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RESEARCH ARTICLE

ASSESSMENT OF RADIO-SENSITIVITY FOR THREE BAMBARA GROUNDNUT [*VIGNA SUBTERRANEA* (L.) VERDCOURT] VARIETIES TO GAMMA-RAY IRRADIATION IN BURKINA FASO

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ABSTRACT

Bambara groundnut [*Vigna subterranea* (L.) Verdcourt] is a highly nutritious food legume. However, the low genetic variability of Bambara groundnut is a limitation to its improvement to address various biotic and abiotic constraints. Gamma-irradiation mutagenesis is one of the techniques to create genetic variation in order to select new varieties to meet users' needs. However, the effectiveness of such method depends on identifying the appropriate radiation dose for each variety. This study aimed to determine the optimal lethal doses of mutagens producing maximum mutations with minimum damage. Seeds of three Bambara groundnut varieties (KVS115, KVS234 and KVS259) were subjected to five gamma-ray irradiation doses (200, 250, 300, 350 and 400 Gray). The radiation source was Cobalt-60, with an irradiation rate of 28.81 Gray/min. Irradiated and non-irradiated (control) seeds were sown in the field at INERA Saria station using a complete block design. Data were collected on parameters relating to seed germination, plant survival and pod yield of the varieties. A linear regression model was developed to determine the mean lethal dose (LD) and reduction dose (RD) of both varieties. The results revealed a decrease in germination and survival rates and a drop in pod weight with increasing irradiation doses. The KVS259 variety recorded 100% lethality at the 250 Gray dose and was the most sensitive to gamma irradiation. Variety KVS115 was the least sensitive to gamma irradiation, with 75% lethality at the highest dose of 400 Gray. Optimal doses varied between 148 Gray and 363 Gray depending on the variety. These results could be used in mutagenesis breeding programs to select mutants with desirable agronomic and nutritional traits for farmers and consumers.

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INTRODUCTION

Bambara groundnut[*Vigna subterranea* (L.) Verdcourt] is a legume belonging to the Fabaceae family (Bamshaiye *et al*., 2011). It is one of the most important food legumes in Africa, especially for many rural and urban populations in Burkina Faso (Ouaba *et al*., 2016). Bambara groundnut production provides a source of agricultural income mainly for women, who are the main producers in Burkina Faso (Ouaba *et al*., 2016). Its highly nutritious seeds contain 21% protein, 6% fat, 60% carbohydrates, 6% fiber and important trace elements The seeds also contain lysine and methionine, two essential amino acids with contents of 80.2 mg/g and 6.4 mg/g respectively (Halimi *et al*., 2019).Being a legume crop, rhizobiastrains found in Bambara groundnut can fix atmospheric nitrogen for soil improvement (Muhammad *et al*., 2021).Due to its various benefits, the crop is crucial in the strategies to enhance the resilience of populations to food and nutritional insecurity, in the current context of climate change. However, the production and promotion of Bambara groundnut are severely hampered by several constraints. Indeed, despite the acceptable soil conditions for its growing, the low yield potential of current varieties limits its productivity.

The maximumyield observed so farin Burkina Faso is about 1,600 kg.ha^{-1}, whereas, the crop's yield potential could reach 3,000 to 4,000 kg.ha^{-1} (Pungulani *et al.,* 2021).Furthermore, anti-nutritional factors such as phytates, tannins and fibers (House, 1999)that are abundant in Bambara groundnut seeds resulting in bloating and flatulence constitute a barrier to large-scale consumption. In addition to this factor, the long cooking time of the grains becomes a challenge for consumers. Therefore, varietal improvement will enable the crop to flourish and establish a sustainable basis for its promotion and production. Varietal improvement makes it possible to exploit variability and bring together genes of interest within a single genotype. However, several studies (Konate *et al*, 2017; Ouaba *et al*., 2017) have reported low genetic variability within Bambara groundnut genotypes in Burkina Faso. But, control crosses through hybridization have recorded less than 2% success due to the small size and nature of the flowers couple with low seed set success (Muhammad *et al*., 2021; Massawe *et al*., 2003).Consequently, one of the alternatives to the classical method is mutagenesis by gamma-ray irradiation. Mutagenesis is a promising method for inducing variability which is very crucial in crop breeding and improvement. The purpose of mutation induction is to create genotypic and phenotypic variations that allow the selection of plants with desirable characteristics (Muhammad *et al*., 2021). It has demonstrated its effectiveness in the varietal improvement of many food crops worldwide, including rice, rapeseed and wheat(FAO/AIEA, 2020). In Burkina Faso, this method has been used to improve cowpea (Gnankambary *et al*., 2019)and sorghum (Nikiema *et al*., 2020). Its application to Bambara groundnut can generate variability, which is important for developing nutritious, resilient, efficient and high-yielding varieties to address the needs of producers and consumers. To achieve optimal plant mutagenesis, the appropriate gamma irradiation rate must be determined individually for each variety through a radiosensitivity study (FAO/AIEA, 2020; Hasan *et al*., 2020). This study aimed to assess the level of sensitivity of three Bambara groundnut varieties to gamma irradiation. Specifically, the aim was (i) to study the effect of gamma radiation on germination, survival, grown and pod production and (ii) to identify the optimum gamma radiation rate.

