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Effects of Gamma Irradiation on Submergence Tolerance of Some Lowland Rice (*Oryzasativa* L.) Mutant Lines

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Abstract: Submergence tolerance is an important breeding objective intended to reduce to the barest minimum yield losses in rice especially in rain-fed lowland areas. Faro 44 and Faro 52 rice varieties are known to have novel characteristics but are susceptible to submergence due to flooding. Thus there is the need to provide farmers with a cost-effective option in flood prone areas. In this study, twenty-three mutant lines were subjected to submergence tolerance for 14 and 21 days. All the mutants were tolerant to submergence except FARO60-check (submergence susceptible check variety) which was susceptible to submergence effects. FARO52-50G$_1$, FARO52-150G$_1$, FARO44-150G$_2$, FARO44-200G$_4$ and FARO44-150G$_1$ all showed a high tolerance to submergence for 21 days. Thus gamma irradiation was successful in inducing genetic variability in the FARO 44 and FARO 52 rice variety as well as improving their submergence tolerance ability.

Keywords: FARO 44, FARO 52, Mutant lines, Flood, Rain-fed lowland, Submergence tolerance

Introduction

Rice (*Oryzasativa* L.) is the fastest growing food source in Africa (Abebrese and Yeboah, 2021), representing close to 40 % of the total volume of cereal consumed in West Africa (Duvalletet al.,2021). It provides one-third of calorie intake of nearly 1.5 billion people in Africa and Latin America (Khan et al., 2015). Approximately 480 million metric tons of rice are produced annually, with China and India accounting for 50 % of the rice grown and consumed (Mohammed et al., 2019). In Nigeria, where rice is a major staple food consumed across the all geo-political zones and socio-economic classes, only about 57 % of the 6.7 million metric tonnes of rice consumed annually is locally produced, leading to a supply deficit of about 3 million metric tonnes (KPMG, 2019) due to submergence as approximately 70 % rain-fed lowland rice farms are prone to seasonal flooding which is a major constraint to rice production in some major rice producing states in Nigeria which in turn leads to great loses due to flood(Akinwaleet al., 2012).

Submergence is mainly caused by flash flood (rapid flooding of low-lying areas mostly caused by heavy rains) during the rainy season with varying intensity and periods (Tiwari, 2018). Submergence due to highly unpredictable flash floods can occur at any growth stage of the rice crop, and can result in yield loss of 10 % to 100 %, depending on water depth, duration of submergence, temperature, turbidity of water, light intensity, and age of the crop (Akinwaleet al., 2015). In Nigeria, approximately 70 % rain-fed lowland rice farms are prone to seasonal flooding which is a major constraint to rice production in some major rice producing states, and each year, rice farmers in these parts of the country lose most of their crops to flooding (Akinwaleet al., 2012).

Faro 44 and Faro 52 rice varieties that are mostly cultivated by subsistence farmers which include women and children, in Nigeria; are known to have novel characteristics such as high yielding and long grain, but are susceptible to submergence due to flooding (Africa Rice Centre, 2017; Mohammed et al.,2018). Such high yielding and submergence intolerant rice varieties that are grown in large scale are frequently affected by flash floods which are triggered by unpredicted variability in weather factors causing erratic rainfall during the rainy season (Septiningsihet al., 2009).Approximately one-fourth of the global rice crops (estimated at 40 million hectares) are grown in rain-fed lowland plots that are prone to seasonal flooding (Panda and Barik, 2021).

Submergence tolerance has long been regarded as an important breeding objective intended to reduce, to the barest minimum, yield losses recorded in rain-fed lowland and deep water rice areas (Akinwaleet al., 2012). Most higher yielding modern rice varieties die within a week of complete submergence, making them unsuitable alternatives of traditional rice landraces (Singh et al*.,* 2014) therefore developing high-yielding, stress-tolerant varieties is thus a strategic imperative that aims to provide farmers with a cost-effective option in flood affected areas ((Mackillet al., 2012; Ismail, 2013; Septiningsih et al., 2013; Singh et al., 2013).

Although, there are many kinds of ionizing radiation, however, gamma rays are widely employed for mutation studies as they are capable of penetrating deep into plant tissues (Kianiet al., 2022), and as such, they are more effective for producing viable mutants and are capable of producing not only such genotype with improved submergence tolerant attributes, but also those with improved many other important economical traits.

