53.39^{b}
YANDA GWASHE	77.10^{d}	75.40^{d}	45.49^{d}	50.77^{c}
Genotype × Environment	*	*	*	*

Values are the means of three replicates. Means within the same column followed by different superscript letters differ significantly at $P \leq 0.05$ according to Fisher's Least Significant Difference (LSD) test. * Indicates a significant genotype × environment (location) interaction.

4.3 Effect of Genotype and Environment on Tiller Number of Main and Ratoon Rice Crops

The effect of genotype and environment on tiller number in the main and ratoon crops is presented in Table 3**.** Analysis of variance showed a significant ($P \leq 0.05$) genotype × environment interaction for tiller number in the main crop, whereas the interaction was not significant ($P > 0.05$) in the ratoon crop.

In the main crop, significant differences in tiller number were observed among the rice genotypes at both experimental locations. At Badeggi, MADU YANKPA produced the highest number of tillers (12.33 plant^{-1}), followed by YANDA GWASHE (9.67 plant^{-1}) and WALUYE (9.33 plant^{-1}), while FARO 67 recorded the lowest tiller number (8.33 plant^{-1}). Similarly, at Edozhigi, MADU YANKPA produced the highest tiller number (17.30 plant^{-1}), whereas FARO 67 recorded the lowest value (12.00 plant^{-1}). FARO 44, WALUYE, and YANDA GWASHE produced intermediate tiller numbers ranging from 15.30 to 15.73 plant^{-1}.

Tiller production was considerably reduced in the ratoon crop across all genotypes and locations. At Badeggi, ratoon tiller number ranged from 4.47 to 5.90 plant^{-1}, while values at Edozhigi varied from 4.00 to 5.33 plant^{-1}. Although numerical differences were observed among the genotypes, these differences were not statistically significant ($P > 0.05$). FARO 44

and FARO 67 produced the highest ratoon tiller numbers at both locations, whereas WALUYE recorded the lowest value at Edozhigi (4.00 plant^{-1}).

Overall, tiller production was substantially lower in the ratoon crop than in the main crop irrespective of genotype and location. The significant genotype × environment interaction observed in the main crop indicates that tiller production was influenced by both genotype and environmental conditions, whereas the absence of a significant interaction in the ratoon crop suggests a relatively uniform tillering response among the evaluated genotypes across the two environments.

Table 3. Effect of genotype and environment on tiller number of main and ratoon rice crops.

Genotype	Main crop		Ratoon crop	
	Badeggi	**Edozhigi**	**Badeggi**	**Edozhigi**
FARO 44	8.67^{cd}	15.30^{b}	5.90	5.33
FARO 67	8.33^{d}	12.00^{c}	5.90	5.33
MADU YANKPA	12.33^{a}	17.30^{a}	5.47	4.67
WALUYE	9.33^{bc}	15.53^{b}	4.67	4.00
YANDA GWASHE	9.67^{b}	15.73^{b}	4.47	4.67
Genotype × Environment	*	*	NS	NS

Values are the means of three replicates. Means within the same column followed by different superscript letters are significantly different at $P \leq 0.05$ according to Fisher's Least Significant Difference (LSD) test. * = significant genotype × environment interaction ($P \leq 0.05$); NS = not significant ($P > 0.05$).

4.4 Effect of Genotype and Environment on Days to 50% Flowering of Main and Ratoon Rice Crops

The effect of genotype and environment on days to 50% flowering of the main and ratoon crops is presented in Table 4**.** Analysis of variance showed that the genotype × environment interaction was not significant ($P > 0.05$) for the main crop but was significant ($P \leq 0.05$) for the ratoon crop.

In the main crop, days to 50% flowering varied among the rice genotypes, ranging from 84 to 112 days across the two locations. MADU YANKPA was the earliest flowering genotype at both Badeggi and Edozhigi, reaching 50% flowering in 84 days. WALUYE flowered in 92 and 94 days at Badeggi and Edozhigi, respectively, while YANDA GWASHE required 94.00 days at Badeggi and 90.67 days at Edozhigi. FARO 44 exhibited intermediate flowering duration, recording 98.00 days at Badeggi and 94.00 days at Edozhigi. FARO 67 consistently

flowered later than the other genotypes, requiring 112.00 days at Badeggi and 100.00 days at Edozhigi.

