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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:**

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. This paper examined the extent of variability caused by three gamma irradiation doses in the M<sub>1</sub> and M<sub>2</sub> populations of two submergence-tolerant rice (*Oryza sativa*) varieties (FARO 67 and FARO 68) evaluated under irrigated conditions during the 2023/2024 (M<sub>1</sub>) and 2024/2025 (M<sub>2</sub>) dry seasons. Data on morphology and yield attributes were recorded following standard protocols. 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<sub>2</sub> population based on earliness (5-15 days), plant height (<80cm), tillering (>15), spikelet sterility (<10%), grain yield (>35g), flag leaf orientation (30-45°), panicle type (open panicles) and panicle exertion (well-exserted 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. 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.

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## Introduction

Rice (*Oryza sativa* L.) serves as a staple food source for more than half of the world's population (Xu *et al.*, 2021). It plays 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 for rice 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).

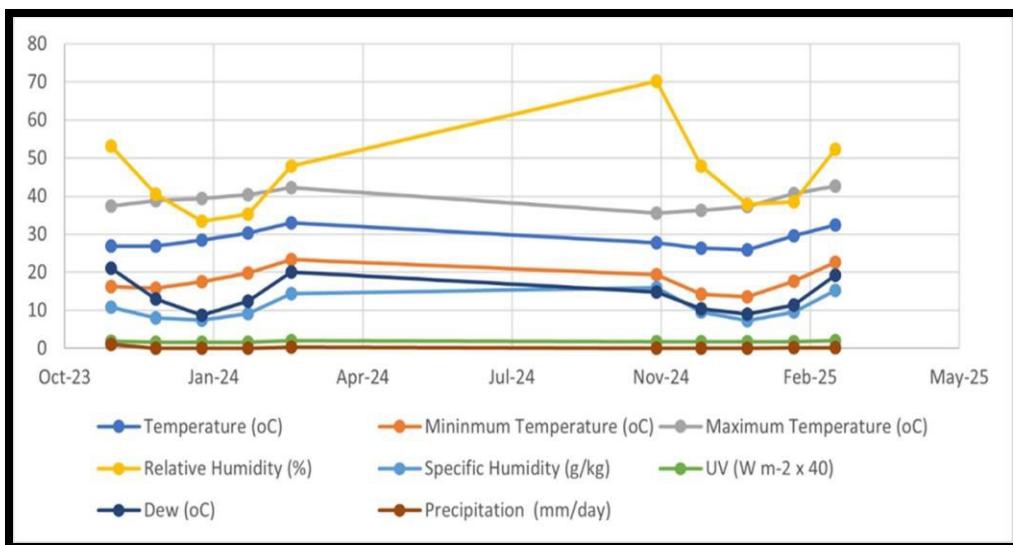
Although Nigeria has the potential for large-scale rice production, the lack of adaptable varieties has been a major constraint (Abegunde *et al.*, 2024). Since the genetic improvement potential of any breeding population is largely dependent on the genetic variability present (Sanchez *et al.*, 2023), 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 68 are 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 (NCRI) Badeggi, 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<sub>1</sub> 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<sub>2</sub> 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 300 Gy in both varieties, across generations. This could be attributed to physiological injuries which impaired 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  $M_2$  FARO 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<sub>2</sub>FARO 67. The highest tillering was observed in FARO 68 exposed to 300Gy at the M<sub>2</sub> generation (16.2). The number of days to heading was significantly influenced by irradiation. In M<sub>1</sub> 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 <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>