MATERIALS AND METHODS

Experimental sites: The study was carried out in the laboratory and in the field. The different varieties seeds were irradiated at the laboratory of the Insectarium of Bobo Dioulasso (IBD), coordinates 11° 02’ N latitude, 4°21’ W longitude. Field trial was conducted at the research station of the “*Institut de l’Environnement et de Recherches Agricoles*” (INERA) of Saria, located in the Boulkiemdé province, 12°16' N latitude and 2°09' W longitude and 300 m altitude. The station's climate is North Sudanian (Guinko, 1984) and its soils are leached tropical ferruginous soils deficient in phosphorus and poor in organic matter (Hien, 2004).

Plant material: Three registered Bambara groundnut varieties sourced from the INERA were used in this study. The varieties are KVS115, having a black seed coat, and KVS234 and KVS259 with cream seed coats (Fig. 1). These varieties characterized by readings of 1,500 to 1,600 kg.ha^{-1} yields, large seed size, earlier maturing time of 80 to 90 days (Ouoba *et al*., 2016).Seed moisture levels measured before irradiation were 7,8%; 7,7% and 7,7% at 24°C respectively for KVS115, KVS234 and KVS259.

Seed irradiation method: Seed irradiation was carried out in October 2022 using the IBD irradiator, following the protocol proposed by the FAO/IAEA Division for seed irradiation (FAO/AIEA, 2020). The gamma radiation source used was Cobalt-60 with an irradiation rate of 28.81 Gray/min. A sample of 200 seeds of each variety were treated with five different doses of gamma rays, namely 200, 250, 300, 350 and 400 Gray. Irradiated seeds were stored at a temperature of -4°C for sixteen weeks.

Experimental design: Irradiated seeds (150 seeds per dose) and non-irradiated seeds (check) were assessed in the field at the INERA's Saria research station, using a complete block design subdivided into three sub-blocks. Each block was planted with one variety and each sub-blocks was planted with all the treatments of that variety, i.e. the five irradiation doses (200, 250, 300, 350 and 400 Gray) and the absolute check (0 Gray). A distance of 1 m was left apart from each block and 0.8 m apart each sub-block. Each treatment was sown in two rows of 3.6 m each. Inter and intra-row spacing was 0.4 m and 0.15 m, respectively. The trial measured 16.3 m x 12.8 m, with a total area of 208.64 m^2.

Mutants M1 generation cultivations practices: After deep ploughing, manual plot leveling were done prior to sowing. Sowing was done on February 19, 2023. After emergence, four weedings were done on request in order to adequately control weeds.Then, earthing-up were built just after flowering of the plants in order to encourage fruit production.A compound fertilizer (NPK 14-23-14) was applied at the rate of 100 kg.ha^{-1}at 15 days after planting. Irrigation was done through a furrow at 4 days frequency.

Data collection: Data was collected on twelve characteristics obtained by counting, measurement or calculation. These are:

- the number of emerged seeds, counted 15 days after sowing (DAS);
- germination rate over control was calculated using following formula proposed by (Tabti *et al*., 2018),

$$\text{i.e.germination rate (\%)} = \frac{\text{number of germinated seedlings}}{\text{number of control germinated seedlings}} x\ 100\ ;$$

- Observations on plant morphological traits such as plant height, number of stems and number of leaves,were recorded 30 DAS by measurement and counting;
- The number of living plants counted at the 50% flowering stage;
- The survival rate was calculated using following formula proposed by (Olasupo *et al*., 2016)

$$\text{i.e.survival rate (\%)} = \frac{\text{number of survived seedling}}{\text{number of germinated seedlings}} x100$$

- the seedling lethality rate was calculated using the survival rates of the control and treated according to the formula proposed by (Bassir, 2012),

$$\text{lethality rate (\%)} = \frac{\text{(control – traited)}}{\text{control}} x\ 100$$

- the dry pods weight per plant was obtained by weighing of the pods after two weeks of drying

- the percentage reduction in pods weight over control were obtained using the formula:

percentage reduction in pods weight $= \frac{(\text{contrôle} - \text{traité})}{\text{contrôle}} x\ 100$;

- phenological characteristics such as days to first flowering and days to maturity were obtained by counting the number of days between sowing and the appearance of the first flower and maturity respectively.

