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Genetic Variability and Diversity in the Agro-morphology of Gamma-irradiated Rice (*Oryza sativa* L.) Across Two Generations for Potential Mutant Development

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Abstract:
Problem: Nigeria's rice production system often experiences both excessive and deficient water levels within the same season. In rained lowland fields, a significant yield is lost due to water stress and the absence of adaptable varieties. **Approach:** T his paper examined the extent of variability caused by three gamma irradiation doses in the M_1 and M_2 populations of two submergence-tolerant rice (*Oryza sativa*) varieties (FARO 67 and FARO 68) evaluated under irrigated conditions during the 2023/2024 (M_1) and 2024/2025 (M_2) dry seasons. Data on morphology and yield attributes were recorded following standard protocols. **Findings:** Results revealed variation in radio sensitivity of FARO 67 and FARO 68. Significant differences were observed among irradiation treatments for most traits. The mutant population exhibited several promising mutants with desirable traits, and a total of 749 mutant plants were isolated from the M_2 population based on earliness (5-15 days),plant height (<80cm), tailoring (>15), spikelet sterility (<10%), grain yield (>35g),flag leaf orientation (30-45°),panicle type (open panicles) and panicle exertion (well-exerted panicles). The dose of 300Gy produced the highest number of mutants. The plant height, flag leaf length, days to heading, productive tillers, panicle length and spikelet sterility exhibited a high heritability (>60%). Seedling emergence, tillers per plant and productive tillers played predominant roles in contributing to the overall divergence. **Conclusion:** This research provides new mutant lines that can be further evaluated in successive generations and mutants with superior agronomic traits can be used as breeding materials for achieving rice breeding objectives, particularly, in drought-prone environments.

Keywords: Breeding, gamma-irradiation, mutant varieties, rice, water stress.

Introduction

Rice (*Oryza sativa* L.) serves as a staple food source for more than half of the world's population (Xu *et al*., 2021).Itplays an important role in ensuring food security, particularly in West Africa (Arouna *et al.* 2020). Approximately, one-tenth of the world's arable land is cultivated for rice, yet the demand for high-quality rice continues to increase, and it is estimated to surpass global production (Guite and Sharma, 2023).

In Africa, the increasing demand has been met through an increase in production and importation (Yuan *et al.,* 2024). However, domestic production gains have primarily resulted from expansion of rice area under cultivation, rather than improvements in yield (Food and Agricultural Organization, 2022). Currently, Nigeria ranks as the third-largest importer of milled rice in the world, with recent annual imports fluctuating between 1.885 MMT and 2.450 MMT. In 2024, Nigeria's rice imports increased by 27.32% relative to 2023, reaching 2.4 MMT (IndexMundi 2024).

Although Nigeria has the potential for large-scale rice production, the lack of adaptable varieties has been a major constraint (Abegunde *et al.,* 2024). Since the genetic improvement potential of any breeding population is largely dependent on the genetic variability present (Sanchez *et al.,*2023),generating new variation becomes essential.Gamma-irradiation has been the most efficient method for creating variability in plants (Sharma *et al*., 2024), and gives room for the selection of superior genotypes (Amri-Tiliouine *et al*., 2018).

FARO 67 and FARO 68are high-yielding lowland varieties that are submergence-tolerant. FARO 67 exhibits moderate tolerance to iron toxicity, while FARO 68 shows resistance to major diseases. These make them attractive to subsistence farmers and contribute to their widespread cultivation. However, rainfall regimes are highly uneven (Feldman *et al*., 2024), and fluctuations in rainfall patterns could result in drought and significant yield loss (Khan *et al.,* 2022).Despite this challenge, lowland rice research in drought-prone areas of Nigeria has been extremely limited.This research aimed to assess the genetic variability of gamma-irradiated rice varieties in irrigated environments across two generations.

Materials and Methods

Study area

This research was conducted at the experimental field of the National Cereals Research Institute Badeggi (NCRI), Nigeria (9.0652195 °N; 6.0986163 °E). The microclimatic conditions of the experimental site during the study period are presented in Figure 1.