FARO 67-0	95.3 <sup>b</sup>	96.6 <sup>b</sup>	89.7 <sup>b</sup>	93.2 <sup>b</sup>	104.1 <sup>a</sup>	102.7 <sup>a</sup>	23.4 <sup>a</sup>	24.0 <sup>a</sup>	12.0 <sup>a</sup>	12.3 <sup>a</sup>	120.0 <sup>b</sup>	114.0 <sup>a</sup>
FARO 67-100	90.1 <sup>b</sup>	94.5 <sup>a</sup>	85.4 <sup>b</sup>	91.1 <sup>b</sup>	102.3 <sup>a</sup>	101.9 <sup>a</sup>	24.8 <sup>a</sup>	35.7 <sup>b</sup>	13.3 <sup>a</sup>	12.9 <sup>a</sup>	109.0 <sup>a</sup>	110.0 <sup>a</sup>
FARO 67-200	84.6 <sup>a</sup>	93.1 <sup>a</sup>	79.7 <sup>a</sup>	87.4 <sup>ab</sup>	109.6 <sup>a</sup>	102.5 <sup>a</sup>	30.7 <sup>a</sup>	24.2 <sup>a</sup>	12.4 <sup>a</sup>	14.1 <sup>a</sup>	113.0 <sup>ab</sup>	113.0 <sup>a</sup>
FARO 67-300	85.4 <sup>a</sup>	92.4 <sup>a</sup>	79.6 <sup>a</sup>	76.9 <sup>a</sup>	108.4 <sup>a</sup>	109.2 <sup>a</sup>	28.1 <sup>a</sup>	37.3 <sup>b</sup>	12.1 <sup>a</sup>	14.6 <sup>a</sup>	128.0 <sup>c</sup>	110.0 <sup>a</sup>
FARO 68-0	94.2 <sup>c</sup>	96.8 <sup>b</sup>	87.3 <sup>b</sup>	92.2 <sup>b</sup>	95.2 <sup>c</sup>	86.0 <sup>b</sup>	16.7 <sup>a</sup>	16.9 <sup>a</sup>	11.6 <sup>a</sup>	13.2 <sup>ab</sup>	129.0 <sup>c</sup>	126.0 <sup>b</sup>
FARO 68-100	83.6 <sup>b</sup>	96.3 <sup>b</sup>	77.6 <sup>ab</sup>	89.7 <sup>ab</sup>	85.2 <sup>b</sup>	80.1 <sup>b</sup>	22.6 <sup>a</sup>	23.4 <sup>a</sup>	11.1 <sup>a</sup>	11.4 <sup>a</sup>	120.0 <sup>b</sup>	112.0 <sup>a</sup>
FARO 68-200	86.1 <sup>b</sup>	93.0 <sup>b</sup>	79.1 <sup>a</sup>	87.7 <sup>a</sup>	68.7 <sup>a</sup>	64.7 <sup>a</sup>	23.2 <sup>a</sup>	17.6 <sup>a</sup>	13.0 <sup>a</sup>	13.8 <sup>ab</sup>	107.0 <sup>a</sup>	109.0 <sup>a</sup>
FARO 68-300	77.3 <sup>a</sup>	88.2 <sup>a</sup>	71.6 <sup>a</sup>	80.7 <sup>a</sup>	61.0 <sup>a</sup>	59.3 <sup>a</sup>	24.1 <sup>a</sup>	21.0 <sup>a</sup>	11.3 <sup>a</sup>	16.2 <sup>b</sup>	110.0 <sup>a</sup>	108.0 <sup>a</sup>
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<sub>1</sub> population of FARO 67 (25.4 and 27.9cm, respectively). In comparison, only 100Gy increased panicle length in FARO 68 (26.0cm). At M<sub>2</sub> 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<sub>2</sub> 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 antioxidative 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<sub>2</sub> population. Gamma-rays significantly increased grain yield of FARO 68 at M<sub>1</sub> generation. The grain yield of FARO 67 was also significantly increased at 100 and 200Gy in the M<sub>2</sub> plants, while 300Gy significantly increased grain yield in M<sub>2</sub> 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