The optimal doses were estimated for each variety through the simple linear regression model considering 100% of seed germination and survival rate of the control.

Statistical analysis: Data were subjected to an analysis of variance (ANOVA) using XLSTAT 2023, where the influence factor was the radiation dose with a significance level of 0.05. Mean comparisons were performed using Newman-Keuls Multiple range test. A linear regression analysis of germination rate, plant survival and pod weight per plant was performed using XLSTAT. The lethal dose LD50 and the pod weight reduction dose DR50 were determined from the regression line following the equation y = mx + c; where "y" is the response variable (germination rate), "x" is the independent variable (irradiation dose), "m" the slope and "c" the germination percentage at zero dose.

RESULTS

Effect of gamma radiation on Bambara groundnut germination and seedling survival in M1 generation: The number of germinated seeds, number of living plants, seed germination and seedling survival rate data are presented in Table 1. The ANOVA results reveal a positive significant effect of gamma rays (P<0.001) in all varieties. Generally, the result indicates a gradual reduction in the number of germinated seeds, number of living plants, germination rate and seedling survival rate with increased gamma-irradiation doses, with some fluctuations between varieties (Fig. 2). The highest germination and survival rates were recorded at doses ranging from 200 to 300 Gray, depending on the variety. Germination rates varied from 16.6 to 58.3% and from 71 to 80% for KVS115 and KVS234 respectively. Survival rates ranged from 36.38 to 61.18% for KVS115 and from 91.27 to 95.64% for KVS234. On the other hand, the highest germination and survival rates were obtained only at the 200 Gray dose for the KVS259 variety. The 100% lethal radiation dose was attained in KVS259 at 250 Gray, and in KVS234 at 400 Gray but not in KVS115. At the 250 Gray dose, lethality was 63% and 8% respectively for varieties KVS115 and KVS234. At 400 Gray, KVS115 variety indicated 97% lethality.

Gamma radiation effects onBambara groundnut M1 mutants' growth, developmentand pods production: The evaluation of plant height, number of stems, number of leaves and dry pod production per plant results of the three studied varieties are presented in Table 2. The ANOVA results showed that Gamma irradiation had different effects on plant height in the three varieties. In fact, there was no significant difference (P>0.05) between the irradiated plants and the controls for plant height in the KVS115 and KVS259 varieties. Plant height varied with irradiation dose from 17.8cm to 21.5cm in KVS115 and from 17.8cm to 19.6cm in KVS259. However, a significant difference (P = 0.000) was observed between the irradiation doses for plant height in the KVS234 variety. The highest plant height (19.9cm) was recorded in the non-irradiated control (0 Gray) and the lowest plant height (9.7cm) in irradiated plants at the 400 Gray dose. Gamma irradiation had a significant effect on the number of stems per plant in varieties KVS115 (P=0.002) and KVS234 (P=0.023). The number of stems per plant fluctuated with an upward trend with increasing irradiation dose for the KVS115 variety, rising from 4 for the non-irradiated control to 7.7 stems for irradiated plants at the 400 Gray dose. In the KVS234 variety, this number fluctuated from 4.5 for irradiated plants at the 300 Gray dose to 6.6 stems per plant for the unirradiated control and irradiated plants at the 350 Gray dose for the KVS234 variety. The number of leaves per plant fluctuated with increasing irradiation dose in all varieties. A significant difference (P = 0.049) was observed between irradiation doses only for the KVS115 variety where the maximum number of leaves (47.3) was recorded at the 400 Gray dose and the minimum number of leaves (20) at the 250 Gray dose. In the varieties KVS234 and KVS259, the maximum number of leaves per plant was recorded in the non-irradiated controls with 29 and 43 leaves per plant respectively. The ANOVA results showed highly to very highly significant effect of gamma irradiation on pod weight per plant in all varieties. In comparison to the control, increasing doses of gamma irradiation resulted in a reduction of pod weight per plant, with some fluctuations (Fig. 3). KVS259 recorded its highest pod weights (5.4g) at the 200 Gray dose, KVS234 (4.8g) at the 250 Gray dose, and KVS115 (5.5 g) at the 400 Gray dose. Compared to the controls, the minimum reduction (0%) in pod weight was observed for variety KVS115 at the 350 Graydose while the maximum reduction (100%) indicating total absence of pods was observed for KVS234 at the same dose.

