


# Gamma-Ray-Induced Genetic Variability for Yield Traits in M4 Generation in Upland Rice

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## Abstract

Varietal deficiencies of upland rice lead to a low paddy grain yield. The aim of this study was to mutagenesis upland rice varieties to improve their agronomic performance. Seeds of varieties FKR45N and FKR47N were therefore irradiated with doses 300, 350 and 400 Gy. The irradiated seeds were sown and the panicles of the M1 plants were individually harvested, and then were advanced to M4 using the “one panicle - one progeny” method. The agronomic performance of M4 lines was compared to that of their parent. The gamma ray mutagenesis has induced significant variability in five yield components, i.e., plant height, main panicle length, total numbers of tillers and productive tillers and paddy grain yield between mutant lines. The highest variabilities were shown for the total number of tillers and the number of productive tillers as well as FKR45N (CV% = 40 % and 36%) and FKR47N (CV% = 31% and 30%) mutant lines. Principal component analysis led to rank the mutant lines from each variety in three clusters. The Pearson correlation showed that the paddy grain yield was significantly and positively correlated with the number of productive tillers ( $r = 0.61$ ) and plant height ( $r = 0.66$ ) for FKR47N mutant lines, and these correlation coefficients were  $r = 0.52$  and  $r = 0.51$  for FKR45N mutant lines, respectively. Gamma-ray irradiation also induced an earliness of 50% flowering of 62 days after sowing (DAS) in two FKR45N mutant lines and 67 DAS in one of KR47N mutant lines. The paddy grain yield was improved by 120% and 20% in two FKR45N and FKR47N mutant lines, respectively. A dwarf FKR45N mutant line with an early flowering of 67 DAS and a paddy grain yield ( $2.34 \text{ t ha}^{-1}$ ) was generated. These results suggested that any positive increase in the six quantitative traits will increase the paddy grain yield.

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## Keywords

Upland Rice, Mutagenesis, Genetic Variability, Agronomic Performance

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### 1. Introduction

Rice (*Oryza sativa* L.) is the most widely grown cereal in the world after wheat [1]. Nearly half the world's population depends on rice as a staple food [2]. Rice has become a strategic crop for food security and political stability for a majority of African countries, particularly in West Africa [3] [4]. Despite efforts and political commitment, local productions are still unable to meet the food needs of local populations on the African continent [3], as demand for rice has more than tripled from 1.9 to 5.8 million tons over the past two decades in sub-Saharan African countries [5]. In Burkina Faso, farming is essentially rain-fed, subsistence agriculture based on cereals, which account for more than 88% of the annual area under cultivation. Cereals constitute the staple diet of the population and, among them, rice ranks 4<sup>th</sup> after sorghum, millet and maize in terms of cultivated area and food production. Rice production has risen thanks to increased acreage, following the lowlands and irrigated lands management, the promotion of rainfed rice varieties and subsidies for agricultural inputs and equipment. However, this increase in national rice production has been achieved at the same time as an increase in the import bill due to population growth and changing eating habits, mainly in urban areas. Annual per capita consumption of rice continues to rise, forcing the government of Burkina Faso to spend around 40 billion F CFA year<sup>-1</sup> [6] to cover the population's rice needs. To reduce this import bill and improve food security, the second phase of Burkina's Rice Development Strategy [7] has been drawn up to increase rice production to 3 million tons of grains rice by 2030 [8] to meet the country's rice needs and increase stakeholders' incomes through the competitiveness and sustainability of the national production. Agricultural industrialization is still in its infancy in Burkina Faso. However, national policy has launched an agricultural offensive aimed at achieving long-term food sovereignty by boosting the mechanization of farming operations, land and water conservation and agricultural product processing. Three agricultural growth poles (Bagr , Samendeni and Sourou) equipped with production, processing and marketing support infrastructures have been set up to make proven technologies available, with the prospect of promoting eight agricultural sectors, including rice ranked as the first strategic crop. Measures to support agricultural production have improved the performance of rice-growing in Burkina Faso, mainly by increasing the average yield per hectare from 2.7 tons to four tons of paddy grain (<http://www.fao.org/mafap/accueil-du-spaaa/fr/>). However, this improvement in rice productivity in farmers' fields is not enough to cover the country's rice requirements. Indeed, national production covers less than 50% of consumption needs and forecast rice requirements in 2025 were estimated at 1.5 million tons,

compared with production of 324,611 tons year<sup>-1</sup> in the period from 2010 to 2019 [8]. Food security in low-income countries such as Burkina Faso is severely compromised by low variety productivity and the vulnerability of agricultural production systems to the adverse effects of climate change [8]. Some initiatives should be considered to increase rice production by promoting efficient breeding techniques to ensure higher yields, resistance to pests and tolerance to abiotic stresses [9]. Following recent food crises, several West African countries have adopted strategies to increase rice production. These strategies included the large-scale use of improved crop varieties, better technical assistance for rice farmers and increasing the area under rice cultivation [10].

Conventional breeding based on crossing genotypes of interest to select hybrids with the desired traits in the progeny is the most widely used method in national breeding programs. The crop variety development therefore involves scientists and the end-users (producers and the processors). The initial development is undertaken at research station for hybrid generation. The field evaluation of progenies based on participatory approach with stakeholders (producers and processors) select the best genotypes and the marker assisted selection (MAS) can be used by scientists for genotyping—final identification of the best materials. The end products (hybrids or composites) are tested by farmers and the best genotypes are registered as varieties in national seed catalog for seed production.