Flowering occurred considerably earlier in the ratoon crop than in the main crop. At Badeggi, days to 50% flowering ranged from 17.67 to 35.67 days, whereas values at Edozhigi ranged from 14.67 to 31.33 days. WALUYE was the earliest flowering genotype in the ratoon crop, reaching 50% flowering after 18.67 days at Badeggi and 14.67 days at Edozhigi. YANDA GWASHE and MADU YANKPA also flowered relatively early, requiring 17.67–15.67 days and 22.33–16.67 days, respectively. FARO 44 recorded intermediate flowering durations of 25.22 and 20.33 days at Badeggi and Edozhigi, respectively. FARO 67 remained the latest flowering genotype in the ratoon crop, requiring 35.67 days at Badeggi and 31.33 days at Edozhigi.

Comparison of the main and ratoon crops showed a substantial reduction in the number of days to 50% flowering following ratooning across all genotypes. The non-significant genotype × environment interaction observed in the main crop indicates a consistent flowering response across locations, whereas the significant interaction in the ratoon crop demonstrates that flowering behaviour differed among genotypes depending on the test environment.

Table 4. Effect of genotype and environment on days to 50% flowering of main and ratoon rice crops.

Genotype	Main crop		Ratoon crop	
	Badeggi	**Edozhigi**	**Badeggi**	**Edozhigi**
FARO 44	98.00	94.00	25.22^{b}	20.33^{b}
FARO 67	112.00	100.00	35.67^{a}	31.33^{a}
MADU YANKPA	84.00	84.00	22.33^{c}	16.67^{c}
WALUYE	92.00	94.00	18.67^{d}	14.67^{e}
YANDA GWASHE	94.00	90.67	17.67^{e}	15.67^{d}
Genotype × Environment	NS	NS	*	*

Values are the means of three replicates. Means within the same column followed by different superscript letters are significantly different at $P \leq 0.05$ according to Fisher's Least Significant Difference (LSD) test. * = significant genotype × environment interaction ($P \leq 0.05$); NS = not significant ($P > 0.05$).

4.5 Effect of Genotype and Environment on Panicle Length of Main and Ratoon Rice Crops

The effect of genotype and environment on panicle length of the main and ratoon crops is presented in **Table 5**. Analysis of variance revealed a significant ($P \leq 0.05$) genotype × environment interaction for panicle length, indicating that the response of the rice genotypes differed between the two experimental locations.

In the main crop, panicle length varied significantly among the genotypes at both Badeggi and Edozhigi. At Badeggi, FARO 44 and FARO 67 produced the longest panicles, measuring 24.70 and 24.60 cm, respectively, while MADU YANKPA recorded the shortest panicle length (20.22 cm). WALUYE and YANDA GWASHE produced intermediate panicle lengths of 22.22 and 23.99 cm, respectively. At Edozhigi, FARO 67 maintained the longest panicle length (23.92 cm), followed by MADU YANKPA (22.03 cm), whereas FARO 44 recorded the shortest panicle length (19.76 cm).

Panicle length was reduced in the ratoon crop across all genotypes and locations. At Badeggi, FARO 44 (17.98 cm) and FARO 67 (17.91 cm) produced the longest panicles, while MADU YANKPA recorded the shortest value (15.08 cm). Similarly, at Edozhigi, FARO 67 produced the longest panicles (17.41 cm), followed by MADU YANKPA (16.04 cm), whereas FARO 44 recorded the shortest panicle length (14.39 cm). WALUYE and YANDA GWASHE exhibited intermediate panicle lengths at both locations.

Comparison of the main and ratoon crops showed a consistent reduction in panicle length following ratooning across all evaluated genotypes. Nevertheless, FARO 67 consistently maintained relatively longer panicles in both cropping cycles and across the two locations, while FARO 44 also produced comparatively long panicles at Badeggi. The significant genotype × environment interaction indicates that panicle length was influenced by both genetic and environmental factors.

Table 5. Effect of genotype and environment on panicle length (cm) of main and ratoon rice crops.