Gamma radiation effects onBambara groundnut M1 mutants' phenology: The irradiation effect on phenology varied according to variety and irradiation dose (Table 3). A significant difference (P<0.001) was observed between doses for days to first flowering in the KVS115 and KVS234 varieties. The first flowers appeared, for the KVS115 variety, between 36 DAS in irradiated plants with the 300 Gray dose and 40.7 DAS in irradiated plants with the 400 Gray dose. In the non-irradiated control plants, the first flowers appeared at 37 DAS. Daysto first flowering varied from 28 DAS for irradiated plants with the 200 Gray dose to 35 DAS for non-irradiated control plants for the KVS234 variety. However, irradiation had no significant effect on days to first flowering for the KVS259 variety, which varied from 37 DAS in the control to 40 DAS in the plants irradiated with the 200 Gray dose. Irradiation caused a reduction in the maturity cycle of the KVS115 and KVS234 varieties. The maturity cycle of the control KVS115, which lasted 107 days, was statistically different from the maturity cycles of the irradiated plants, which lasted between 93 days (300 Gray dose) and 97 days (200 and 400 Gray doses). In the KVS234 variety, the control cycle lasted 99 days compared with 92 to 97 days for the cycle length of plants irradiated at the200 and 400 Gray doses respectively.

Average performance of M1 mutants of the three Bambara groundnut varieties and interactions varieties*doses: Table 4 summarises the average performance of the M1 mutants resulting from irradiation of the three varieties, as well as the interactions varieties*irradiation doses.

Table 1. Effect of gamma mutagen on seed germination and seedling survival of Bambara groundnut varieties

Varieties	Doses (Gray)	Number of seeds sown	Number of germinated seeds	Germination rate (%)	Number of living plants	Survival rate (%)	Lethality survival (%)
KVS115	0	150	132	100 a	132	100 a	0
	200	150	22	16.66 c	14	63.63 b	38.82
	250	150	77	58.33 b	28	36.36 c	63.62
	300	150	7	5.30 d	2	28.57 cd	71.43
	350	150	7	5.30 d	2	28.57 cd	71.43
	400	150	4	3.03 d	1	25.00 d	75
P value				**<0.0001**		**<0.0001**	
KVS234	0	150	124	100 a	124	100.00 a	0
	200	150	89	71.77 b	85	95.50 ab	4.36
	250	150	98	79.03 b	89	90.81b	8.73
	300	150	100	80.64 b	79	79.00 c	21
	350	150	54	43.54 c	35	64.81 d	35.2
	400	150	2	1.61 d	0	0.00 e	100
P value				**<0.0001**		**<0.0001**	
KVS259	0	150	110	100 a	110	100.00 a	0
	200	150	40	36.36 b	17	42.50 b	57.30
	250	150	0	0 c	0	0.00 c	100
	300	150	0	0 c	0	0.00 c	100
	350	150	0	0 c	0	0.00 c	100
	400	150	0	0 c	0	0.00 c	100
P value				**<0.0001**		**<0.0001**	

Note: Means followed by same letter are not significantly different at 5% (Newman-Keuls Multiple range test)

Table 2. Effect of gamma radiation on M1 mutants' growth, development and pods production

Variety	Doses (Gray)	Plant height (cm)	Number of stems	Number of leaves	Pod weight per plant (g)	Pod weight reduction over control (%)
KVS115	0	21.5 a	4.0 c	30.0 ab	7.8 a	0
	200	18.7 a	6.1 ab	29.7 ab	4.7 b	39.74
	250	17.8 a	5.4 bc	20.0 b	5 b	35.89
	300	17.8 a	7.3 ab	34.0 ab	4.2 b	46.15
	350	19.3 a	6.3 ab	31.7 ab	0 c	100
	400	19.6 a	7.7 a	47.3 a	5.5 b	29.48
P value		**0.161**	**0.002**	**0.049**	**<0.0001**	
KVS234	0	19.9 a	6.6 a	29.0 a	9.4 a	0
	200	14.7 b	6.5 a	28.3 a	4.4 b	53.20
	250	13.3 bc	5.8 ab	26.7 a	4.8 b	49.00
	300	12.5 bc	4.5 b	16.0 a	2.9 c	69.15
	350	10.8 bc	6.6 a	25.7 a	0 d	100
	400	9.7 c	4.7 b	11.3 a	0 d	100
P value		**0.000**	**0.023**	**0.076**	**0.001**	
KVS259	0	19.6 a	6.7 a	43.0 a	9.7 a	0
	200	17.8 a	5.7 a	40.3 a	5.4 b	44.33
	250	-	-	-	-	-
	300	-	-	-	-	-
	350	-	-	-	-	-
	400	-	-	-	-	-
P value		**0.202**	**0.221**	**0.554**	**0.005**	