To provide seeds of improved varieties, induced mutagenesis is a breeding tool widely used by plant breeders to generate new crop genotypes that perform better in terms of yield and resilience to bio-aggressors and abiotic constraints [11]. It makes it possible to increase genetic variability and improve quantitative and qualitative crop traits in a much shorter time than conventional breeding [12]. The aim of the present study is to create genetic variability in two upland rice varieties with the prospect of selecting genotypes with desired agronomic performances.

## 2. Materials and Methods

### 2.1. Study Site

Field experiment was conducted at the Kamboinsé environmental and agricultural research Station, located in the village of Kamboinsé, in the Province of Kadiogo. It belongs to the North Sudan zone, with a long dry season that lasts from November to May and a short-rainy season from June to October [13]. Annual rainfall is irregular in space and time, varying between 600 and 800 mm. The research Station's soils are tropical, ferruginous and leached [14]. The climate is Sudan-Sahelian.

### 2.2. Plant Material

Parental considered as M0 seeds of two (02) upland rice varieties, FKR45N and FKR47N were irradiated with gamma rays (<sup>60</sup>Co) at selected doses of 300, 350 and 400 Gy at the Plant Genetics and Breeding Laboratory in Seibersdorf, Austria.

The irradiated seeds (M1) and those of their parents were sown and the panicles of the M1 plants were individually harvested and then the M2 seeds were sown using the “one panicle to one progeny” method. M2 families were successively advanced in  $n + 1$  using this method up to M4. The M4 lines were compared to their parent for agronomic performances.

The plant material consisted of 289 mutant lines of the M4 generation, of which 153 lines were generated from FKR47N and 136 lines from FKR45N. These mutant lines were selected for their ability to induce low *Striga hermonthica* emergence (0 to 3 *Striga* plants hill<sup>-1</sup>). FKR45N and FKR47N are upland Rice varieties adopted by farmers in Burkina Faso [15]. The agronomic traits of both upland rice varieties are described in **Table 1**.

**Table 1.** Quantitative traits of FKR45N and FKR47N upland rice varieties [16].

Agronomic traits	Upland rice variety	
	FKR45N	FKR47N
Plant height (cm)	115	117
Sowing-maturity (DAS)	95	100
Plant tillering	Medium	Medium
1000-seeds weight (g)	34.3	33.2
Resistance to blast disease	Fairly good	Fairly good
Nitrogen response	Good	Good
Average farmer's yield (t ha <sup>-1</sup> )	1 - 2	1 - 2
Seed size	10.1/2.9	10.1/2.7

## 2.3. Methods

Each genotype was sown on a 2.2 m-long ridge. Ridge to ridge and plant to plant distances were 0.2 m i.e., 11 hills ridge<sup>-1</sup>. Sowing was carried out at a rate of 2 - 3 seeds hill<sup>-1</sup>, and the seedlings were thinned 14 DAS to one seedling hill<sup>-1</sup>.

The mutant lines were compared with their respective parents using the “augmented design” experimental design. Each genotype was planted on one ridge, except the wide-type parents (Controls) that were replicated 3 - 4 times depending on the number of populations of each mutant line.

### 2.3.1. Crop Management

The seed bed was manually ploughed to a depth of 8 - 10 cm, followed by levelling and ridging. Before ridging, cow dung was applied at 2.5 t ha<sup>-1</sup>. The soil was also amended with mineral fertilizer including 200 kg NPK ha<sup>-1</sup> before the sowing. Additional amendments of 35 and 65 kg urea ha<sup>-1</sup> were applied 21 and 60 DAS, respectively.

Weeds were manually pulled at 21, 45 and 60 DAS. Rice plants, watered on request, were treated with the insecticide PENDISTAR (400 g l<sup>-1</sup>) to control insect pest attacks.

### 2.3.2. Data Collection and Statistical Analysis

For each rice genotype, yield component data were collected from 5 randomly

selected plants: total number of tillers (TNT) plant<sup>-1</sup>, number of productive tillers (NPT) plant<sup>-1</sup>; main panicle length (PL), days to 50% flowering (x50\_Fl), corresponding to 50% of plants in flowering phase ridge<sup>-1</sup>, main plant height (PH) (cm) and paddy grain weight (GrW) (g) plant<sup>-1</sup>.

The analysis of variance (ANOVA) of the data collected was carried out using the software SAS.1.9, and means were separated using the Student-Newman-Keuls test at the 5% threshold. Principal component analysis using “R.643.5.2 software versions 2019” revealed correlations between quantitative traits. A hierarchical ascending classification (HAC) was performed, allowing the structuring of variability within the mutant lines generated from the same rice variety.

### 3. Results

#### 3.1. Descriptive Analysis of Quantitative Traits

From descriptive analysis of the variables recorded, plant height was ranged from 19 to 109 cm for FKR45N mutant lines and from 21 to 108 cm for FKR47N mutant lines. Panicle length varied from 13.10 to 37 cm and from 13.1 to 37 cm for FKR45N and FKR47N mutant lines, respectively. The coefficient of variation for FKR45N mutant lines ranged from 7.85 to 40.33%, compared with 8.44 to 30.56% for the wild-type FKR47N. A significant difference ( $P < 0.0001$ ) was shown for plant height, panicle length, total tiller number plant<sup>-1</sup> and productive tiller number plant<sup>-1</sup> for FKR47N mutant lines (**Table 2**).