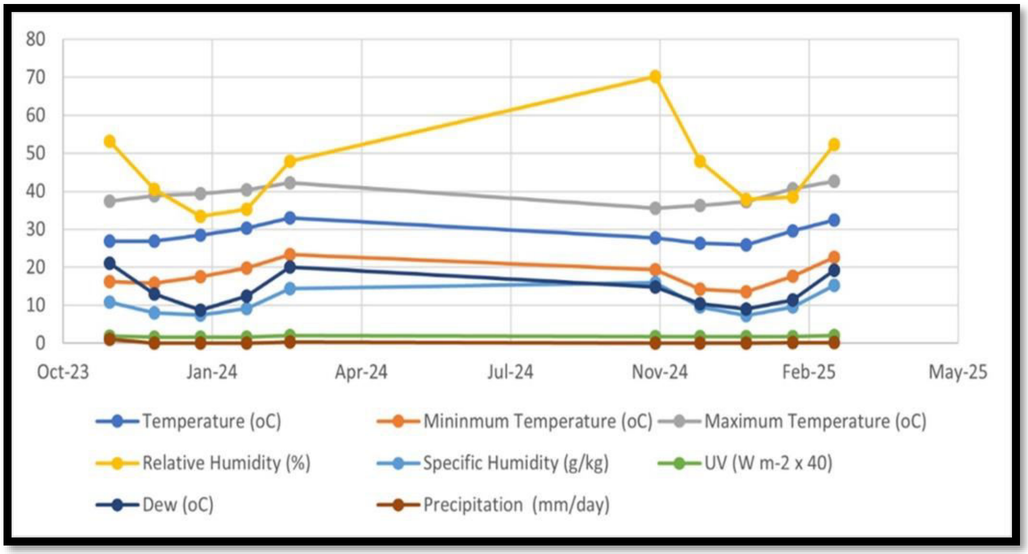

Figure 1: Microclimatic conditions of the experimental site during the study period.
Source: power.larc.nasa.gov

Irradiation of seeds

Two hundred healthy seeds of FARO 67 and 68 were exposed to gamma-irradiation doses of 100, 200 and 300Gy derived from a Co-60 source situated at the Radiology Department, Centre for Energy Research and Training (CERT), Ahmadu Bello University Zaria, Nigeria. Seed samples packed similarly without irradiation served as control.

Experimental design

Seeds were sown in a nursery bed, and the 27-day-old seedlings were transplanted in a Randomized Complete Block Design (RCBD)with three replicates in the 2023/2024 dry season to raise the M_1 plants. During panicle emergence, 24 rice plants from the middle rows of each block were selected, and the first three panicles were bagged (Elsherbiny *et al.,* 2024).

In the 2024/2025 dry season, seeds harvested from the bagged tillers were seeded in a nursery bed and were transplanted to the field at 27 d. The 24 plant progenies from each treatment group were grown in a RCBD to raise the M_2 population (1,728 plants). All recommended agronomic practices by the International Rice Research Institute (IRRI, 1980) were adopted. The irrigation schedule was determined with emphasis on the precipitation levels of the research area. Intermittent irrigation was applied at 10-day intervals using a PMT 3-inch model water pump starting 8 days after transplanting until the plants were harvested.

Data collection

Seedling emergence was expressed as the percentage of emerged seedlings relative to the total number of seeds sown, seedling survival was calculated as 100 times the ratio of survived seedlings at transplanting to total number of emerged seedlings, plant height was measured from the base of the shoot to the tip of the tallest leaf blade, flag leaf length was measured from the base of the flag leaf to its tip, tiller count, productive tillers and grains per panicle were recorded by direct counting, days to heading from effective seeding date to 50% heading, panicle length was measured from the base to the tip of the panicle, spikelet sterility was recorded as the ratio of unfilled grains to the total number of grains and expressed in percentage, hundred grain weight and grain yield were weighed using a precision weighing balance (SF-400 model).Qualitative data were recorded following standard descriptors (IRRI, 1980). Flag leaf angle was scored as 1-erect, 3-intermediate, 5-horizontal, 7-descending, Panicle type was scored as 1-compact, 5-intermediate, 9-open, panicle exsertion was scored as 1-well exserted, 3-moderately well exserted, 5-just exserted, 7-partly exserted, 9-enclosed and panicle shattering as 1-very low (less than 1%), 3-low (1–5%), 5-moderate (6–25%), 7-moderately high (26–50%), 9- high (more than 50%).