Note: Means followed by same letter are not significantly different at 5% (Newman-Keuls Multiple range test)

Table 3. Effect of gamma radiation on M1 mutants phenology

Variety	Doses (Gray)	Days to first flowering	Days to maturity
KVS115	0	37.0 c	107.0 a
	200	39.0 b	97.3 b
	250	37.7 c	95.0 c
	300	36.3 c	93.3 c
	350	40.0 ab	98.3 b
	400	40.7 a	97.7 b
P value		<0.0001	<0.0001
KVS234	0	35.0 a	99.0 a
	200	28.0 b	92.7 b
	250	29.0 b	94.0 b
	300	30.3 b	95.3 b
	350	29.0 b	93.3 b
	400	29.7 b	95.7 b
P value		<0.0001	0.005
KVS259	0	37.3 a	102.0 a
	200	40.0 a	104.3 a
	250	-	-
	300	-	-
	350	-	-
	400	-	-
P value		**0.065**	**0.421**

Table 4. Average performance of M1 mutants of the three Bambara groundnut varieties and interactions varieties*doses

Variety	GR (%)	SR (%)	PH (cm)	NS	NL	PWP (g)	DFF	DM
KVS115	31.44 b	46.60 b	19.14 a	6.13 a	32.1 b	4.30 b	38.4 a	95 b
KVS234	62.76 a	71.80 a	13.48 b	5.79 a	22.8 c	3.60 b	30.2 b	98 b
KVS259	36.36 b	42.50 b	17.80 ab	5.70 a	40.3 a	5.45 a	40.0 a	104 a
Pr > F (variety)	<0.0001	<0.0001	<0.0001	0.420	0.000	0.001	<0.0001	0.004
Pr>F (Variety*Dose)	<0.0001	0.000	<0.0001	0.000	0.007	0.000	<0.0001	<0.0001

GR: germination rate, SR: survival rate, PH: plant height, NS: Number of stems, NL: Number of leaves, PWP: Pods weight per plant, DFF: days to first flower, DM: days to maturity

Table 5. The optimal dose (LD50%) of seed germination of Bambara groundnut varieties

Variety	Regression line	DL50 (Gray)	R^2(%)
	optimal dose of seed germination		
KVS234	y = -0,1996x + 112,67	313	56
KVS115	y = -0.2458x + 92.895	174	72
KVS259	y = -0,2682x + 89,772	148	84
	optimal dose for plant survival		
KVS234	y = -0.1913x + 119.62	363	40
KVS115	y = -0.1727x + 88.749	224	77
KVS259	y = -0.2714x + 91.621	153	84
	optimal dose for pod weight reduction rate(RD50)		
KVS234	y = 0.258x – 2.6021	203	93
KVS115	y = 0.1474x + 5.0204	305	25
KVS259	y = 0.2778x + 4.5963	163	81

Note: DL_{50} : 50% Lethal Dose, DR_{50} : 50% Reduction Dose, R^2 : coefficient of determination