**Table 2.** Mean range and coefficient of variation for yield traits of M4 mutant lines generated from FKR45N and FKR47N upland rice varieties.

Variables	FKR45N mutant lines		FKR47N mutant lines	
	Mean	CV %	Mean	CV %
Plant height (cm)	85.22***	8.99	80.83***	8.44
Panicle length (cm)	22.52***	7.65	22.37***	10.23
Total number of tillers plant <sup>-1</sup>	7.85 ns	40.33	9.46***	30.56
Number of productive tillers plant <sup>-1</sup>	5.00***	36.16	7.00***	30.14
Grain weight paddy plant <sup>-1</sup>	1.86***	8.91	2.29***	6.56
Days to 50% flowering	77***	3.09	77***	2.91

\*\*\*: Significance  $P < 0.0001$ ; ns = Not significant.

#### 3.2. Diversity of Induced Yield Traits

##### 3.2.1. Correlation between Quantitative Traits

Pearson correlation matrix revealed six correlations between the parameters recorded with the FKR45N mutant lines (**Table 3**). Paddy grain yield was significantly correlated with plant height ( $r = 0.51$ ) and productive tiller number ( $r = 0.52$ ). Other Significant correlations were observed between days to 50% flowering, plant height ( $r = 0.52$ ) and total tiller number ( $r = -0.60$ ), between plant height, panicle length ( $r = 0.53$ ) and of productive tiller number ( $r = 0.50$ ),

between total number of tillers and productive tiller number ( $r = 0.55$ ).

**Table 3.** Correlations between yield traits of FKR45N upland rice mutant lines.

Yield traits	GrW	x50_Fl	PH	PL	TNT	NPT
Paddy grain yield (GrW)	1					
Days to 50% flowering (x50_Fl)	0.22*	1				
Plant height (cm)	0.51***	0.52***	1			
Plant length (cm)	0.02	-0.02	0.53***	1		
Total number of tillers (TNT)	-0.24*	-0.6***	-0.11	0.20*	1	
Number of productive tillers (NPT)	0.52***	0.06	0.50***	0.15	0.55***	1

\*: Correlation significant at 5% threshold; \*\*\*: correlation very highly significant at 5% threshold.

The Pearson correlation matrix revealed eleven (11) significant positive correlations between the yield traits of the FKR47N mutant lines (Table 4). A significant correlation was therefore revealed between paddy grain yield and productive tiller number ( $r = 0.61$ ), between total tiller number and productive tiller number ( $r = 0.66$ ), between plant height and paddy grain yield ( $r = 0.66$ ), between plant height and panicle length ( $r = 0.50$ ), between plant height and productive tiller number ( $r = 0.50$ ). However, a weak positive correlation was found between panicle length and plant height ( $r = 0.43$ ), between yield and panicle length ( $r = 0.33$ ), between paddy grain yield and total number of tillers ( $r = 0.24$ ), between sowing time-50% flowering and total number of tillers ( $r = 0.24$ ), between days to 50% flowering and productive tiller number ( $r = 0.22$ ), between panicle length and productive tiller number ( $r = 0.23$ ). A single negative correlation was shown between panicle length and days to 50% flowering ( $r = -0.19$ ) (Table 4).

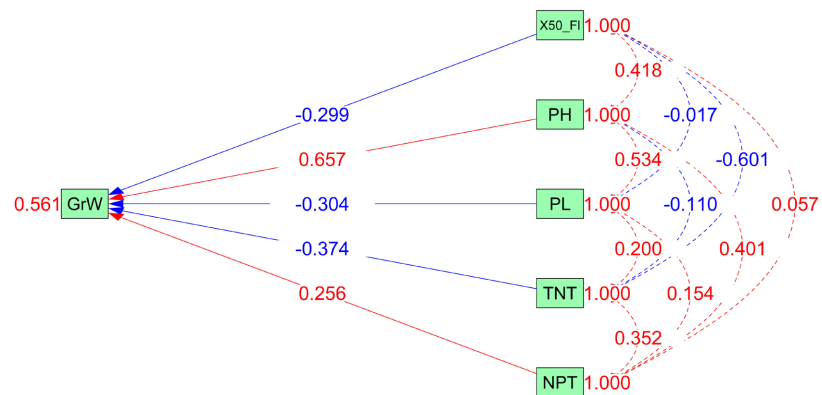
**Table 4.** Person Correlations between yield traits of FKR47N upland rice mutant lines.