Materials and methods

Seed source

Twenty-one distinct rice mutant lines irradiated with gamma rays at doses of 50 Gy, 100 Gy, 150 Gy and 200 Gy were selected from the gene bank of the Department of Plant Biology, Federal University of Technology Minna, Niger State, Nigeria and two additional rice varieties; FARO 60 and FARO66 were selected to serve as submergence susceptible and submergence tolerant checks respectively.

Experimental site

The experiment was conducted at the experimental garden of the Department of Plant Biology, Federal University of Technology, Minna, Nigeria. Minna is geographically located in the North Central Zone of Nigeria, within longitude 60 33' East and latitude 90 37' North. It is basically a grassland savannah area, and has a tropical climatic condition with a mean annual temperature, relative humidity and rainfall of 20-300C, 61.00% and 1334.00 cm respectively. The climate brings about two seasons: a rainy season between May and October and a dry season between November and April (Odegbenro, 2017).

Experimental Design

The experimental design used for this study is a Complete Randomised Block Design (CRBD). Twenty-one (21) distinct rice mutant lines and two check rice varieties were grouped in replicates of three each, for the two levels of submergence designed for this research. The first level of submergence i.e. submergence for 14 days, was represented on Plot B while submergence for 21 days was represented on Plot C. An un-submerged group of tworeplicates served as the control and was represented on Plot A. A total of one hundred and eighty-four (184) experimental pots were thus used for the research. Five seeds each from all the lines were planted per pot in a 10 litres plastic planting buckets filled with clayey loam soil to the 7 litresmark. The plants were later thinned to three plants per pot (Nio et al., 2019) for optimal growth.

Submergence Tolerance Test

Submergence was carried out on the mutant lines and the check varieties, with the exception of the control group, from 21 days after seeding for 14 and 21 days in an 11ft by 13ft by 4ft cemented pond which was lined with tarpaulin sheets. Sixty-nine (69) pots were submerged for 14 days and another set for 21 days. Each block of sixty-nine (69) pot consisted of the twenty-three (23) distinct rice line with three replicates.

The following parameters were collected for submergence tolerance test as described by Mohammed et al.(2018) with minor modifications:

i. Plant height before submergence: This was achieved using a meter ruler by measuring (in centimetre) from the base of the shoot to the tip of the tallest leaf blade one day before submergence (Mlakiet al., 2019).
ii. Plant height after de-submergence (after submerging for 14 and 21 days respectively)

iii. Number of susceptible and tolerant plants per population: The Standard Evaluation System (SES) developed by the International Rice Research Institute (IRRI, 2013) was used to score the rice population based on visual stress injury as described in Table 1.

iv. 100 seed weight: The weight of 100 seeds was measured in grams.

v. Grain yield per plant: The weight of each plant was measured in grams.

Data Analysis

The data generated was analysed following standard procedures of Plant Breeding Tools (PBTools 1.4) and Statistical Tools for Agricultural Research (STAR 2.0.1). The submergence tolerance test data was subjected to a one-way Analysis of variance (ANOVA) to show the significant difference(s) among the mutant lines. Duncan Multiple Range Test (DMRT) was used to separate the means, and the Pearson's correlation was used to show relationships between the mutant lines and the submergence tolerance parameters.

Table 1: Standard Evaluation System (SES) for Tolerance level to submergence stress in Rice (IRRI, 2013)

Score	Observation	Tolerance Level
1	Normal growth, no leaf symptoms	Highly tolerant
3	Nearly normal growth, but leaf tips or few leaves whitish and rolled	Tolerant
5	Growth severely retarded; most leaves rolled; only a few are elongating	Moderately tolerant
7	Complete cessation of growth; most leaves dry; some plants are dying	Susceptible
9	Almost all plants dead or dying	Highly susceptible