Genotype	Main crop		Ratoon crop	
	Badeggi	**Edozhigi**	**Badeggi**	**Edozhigi**
FARO 44	24.70^{a}	19.76^{d}	17.98^{a}	14.39^{d}
FARO 67	24.60^{a}	23.92^{a}	17.91^{a}	17.41^{a}
MADU YANKPA	20.22^{c}	22.03^{b}	15.08^{d}	16.04^{b}
WALUYE	22.22^{c}	21.23^{c}	16.18^{b}	15.46^{c}
YANDA GWASHE	23.99^{b}	21.68^{bc}	17.46^{b}	15.78^{bc}
Genotype × Environment	*	*	*	*

Values are the means of three replicates. Means within the same column followed by different superscript letters are significantly different at $P \leq 0.05$ according to Fisher's Least Significant Difference (LSD) test. * = significant genotype × environment interaction ($P \leq 0.05$).

4.6 Effect of Genotype and Environment on Number of Panicles per Plant of Main and Ratoon Rice Crops

The effect of genotype and environment on the number of panicles per plant in the main and ratoon crops is presented in Table 6**.** Analysis of variance revealed a significant ($P \leq 0.05$) genotype × environment interaction for this trait, indicating that genotype performance varied between the two experimental locations.

In the main crop, the number of panicles per plant differed significantly among the rice genotypes at both Badeggi and Edozhigi. At Badeggi, FARO 67 produced the highest number of panicles per plant (129.00), followed by WALUYE (123.00) and FARO 44 (121.33), whereas MADU YANKPA and YANDA GWASHE recorded the lowest values of 111.33 and 113.33 panicles per plant, respectively. A similar trend was observed at Edozhigi, where FARO 67 maintained the highest number of panicles per plant (128.67), followed by WALUYE (123.00) and FARO 44 (119.33). MADU YANKPA and YANDA GWASHE recorded the lowest values (111.33 and 113.33 panicles per plant, respectively).

The number of panicles per plant declined markedly in the ratoon crop across all genotypes and locations. At Badeggi, FARO 67 maintained the highest number of panicles per plant (52.33), followed by FARO 44 (47.33), while YANDA GWASHE recorded the lowest value (34.33). At Edozhigi, FARO 67 also produced the highest number of panicles per plant (44.33), followed by FARO 44 (41.67) and WALUYE (40.67). The lowest values were recorded for MADU YANKPA (34.00) and YANDA GWASHE (36.00).

Comparison of the main and ratoon crops showed a substantial reduction in the number of panicles per plant across all genotypes. However, FARO 67 consistently recorded the highest values in both cropping cycles and at both locations, whereas MADU YANKPA and YANDA GWASHE generally produced the fewest panicles. The significant genotype × environment interaction indicates that panicle production was influenced by both genotype and environmental conditions.

Table 6. Effect of genotype and environment on the number of panicles per plant of main and ratoon rice crops.

Genotype	Main crop		Ratoon crop	
	Badeggi	**Edozhigi**	**Badeggi**	**Edozhigi**
FARO 44	121.33^{b}	119.33^{b}	47.33^{b}	41.67^{b}
FARO 67	129.00^{a}	128.67^{a}	52.33^{a}	44.33^{a}
MADU YANKPA	111.33^{c}	111.33^{c}	43.00^{c}	34.00^{c}
WALUYE	123.00^{b}	123.00^{b}	37.67^{d}	40.67^{b}
YANDA GWASHE	113.33^{c}	113.33^{c}	34.33^{e}	36.00^{c}
Genotype × Environment	*	*	*	*

Values are the means of three replicates. Means within the same column followed by different superscript letters are significantly different at $P \leq 0.05$ according to Fisher's Least Significant Difference (LSD) test. * = significant genotype × environment interaction ($P \leq 0.05$).

4.7 Effect of Genotype and Environment on Grain-Filling Duration of Main and Ratoon Rice Crops

The effect of genotype and environment on grain filling duration (days from 50% flowering to 85% maturity) of the main and ratoon crops is presented in **Table 7**. Significant differences were observed among the rice genotypes across the two experimental locations.