<b>Dose (Gy)</b>	<b>Productive tillers</b>		<b>Panicle length (cm)</b>		<b>Grains per panicle</b>		<b>Spikelet sterility (%)</b>		<b>Hundred grain weight (g)</b>		<b>Grain yield (g)</b>	
	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>
FARO 67-0	10.2 <sup>a</sup>	10.1 <sup>a</sup>	23.2 <sup>ab</sup>	26.6 <sup>b</sup>	105.3 <sup>a</sup>	117.0 <sup>a</sup>	12.5 <sup>a</sup>	14.4 <sup>b</sup>	2.5 <sup>b</sup>	2.7 <sup>c</sup>	33.3 <sup>a</sup>	32.2 <sup>a</sup>
FARO 67-100	9.2 <sup>a</sup>	9.3 <sup>a</sup>	25.4 <sup>b</sup>	23.0 <sup>a</sup>	94.7 <sup>a</sup>	196.0 <sup>c</sup>	10.0 <sup>a</sup>	7.3 <sup>a</sup>	2.2 <sup>a</sup>	2.1 <sup>b</sup>	30.0 <sup>a</sup>	38.6 <sup>b</sup>
FARO 67-200	9.7 <sup>a</sup>	11.2 <sup>a</sup>	27.9 <sup>c</sup>	24.5 <sup>a</sup>	108.2 <sup>a</sup>	115.0 <sup>a</sup>	18.5 <sup>b</sup>	13.8 <sup>b</sup>	2.0 <sup>a</sup>	1.9 <sup>a</sup>	34.3 <sup>a</sup>	37.7 <sup>b</sup>
FARO 67-300	9.0 <sup>a</sup>	9.7 <sup>a</sup>	20.3 <sup>a</sup>	24.7 <sup>a</sup>	92.3 <sup>a</sup>	132.0 <sup>b</sup>	16.5 <sup>b</sup>	19.8 <sup>c</sup>	2.1 <sup>a</sup>	2.1 <sup>b</sup>	30.1 <sup>a</sup>	31.0 <sup>a</sup>
FARO 68-0	9.6 <sup>a</sup>	11.5 <sup>a</sup>	21.6 <sup>ab</sup>	22.2 <sup>a</sup>	107.1 <sup>a</sup>	126.3 <sup>a</sup>	10.3 <sup>a</sup>	5.6 <sup>b</sup>	2.0 <sup>a</sup>	1.8 <sup>a</sup>	35.8 <sup>a</sup>	34.6 <sup>ab</sup>
FARO 68-100	9.7 <sup>a</sup>	10.2 <sup>a</sup>	26.0 <sup>b</sup>	21.5 <sup>a</sup>	105.1 <sup>a</sup>	136.0 <sup>a</sup>	10.4 <sup>a</sup>	12.3 <sup>a</sup>	2.4 <sup>b</sup>	2.3 <sup>b</sup>	38.6 <sup>b</sup>	33.4 <sup>a</sup>
FARO 68-200	9.9 <sup>a</sup>	11.5 <sup>a</sup>	19.1 <sup>ab</sup>	25.2 <sup>ab</sup>	83.0 <sup>a</sup>	116.7 <sup>a</sup>	15.5 <sup>b</sup>	10.1 <sup>a</sup>	2.5 <sup>b</sup>	2.1 <sup>a</sup>	37.7 <sup>b</sup>	31.3 <sup>a</sup>
FARO 68-300	9.9 <sup>a</sup>	14.8 <sup>b</sup>	17.9 <sup>a</sup>	27.0 <sup>b</sup>	121.0 <sup>a</sup>	194.3 <sup>b</sup>	17.2 <sup>b</sup>	12.0 <sup>a</sup>	2.0 <sup>a</sup>	1.9 <sup>a</sup>	37.9 <sup>b</sup>	41.7 <sup>b</sup>
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 GA demonstrate 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<sub>2</sub>FARO 67 and FARO 68

Traits	Mean	Range		Variance		Coefficient of variation			h <sup>2</sup> <sub>b</sub> (%)	GA	GAM (%)
		Min.	Max.	σ <sup>2</sup> p	σ <sup>2</sup> g	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,  $\sigma^2 p$ : Phenotypic variance,  $\sigma^2 g$ : 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 that 300Gy 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).