Results and discussion

Plant height before submergence

The results from the Analysis of Variance (ANOVA) revealed that the plant height of the mutant lines varied significantly ($P < 0.05$). At plot A (un-submerged plot), the highest height was recorded in FARO52-200G_1 (73.33 cm) which was significantly different ($P < 0.05$) from the controls FARO44-0G (55.63 cm) and FARO52-0G (59.33 cm); as well as the checks FARO60-check (46.07 cm) and FARO66-check (64.46 cm). However, the least height was observed in FARO44-50G_2 (32.93 cm) (Table 2). Similarly, significant increment in plant height before submergence was experienced in plot B (submergence for 14 days) for FARO52-200G_1 (71.07 cm) over the controls FARO44-0G (62.97 cm), FARO52-0G (63.73 cm) and FARO60-check (53.23 cm) and FARO66-check (59.57 cm). At plot C (submergence for 21 days), FARO52-200G_1 (73.17 cm) and FARO52-50G_1 (68.10

cm) mutants lines had significant increment in plant height before submergence when compared to the checks, controls and other mutants lines (Table 2).

Table 2: Plant height before submergence

Mutants lines	Plot A (cm)	Plot B (cm)	Plot C (cm)
FARO44-0G	55.63 ± 1.48^{jk}	62.97 ± 1.47^{ijk}	60.60 ± 1.20^{efg}
FARO52-0G	59.33 ± 0.67^{k}	63.73 ± 0.84^{j}	66.97 ± 1.50^{h}
FARO60-check	46.07 ± 1.55^{defgh}	53.23 ± 1.94^{cdef}	60.03 ± 0.98^{efg}
FARO66-check	64.46 ± 0.67^{l}	59.57 ± 0.75^{ghij}	65.20 ± 2.13^{gh}
FARO44-150G$_5$	43.50 ± 0.87^{cdef}	42.10 ± 1.25^{a}	50.43 ± 1.37^{bc}
FARO52-200G$_1$	73.33 ± 2.03^{m}	71.07 ± 1.16^{k}	73.17 ± 1.70^{i}
FARO52-50G$_1$	49.20 ± 0.62^{ghi}	57.27 ± 1.39^{efgh}	68.10 ± 1.53^{hi}
FARO52-100G$_1$	51.23 ± 3.53^{hij}	51.67 ± 0.80^{bcd}	54.73 ± 2.03^{cde}
FARO52-150G$_1$	50.33 ± 0.88^{ghij}	54.37 ± 0.68^{cdefg}	57.00 ± 1.15^{def}
FARO52-50G$_5$	42.10 ± 1.82^{cd}	52.83 ± 2.78^{cdef}	62.60 ± 0.83^{fgh}
FARO44-50G$_5$	54.33 ± 2.33^{ijk}	61.37 ± 1.25^{hij}	65.53 ± 1.72^{gh}
FARO52-200G$_3$	42.87 ± 1.12^{cd}	50.00 ± 0.59^{bcd}	49.57 ± 1.55^{bc}
FARO44-50G$_4$	43.27 ± 0.93^{cde}	46.87 ± 1.76^{ab}	43.67 ± 1.31^{a}
FARO52-150G$_4$	48.97 ± 1.18^{fghi}	51.90 ± 0.76^{bcdef}	65.53 ± 1.75^{gh}
FARO44-150G$_2$	43.17 ± 1.92^{cde}	53.33 ± 0.26^{cdef}	62.63 ± 2.87^{fgh}
FARO52-200G$_5$	45.07 ± 2.25^{cdefg}	55.03 ± 1.83^{defg}	62.43 ± 1.29^{fgh}
FARO44-100G$_5$	46.83 ± 1.36^{defgh}	56.47 ± 4.46^{efgh}	57.67 ± 1.45^{def}
FARO52-150G$_5$	48.67 ± 2.33^{efgh}	57.67 ± 1.45^{fghi}	65.80 ± 1.17^{gh}
FARO44-200G$_4$	36.33 ± 1.39^{ab}	43.00 ± 1.15^{a}	48.37 ± 1.42^{ab}
FARO44-150G$_1$	40.27 ± 2.08^{c}	55.80 ± 2.96^{defgh}	60.27 ± 4.24^{efg}
FARO44-100G$_1$	44.73 ± 2.03^{cdefg}	48.90 ± 1.63^{bc}	54.10 ± 2.08^{bcd}
FARO52-150G$_2$	51.33 ± 2.03^{hij}	52.27 ± 2.32^{bcdef}	54.83 ± 1.72^{cde}
FARO44-50G$_2$	32.93 ± 1.15^{a}	42.67 ± 1.32^{a}	48.33 ± 0.88^{ab}

Values are mean ± standard error of the mean. Values along the same column with different superscripts are significantly different at $P < 0.05$. Plot A= Un-submerged group, Plot B= Submergence for 14 days, Plot C= Submergence for 21 days.