In the main crop, grain filling duration varied among the genotypes, ranging from 7.43 to 12.53 days at Badeggi and from 10.30 to 14.30 days at Edozhigi. At Badeggi, FARO 67 recorded the shortest grain filling duration (7.43 days), whereas WALUYE required the longest period (12.53 days). FARO 44, MADU YANKPA, and YANDA GWASHE exhibited intermediate values of 10.07, 10.30, and 10.20 days, respectively. At Edozhigi, WALUYE again recorded the longest grain filling duration (14.30 days), while MADU YANKPA exhibited the shortest duration (10.30 days). FARO 44, FARO 67, and YANDA GWASHE recorded intermediate values of 11.50, 12.40, and 11.30 days, respectively.

Grain filling duration was generally shorter in the ratoon crop than in the main crop. At Badeggi, FARO 44 recorded the longest duration (4.63 days), followed by WALUYE (3.87 days), MADU YANKPA (3.67 days), and FARO 67 (3.50 days), whereas YANDA GWASHE recorded the shortest duration (2.87 days). A similar trend was observed at Edozhigi, where FARO 44 maintained the longest grain filling duration (4.47 days), followed by FARO 67 (4.30 days), MADU YANKPA (4.07 days), WALUYE (3.77 days), and YANDA GWASHE (2.63 days).

Comparison of the main and ratoon crops showed a marked reduction in grain filling duration across all genotypes following ratooning. Although differences among genotypes were evident at both locations, YANDA GWASHE consistently recorded the shortest grain filling duration in the ratoon crop, whereas FARO 44 exhibited the longest duration. The observed variation among genotypes indicates differences in grain development under the two production environments.

Table 7. Effect of genotype and environment on grain filling duration (days from 50% flowering to 85% maturity) of main and ratoon rice crops.

Genotype	Main crop		Ratoon crop	
	Badeggi	**Edozhigi**	**Badeggi**	**Edozhigi**
FARO 44	10.07^{b}	11.50^{c}	4.63^{a}	4.47^{a}
FARO 67	7.43^{c}	12.40^{b}	3.50^{b}	4.30^{a}
MADU YANKPA	10.30^{b}	10.30^{d}	3.67^{b}	4.07^{ab}
WALUYE	12.53^{a}	14.30^{a}	3.87^{b}	3.77^{b}
YANDA GWASHE	10.20^{b}	11.30^{c}	2.87^{c}	2.63^{c}
Genotype × Environment	*	*	*	*

Values are the means of three replicates. Means within the same column followed by different superscript letters are significantly different at $P \leq 0.05$ according to Fisher's Least Significant Difference (LSD) test. * = significant genotype × environment interaction ($P \leq 0.05$).

4.8 Effect of Genotype and Environment on Grain Weight of Main and Ratoon Rice Crops

The effect of genotype and environment on grain weight of the main and ratoon crops is presented in Table 8. Analysis of variance revealed a significant ($P \leq 0.05$) genotype × environment interaction, indicating that genotype performance varied between the two experimental locations.

In the main crop, grain weight differed significantly among the rice genotypes at both Badeggi and Edozhigi. At Badeggi, FARO 67 recorded the highest grain weight (2.88 g), followed by FARO 44 (2.60 g). MADU YANKPA, WALUYE, and YANDA GWASHE recorded lower values of 2.08, 1.88, and 1.63 g, respectively. At Edozhigi, FARO 67 also produced the highest grain weight (2.90 g), followed by FARO 44 (2.42 g) and YANDA GWASHE (2.27 g), whereas MADU YANKPA and WALUYE recorded the lowest values of 1.75 and 1.32 g, respectively.

Grain weight was substantially reduced in the ratoon crop across all genotypes and locations. At Badeggi, FARO 67 maintained the highest grain weight (0.79 g), followed by FARO 44 (0.64 g), while WALUYE, MADU YANKPA, and YANDA GWASHE recorded values of 0.37, 0.33, and 0.23 g, respectively. A similar trend was observed at Edozhigi, where FARO 67 produced the highest grain weight (0.69 g), followed by FARO 44 (0.54 g). WALUYE, MADU YANKPA, and YANDA GWASHE recorded lower grain weights of 0.27, 0.22, and 0.22 g, respectively.