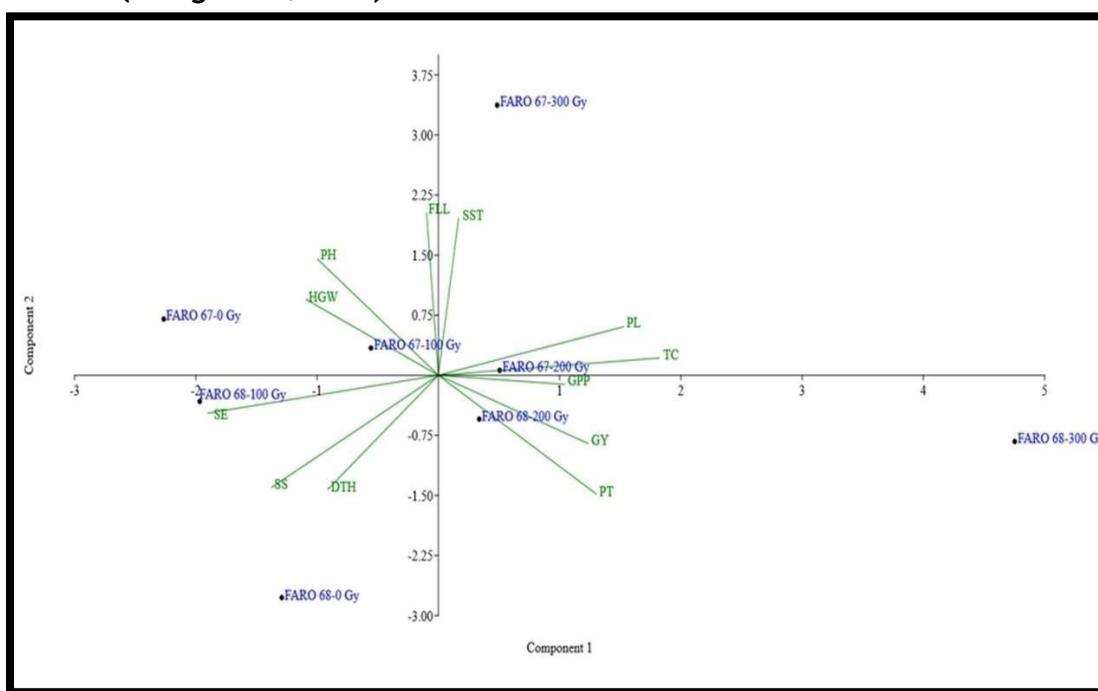


Figure 2: PCA of agro morphological traits of the M<sub>2</sub> population. SE: seedling survival, SS: seedling survival, DTH: days to heading, SN: spikelet number, PT: productive tillers, TW: test weight, GPP: grains per panicle, TC: tiller count, PL: panicle length, SST: spikelet sterility, FLL: flag 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<sub>1</sub>FARO 68 (Table 4). However, 300Gy revealed the highest mean rank in the M<sub>2</sub> 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 Naibahoet *et al.* (2023). Banjereet *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<sub>2</sub>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<sub>1</sub> and at 100Gy in M<sub>2</sub> population. FARO 68 revealed least mean ranks at 100 and 200Gy in both M<sub>1</sub> and M<sub>2</sub> 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<sub>1</sub>, and at 300Gy in M<sub>2</sub>. 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<sub>1</sub> and M<sub>2</sub>FARO 67 and FARO 68