Statistical analyses

Quantitative agro morphological data were subjected to a three-way factorial ANOVA with Tukey's significant test, while qualitative data were subjected to Kruskal-Wallis's test, and Dunn's test with Bonferroni correction was used to test for significant difference in R package (version 4.5.1). All results were considered significant at $p<0.05$.

Results and Discussion

Gamma-irradiation significantly ($p<0.05$) decreased emergence and survival percentages in M_1 and M_2 populations (Table 1). The least emergence and survival percentages were observed at 300Gyin both varieties, across generations. This could be attributed to physiological injuries which impair seed vigour and cellular metabolism, leading to a delay in mitotic activity (Barela *et al*. 2022). Similar findings have been reported by Elsherbiny *et al.* (2024).Results revealed higher germination and survival rate at the M_2 generation. This could be due to DNA repair mechanism or diplontic selection towards recovery or improvement (Hong *et al.,* 2022).

Irradiation significantly decreased plant height in M_1 and M_2FARO 68 (Table 1).This could be attributed to the inhibition of phytohormones or the synthesis of nucleic acids that are essential for mitotic activities, causing cell division to stop, hence, growth reductions (Hasan *et al*., 2021). The differing responses between the two varieties could be due to the random nature of mutations and variations in plant sensitivity, leading to distinct reactions (Suliartini*et al.,* 2020).Rice breeders prefer to select short plants (Luz *et al.,* 2016) because tall plants tend to have lower yields.

The dose of 100 and 300Gy significantly increased flag leaf length in M_2FARO 67.The highest tillering was observed in FARO 68 exposed to 300 Gy at the M_2 generation (16.2). The number of days to heading was significantly influenced by irradiation. In M_1 plants, 100Gy decreased the number of days to heading (109d) in FARO 67, and all irradiation doses significantly reduced the days to heading in FARO 68 (Table 1). High yielding and superior quality are the objectives of rice breeding. The reduction in days to heading (5-15 days) may be linked to the impact of irradiation on the biochemical pathway involved in synthesizing flower-inducing substances, leading to early flowering. Reduction in days to heading has been a major target of selection in rice breeding, enabling rice to adapt to diverse environments by altering the length of growing season and avoiding unfavourable conditions (Huang *et al.,* 2012). A comparable decrease in days to heading have been reported by Ali *et al*. (2022).

Table 1: Agro morphological characters of gamma-irradiated FARO 67 and FARO 68

Dose (Gy)	Seedling Emergence (%)		Seedling survival (%)		Plant height (cm)		Flag leaf length (cm)		Tiller count		Days to heading (d)	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
FARO 67-0	95.3^{b}	96.6^{b}	89.7^{b}	93.2^{b}	104.1^{a}	102.7^{a}	23.4^{a}	24.0^{a}	12.0^{a}	12.3^{a}	120.0^{b}	114.0^{a}
FARO 67-100	90.1^{b}	94.5^{a}	85.4^{b}	91.1^{b}	102.3^{a}	101.9^{a}	24.8^{a}	35.7^{b}	13.3^{a}	12.9^{a}	109.0^{a}	110.0^{a}
FARO 67-200	84.6^{a}	93.1^{a}	79.7^{a}	87.4^{ab}	109.6^{a}	102.5^{a}	30.7^{a}	24.2^{a}	12.4^{a}	14.1^{a}	113.0^{ab}	113.0^{a}
FAR067-300	85.4^{a}	92.4^{a}	79.6^{a}	76.9^{a}	108.4^{a}	109.2^{a}	28.1^{a}	37.3^{b}	12.1^{a}	14.6^{a}	128.0^{c}	110.0^{a}
FARO 68-0	94.2^{c}	96.8^{b}	87.3^{b}	92.2^{b}	95.2^{c}	86.0^{b}	16.7^{a}	16.9^{a}	11.6^{a}	13.2^{ab}	129.0^{c}	126.0^{b}
FARO 68-100	83.6^{b}	96.3^{b}	77.6^{ab}	89.7^{ab}	85.2^{b}	80.1^{b}	22.6^{a}	23.4^{a}	11.1^{a}	11.4^{a}	120.0^{b}	112.0^{a}
FARO 68-200	86.1^{b}	93.0^{b}	79.1^{a}	87.7^{a}	68.7^{a}	64.7^{a}	23.2^{a}	17.6^{a}	13.0^{a}	13.8^{ab}	107.0a	109.0a
FAR068-300	77.3^{a}	88.2^{a}	71.6^{a}	80.7^{a}	61.0^{a}	59.3^{a}	24.1^{a}	21.0^{a}	11.3^{a}	16.2^{b}	110.0a	108.0a
SE	1.580		2.650		2.650		2.240		0.800		2.120	

Values are mean. Values along the same column with different superscript are significantly different at p<0.05.