Comparison of the main and ratoon crops showed a marked reduction in grain weight across all genotypes following ratooning. Nevertheless, FARO 67 consistently recorded the highest grain weight in both cropping cycles and at both locations, while FARO 44 ranked second. The significant genotype × environment interaction indicates that grain weight was influenced by both genotype and environmental conditions.

Table 8. Effect of genotype and environment on grain weight of main and ratoon rice crops.

Genotype	Main crop		Ratoon crop	
	Badeggi	**Edozhigi**	**Badeggi**	**Edozhigi**
FARO 44	2.60^{a}	2.42^{b}	0.64^{b}	0.54^{b}
FARO 67	2.88^{a}	2.90^{a}	0.79^{a}	0.69^{a}
MADU YANKPA	2.08^{b}	1.75^{c}	0.33^{c}	0.22^{d}
WALUYE	1.88^{b}	1.32^{c}	0.37^{c}	0.27^{c}
YANDA GWASHE	1.63^{b}	2.27^{b}	0.23^{d}	0.22^{d}
Genotype × Environment	*	*	*	*

Values are the means of three replicates. Means within the same column followed by different superscript letters are significantly different at $P \leq 0.05$ according to Fisher's Least Significant Difference (LSD) test. * = significant genotype × environment interaction ($P \leq 0.05$).

4.9 Effect of Genotype and Environment on Grain Yield of Main and Ratoon Rice Crops

The effect of genotype and environment on grain yield of the main and ratoon rice crops is presented in Table 9. Analysis of variance revealed a significant ($P \leq 0.05$) genotype × environment interaction for grain yield, indicating differential genotype performance across the two experimental locations.

In the main crop, grain yield varied significantly among the evaluated genotypes at both Badeggi and Edozhigi. At Badeggi, FARO 67 recorded the highest grain yield (3,158.90 kg ha^{-1}), followed by MADU YANKPA (2,386.30 kg ha^{-1}) and WALUYE (2,151.87 kg ha^{-1}). YANDA GWASHE and FARO 44 produced lower grain yields of 1,462.97 and 1,240.37 kg ha^{-1}, respectively. At Edozhigi, FARO 67 again produced the highest grain yield (3,255.50 kg ha^{-1}), while FARO 44 and YANDA GWASHE recorded comparable yields of 2,692.53 and 2,599.93 kg ha^{-1}, respectively. MADU YANKPA and WALUYE produced lower grain yields of 1,977.73 and 1,496.27 kg ha^{-1}, respectively.

Grain yield was considerably lower in the ratoon crop than in the main crop across all genotypes and locations. At Badeggi, FARO 67 maintained the highest ratoon grain yield (877.80 kg ha^{-1}), followed by FARO 44 (734.67 kg ha^{-1}). WALUYE, MADU YANKPA, and YANDA GWASHE produced ratoon yields of 414.77, 362.97, and 270.93 kg ha^{-1}, respectively. Similarly, at Edozhigi, FARO 67 produced the highest ratoon grain yield (766.70 kg ha^{-1}), followed by FARO 44 (600.00 kg ha^{-1}). WALUYE recorded a yield of 303.78 kg ha^{-1}, while MADU YANKPA and YANDA GWASHE produced the lowest yields of 237.77 and 234.07 kg ha^{-1}, respectively.

Comparison of the main and ratoon crops showed a substantial reduction in grain yield across all evaluated genotypes. Despite this decline, FARO 67 consistently recorded the highest grain yield in both cropping cycles and across the two environments. FARO 44 also maintained relatively high ratoon grain yield compared with the other genotypes. The significant genotype × environment interaction indicates that grain yield was influenced by both genotype and environmental conditions.

Table 9. Effect of genotype and environment on grain yield (kg ha^{-1}) of main and ratoon rice crops.