<b>Dose (Gy)</b>	<b>Flag Leaf Angle</b>		<b>Panicle Type</b>		<b>Panicle Exsertion</b>		<b>Panicle Shattering</b>	
	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>
FARO 67-0	5.0 <sup>a</sup>	4.5 <sup>a</sup>	10.5 <sup>a</sup>	9.0 <sup>a</sup>	9.0 <sup>a</sup>	5.0 <sup>a</sup>	15.5 <sup>b</sup>	18.0 <sup>c</sup>
FARO 67-100	12.2 <sup>ab</sup>	11.7 <sup>b</sup>	10.5 <sup>a</sup>	9.0 <sup>a</sup>	9.0 <sup>a</sup>	16.0 <sup>d</sup>	5.5 <sup>a</sup>	10.5 <sup>b</sup>
FARO 67-200	14.4 <sup>b</sup>	14.1 <sup>c</sup>	10.5 <sup>a</sup>	15.0 <sup>b</sup>	9.0 <sup>a</sup>	9.4 <sup>b</sup>	15.5 <sup>b</sup>	10.5 <sup>b</sup>
FARO 67-300	10.4 <sup>ab</sup>	11.7 <sup>b</sup>	10.5 <sup>a</sup>	9.0 <sup>a</sup>	15.0 <sup>b</sup>	11.6 <sup>c</sup>	5.5 <sup>a</sup>	3.0 <sup>a</sup>
FARO 68-0	8.5 <sup>a</sup>	8.5 <sup>a</sup>	7.5 <sup>a</sup>	6.5 <sup>a</sup>	15.0 <sup>b</sup>	17.0 <sup>c</sup>	5.5 <sup>a</sup>	15.5 <sup>c</sup>
FARO 68-100	8.5 <sup>a</sup>	9.5 <sup>b</sup>	13.5 <sup>b</sup>	14.5 <sup>b</sup>	7.5 <sup>a</sup>	6.6 <sup>a</sup>	13.0 <sup>b</sup>	8.0 <sup>b</sup>
FARO 68-200	16.5 <sup>b</sup>	9.5 <sup>b</sup>	13.5 <sup>b</sup>	14.5 <sup>b</sup>	8.7 <sup>a</sup>	6.6 <sup>a</sup>	5.5 <sup>a</sup>	3.0 <sup>a</sup>
FARO 68-300	8.5 <sup>a</sup>	14.5 <sup>c</sup>	7.5 <sup>a</sup>	6.5 <sup>a</sup>	10.8 <sup>ab</sup>	11.8 <sup>b</sup>	18.0 <sup>c</sup>	15.5 <sup>c</sup>

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 (PCoA) of qualitative traits of the M<sub>2</sub> 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.

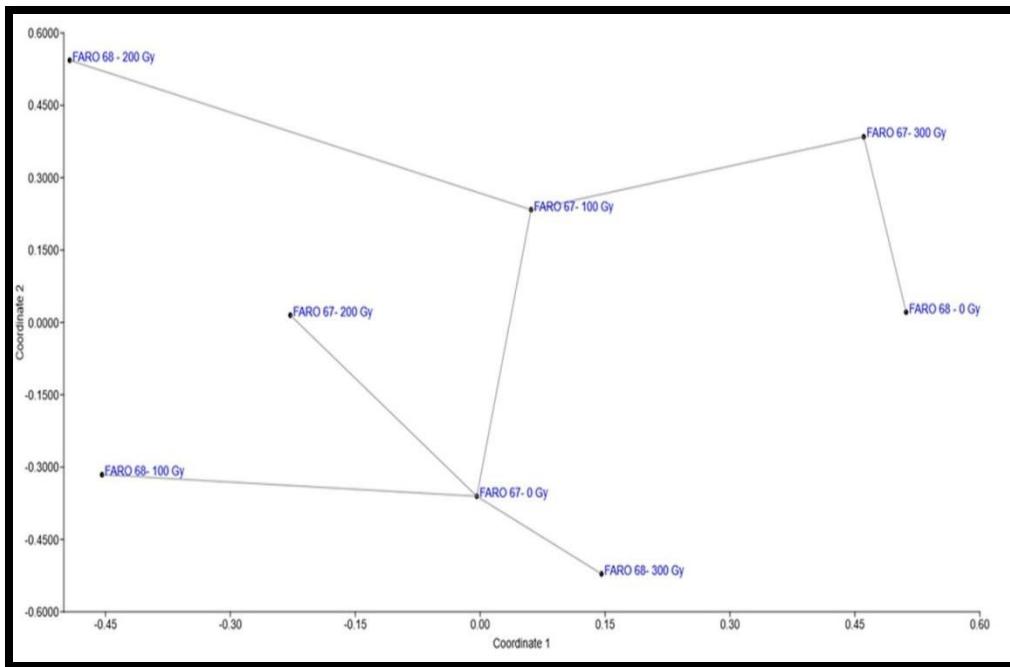


Figure 3: PCoA (Gower similarity index) and minimum spanning tree using qualitative trait score

A total of 749 mutants were selected from the M<sub>2</sub> 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 (<80cm tall), 138 mutants for tillers per plant (>15.0), 60 mutants for spikelet sterility (<10%), and 173 mutants for grain yield (>35g). The irradiation dose of 300Gy produced the highest number of mutants with desirable traits (281) (Table 5).