The dose of 100 and 200Gy increased panicle length in M_1 population of FARO 67 (25.4 and 27.9cm, respectively). In comparison, only100Gy increased panicle length in FARO 68 (26.0cm). At M_2 generation, irradiation significantly decreased panicle length in FARO 67(Table 2). However, 200 and 300Gy significantly increased panicle length of FARO 68(25.2 and 27.0cm). This variability could be attributed to free radical activity, which could have promoted/inhibited plant growth (Shah *et al*., 2008). Similar findings have been reported by Choi *et al*. (2021). Irradiation dose of 100Gy revealed the highest grains per panicle in M_2 population of FARO 67 (196.0), while 300Gy revealed the highest in FARO 68 (194.3). This variability might be due to heightened physiological processes at the genetic level, triggered by the ionizing impact of gamma-rays.Ali *et al.* (2015) noted that gamma-rays can enhance anti oxidative capacity of cells and stimulate plant growth characters.

Low gamma-irradiation dose of 100Gy decreased spikelet sterility in FARO 67 (7.3%)(Table 2). This could be attributed to the theory of radiation hormesis, suggesting that low doses of irradiation have a positive impact on plant development (Baldwin and Grantham, 2015).

Irradiation doses of 100 and 200Gy increased the hundred grain weight of FARO 67 (2.4 and 2.5g, respectively), while the dose of 100Gy increased the grain weight of FARO 68 (2.3g) in the M_2 population. Gamma-rays significantly increased grain yield of FARO 68 at M_1 generation. The grain yield of FARO 67 was also significantly increased at100 and 200Gy in the M_2 plants, while 300Gy significantly increased grain yield in M_2 FARO 68 (41.7g) (Table 2). These increase may be attributed to DNA and chromosomal aberrations resulting in enhanced hormonal and enzymatic activities (Kumar *et al*., 2024). This conforms with findings of Pujiasmanto and Chasanah (2021).

Table 2: Yield attributes of gamma-irradiated FARO 67 and FARO 68

Dose (Gy)	Productive tillers		Panicle length (cm)		Grains per panicle		Spikelet sterility (%)		Hundred grain weight (g)		Grain yield (g)	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
FARO 67-0	10.2^a	10.1^a	23.2^{ab}	26.6^b	105.3^a	117.0^a	12.5^a	14.4^b	2.5^b	2.7^c	33.3^a	32.2^a
FARO 67-100	9.2^a	9.3^a	25.4^b	23.0^a	94.7^a	196.0^c	10.0^a	7.3^a	2.2^a	2.1^b	30.0^a	38.6^b
FARO 67-200	9.7^a	11.2^a	27.9^c	24.5^a	108.2^a	115.0^a	18.5^b	13.8^b	2.0^a	1.9^a	34.3^a	37.7^b
FAR067-300	9.0^a	9.7^a	20.3^a	24.7^a	92.3^a	132.0^b	16.5^b	19.8^c	2.1^a	2.1^b	30.1^a	31.0^a
FARO 68-0	9.6^a	11.5^a	21.6^{ab}	22.2^a	107.1^a	126.3^a	10.3^a	5.6^b	2.0^a	1.8^a	35.8^a	34.6^{ab}
FARO 68-100	9.7^a	10.2^a	26.0^b	21.5^a	105.1^a	136.0^a	10.4^a	12.3^a	2.4^b	2.3^b	38.6^b	33.4^a
FARO 68-200	9.9^a	11.5^a	19.1^{ab}	25.2^{ab}	83.0^a	116.7^a	15.5^b	10.1^a	2.5^b	2.1^a	37.7^b	31.3^a
FAR068-300	9.9^a	14.8^b	17.9^a	27.0^b	121.0^a	194.3^b	17.2^b	12.0^a	2.0^a	1.9^a	37.9^b	41.7^b
SE	0.648		0.871		15.000		1.110		0.136		1.640	

Values are mean. Values along the same column with different superscripts are significantly different at $p<0.05$.