Plant height at 11 days after de-submergence

The gamma irradiated mutants significantly differed ($P < 0.05$) in Plant height at day 11 after de-submergence. At plot A, the FARO52-200G$_1$ (86.67 cm) experienced the highest value. A similar increment was observed in FARO52-0G (70.40 cm), FARO44-0G (74.17 cm), FARO66-check (78.50 cm). However, the lowest height was observed in FARO44-50G$_2$ (45.67 cm) which significantly differed ($P < 0.05$) from other mutants (Table 3).

In plot B, the lowest value obtained from FARO44-50G_2 (51.70 cm) was significantly different ($P < 0.05$) from the value of FARO52-200G_1 (83.00 cm) which recorded highest. Other mutants with increased heights include FARO44-0G (75.40 cm), FARO52-0G (75.87 cm), FARO66-check (70.00 cm), FARO52-50G_1 (70.73 cm), FARO44-50G_5 (74.00 cm), FARO52-200G_5 (71.53 cm), FARO44-100G_5 (70.53 cm) and FARO52-150G_5 (71.77 cm) (Table 3).

In plot C, the highest height was observed in FARO52-200G_1 (84.57 cm) which was significantly different ($P < 0.05$) from other treatments and controls although the least was observed in FARO44-50G_4 (54.50 cm). Mutants with high mean heights comprised FARO52-200G_1 (84.75 cm), FARO44-0G (73.55 cm), FARO52-0G (74.36 cm), FARO66-check (75.68 cm), FARO44-50G_5 (71.80 cm) and FARO52-150G_5 (70.81 cm) (Table 3).

Table 3: Plant height @ 11 days after de-submergence

Mutants lines	**Plot A (cm)**	**Plot B (cm)**	**Plot C (cm)**
FARO44-0G	74.17 ± 1.07^{l}	75.40 ± 0.83^{gh}	71.07 ± 1.17^{efg}
FARO52-0G	70.40 ± 0.67^{k}	75.87 ± 1.45^{gh}	76.80 ± 0.87^{hi}
FARO60-check	57.60 ± 1.96^{efg}	65.27 ± 2.27^{cd}	73.37 ± 1.36^{fgh}
FARO66-check	78.50 ± 0.71^{m}	70.00 ± 0.75^{ef}	78.53 ± 1.44^{hi}
FARO44-150G_5	55.70 ± 1.46^{def}	53.77 ± 1.67^{ab}	64.07 ± 1.76^{bcd}
FARO52-200G_1	86.67 ± 1.34^{n}	83.00 ± 0.64^{i}	84.57 ± 1.27^{j}
FARO52-50G_1	57.03 ± 0.70^{ef}	70.73 ± 0.88^{ef}	81.57 ± 2.23^{ij}
FARO52-100G_1	63.37 ± 0.50^{ij}	62.87 ± 1.34^{cd}	64.57 ± 2.02^{cd}
FARO52-150G_1	61.17 ± 1.22^{fghi}	65.00 ± 1.15^{cd}	69.00 ± 1.53^{def}
FARO52-50G_5	58.73 ± 1.51^{fgh}	56.80 ± 1.74^{b}	74.73 ± 1.46^{gh}
FARO44-50G_5	66.67 ± 1.67^{j}	74.00 ± 1.06^{fgh}	74.73 ± 1.46^{gh}
FARO52-200G_3	52.23 ± 2.21^{cd}	63.23 ± 1.58^{cd}	61.07 ± 1.67^{bc}
FARO44-50G_4	52.33 ± 0.39^{cd}	63.47 ± 0.90^{cd}	54.50 ± 1.61^{a}
FARO52-150G_4	62.83 ± 1.13^{i}	64.53 ± 1.07^{cd}	78.17 ± 1.71^{hi}
FARO44-150G_2	51.67 ± 1.20^{c}	64.77 ± 1.25^{cd}	77.43 ± 2.19^{hi}
FARO52-200G_5	56.10 ± 1.81^{def}	71.53 ± 0.87^{fg}	75.00 ± 1.15^{gh}
FARO44-100G_5	56.47 ± 0.95^{ef}	70.53 ± 0.48^{ef}	77.73 ± 1.07^{hi}
FARO52-150G_5	63.87 ± 1.09^{ij}	71.77 ± 1.59^{fgh}	76.80 ± 1.33^{hi}
FARO44-200G_4	47.97 ± 1.19^{ab}	54.90 ± 0.98^{ab}	60.67 ± 1.36^{bc}
FARO44-150G_1	50.70 ± 0.35^{bc}	66.93 ± 1.30^{de}	70.80 ± 3.63^{efg}
FARO44-100G_1	54.30 ± 0.47^{cde}	61.93 ± 2.78^{c}	67.37 ± 1.63^{de}
FARO52-150G_2	62.00 ± 1.53^{hi}	64.00 ± 0.56^{cd}	64.93 ± 1.30^{cd}
FARO44-50G_2	45.67 ± 0.54^{a}	51.70 ± 0.91^{a}	59.10 ± 1.31^{ab}