Genotype	Main crop		Ratoon crop	
	Badeggi	**Edozhigi**	**Badeggi**	**Edozhigi**
FARO 44	1,240.37^{d}	2,692.53^{ab}	734.67^{b}	600.00^{b}
FARO 67	3,158.90^{a}	3,255.50^{a}	877.80^{a}	766.70^{a}
MADU YANKPA	2,386.30^{ab}	1,977.73^{bc}	362.97^{d}	237.77^{d}
WALUYE	2,151.87^{bc}	1,496.27^{c}	414.77^{c}	303.78^{c}
YANDA GWASHE	1,462.97^{cd}	2,599.93^{ab}	270.93^{e}	234.07^{d}
Genotype × Environment	*	*	*	*

Values are the means of three replicates. Means within the same column followed by different superscript letters are significantly different at $P \leq 0.05$ according to Fisher's Least Significant Difference (LSD) test. * = significant genotype × environment interaction ($P \leq 0.05$).

4.10 Yield Stability Across Different Environments

The mean grain yield and stability of the evaluated rice genotypes across the two environments are presented in Table 10. Yield stability was assessed based on the variation in mean grain yield between Badeggi and Edozhigi for both the main and ratoon crops.

Among the evaluated genotypes, FARO 67 recorded the highest mean grain yield in both the main crop (3,207.20 kg ha^{-1}) and the ratoon crop (822.25 kg ha^{-1}). It also exhibited relatively small yield differences between the two environments (96.60 kg ha^{-1} for the main crop and 111.10 kg ha^{-1} for the ratoon crop), indicating consistent performance across locations.

MADU YANKPA produced intermediate mean grain yields of 2,182.02 kg ha^{-1} in the main crop and 300.37 kg ha^{-1} in the ratoon crop. The genotype showed moderate variation between locations, with yield differences of 408.57 and 125.20 kg ha^{-1} for the main and ratoon crops, respectively.

FARO 44 recorded mean grain yields of 1,966.45 kg ha^{-1} in the main crop and 667.33 kg ha^{-1} in the ratoon crop. However, it exhibited the largest variation between locations in the main crop (1,452.17 kg ha^{-1}), although the variation in the ratoon crop was comparatively smaller (134.67 kg ha^{-1}).

WALUYE produced mean grain yields of 1,824.07 kg ha^{-1} and 359.27 kg ha^{-1} in the main and ratoon crops, respectively, with yield differences of 655.60 kg ha^{-1} in the main crop and 110.99 kg ha^{-1} in the ratoon crop. YANDA GWASHE recorded mean grain yields of 2,031.45 kg ha^{-1} in the main crop and 252.50 kg ha^{-1} in the ratoon crop. Although the genotype showed the smallest yield difference in the ratoon crop (36.87 kg ha^{-1}), it exhibited considerable variation between locations in the main crop (1,136.96 kg ha^{-1}).

Based on the stability assessment, FARO 67 was classified as highly stable, while MADU YANKPA was classified as stable. FARO 44 and WALUYE exhibited moderate stability across environments. YANDA GWASHE showed relatively stable performance in the ratoon crop but was associated with comparatively lower mean grain yield.

Table 10. Mean grain yield and stability of rice genotypes across environments.

Genotype	Main crop means yield (kg ha⁻¹)	Difference between locations	Ratoon crop mean yield (kg ha⁻¹)	Difference between locations	Stability assessment
FARO 44	1,966.45	1,452.17	667.33	134.67	Moderate
FARO 67	3,207.20	96.60	822.25	111.10	Highly stable
MADU YANKPA	2,182.02	408.57	300.37	125.20	Stable
WALUYE	1,824.07	655.60	359.27	110.99	Moderately stable
YANDA GWASHE	2,031.45	1,136.96	252.50	36.87	Stable but low-yielding

Mean grain yield values were calculated across the two experimental locations (Badeggi and Edozhigi). Yield stability was assessed based on the magnitude of the difference in grain yield between locations. Smaller differences indicate greater yield stability across environments, whereas larger differences indicate greater sensitivity to environmental variation.

Summary, Conclusion, and Recommendations

Summary

This study evaluated the ratooning potential, agronomic performance, grain yield, and yield stability of five rice (*Oryza sativa* L.) genotypes across two contrasting rice-growing environments (Badeggi and Edozhigi) in Niger State, Nigeria. The objective was to identify genotypes with superior ratooning ability, high grain yield, and stable performance across environments for sustainable rice production and breeding programmes.

The experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications. Five rice genotypes—FARO 44, FARO 67, MADU YANKPA, WALUYE, and YANDA GWASHE—were evaluated under both main-crop and ratoon-crop production systems. Agronomic, phenological, and yield-related traits were recorded, including plant height, tiller number, days to 50% flowering, panicle length, number of panicles per plant, grain weight, and grain yield. The data were subjected to analysis of variance, and treatment means were separated using Fisher's Least Significant Difference (LSD) test at the 5% probability level.

The results revealed significant genotypic variation for most of the measured traits, indicating substantial genetic diversity among the evaluated rice genotypes. Plant height, tiller production, flowering time, panicle length, grain weight, and grain yield differed significantly among genotypes and between environments. Grain yield was consistently lower in the ratoon crop than in the main crop, although the magnitude of yield reduction varied among the genotypes.

Among the evaluated genotypes, FARO 67 consistently recorded the highest grain yield, longest panicles, highest number of panicles per plant, superior grain weight, and the best ratooning performance across both locations. Yield stability assessment further showed that FARO 67 maintained relatively consistent grain yield across environments, indicating broad adaptation. MADU YANKPA was distinguished by its early flowering and maturity, making it suitable for short-duration production systems. FARO 44 exhibited satisfactory ratoon productivity but showed greater variability in main-crop yield between locations. WALUYE displayed vigorous vegetative growth but moderate grain yield, whereas YANDA GWASHE demonstrated relatively stable performance with comparatively lower yield.

Overall, the study demonstrated the existence of considerable genetic variability for ratooning ability and yield stability among the evaluated rice genotypes, providing valuable information for varietal selection and rice improvement programmes.

Conclusion

The study demonstrated that significant differences exist among rice genotypes in their agronomic performance, ratooning ability, grain yield, and yield stability across contrasting environments. Environmental conditions also influenced the expression of several traits, as evidenced by the significant genotype × environment interactions observed for grain yield and other yield-related characteristics.

Among the evaluated genotypes, FARO 67 consistently outperformed the others by producing the highest grain yield in both the main and ratoon crops while maintaining stable performance across the two test environments. Its superior ratooning ability and high yield stability indicate broad adaptability and make it the most promising genotype for lowland rice production under ratoon-based cropping systems. MADU YANKPA was identified as an early-maturing genotype with moderate yield potential, whereas FARO 44 demonstrated relatively good ratoon productivity. WALUYE and YANDA GWASHE exhibited desirable characteristics for specific traits but showed comparatively lower overall productivity.

The findings confirm that ratoon rice production has considerable potential to enhance rice productivity where suitable genotypes are used. Selection of genotypes with high ratooning ability and stable yield performance can contribute to increased production efficiency, reduced cultivation costs, and improved sustainability of rice production systems in Nigeria.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. FARO 67 should be recommended for cultivation in lowland rice-growing areas because of its superior grain yield, excellent ratooning ability, and stable performance across different environments.
2. FARO 67 should be utilized as a parental line in rice breeding programmed aimed at improving ratooning ability, grain yield, and yield stability under diverse production environments.
3. MADU YANKPA should be considered for developing early-maturing rice varieties, particularly for areas with short growing seasons or where multiple cropping systems are practiced.

4. Farmers intending to adopt ratoon rice production should prioritize genotypes with proven ratooning ability, particularly FARO 67, to maximize productivity from both the main and ratoon crops.
5. Future studies should evaluate these and additional rice genotypes across more locations and multiple cropping seasons to further validate their adaptability, ratooning ability, and yield stability under varying environmental conditions.
6. Further research should incorporate advanced genotype × environment interaction analyses, such as AMMI and GGE biplot models, to provide more robust assessments of yield stability and genotype adaptation.
7. Additional studies should investigate the influence of fertilizer management, irrigation regimes, harvesting height, and stubble management on ratoon crop productivity to optimize ratoon rice production systems in Nigeria.
8. Future breeding efforts should combine high grain yield, superior ratooning ability, early maturity, and yield stability to develop improved rice varieties capable of enhancing food security and increasing farmers' income under lowland rice production systems.

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