The phenotypic coefficient of variation (PCV) values was higher than the genotypic coefficient of variation (GCV) values for all traits studied (Table 3), suggesting that the prominent variance in the expression of the traits was caused by both the environmental and genetic factors. Similar findings were reported by Kulsum *et al*. (2022). This could be attributed to the recessive nature of favourable mutants, particularly in the early generations. All traits revealed low magnitude between the PCV and GCV, except for grains per panicle, signifying minimal influence of the environment on the expression of these traits. Therefore, phenotypic selection might be a successful method for improvement of these attributes (Regmi *et al*., 2021).

Plant height, flag leaf length, days to heading, productive tillers, panicle length and spikelet sterility revealed high heritability (>60%). Genetic advance (GA) ranged from low to high, with plant height having the highest GA (37.88%).High heritability and GAdemonstrate that additive genes primarily control the traits and suggests that there is a better scope for improvement through pedigree method of selection (Tena *et al*., 2023).

High heritability and moderate GA observed in days to heading and flag leaf length suggests the presence of both additive and non-additive gene action in their inheritance, and their selection after hybridization would be more appropriate rather than direct selection (Roychowdhury and Tah, 2013). High heritability coupled with low GA in productive tillers and spikelet sterility indicates that non-additive gene actions control these traits(Bartaula*et al*., 2019).

Table 3: Genetic parameters of M_2FARO 67 and FARO 68

Traits	Mean	Range		Variance		Coefficient of variation			h^2_b (%)	GA	GAM (%)
		Min.	Max.	σ^2p	σ^2g	CV	PCV	GCV			
SE	93.87	84.00	98.78	12.21	6.44	2.56	3.72	2.70	52.76	3.79	4.05
SS	87.37	70.00	96.67	48.23	25.20	5.49	7.95	5.75	52.25	7.48	8.56
PH	88.30	57.89	112.63	366.7	352.1	4.33	21.69	21.25	96.02	37.88	42.90
FLL	24.99	14.90	46.70	73.67	49.99	19.47	34.35	28.30	67.86	12.00	48.02
TC	13.55	11.10	16.24	6.59	3.67	11.97	17.99	13.43	55.71	2.95	20.64
DTH	112.88	106.00	130.00	37.97	31.57	2.24	5.46	4.98	83.14	10.55	9.35
PT	10.66	9.01	14.82	4.13	3.39	7.79	18.42	16.69	82.11	3.44	31.15

PL	24.33	20.47	29.63	5.31	3.22	5.94	9.47	7.38	60.64	2.88	11.83
GPP	141.67	86.00	232.00	1889.33	472.33	26.02	30.05	15.02	25.00	22.39	15.47
SST	12.29	6.34	22.76	17.87	13.13	17.89	34.73	29.77	73.48	6.40	52.57
HGW	2.11	1.80	3.00	0.10	0.04	10.21	13.54	8.89	43.15	0.27	12.04
GY	35.08	28.71	46.42	23.51	10.80	10.16	13.82	9.37	45.95	4.59	13.82

SE: seedling emergence, SS: seedling survival, PH: plant height, FLL: flag leaf length, TC: tiller count, DTH: days to heading, PT: productive tillers, PL: panicle length, GPP: grains per panicle, SST: Spikelet sterility, HGW: Hundred grain weight, GY: Grain yield, σ^2p: Phenotypic variance, σ^2g: Genotypic variance, CV: Coefficient of variation, PCV: Phenotypic coefficient of variation, GCV: Genetic coefficient of variation, h^2_b: broad sense heritability, GA: Genetic advance, GAM: Genetic advance as percentage of mean.

The PCA biplot revealed that the SST, PL, TC, GPP, GY and PT were positively correlated and appeared on the positive side of the PC1, while other traits were located on the negative side of the PC1 (Figure 2).The biplot demonstrated that SE, TC and PT had the longest vectors, representing their role in contributing to the overall divergence. Mutants loaded on the positive side of the PC1, particularly FARO 68-300Gy demonstrated stronger associations with yield attributes. The positioning of FARO 67-300Gy suggests that300Gy dose in FARO 67 revealed the highest flag leaf length and spikelet sterility. This is in line with the report of Pragmatic *et al.* (2023) who have reported improvement of different plant traits at different irradiation doses and also reflects the differences in varietal response to irradiation due to antioxidant reaction, repair process and cell cycle kinetics-related differences (Hong *et al.*, 2022).