Yield traits	GrW	x50_Fl	PL	PH	TNT	NPT
Paddy grain yield (GrW)	1					
Days to 50% flowering (x50_Fl)	-0.08	1				
Plant height (cm)	0.33**	-0.19*	1			
Plant length (cm)	0.66***	-0.3	0.50***	1		
Total number of tillers (TNT)	0.24**	-0.24**	0.03	0.08	1	
Number of productive tillers (NPT)	0.61***	-0.22**	0.23**	0.50***	0.66**	1

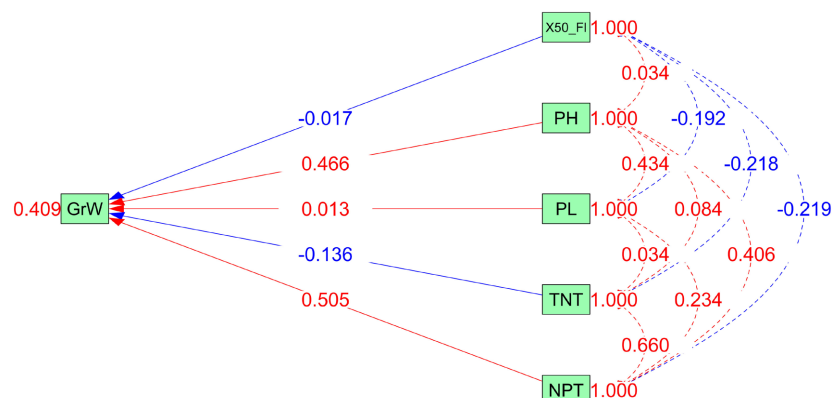
\*: correlation significant at 5% threshold, \*\*: significant correlation at 5% threshold, \*\*\*: significant correlation at 5% threshold.

The plant height ( $r = 0.657$ ) and the productive tiller number ( $r = 0.256$ ) positively account for grains filling panicle<sup>-1</sup> while the total tiller number ( $r = -0.374$ ), the panicle length ( $r = -0.304$ ) and days to 50% flowering ( $r = -0.299$ ) affect the filled grains panicle<sup>-1</sup> of FKR45N mutant lines (**Figure 1**).

With regard to FKR47N mutant lines, three traits i.e productive tiller number, ( $r = 0.505$ ), plant height ( $r = 0.466$ ) and panicle length account for grains filling panicle<sup>-1</sup> in contrast to total tiller number ( $r = -0.136$ ) and days to 50% flowering ( $r = -0.017$ ) (**Figure 2**).



**Figure 1.** Traits that contribute to a good grain filling panicle<sup>-1</sup> of FKR45N upland rice mutant lines. *GrW*: paddy grains yield; *x50\_Fl*: days to 50% flowering; *PH*: Plant height; *LP*: panicle length; *TNT*: total number of tillers; *NPT*: number of productive tillers.



**Figure 2.** Traits that contribute to a good grain filling panicle<sup>-1</sup> of FKR47N upland rice mutant lines. *GrW*: paddy grains yield; *x50\_Fl*: days to 50% flowering; *PH*: Plant height; *LP*: panicle length; *TNT*: total number of tillers; *NPT*: number of productive tillers.

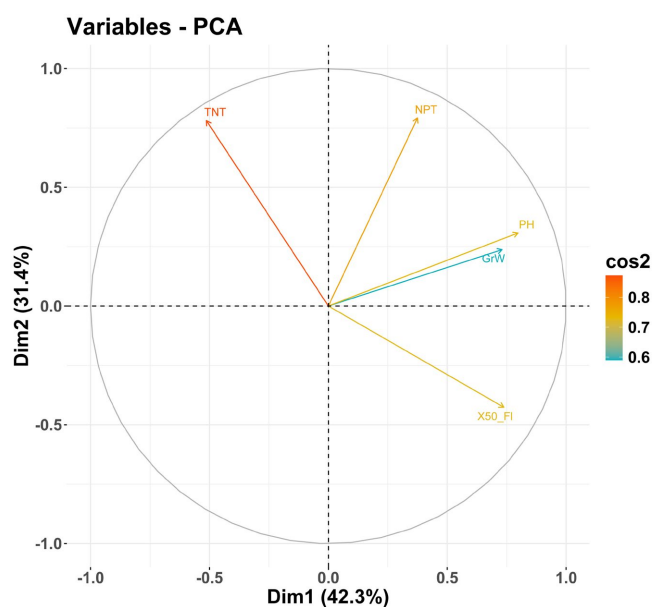
### 3.2.2. Principal component analysis (PCA) and hierarchical classification KR45N upland rice mutant lines

The axes 1 and 2 contributed for 73.74% of the variability induced between five quantitative variables. Plant height, paddy grain yield and days-50% flowering were correlated with axis 1 that can be considered as the paddy grain productivity axis and contributes to 42.35% of the variability (**Figure 3**) with a value of 2.12. On the other hand, the total number of tillers and the number of productive tillers

are correlated with axis 2, which expresses straw production and contributes to 31.39% of the variability (**Table 5**).

**Table 5.** Main yield components of FKR45N upland rice mutant lines.

Yield traits	Axis 1	Axis 2	Axis 3	Axis 4
Paddy grain yield	0.53	0.06	0.37	0.02
Days-50%Flowering	0.54	0.18	0.20	0.01
Plant height	0.64	0.09	0.01	0.25
Total number of tillers	0.26	0.61	0.01	0.03
Number of productive tillers	0.14	0.63	0.07	0.14
Value	2.12	1.57	0.66	0.44
CV%	42.35	31.39	13.23	8.79



GrW: paddy grain yield; PH: plant height; TNT: total number of tillers; NPT: number of productive tillers.