Fig. 1. Seeds of studied Bambara groundnut varieties

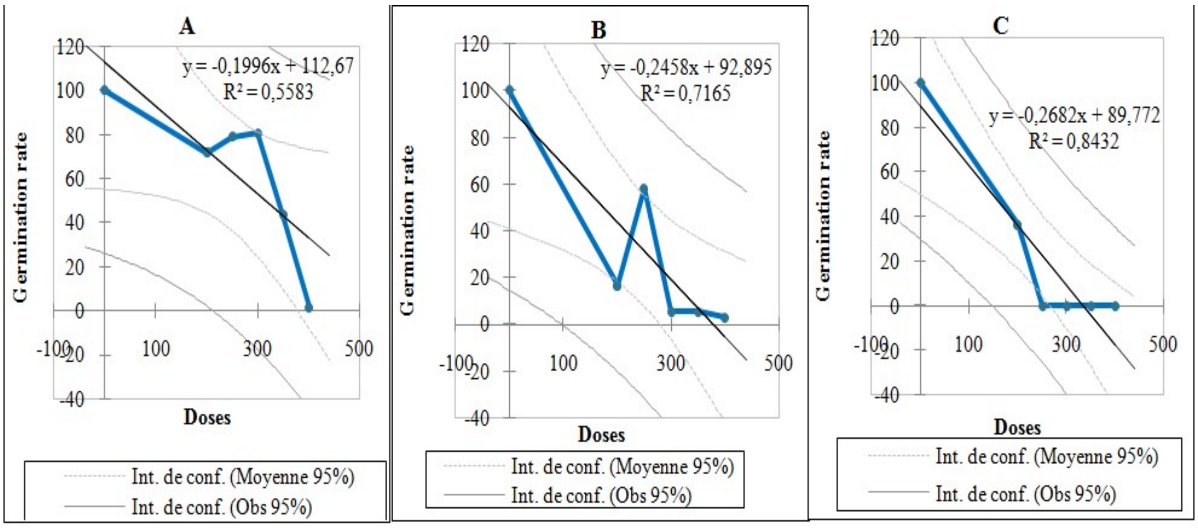

Fig. 2. The regression of germination rate for gamma irradiation (A) germination of KVS234, (B) germination of KVS115, (C) germination of KVS259

A highly significant difference was observed between the mutants from the three varieties for all studied traits except the number of stems per plant. Mutants derived from KVS234 had the highest germination and plant survival rates (62.76% and 71.80% respectively), the lowest pod weights per plant (3.60 g) and the earliest days to flowering (30 days) and days to maturity (98 days). Mutants derived from the KVS115 variety were the tallest plants (19.14 cm) with the earliest maturity cycles (95 days). Finally, mutants derived from the KVS259 variety had the highest number of leaves per plant (40.3), the highest pod weights per plant (5.45 g) and the longest days to flowering (40 days) and days to maturity (104 days).

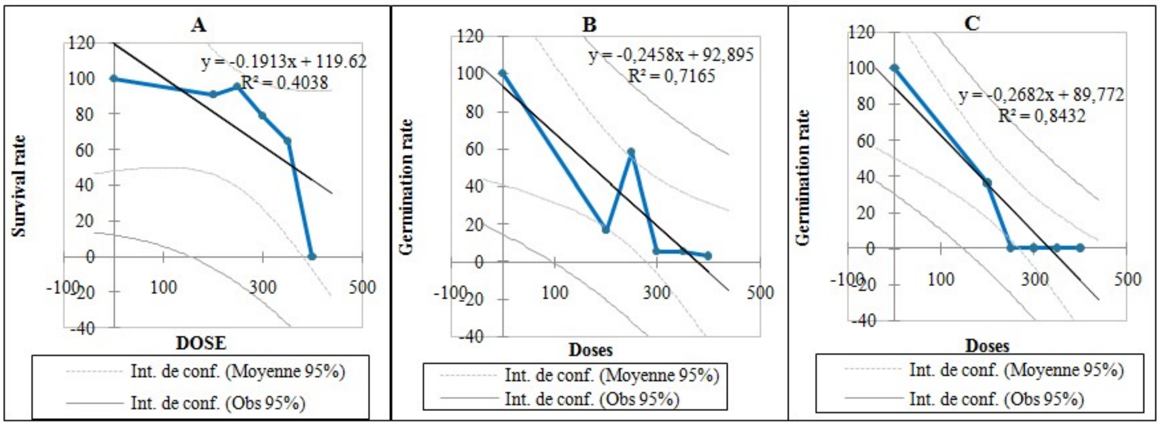

Fig. 3. The regression of survival rate for gamma irradiation (A) survival of KVS234, (B) survival of KVS115, (C) survival of KVS259