Values are mean ± standard error of the mean. Values along the same column with different superscripts are significantly different at $P < 0.05$.

The result for plant height after de-submergence revealed that the control and checks recorded higher plant heights over the gamma irradiated mutants. This in accordance with Chenet al. (2021) who reported that plant height was higher in the control treatment than in the submergence treatment and shoot lengths in the period between de-submergence and maturity was also higher in the control treatment than that in the submergence treatment. These results indicated that submergence limit shoot growth in height from the first day after de-submergence to when plants reached maturity. This may be due to susceptible varieties tend to have rapid elongation during submergence which required carbohydrates and energy, leaving less available energy and maintenance required for survival during submergence while the tolerant varieties tend to limit stem elongation (Hasanet al., 2020). According to Colmeret al.(2014) two types of shoot growth moderation are suggested in genotypes that can tolerate submersion: slowed development with lower energy expenditure and elongation of the internode area of the shoot in response to rising water levels.

Number of susceptible and tolerant population

The results of the submergence tolerance for both the plot B (submergence for 14 days) and plot C (submergence for 21 days) revealed that the mutants significantly differed slightly in their response to submergence as scored using the Standard Evaluation System for submergence (Table 4). All the mutants were tolerant to submergence except FARO60-check (submergence susceptible check variety) which was susceptible (7.00) to submergence effects. The FARO52-50G$_5$, FARO52-150G$_5$, FARO52-200G$_3$, FARO52-150G$_2$, FARO44-50G$_4$, FARO44-50G$_5$ and FARO44-100G$_5$, were all highly tolerant to submergence (1.00) after being submerged for both 14 and 21days respectively (Table 4).

Similar to the FARO 66 check variety (submergence tolerant check variety) which showed tolerance to submergence at 14 days and a high tolerance to submergence at 21 days, the FARO52-50G$_1$, FARO52-150G$_1$, FARO44-150G$_2$, FARO44-200G$_4$ and FARO44-150G$_1$ all showed the same trend of being tolerant to submergence at 14 days (3.00) and a high tolerance to submergence at 21 days (1.00) (Table 4).

Table 4: Number of susceptible and tolerant population

Mutants lines	Plot B	Plot C
FARO44-0G	3.00±0.00 ^{b}	3.00±0.00 ^{b}
FARO52-0G	3.00±0.00 ^{b}	3.00±0.00 ^{b}
FARO60-check	7.00±0.00 ^{c}	7.00±0.00 ^{c}
FARO66-check	3.00±0.00 ^{b}	1.00±0.00 ^{a}
FARO44-150G$_5$	3.00±0.00 ^{b}	3.00±0.00 ^{b}
FARO52-200G$_1$	3.00±0.00 ^{b}	3.00±0.00 ^{b}
FARO52-50G$_1$	3.00±0.00 ^{b}	1.00±0.00 ^{a}