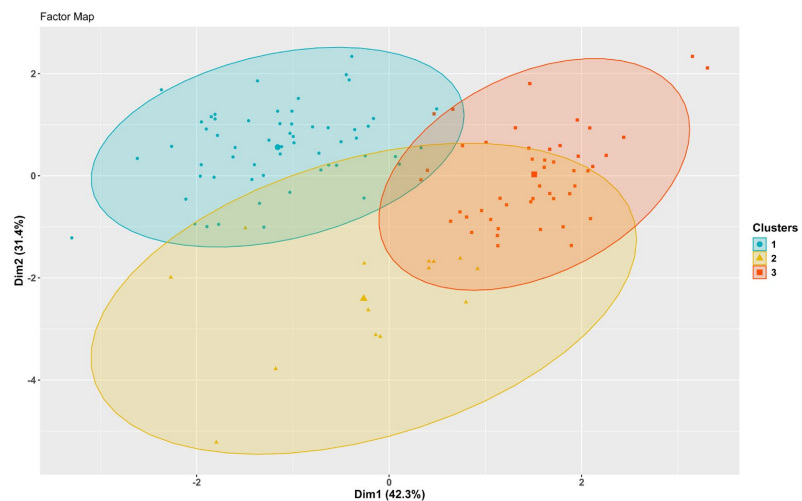
**Figure 3.** Principal component analysis depicting correlations between yield components in FKR45N upland rice mutant lines at M4 generation.

FKR45N mutant lines were clustered according to their yield components (**Figure 4**). The cluster 1, made up of 57 mutant lines plus NERICA4, was characterized by a paddy grain yield estimated at 1.50 t ha<sup>-1</sup>, an average number of 9.3 tillers hill<sup>-1</sup>, an average plant height of 81.1 cm and early flowering with an average duration of 67 days to 50% flowering (**Table 6**). The mutants in cluster 2 consisted of 14 mutant lines, had 5.2 tillers hill<sup>-1</sup>, an average paddy grain yield of 1.22 t ha<sup>-1</sup>, an average plant height of 77.8 cm and days-50% flowering of 85 DAS. The cluster 3 involved 46 lines plus the parental variety (Control), characterized by high plants (92.49 cm), long time of days to 50% flowering (84.36 DAS), high total number of tillers (7 tillers plant<sup>-1</sup>) and productive tillers (6 tillers plant<sup>-1</sup>) and paddy grain yield (2.53 t ha<sup>-1</sup>). Among these lines, 9 mutants performed better than the parent variety (Control) (**Table 6**).

**Table 6.** Clustering of FKR45N upland rice mutant lines according to discriminant yield components.

Yield traits	Cluster 1			Cluster 2			Cluster 3		
	CM	OM	V.test	CM	OM	V.test	CM	OM	V.test
Days-50% Flowering	68.85	76.83	-9.75	84.57	76.83	3.55	84.36	76.83	7.63
Paddy grain yield	1.50	1.87	-3.81	1.22	1.87	-2.51	2.53	1.87	5.55
Plant height	81.11	85.22	-5.17	77.85	85.22	-3.47	92.49	85.22	7.58
Total tiller number	9.27	7.86	7.33	5.17	7.86	-5.24	5.76	5.23	3.85
Productive tiller number				3.43	5.23	-5.93	6.92	7.86	-4.05

CM: Cluster mean, OM: overall mean.

**Figure 4.** Clustering diagram of FKR45N upland rice mutant lines at generation M4.

Significant differences ( $P < 0.0001$ ) were observed between mutant lines for six yield components. The M450P1/350 and M451P1S/400 lines have showed a flowering earliness of 62 DAS compared with 80 DAS for the wild-type. The paddy grain yield recorded with the M450P2S/350 line was significantly higher ( $4 \text{ t ha}^{-1}$ ), followed by that ( $3.2 \text{ t ha}^{-1}$ ) recorded with three lines (M450P1/350, M450P3S/350 and M451P3/400). In terms of plant height and panicle length, only the mean values of the M437P1S line were statistically reduced compared to those of the FKR45N parent and the other mutant lines, which form a homogeneous cluster (Table 7).

**Table 7.** Mean performance of mutant lines of the FKR45N upland rice variety on agronomic traits related to paddy grain yield.

Upland rice genotypes	Days to 50% Flowering (DAS)	Paddy grain yield ( $\text{t ha}^{-1}$ )	Plant height (cm)	Panicle length (cm)	Total tiller number plants	Productive tiller number
Parent FKR45N	$80.48 \pm 2.70 \text{ a}$	$1.84 \pm 0.84 \text{ i}$	$89.69 \pm 7.68 \text{ a}$	$23.14 \pm 1.73 \text{ a}$	$7.81 \pm 2.89 \text{ a}$	$4.87 \pm 2.12 \text{ a}$