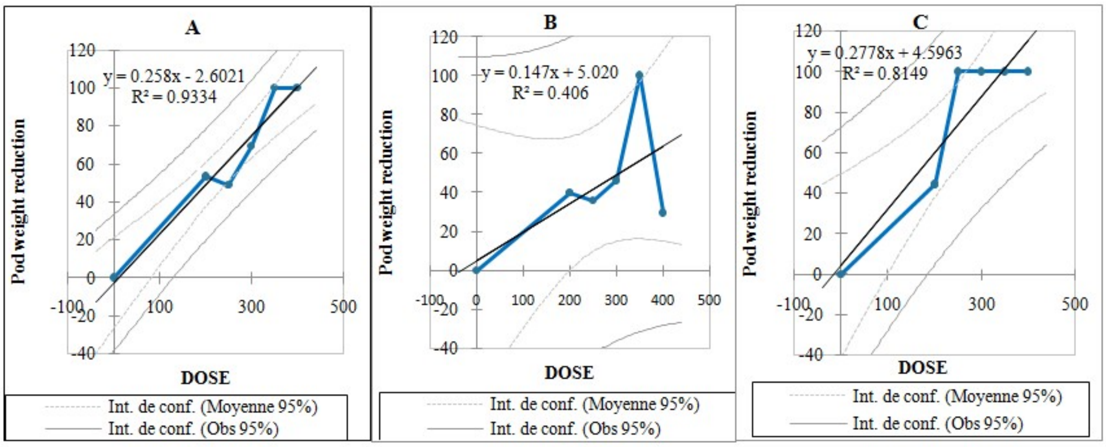

Fig. 4. The regression of pod weight reduction rates over control for gamma irradiation (A) pod weight reduction of KVS234, (B) pod weight reduction of KVS115, (C) pod weight reduction of KVS259

The interaction variety*dose was significant for all the studied characteristics, which that the effect of gamma irradiation varies from one variety to another.

Optimal gamma irradiation doses determination: Fig.2 and fig.3 showed the linear regression of germination rates, survival rates and percentage reduction in pod weight with increasing irradiation doses. Optimal lethal doses (LD50) for germination and survival varied according to variety but remained roughly equal for the same variety (Tables 5). The highest values for optimal germination and survival doses were recorded for KVS234 (313 Gray and 363 Gray) and the lowest for KVS259 (148 Gray). KVS115 recorded optimum doses of 174 Gray and 168 Gray for germination and survival respectively. The optimum dose for pod weight reduction (Table 5) ranged from 163 Gray for KVS259 (r^2 = 81%) through 203 Gray for KVS234 (r^2 = 93%) to 305 Gray for KVS115 (r^2 = 25%). Based on these results it can be seen that KVS259 variety has most sensitivity to gamma-irradiation treatment when compared to the KVS115 and KVS234 varieties.

DISCUSSION

The percentage germination was one of the most important variables to be considered in any plant mutagenesis experiment because plant mortality rate signifies the extent of damage caused as a result of exposure of seeds or seedlings to gamma radiation treatments (Muhammad *et al*., 2021).In this study, the results analysis showed that the increase of gamma radiation dose gradually decreased seed germination and seedling survival rate compared to control. The decrease in germination and survival rates with increasing irradiation dose could be explained by an increase in the chromosomal damage frequencies with increasing irradiation dose (Kiong *et al*., 2008). Gamma irradiation caused a metabolic disorder in seeds, rendering them unable to germinate or survive for more than a few days. Gamma-ray treatment leads to the destruction of auxin, changes in ascorbic acid content and biochemical disturbances resulting in germination inhibition (Sah *et al*., 2008). The impact of the mutagen on the meristematic tissues of the seeds and damage to the chromosome might be the cause of the lower survival rate of plants. Physiological disproportion and different forms of chromosomal distortion could be the leading causes of the decrease in plant survival (Khursheed *et al*., 2015). This decline in survival percentage due to mutagenic treatments among the biological samples can be linked to the extent of cell differentiation and embryo development at the time of mutagenic treatments. According to (Manju P. and Gopimony, 2009), the reduction in plant survival is an index of post-germination mortality as a result of cytological and physiological disturbances due to the effect of radiation.

Similar results were reported by (Muhammad *et al*., 2021) on an evaluation of the acute and chronic gamma- irradiation effect on two Bambara groundnut varieties. These results also corroborate the findings of several studies in many crops such as cowpea (Vanmathi *et al*., 2021; Gnankambary *et al*., 2019; Girijaand Dhanavel, 2013; Rizwana *et al*., 2005), lentil (Tabti *et al*., 2018), groundnut (Ganesan *et al*., 2022), black gram (Thilagavathi and Mullainathan, 2011), (Yasmin and Arulbalachandran, 2016), soybean (Kusmiyati *et al*., 2018; Mudibu *et al*., 2012), finger millet (Sellapillaibanumathi *et al*., 2022) and okra (Yakoro *et al*., 2023).However, Borzouei *et al*. (2010) found that the final germination rate was not significantly affected by gamma radiation at doses ranging from 100 to 400 Gray in wheat. This could be explained by the inadequacy of the gamma irradiation doses used. According to FAO/AIEA (2020), the gamma irradiation optimum dose range in wheat is between 450 and 600 Gray. Increasing doses of gamma irradiation from 200 to 400 Gray resulted in a reduction of pod weight per plant and plant heightcompared to control. However, the KVS115 and KVS234 varieties, whose plants survived doses of 350 to 400 Gray, did not produce any pods. These results could be explained by the increased of chromosomal damage frequencies as the dose increases, which would reduce the reproductive and production capacity of the plants. The reduction in reproductive capacity induced by the mutagen includes severe growth retardation which prevents flowering, lack of reproductive structures of flowers, abortion of pollen and/or ovules or abortion of embryos before maturity(FAO/AIEA, 2020), reduction in pollen fertility. The physiological disturbance or chromosomal damage caused by mutagens to the plants' cells has been connected to the reduction in pod production per plant, quantitative and yield characteristics (Thilagavathi and Mullainathan, 2011). Several researchers reported a significant reduction in growth and yield traits at higher mutagen doses in black gram (Thilagavathi and Mullainathan, 2011), chickpea (Amri-Tiliouine *et al*., 2018), chili pepper (Thisawech *et al*., 2020) and groundnut (Ganesan *et al*., 2022).