Table 5: Number of desirable mutants at M<sub>2</sub> 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 with 300Gy producing the highest number of mutants. A total of 749 mutants were isolated from the M<sub>2</sub> 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. Mustapha OT and Olorunmaiye KS: methodology, validation, project administration and supervision.

### References

1. **Abegunde, I**(2024). **Journal of Agricultural Sciences (Belgrade)**, Analysis of genotypic and phenotypic correlations and path coefficients in 40 genotypes of rain-fed upland rice (*Oryza sativa* L.) in Oyo and Ogun States regions of Nigeria. **Volume 69 Number 2**: Page.207-224.
2. **Ali, A. H. A., Galal, O. A., Elmoghazy, A. M. and Abd Elrazek, M. M** (2022). **Fresenius Environmental Bulletin**, Use of Gamma rays for inducing short stature and early maturing mutants in Egyptian Jasmine rice variety. **Volume 31 Number 6**: Page. 5783-5787.
3. **Ali, H., Ghori, Z., Sheikh, S. and Gul, A** (2015). **In Crop production and global environmental issues**, Effects of gamma radiation on crop production. Cham: Springer International Publishing.

4. **Amri-Tiliouine, W., Laouar, M., Abdelguerfi, A., Jankowicz-Cieslak, J., Jankuloski, L. and Till, B. J** (2018). **Frontiers in Plant Science**, Genetic variability induced by gamma rays and preliminary results of low-cost TILLING on M2 generation of chickpea (*Cicer arietinum* L.). **Volume 9**: Page. 1568.
5. **Arouna, A., Soullier, G., Del Villar, P. M. and Demont, M** (2020). **Global Food Security**, Policy options for mitigating impacts of COVID-19 on domestic rice value chains and food security in West Africa. **Volume 26**:Page. 100405.
6. **Baldwin, J. and Grantham, V** (2015). **Journal of nuclear medicine technology**, Radiation hormesis: historical and current perspectives. **Volume 43 Number 4**: Page. 242-246.
7. **Banjare, B., Katiyar, P., Magar, A.S. and Thakur, N** (2024). **Journal of Experimental Agriculture International**, Exploring the correlation between morpho-physiological traits and growth attributes associated with yield characteristics in rice (*Oryza sativa* L.). **Volume 46 Number 8**: Page. 158-164.
8. **Barela, A., Jain, S., Tiwari, S., Rahangdale, S. and Singh, P** (2022). **The Pharma Innovation Journal**, Impact of gamma radiations on seed germination and morphological characteristics of pea (*Pisum sativum* L.). **Volume 11 Number 8**: Page. 464-467.
9. **Bartaula, S., Panthi, U., Timilsena, K., Acharya, S. S. and Shrestha, J** (2019). **Research in Agriculture Livestock and Fisheries**, Variability, heritability and genetic advance of maize (*Zea mays* L.) genotypes. **Volume 6 Number 2**: Page 163-169.
10. **Chakraborty, N.R., Kant, A. and Debnath, S** (2024). **A review – in: nitish k. (eds), plant mutagenesis and crop improvement, CRC Press**, 5 Application techniques of crop nuclear improvement. Page. 98-123.
11. **Choi, H. I., Han, S. M., Jo, Y. D., Hong, M. J., Kim, S. H. and Kim, J. B** (2021). **Plants**, Effects of acute and chronic gamma irradiation on the cell biology and physiology of rice plants. **Volume 10 Number 3**: Page. 439.
12. **Elsherbiny, H. A., Gaballah, M. M., Hamad, H. S., Sakr, S. M., Elbadawy, O. A., Alwutayd, K. M., ... and Bleih, E. M** (2024). **Chilean Journal of Agricultural Research**, Inducing potential mutants in rice using different doses of gamma rays for improving agronomic traits. **Volume 8 Number 3**: Page. 380-390.
13. **Feldman, A. F., Feng, X., Felton, A. J., Konings, A. G., Knapp, A. K., Biederman, J. A. and Poulter, B.** (2024). **Nature Reviews Earth & Environment**, Plant responses to changing rainfall frequency and intensity. **Volume 5 Number 4**: Page. 276-294.
14. **Food and Agriculture Organization of the United Nations**, Crops and Livestock Products. [www.fao.org](http://www.fao.org) Accessed 30 November 2025.
15. **Guite, S. and Sharma, H. I** (2023). **Journal of Land and Rural Studies**, A study on agrarian economy in the hills of Manipur with special reference to Thadou-Kuki ethnic group. **Volume 11 Number 2**: Page. 179-206.
16. **Hasan, N. A., Rafii, M. Y., Harun, A. R., Ahmad, F., Jaafar, N. N. and Shukri, A. A** (2021). **IOP Conference Series: Earth and Environmental Science**, Agromorphological response of rice (*Oryza sativa* L.)(cv MR 284) to chronic gamma irradiation. **Volume 756 Number 1**: Page. 012009.