## Continued

M437P1S/300	70.00 ± 0.71 b	2.34 ± 1.05 h	69.20 ± 9.0 b	18.64 ± 2.22 b	9.00 ± 3.87 a	7.20 ± 3.11 a
M450P1/350	62.50 ± 0.53 f	3.17 ± 0.01 d	86.10 ± 2.42 a	22.24 ± 0.46 a	7.60 ± 2.63 a	5.70 ± 1.34 a
M450P1S/350	66.00 ± 0.71 d	3.46 ± 0.01 b	85.40 ± 4.28 a	22.04 ± 0.93 a	5.40 ± 1.34 a	5.40 ± 0.55 a
M450P2/350	67.60 ± 1.14 c	3.25 ± 0.01 c	83.60 ± 1.34 a	21.92 ± 0.18 a	8.80 ± 2.28 a	5.00 ± 10.0 a
M450P2S/350	65.80 ± 0.84 d	4.05 ± 0.02 a	86.00 ± 4.00 a	22.40 ± 0.89 a	6.00 ± 1.87 a	5.80 ± 0.84 a
M450P3/350	67.00 ± 0.71 c	3.06 ± 0.04 e	90.40 ± 3.65 a	23.36 ± 0.81 a	7.00 ± 2.35 a	5.60 ± 1.34 a
M450P3S/350	64.00 ± 0.71 e	3.18 ± 0.02 d	85.20 ± 0.84 a	22.08 ± 0.11 a	7.40 ± 3.65 a	4.60 ± 0.89 a
M451P1S/400	62.60 ± 1.14 f	2.61 ± 1.03 f	82.80 ± 2.17 a	21.50 ± 0.48 a	7.40 ± 2.79 a	4.60 ± 0.89 a
M451P2/400	64.00 ± 0.71 e	2.54 ± 1.02 g	84.80 ± 3.27 a	22.04 ± 0.71 a	9.20 ± 3.83 a	4.20 ± 1.79 a
M451P3/400	65.00 ± 0.71 d	3.18 ± 0.01 d	84.20 ± 4.02 a	21.90 ± 0.88 a	6.40 ± 4.98 a	6.20 ± 1.10 a
Mean	74	2.37	87.27	22.59	7.65	5.11
CV%	2.99	2.87	7.48	6.53	38.77	37.02

**FKR47N Upland Rice Mutant Lines**

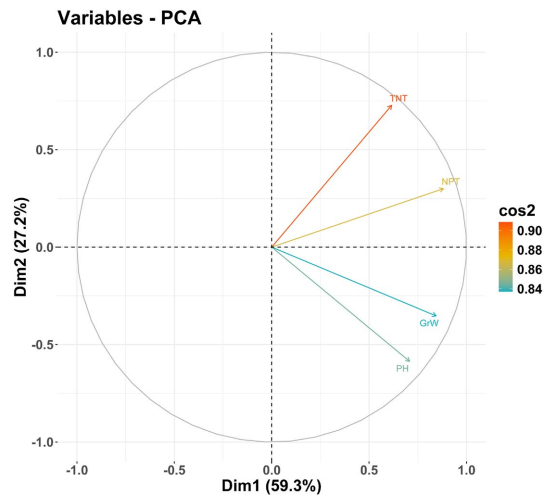
The first two axes 1 and 2 accounted for 86.46% to the variability (Figure 5). Plant height, paddy grain yield and productive tiller number were correlated with axis 1 considered as the paddy grain productivity axis, and alone contributes 59.27% of variability with a value of 2.37. On the other hand, the total number of tillers is correlated with axis 2, which expressed the rice straw production of the mutant lines, and contributed 27.37%.

The variability of four yield components led to cluster the FKR47N mutant lines (Figure 6). Cluster 1, made up of 56 mutant lines, had an average plant height of 74.1 cm, an average number of 8 tillers plant<sup>-1</sup>, an average number of 6 productive tillers plant<sup>-1</sup> and an average paddy grain yield estimated at 1.01 t ha<sup>-1</sup>, which is lower than those recorded with the other two clusters. Cluster 2, comprising 47 mutant lines plus the parent (Control), showed an average number of 8 tillers plant<sup>-1</sup> and the highest average paddy grain yield (2.8 t ha<sup>-1</sup>) (Table 8).

**Table 8.** Main production components of FKR47N upland rice mutant lines.

Agronomic traits	Axis 1	Axis 2	Axis 3	Axis 4
Paddy grain yield	0.71	0.12	0.11	0.05
Plant height	0.50	0.34	0.15	0.00
Total number of tillers	0.38	0.53	0.05	0.04
Number of productive tillers	0.78	0.09	0.02	0.11
Value	2.37	1.09	0.33	0.251
Variability (%)	59.27	27.19	8.28	5.2

The mutant lines in cluster 2 had an average plant height of 84.42 cm, with a low number of tillers. The cluster 3 involving 35 mutant lines, stood out from those in the other two clusters with positive test values for the yield variables: 8.51 for the total number of tillers plant<sup>-1</sup>, 7.58 for the number of productive tillers, 6.64 cm for plant height and 4.78 t ha<sup>-1</sup> for paddy grain yield (Table 9).



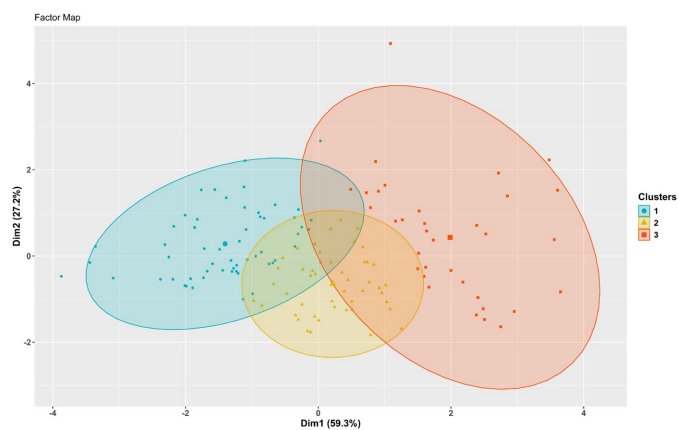
RGr: paddy grain yield; HP: plant height; NT: total number of tillers; NTU: number of useful tillers.