FARO52-100G_1	3.00±0.00^{b}	3.00±0.00^{b}
FARO52-150G_1	3.00±0.00^{b}	1.00±0.00^{a}
FARO52-50G_5	1.00±0.00^{a}	1.00±0.00^{a}
FARO44-50G_5	1.00±0.00^{a}	1.00±0.00^{a}
FARO52-200G_3	1.00±0.00^{a}	1.00±0.00^{a}
FARO44-50G_4	1.00±0.00^{a}	1.00±0.00^{a}
FARO52-150G_4	3.00±0.00^{b}	3.00±0.00^{b}
FARO44-150G_2	3.00±0.00^{b}	1.00±0.00^{a}
FARO52-200G_5	3.00±0.00^{b}	3.00±0.00^{b}
FARO44-100G_5	1.00±0.00^{a}	1.00±0.00^{a}
FARO52-150G_5	1.00±0.00^{a}	1.00±0.00^{a}
FARO44-200G_4	3.00±0.00^{b}	1.00±0.00^{a}
FARO44-150G_1	3.00±0.00^{b}	1.00±0.00^{a}
FARO44-100G_1	3.00±0.00^{b}	3.00±0.00
FARO52-150G_2	1.00±0.00^{a}	1.00±0.00^{a}
FARO44-50G_2	3.00±0.00^{b}	3.00±0.00^{b}

Values are mean ± standard error of the mean. Values along the same column with different superscripts are significantly different at $P < 0.05$. 1 – Highly tolerant, 3- tolerant, 5- moderately tolerant, 7- susceptible, 9- highly susceptible

The ability of the mutant lines to show tolerance to submergence is in line with the work of Pradhanet al. (2015) who subjected 90 lowland rice genotypes along with five (5) susceptible check varieties to submergence screening for about 14 days of complete submergence. Their results, after scoring using the Standard Evaluation System for rice developed by the International Rice Research Institute Manila, showed nine (9) were tolerant with 100 % survival while thirteen (13) were moderately tolerant to submergence. Similarly, Weninget al. (2019) subjected 99 genotypes of rice to submergence for 11 days. The result classified ten (10) lines as very tolerant with a percentage of survival of 100 %, and four (4) lines as tolerant with survival rate between 95-99 % according to the Standard Evaluation System of Rice of the International Rice Research Institute.

100 seed weight

The mutant lines revealed significant differences ($P < 0.05$) in the weight of 100 seed (Table 5). In plot A, the highest weight was recorded in FARO44-150G_2 (2.50 g) while the lowest was FARO52-50G_5 (1.60 g) and FARO52-150G_4 (1.60 g). In plot B, mutants with high weight of hundred seed comprised of FARO44-150G_2 (2.63 g), FARO44-200G_4 (2.60 g), FARO44-100G_1 (2.70 g) while the lowest value was recorded in FARO52-50G_5 (1.70 g). In plot C, the least weight of hundred seed was recorded in FARO60-check (1.80 g) and FARO52-50G_5 (1.80 g) which significantly differed ($P < 0.05$) from FARO44-150G$_2$ (2.63g) which recorded the highest (Table 5).