17. **Hong, M. J., Kim, D. Y., Jo, Y. D., Choi, H. I., Ahn, J. W., Kwon, S. J., ... and Kim, J. B** (2022). **Applied Sciences**, Biological effect of gamma rays according to exposure time on germination and plant growth in wheat. **Volume 12 Number 6**: Page. 3208.
18. **Huang, X., Karats, N., Wei, X., Wang, Z. X., Wang, A., Zhao, Q., and Han, B** (2012). **Nature**, A map of rice genome variation reveals the origin of cultivated rice. **Volume 490 Number 7421**:Page. 497-501.
19. **IndexMundi(2024). Nigeria – Rice imports by year**.Retrieved from [www.indexmundi.com](http://www.indexmundi.com)
20. **IRRI (1980).Descriptors for rice (*Oryza sativa L.*)**, International Rice Research Institute and International Board for Plant Genetic Resources, Manila, Philippines. Page. 1-28.
21. **Khan, F., Naaz, S., Singh, N., Shukla, P. K., Tripathi, R., Yadav, H. K. and Shirke, P. A**(2022).**Current Plant Biology**,Molecular, physiological and agronomic assessment of genetic diversity in ricevarietiesin relation to drought treatment. **Volume 29**:Page. 100232.
22. **Kulsum, U., Sarker, U. and Rasul, M. G** (2022). **Genetika**,Genetic variability, heritability and interrelationship in salt-tolerant lines of T. Aman rice. **Volume 54 Number 2**:Page. 761-776.
23. **Kumar, G., Pandey, S., Tiwari, N. K., Pandey, P. and Yadav, J** (2024). **Jordan Journal of Biological Sciences**,Effect of gamma irradiation on morphological biochemical and cytological attributes of *Salvia hispanica L.* **Volume 17 Number 1**: Page. 67-75.
24. **Li, F., Komatsu, A., Ohtake, M., Eun, H., Shimizu, A. and Kato, H** (2020). **Scientific Reports**, Direct identification of a mutation in OsSh1 causing non-shattering in a rice (*Oryza sativa L.*) mutant cultivar using whole-genome resequencing. **Volume 10 Number 1**:Page. 14936.
25. **Luz, V. K. D., Silveira, S. F. D. S., Fonseca, G. M. D., Groli, E. L., Figueiredo, R. G., Baretta, D., and Oliveira, A. C. D** (2016). **Bragantia**, Identification of variability for agronomic ally important traits in rice mutant families. **Volume 75 Number 1**:Page. 41-50.
26. **Naibaho, D., Purba, E., Hanafiah, D. S., and Hasibuan, S** (2023).**Biodiversitas: Journal of Biological Diversity**, Improvement of morphology, biochemical characters, and molecular changes of local upland rice cv. Sidikalang M3 generation through induction of gamma-ray irradiation. **Volume 24 Number 1**: Page. 200-207.
27. **National Aeronautics and Space Administration. Data Access Viewer**:power.larc.nasa.gov on 12<sup>th</sup> August, 2025.
28. **Parida, A. K., Sekhar, S., Panda, B. B., Sahu, G. and Shaw, B. P** (2022). **Frontiers in Genetics**,Effect of panicle morphology on grain filling and rice yield: genetic control and molecular regulation. **Volume 13**:Page. 876198.
29. **Pramanik, B., Debnath, S., Rahimi, M., Helal, M. M. U. and Hasan, R** (2023). **PLoS One**,Morph metric frequency and spectrum of gamma-ray-induced chlorophyll mutants identified by phenotype and development of novel variants in lentil (*Lens culinaris*Medik). **Volume 18 Number 6**: Page. e0286975.
30. **Pujiasmanto, B. and Chasanah, U** (2021). **IOP Conference Series: Earth and Environmental Science. IOP Publishing**, The yield of three promising lines