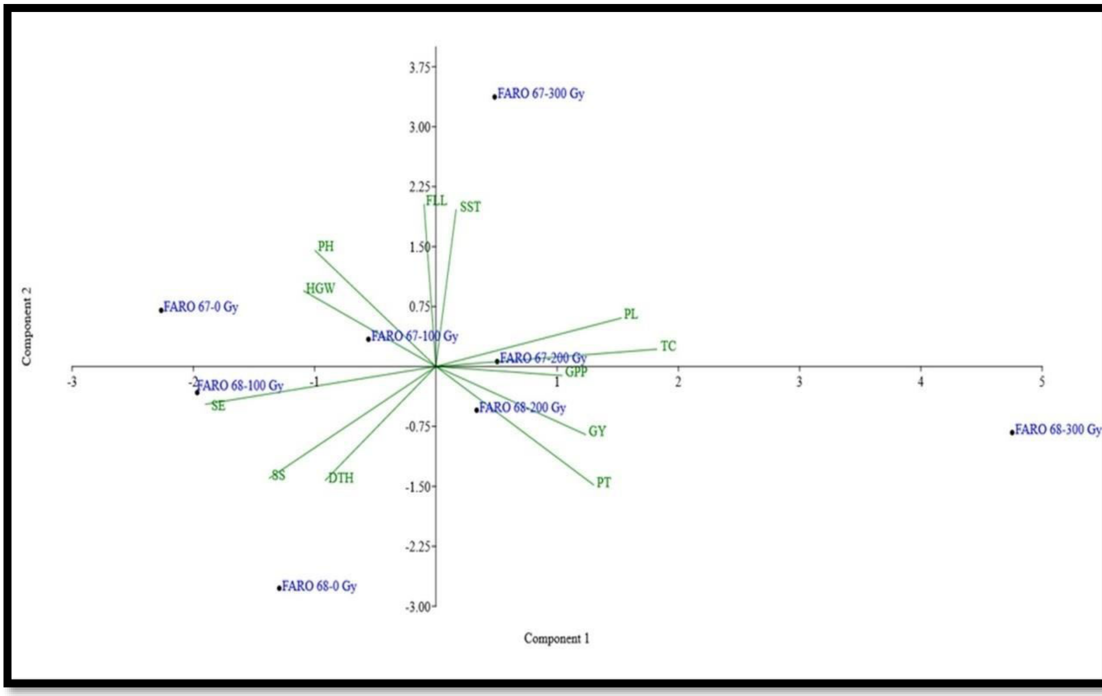

Figure 2: PCA of agro morphological traits of the M_2 population. SE: seedling survival, SS: seedling survival, DTH: days to heading, SN: spikelet number, PT: productive tillers, TW: test weight, GPP: grains per panicle, TC: tiller count, PL: panicle length, SST: spikelet sterility, FLL: flag leaf length, PH: plant height, HGW: hundred grain weight, GY: Grain yield.

Results revealed that irradiation dose of 200Gy had the highest mean rank for flag leaf angle in FARO 67 across generations, and in M_1FARO 68 (Table 4). However, 300Gy revealed the highest mean rank in the M_2 population of FARO 68, indicating more intermediate and horizontal flag leaf angles following irradiation. This could be due to the influence of irradiation on hormonal activities, enabling plants to better respond to light intensity (Wi *et al.,* 2007). Similar findings have been reported by Naibaho*et al*. (2023).Banjere*et al*. (2024) noted that the flag leaf plays a crucial role in grain yield, contributing about 45% to photosynthesis, and intermediate flag leaves (30-45°) enhance direct light capture, leading to improved resource use efficiency.

In M_2 FARO 67, the highest mean rank for panicle type was observed at 200Gy, while in FARO 68, 100 and 200Gy revealed higher and identical mean ranks across generations, indicating a shift towards open panicles. This could be attributed to variation in chromosomal structure controlling panicle morphology caused by irradiation (Kumar *et al*., 2024). Parida *et al*. (2022) opined that rice grain yield can be increased by 30% through the conversion of compact panicles to lax/open panicles. Open panicles improve yield and increase disease resistance in environments with high humidity and low sunlight (Yang *et al.,* 2024).