Gamma irradiation reduced the flowering start and the maturity cycle of two studied varieties and had no effect on the other variety. The flowering initiation may be affected as a result of mutagenic treatments because many biosynthetic pathways are believed to be altered, which are directly as well as indirectly associated with the flowering physiology (Bosila *et al*., 2019; Ismael and Mohmoud, 2015). According to Fowler and Mac Queen (1972), most of the reported stimulatory effects of low doses of radiation was due to early modifications in axillary bud development and changes in the initial rate of floral differentiation. It may also be due tothe mechanisms or inhibition of mitotic and chromosomal changes or damage with association of secondary physiological damage (Kumari and Kumar, 2015). The listed effects on the flowering start could also have influenced the ripening cycle. Similar results on the effect of gamma radiation on flowering have been reported by Bosila *et al*. (2019) on chrysanthemum and by Estrada-Basaldua *et al*. (2011) on *Polyanthes tuberosa.* Optimum gamma radiation doses varied from 148 Gray to 363 Gray for the three Bambara groundnut varieties studied. The lowest LD50% values for seed germination and seedling survival were recorded for KVS259. KVS259 variety has most sensitivity to gamma-irradiation treatment when compared to the KVS115 and KVS234 varieties. Optimum doses ranging from 148 Gray to 264 Gray were observed in Bambara groundnut by (Muhammad *et al*., 2021). This difference indicates that different genotypes from the same family can vary considerably in their sensitivity response to gamma irradiation (Hernandez *et al*., 2017). The significant variety*dose interaction for all the studied traits supports the view that the effect of gamma irradiation varies from one variety to another within the same species. Consequently, the optimum dose of gamma irradiation should be determined individually for each variety. The variation in optimal doses between varieties could be explained by the characteristics of the seeds and the environmental conditions of the experiment. Indeed, oxygen is one of the well-known modifiers of radiation sensitivity, followed by seed water content. Even insignificant variations from 0.2 to 0.3% in seed water content can lead to very a significant impact on the final biological effect, and considerably alter the radiosensitivity of certain species (FAO/AIEA, 2020).

CONCLUSION

This study on evaluation of the radio sensitivity of three Bambara groundnut varieties showed a significant effect of gamma radiation on all three varieties for all the traits studied. Generally, an increase in gamma-ray irradiation resulted in a subsequent decrease and inhibition in seed germination, plant survival rate and pod weight per plant. However, irradiation increased the aerial biomass of some M1 mutants and shortened the maturity cycle of others. These mutants could be used to make crops more resilient to climate change, which tends to shorten the rainy season. All three Bambara groundnut varieties are therefore susceptible and revealed different degrees of sensitivity to gamma-ray irradiation. The KVS259 variety was the most sensitive to gamma irradiation, with the lowest LD50 lethal dose (148 Gray) and the lowest 100% lethal dose (250 Gray). Optimum gamma radiation doses in this study were varied from 148 Gray to 363 Gray for the three Bambara groundnut varieties studied. These results could be used in mutagenesis breeding programs to select mutants with desirable agronomic and nutritional traits for farmers and consumers. Evaluation of the second generation of M2 mutants will enable us to select mutants with traits of interest.

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Glossary of Abbreviations

ANOVA: Analyse of variances
DAS: Days after sowing
DFF: Days to first flower
DM: Days to maturity
FAO: Food and Agriculture Organization of the United Nations

GR:	Germination rate
IAEA:	International Atomic Energy Agency
IBD:	Insectarium de Bobo Dioulasso
INERA:	Institute for the Environment and Agricultural Research
LD50:	50% Lethal dose
NL:	Number of leaves
NS:	Number of stems
PH:	Plant height
PWP:	Pods weight per plant
RD50:	50% Reduction dose
SR:	Survival rate

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