**Figure 5.** Principal component analysis showing correlations between yield components in FKR47N mutant lines in the M4 generation.

**Table 9.** Clustering of FKR47N upland rice mutant lines according to discriminant yield components.

Yield components	Cluster 1			Cluster 2			Cluster 3		
	CM	OM	v.test	CM	OM	v.test	CM	OM	v.test
Total number of tillers	8.40	9.46	-3.68	8.43	9.46	-3.11	12.62	9.46	7.58
Number of productive tillers	5.89	7.34	-6.80	-	-	-	9.96	7.34	8.51
Plant height	74.11	80.84	-7.64	84.42	80.84	3.55	86.88	80.84	4.78
Paddy grain yield	1.01	2.27	-8.83	2.84	2.27	3.45	3.55	2.27	6.24

CM: Cluster mean, OM: overall mean.



**Figure 6.** Clustering diagram for FKR47N upland rice mutant lines in the M4 generation.

ANOVA showed significant differences ( $P < 0.0001$ ) between mutant lines with regard to days to 50% flowering and paddy grain yield. Mutagenesis has induced an early flowering of 67 DAS in line M430P1S/300 ( $P < 0.0001$ ) and paddy grain yield ( $4.7 \text{ t ha}^{-1}$ ) ( $P < 0.0001$ ), total number of tillers ( $15 \text{ tillers plant}^{-1}$ ) ( $P < 0.00236$ ) and number of productive tillers ( $13 \text{ productive tillers plant}^{-1}$ ) ( $P < 0.0159$ ) significantly higher in line M422P3/300 compared to 75 DAS,  $3.95 \text{ t ha}^{-1}$ ,  $10 \text{ tillers plant}^{-1}$  and eight productive tillers  $\text{plant}^{-1}$  for parent FKR47N, respectively (Table 10).

**Table 10.** Mean performance of mutant lines of the FKR47N upland rice variety on agronomic traits related to paddy grain yield.

Upland rice genotypes	Days to 50% flowering (DAS)	Paddy grains yield ( $\text{t ha}^{-1}$ )	Plant height (cm)	Panicle length (cm)	Total number of tillers	Number of productive tillers
<b>Parent FKR47N</b>	<b>75.29 ± 0.96 a</b>	<b>3.95 ± 0.01 i</b>	<b>79.45 ± 10.43 a</b>	<b>23.16 ± 3.02 a</b>	<b>10.02 ± 3.39 abc</b>	<b>7.61 ± 3.46 b</b>
M421P2/300	71.00 ± 10.00 bc	4.10 ± 0.01 g	81.60 ± 2.70 a	24.00 ± 1.22 a	11.60 ± 1.82 abc	9.80 ± 1.30 ab
M421P3S/300	70.80 ± 0.84 bc	4.24 ± 0.02 f	79.60 ± 2.19 a	24.60 ± 1.67 a	12.40 ± 4.22 abc	9.20 ± 1.48 ab
M420P2/300	69.80 ± 0.84 cd	4.32 ± 0.02 e	85.40 ± 8.35 a	23.40 ± 2.97a	14.20 ± 5.17 ab	9.80 ± 2.17 ab
M429P2/300	70.60 ± 0.89 bc	4.39 ± 0.01 c	81.40 ± 4.98 a	23.60 ± 1.67 a	07.60 ± 1.67 c	7.00 ± 2.00 b
M430P1S/300	67.00 ± 0.84 d	3.97 ± 0.12 h	72.60 ± 7.99 a	20.80 ± 1.10 a	08.40 ± 1.82 bc	7.20 ± 1.30 b
M49P1S/350	70.80 ± 0.84 bc	4.39 ± 0.01 c	84.60 ± 3.71 a	24.00 ± 1.87 a	10.00 ± 1.00 abc	7.00 ± 2.24 b
M422P3/300	71.60 ± 1.14 b	4.75 ± 0.02 a	83.40 ± 2.41 a	22.00 ± 2.12 a	15.40 ± 6.73 a	13.40 ± 5.50 a
M414P1S/300	71.80 ± 0.84 b	4.46 ± 0.02 b	81.40 ± 1.67 a	24.80 ± 0.45 a	08.40 ± 0.89 bc	8.00 ± 0.71 b
M414P2/300	71.80 ± 0.84 b	4.33 ± 0.13 d	80.6 ± 1.34 a	23.00 ± 2.24 a	08.80 ± 0.45 bc	7.60 ± 0.55 b
Mean	73.17	4.13	80.26	23.25	10.36	8.15
CV%	12.78	14.36	10.59	11.14	32.53	37.43

Means with the same letter in the same letter column are statistically equivalent at the 5% threshold according to the Newman Keuls Multiple Range test.

#### 4. Discussion

Mutagenesis induced by gamma irradiation of seeds influenced the yield components of upland rice mutant lines at M4 generation. Significant variations were observed between mutant lines generated from the same rice variety for numbers of tillers and productive tillers, plant height, panicle length, paddy grain yield and days to 50% flowering. These significant differences result in genetic variability between mutant lines of the same parent variety. The days to 50% flowering of FKR45N or FKR47N mutant lines would be influenced by the effect of the coolness occurred during the plant growth phase coincided with the cool period of the year. This coolness may affect the development of rice seedlings by raising the days to 50% flowering.