The highest mean rank for panicle exsertion in FARO 67 was observed at 300Gy in M_1 and at 100Gy in M_2 population. FARO 68 revealed least mean ranks at 100 and 200Gy in both M_1 and M_2 generations, indicating well exserted panicles. These variations could be due to disturbances in hormonal balance and enzyme activity which may lead to variations in length due to insufficient water and mineral supply to the plants (Kumar *et al.,* 2024). Similar findings have been reported by Chakraborty *et al.* (2024). Reduction in panicle exsertion often results in panicle enclosure. This study demonstrates a significant increase in panicle exsertion of FARO 68 at 100 and 200Gy. This is a highly desirable trait in rice breeding as better panicle exsertions facilitate efficient pollination and enhances seed development and grain filling.

In FARO 67, the least mean rank for panicle shattering was recorded at 100 and 300Gy in M_1, and at 300Gy in M_2. Reducing panicle shattering is considered a crucial step in crop improvement as it minimizes yield loss during harvest (Turra *et al*., 2024). The significant decrease observed in panicle shattering could be attributed to beneficial mutations affecting genes responsible for abscission layer caused by irradiation. Similar findings have been reported by Li *et al.* (2020).

Table 4: Qualitative agromorphological traits of M_1 and M_2FARO 67 and FARO 68

Dose (Gy)	**Flag Leaf Angle**		**Panicle Type**		**Panicle Exsertion**		**Panicle Shattering**	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
FARO 67-0	5.0^{a}	4.5^{a}	10.5^{a}	9.0^{a}	9.0^{a}	5.0^{a}	15.5^{b}	18.0^{c}
FAR067-100	12.2^{ab}	11.7^{b}	10.5^{a}	9.0^{a}	9.0^{a}	16.0^{d}	5.5^{a}	10.5^{b}
FARO 67-200	14.4^{b}	14.1^{c}	10.5^{a}	15.0^{b}	9.0^{a}	9.4^{b}	15.5^{b}	10.5^{b}
FARO 67-300	10.4^{ab}	11.7^{b}	10.5^{a}	9.0^{a}	15.0^{b}	11.6^{c}	5.5^{a}	3.0^{a}
FARO 68-0	8.5^{a}	8.5^{a}	7.5^{a}	6.5^{a}	15.0b	17.0^{c}	5.5^{a}	15.5^{c}
FARO 68-100	8.5^{a}	9.5^{b}	13.5^{b}	14.5^{b}	7.5^{a}	6.6^{a}	13.0^{b}	8.0^{b}
FARO 68-200	16.5^{b}	9.5^{b}	13.5^{b}	14.5^{b}	8.7^{a}	6.6^{a}	5.5^{a}	3.0^{a}
FARO 68-300	8.5^{a}	14.5^{c}	7.5^{a}	6.5^{a}	10.8^{ab}	11.8^{b}	18.0^{c}	15.5^{c}

Values are mean ranks. Values along the same column with different superscript are significantly different at $p<0.05$. Higher ranks indicate greater magnitude of the trait.

The Principal Coordinate Analysis (P Co A) of qualitative traits of the M_2 population showed spatial distribution of the treatment groups along the two principal axis (coordinate 1 and coordinate 2) (Figure 3). The minimum spanning tree connected the treatment groups according to their relative similarity. Results revealed that FARO 67-0Gy and FARO 68-0Gy occupied distinct positions in the ordination space, indicating inherent varietal differences. Irradiation induced noticeable shifts away from the control positions, indicating that it caused a measurable divergence in the qualitative attributes.

The result also revealed that the treatment groups placed far away from the centroid of the cluster were more diverse while those positioned around the centroid possessed similar qualitative attributes. FARO 67-0Gy and FARO 68-300Gy, FARO 67-300Gy and FARO 68-0Gy were relatively close in the ordination space, indicating similar responses of the treatment groups. The 300Gy treatment for both varieties were positioned farther away from their controls, demonstrating the greatest dissimilarity between the treatment groups.