Table 5: 100 seed weight

Mutants lines	**Plot A**	**Plot B**	**Plot C**
FARO44-0G	1.87 ± 0.09^{bcd}	1.97 ± 0.03^{bcde}	2.10 ± 0.06^{bcde}
FARO52-0G	2.17 ± 0.09^{f}	2.23 ± 0.09^{gh}	2.27 ± 0.09^{ef}
FARO60-check	1.77 ± 0.09^{b}	1.90 ± 0.06^{bcd}	1.80 ± 0.10^{a}
FARO66-check	2.00 ± 0.06^{de}	2.03 ± 0.03^{cdef}	2.13 ± 0.7^{bcdef}
FARO44-150G$_5$	1.93 ± 0.03^{cd}	1.97 ± 0.03^{bcde}	2.00 ± 0.06^{abcd}
FARO52-200G$_1$	1.97 ± 0.03^{d}	2.07 ± 0.03^{defg}	2.13 ± 0.03^{bcdef}
FARO52-50G$_1$	1.97 ± 0.03^{d}	2.10 ± 0.06^{efg}	2.10 ± 0.06^{bcde}
FARO52-100G$_1$	1.80 ± 0.06^{bc}	2.00 ± 0.06^{cdef}	1.93 ± 0.03^{abc}
FARO52-150G$_1$	1.80 ± 0.00^{bc}	1.87 ± 0.09^{abc}	1.90 ± 0.06^{ab}
FARO52-50G$_5$	1.60 ± 0.00^{a}	1.70 ± 0.06^{a}	1.80 ± 0.06^{a}
FARO44-50G$_5$	2.00 ± 0.00^{de}	2.10 ± 0.06^{efg}	2.10 ± 0.06^{bcde}
FARO52-200G$_3$	1.90 ± 0.00^{bcd}	2.00 ± 0.00^{cdef}	2.10 ± 0.00^{bcde}
FARO44-50G$_4$	2.00 ± 0.00^{de}	2.17 ± 0.03^{fgh}	2.17 ± 0.03^{cdef}
FARO52-150G$_4$	1.60 ± 0.00^{a}	1.80 ± 0.06^{ab}	1.93 ± 0.03^{abc}
FARO44-150G$_2$	2.50 ± 0.00^{h}	2.63 ± 0.03^{i}	2.63 ± 0.03^{g}
FARO52-200G$_5$	2.00 ± 0.00^{de}	2.17 ± 0.09^{fgh}	2.23 ± 0.03^{def}
FARO44-100G$_5$	2.13 ± 0.03^{ef}	2.30 ± 0.06^{h}	2.30 ± 0.20^{ef}
FARO52-150G$_5$	2.00 ± 0.00^{de}	2.10 ± 0.06^{efg}	2.17 ± 0.03^{cdef}
FARO44-200G$_4$	2.40 ± 0.06^{g}	2.60 ± 0.06^{i}	2.60 ± 0.11^{g}
FARO44-150G$_1$	2.00 ± 0.00^{de}	2.10 ± 0.06^{efg}	2.27 ± 0.12^{ef}
FARO44-100G$_1$	2.53 ± 0.07^{h}	2.70 ± 0.06^{i}	2.37 ± 0.03^{f}
FARO52-150G$_2$	1.90 ± 0.06^{bcd}	2.00 ± 0.06^{cdef}	2.10 ± 0.06^{bcde}
FARO44-50G$_2$	1.90 ± 0.00^{bcd}	1.87 ± 0.07^{abc}	1.97 ± 0.03^{abc}

Values are mean ± standard error of the mean. Values along the same column with different superscripts are significantly different at $P < 0.05$.

Gamma irradiation significantly affected the weight of 100 grains with the lowest yield at 50 Gy dose. High seed weight was observed between 150-200 Gy. This is in line with the observation of Suliartiniet al. (2023) who reported that higher dose (200-500 Gy) induced higher decreases by 100 grains plants. This may be attributed to higher doses resulting in greater damage in inhibiting generative character in plants (Hong et al., 2022). Rachmawatiet al. (2019) opined that the grain weight per plant is determined by the number of tillers, the amount of grains and the percentage of filled grains.

Grain yield per plant

The highest grain yield per plant in plot A was observed in FARO44-50G$_4$ (4.93 g) which significantly differed ($P < 0.05$) from all the mutants (Table 6). The lowest grain yield was recorded in FARO52-100G$_1$ (3.50 g). FARO60-check (3.57 g), FARO52-200G$_1$ (3.53 g), FARO52-100G$_1$ (3.50 g) and FARO52-150G$_1$ (3.67 g) were not significantly different at $P > 0.05$ (Table 6). In plot B, the least grain yield was recorded in FARO60-check (3.63 g) although, it was significantly different ($P > 0.05$) from FARO52-100G$_1$ (3.73 g) and FARO52-100G$_1$ (3.73 g). The highest grain yield was recorded in FARO44-50G$_4$ (4.77 g) and FARO44-150G$_2$ (4.77 g). In plot C, the highest grain yield was observed in FARO44-50G$_4$ (5.00 g) while the lowest was observed in FARO60-check (3.50 g) (Table 6).