cempoireng black rice M7 generation from gamma-ray irradiation. **Volume 824 Number 1:** Page. 012072.

31. **Regmi, S., Poudel, B., Ojha, B. R., Kharel, R., Joshi, P., Khanal, S. and Kandel, B. P** (2021). **International Journal of Agronomy**, Estimation of genetic parameters of different wheat genotype traits in Chitwan, Nepal. **Volume 1:** Page. 6651325.

32. **Roychowdhury, R. and Tah, J** (2013). **Crop improvement: new approaches and modern techniques**. Boston, MA: Springer US. Mutagenesis—A potential approach for crop improvement. Page. 149-187.

33. **Sanchez, D., Sadoun, S. B., Mary-Huard, T., Allier, A., Moreau, L. and Charcosset, A** (2023). **Proceedings of the National Academy of Sciences**, Improving the use of plant genetic resources to sustain breeding programs' efficiency. **Volume 120 Number 13:** Page. e2205780119.

34. **Shah, F.R., Ahmad, N., Masood, K.R. and Zahid, D.M** (2008). **Pakistan Journal of Botany**, The influence of cadmium and chromium on the biomass production of shisham (*Dalbergia sissooroxb.*) seedlings. **Volume 40 Number 4:** Page. 1341-1348.

35. **Sharma, V., Kordrostami, M., Maan, S. S., Sarsu, F. and Penna, S** (2024). **Sustainable utilization and conservation of plant genetic diversity**, Innovations in artificial induction of plant genetic diversity. Page. 259-287.

36. **Suliartini, N. W. S., Wangiyana, W., Aryana, I. G. P. M. and Sudharmawan, A. A. K** (2020). **Population**, Radio sensitivity and seedling growth of several genotypes of paddy rice mutants irradiated with gamma rays at different doses. **Volume 19 Number 21**.

37. **Tena, E., Tadesse, F., Million, F. and Tesfaye, D** (2023). **Ethiopia. Journal of Crop Improvement**, Phenotypic diversity, heritability, and association of characters in sugarcane genotypes at Metehara Sugar Estate. **Volume 37 Number 6:** Page. 874-897.

38. **Turra, G. M., Li, X., Nunes, A. L., Markus, C., Caicedo, A. L. and Merotto Junior, A** (2024). **Advances in Weed Science**, Experimental methods for phenotypic and molecular analyses of seed shattering in cultivated and weedy rice. **Volume 41:** Page. e020230049.

39. **Wi, S. G., Chung, B. Y., Kim, J. S., Kim, J. H., Baek, M. H., Lee, J. W. and Kim, Y. S** (2007). **Micron**, Effects of gamma irradiation on morphological changes and biological responses in plants. **Volume 38 Number 6:** Page. 553-564.

40. **Xu, Y., Ma, K., Zhao, Y., Wang, X., Zhou, K., Yu, G...and Xu, S** (2021). **The Crop Journal**, Genomic selection: A breakthrough technology in rice breeding. **Volume 9 Number 3:** Page. 669-677.

41. **Yang, G., Wang, Q., Yang, G., Zhang, G., Chen, H., Wang, X and Hu, Y** (2024). **Plants**, Application of open panicle traits in improving the filling characteristics at the base of indica rice panicles. **Volume 13 Number 15:** Page. 20-35.

42. **Yuan, S., Saito, K., Van-Oort, P. A., Van-Ittersum, M. K., Peng, S. and Grassini, P** (2024). **Nature communications**, Intensifying rice production to reduce imports and land conversion in Africa. **Volume 15 Number 1:** Page. 835.