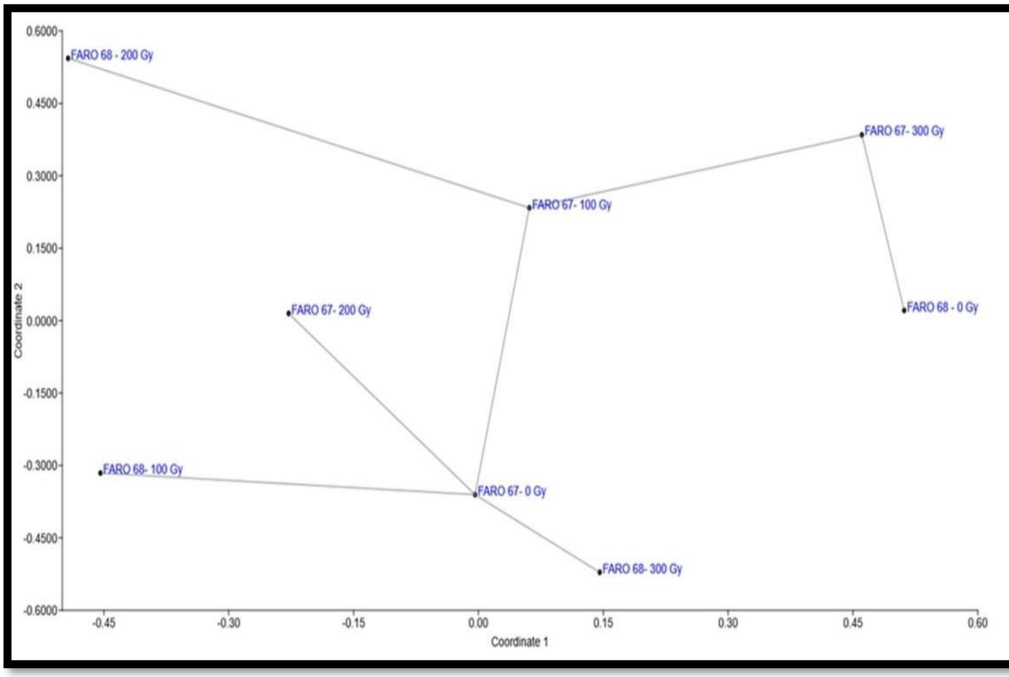

Figure 3: P Co A (Gower similarity index) and minimum spanning tree using qualitative trait score

A total of 749 mutants were selected from the M_2 population. Among them, 56 mutants were isolated for flag leaf angle (30-45°), 62 mutants for panicle type (open panicles from a compact panicle parent), and 51 mutants for panicle exsertion (well exserted panicles), 103 mutants were selected for earliness with 5-15 days early flowering than the average days to heading, 106 mutants for short plant height (< 80 cm tall), 138 mutants for tillers per plant (> 15.0), 60 mutants for spikelet sterility (<10 %), and 173 mutants for grain yield (> 35g), The irradiation of 300 Gy produced the highest number of mutants with desirable traits (281) (Table 5).

Table 5: Number of desirable mutants at M_2 generation based on most important attributes

Mutants	FLA (45°)	PT (Open panicles)	PE (well-exserted panicle	Earliness 5-15 days	PH < 80 cm	TPP > 15	SS < 10%	GY > 35g
FARO 67-100	15	-	-	14	-	8	26	41
FARO 67-200	3	21	-	5	9	15	3	32
FARO 67-300	13	-	-	8	3	17	5	7
FARO 68-100	2	14	21	19	11	9	4	18
FARO 68-200	18	27	16	26	38	32	15	6
FARO 68-300	5	-	14	31	45	57	7	69
Total	56	62	51	103	106	138	60	173

FLA: flag leaf angle, PT: panicle type, PE: panicle exsertion, PH: plant height, TPP: tillers per plant, SS: spikelet sterility, GY: grain yield

Conclusion

Gamma-ray was potent for creating variability in rice cultivated in irrigated environment swath 300Gy producing the highest number of mutants. A total of 749 mutants were isolated from the M_2 population based on important agronomic traits. Seedling emergence, tiller count and productive tillers played predominant roles in contributing to the overall divergence. This research provides new breeding materials that can be further evaluated and exploited in achieving specific rice breeding objectives.

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Conflict of Interest

Authors declare that there is no competing interest

Author Contribution Statement

Audu MAI: Conceptualization, funding acquisition, investigation, data curation, analysis, writing original draft and visualization. MustaphaOT and OlorunmaiyeKS: methodology, validation, project administration and supervision.

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