Table 6: Grain yield per plant

Mutants lines	Plot A (g)	Plot B (g)	Plot C (g)
FARO44-0G	3.70 ± 0.06^{abc}	3.90 ± 0.06^{bc}	3.93 ± 0.09^{cd}
FARO52-0G	4.17 ± 0.03^{defghi}	4.40 ± 0.06^{ef}	4.27 ± 0.12^{efg}
FARO60-check	3.57 ± 0.09^{a}	3.63 ± 0.03^{a}	3.50 ± 0.06^{a}
FARO66-check	4.07 ± 0.12^{defgh}	4.10 ± 0.06^{cd}	4.30 ± 0.06^{efg}
FARO44-150G$_5$	3.97 ± 0.09^{def}	3.93 ± 0.03^{bc}	4.03 ± 0.12^{cd}
FARO52-200G$_1$	3.53 ± 0.03^{a}	3.87 ± 0.03^{abc}	4.00 ± 0.00^{cd}
FARO52-50G$_1$	4.27 ± 0.15^{ghi}	4.20 ± 0.06^{de}	3.90 ± 0.06^{bc}
FARO52-100G$_1$	3.50 ± 0.17^{a}	3.73 ± 0.03^{ab}	3.70 ± 0.06^{ab}
FARO52-150G$_1$	3.67 ± 0.09^{ab}	3.73 ± 0.03^{ab}	4.00 ± 0.06^{cd}
FARO52-50G$_5$	4.00 ± 0.00^{defg}	4.13 ± 0.03^{cd}	4.17 ± 0.03^{def}
FARO44-50G$_5$	4.03 ± 0.03^{defg}	4.23 ± 0.09^{de}	4.30 ± 0.06^{efg}
FARO52-200G$_3$	3.93 ± 0.09^{cde}	4.10 ± 0.06^{cd}	4.10 ± 0.06^{cde}
FARO44-50G$_4$	4.93 ± 0.03^{j}	4.77 ± 0.09^{g}	5.00 ± 0.06^{k}
FARO52-150G$_4$	4.23 ± 0.07^{fghi}	4.57 ± 0.07^{fg}	4.73 ± 0.03^{j}
FARO44-150G$_2$	4.43 ± 0.12^{i}	4.77 ± 0.19^{g}	4.47 ± 0.07^{ghi}
FARO52-200G$_5$	4.20 ± 0.06^{efghi}	4.50 ± 0.17^{f}	4.57 ± 0.12^{hij}
FARO44-100G$_5$	4.23 ± 0.07^{fghi}	4.50 ± 0.12^{f}	4.57 ± 0.12^{hij}
FARO52-150G$_5$	4.10 ± 0.06^{defgh}	4.10 ± 0.06^{cd}	4.17 ± 0.09^{def}
FARO44-200G$_4$	4.33 ± 0.09^{hi}	4.50 ± 0.06^{f}	4.67 ± 0.03^{ij}
FARO44-150G$_1$	4.00 ± 0.06^{defg}	4.23 ± 0.03^{de}	4.37 ± 0.03^{fgh}
FARO44-100G$_1$	4.00 ± 0.06^{defg}	4.07 ± 0.03^{cd}	4.30 ± 0.06^{efg}
FARO52-150G$_2$	3.93 ± 0.07^{cde}	3.87 ± 0.09^{abc}	3.90 ± 0.06^{bc}
FARO44-50G$_2$	3.90 ± 0.06^{bcd}	3.90 ± 0.12^{bc}	4.00 ± 0.06^{cd}

Values are mean ± standard error of the mean. Values along the same column with different superscripts are significantly different at $P < 0.05$.

The study revealed that most gamma irradiated mutants recorded increment in seed yield per plant over the checks. Hasanet al. (2021) reported that treatment of 167.25 Gyresulted in the maximum increase in grains per plant. According to Hariset al. (2013) irradiation causes mutations to occur in the plant leading to an increase in grain weight per plant. The number of filled grains per plant is one of the yield components that affect rice production. The amount of grain yield formed depends on the photosynthesis process (seed filling) of the plant during growth and the genetic characteristics of cultivated rice plants (Awaniset al., 2021).

Conclusion

From this study, it can be concluded that gamma irradiation was successful in inducing genetic variability in the two rice varieties. FARO 44 rice variety induced with Gamma rays at 50 Gy and the FARO 52 rice variety induced at 150 Gy and 200 Gy have showed the highest potential of survival and improvement as such are most promising.

Future scope: The promising mutant lines identified in this study can be exploited further as they are potential candidates for improving submergence tolerance in rice.

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