The coefficient of variation was used to determine the variation between mutant lines generated from the same parent variety for each yield component. The value of this variation could be a reference for the selection of high-performance agronomic genotypes for more effective and efficient crop improvement [17]. The

coefficient of variation can be used to classify variables. For example, if the coefficient of variation for the total number of tillers and the number of productive tillers is greater than 15%, this would explain a high level of variability between mutant lines for both traits. On the other hand, when the coefficient of variation is < 15%, it reveals little variation between mutant lines for the variables [18].

Principal component analysis revealed both positive and negative test values. Positive test values for the variables show that the means of variables in the same cluster are higher than the value of the overall mean. Negative test-values, suggest that the cluster averages for these variables are lower than the overall mean. Clusters 1 and 2 were characterized by low paddy grain yields, high plant height and negative test-values for the variables. On the other hand, the cluster 3, made up of FKR47N mutant lines, was the best-performing cluster, characterized by high paddy grain yields, taller plant and good tillering, with the number of productive tillers corresponding to 78.9% of the total number of tillers. Test-values for these variables were positive. These mutant lines could be selected for their high productivity. FKR47N mutant lines in cluster 2 show similar data of variables to those of cluster 3, with positive test-values for plant height and paddy grain yield, but negative test values for tiller number. Cluster 1 of FKR47N mutant lines was discriminated from cluster 3 by negative test values for total number of tillers, number of productive tillers, plant height and paddy grain yield. Cluster 1 mutant lines were characterized by their dwarfism and low paddy grain yield. However, these lines could be used for hybridization with other lines having agronomic traits of interest. According to [9], the combination of hybridization and gamma-ray mutation has been used to generate new aromatic rice varieties coupled with high paddy grain yield. For example, some FKR47N and FKR45N mutant lines are agronomically efficient, with higher yield components [17]-[19]. Gamma irradiation created high-yielding mutant varieties in several plant species [20] [21]. From our results, the mutagenesis therefore has induced earlier flowering and higher paddy grain yield in 10 and nine mutant lines derived from the FKR45N and FKR47N parents, respectively.

The mutagenesis induced genetic variability in yield components of M2 and M3 lines generated from two cultivars [22] Indeed, the ionizing effects of gamma rays on the growth, morphology and yield of plant species including rice were highlighted [20] [21] whereas the gamma irradiation positively or negatively influenced some yield components of sorghum mutant lines derived from the Sariaso14 and Grinkan varieties [17]. The plant height of the M437P1S/300 mutant line was reduced by 20% compared to that of the FKR45N parent. On the other hand, the induced mutation may lead to an increase in wheat plant height [23]. Mutagenesis has induced either dwarf or tall plants, depending on the plant species or the type of mutagen used.

In addition to varietal productivity, the yield of irrigated rice varieties is higher than that of upland rice due to water control in irrigation conditions. This work has demonstrated that induced mutation using gamma ray has enhanced paddy

grain yields in mutant lines M450P2S/350 (4 t ha<sup>-1</sup>) and M422P3/300 (4.7 t ha<sup>-1</sup>) respectively generated from varieties FKR45N and FKR47N, which are as productive as or more productive than some improved irrigated rice varieties. Indeed, the yields of these two upland rice mutants are similar to those of 16 irrigated varieties (4.5 t ha<sup>-1</sup>) and higher than those of three others (3.3 t ha<sup>-1</sup>), of which agronomic performances have been reported [4]. The yields of these two mutants are higher than those of popularized upland rice varieties. Indeed, an assessment of the contribution of upland rice to increased rice production in Burkina Faso showed that the yield of upland rice varieties varies between 1 t ha<sup>-1</sup> and 3 t ha<sup>-1</sup> for the majority of rice farmers, and the FKR45N variety is more productive than the FKR47N variety [24]. The superior yield of the M422P3/300 line of the FKR47N variety compared to that of the M450P2S/350 mutant line of the FKR45N variety confirms the effect of induced mutation on improving the productivity of a low-yielding genotype.

## 5. Conclusions

The results have shown that mutagenesis induced genetic variability could be a potential source for plant breeding, leading to early flowering and/or high yielding mutant lines. The mutant lines M450P1/350 and M451P1S/400 mutant lines from FKR45N variety and M430P1S/300 from FKR47N variety have shown therefore early flowering. These three mutant lines may be tolerant to post-flowering water stress due to occurrences of drought caused by early cessation of rainfall. The paddy grain yields of lines M450P2S/350 from FKR45N variety and M422P3/300 from FKR47N variety were improved by 120% and 20%, respectively. In addition, M422P3/300 line has high tillering and could, therefore, be recommended to livestock breeders for fodder.

To highlight the environmental stability and adaptability of the four mutant lines, a multi-location evaluation would be carried out in contrasting environments to confirm the agronomic performance observed. This would make it possible to study the genotype x environment interaction. Among rice production constraints, drought and *Striga hermonthica* infection are, respectively, the abiotic and biotic constraints that cause major yield losses for rice growers. An evaluation of these mutant lines for their tolerance to water deficit and their resistance to *S. hermonthica* would, therefore, be considered for sustainable production under the strict rainfed conditions of local agro-ecologies.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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