doi:10.14720/aas.2023.119.3.13423 Original research article / izvirni znanstveni članek

Gamma irradiation of eggplant seeds influences plant growth, yield and nutritional profile in M_1 generation

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Received April 16, 2023; accepted August 31, 2023.
Delo je prispelo 16. aprila 2023, sprejeto 31. avgusta 2023

Gamma irradiation of eggplant seeds influences plant growth, yield and nutritional profile in M_1 generation

Abstract: The study examines agromorphological traits and nutrient compositions in three genotypes of eggplants (*Solanum melongena* 'African Beauty F_1' and 'Melina F_1' and *S. aethiopicum* 'Kotobi') grown from seeds irradiated by gamma rays (γ-ray) with 100 Gy. Experiments were carried out in the screenhouse and experimental field of Crop Science Department, University of Calabar, Nigeria. Completely randomised design with four replications and randomised complete block design with three replications was used in the screenhouse and field experiments respectively. Eggplant × γ-ray effect reduced ($p \leq 0.05$) seedling emergence, plant height and number of leaves in the nursery at 2 and 4 weeks after sowing. In the field, these traits were consistently lower for irradiated Melina F_1 and Kotobi ($p > 0.05$) at ten weeks after transplanting. Irradiated African Beauty F_1 had the highest ($p \leq 0.05$) upper canopy leaf area (429.54 cm^2), higher ($p > 0.05$) plant height and stem width; lower ($p > 0.05$) number of branches and leaves. Un-irradiated and irradiated Kotobi had the highest ($p \leq 0.05$) fruit load, lower ($p \leq 0.05$) fruit volume, weight and yields over four harvest intervals. Carbohydrate and energy contents of Kotobi fruits grown from 100 Gy gamma-ray irradiated seeds were concurrently improved ($p \leq 0.05$). Gamma ray irradiation had both positive and negative influences on the agromorphological traits, mineral composition and nutrient profile of eggplants. However, 100 *Gy* dose of irradiation had a negative effect on fruit characteristics in general. From the results of this study, inconsistent variations in the agromorphological traits of the irradiated eggplants of the three varieties were reported. Therefore, the goal of mutation breeding in eggplant should not undermine the importance of the eggplant genotype as well as the actual radiation dose.

Key words: γ-ray, eggplant, fruits, induced mutation, irradiation, Solanaceae

Obsevanje semen jajčevca z γ-žarki vpliva na rast rastlin, pridelek in prehransko vrednost plodov v M_1 generaciji

Izvleček: Raziskava preučuje agromorfološke lastnosti in prehransko sestavo treh sort jajčevca (*Solanum melongena* 'African Beauty F_1' and 'Melina F_1' in *S. aethiopicum* 'Kotobi') vzgojenih iz semen obsevanih z gama žarki, jakosti 100 Gy. Poskusi so bili izvedeni v rastlinjaku in na poskusnem polju ustanove Crop Science Department, University of Calabar, Nigeria. V obeh primerih je bil poskus zasnovan kot popolni naključni bločni poskus s štirimi ponovitvami. Obsevanje semen jajčevca z gama žarki je zmanjšalo vznik sejank ($p \leq 0{,}05$), višino rastlin in število listov v rastlinjaku dva in štiri tedne po setvi. V poljskem poskusu so bile vrednosti teh parametrov vedno manjše pri obsevanih sortah Melina F_1 in Kotobi ($p > 0{,}05$) deset tednov po presaditvi. Rastline obsevane sorte African Beauty F_1 so imele največjo listno površino ($p \leq 0{,}05$; 429,54 cm^2), večjo višino ($p > 0{,}05$) in večjo debelino stebla, a manjšo število stranskih poganjkov in listov ($p > 0{,}05$). Neobsevane in obsevane rastline sorte Kotobi so imele največ plodov ($p \leq 0{,}05$), manjši volume plodov ($p \leq 0{,}05$), manjšo maso in pridelek v vseh štirjih obdobjih pobiranja plodov. Vsebnosti ogljikovih hidratov in energetska vrednost plodov sorte Kotobi, zrasle iz semen obsevanih z 100 Gy gama žarki sta se izboljšali ($p \leq 0{,}05$). Obsevanje semen jajčevca z gama žarki je imelo pozitivne in negativne učinke na agromorfološke lastnosti, mineralno sestavo in na prehranski profil plodov jajčevca. Doza obsevanja 100 Gy je imela nasplošno negativni učinek na lastnosti plodov. Iz rezultatov raziskave je razvidno, da so spremembe agromorfoloških lastnosti jajčevca vseh treh obravnavanih sort, vzgojenih iz obsevanih semen nekonsistetne. Iz tega sledi, da cilji žlahtnenja z mutacijami ne smejo prezreti pomena genotipa jajčevca kot tudi ne dejanskih doz obsevanja.

Ključne besede: *γ-žarki*, jajčevec, plodovi, inducirane mutacije, obsevanje, Solanaceae

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1 INTRODUCTION

Eggplant is a vegetable crop mostly cultivated in tropical and subtropical regions of the world. It belongs to the Solanaceae family and the genus *Solanum* with more than 90 genera comprising nearly 3,000 species (Melissa, 2017; Singh et al., 2006). Eggplant has been recognized as the fifth most economically important Solanaceous crop after potato (*Solanum tuberosum* L.), tomato (*Solanum lycopersicum* L.), pepper (*Capsicum annuum* L.) and tobacco (*Nicotiana tabacum* L.) (FAO, 2014). Eggplant has a very low caloric value and is considered among the healthiest vegetables with high vitamin, mineral and bioactive compounds (Raigon et al., 2008; Plazas et al., 2013; Docimo et al., 2016). It is very common in rich dishes such as stews and soups (Edem et al., 2009; Chinedu et al., 2008). The need for improved eggplant varieties for sustainable production and adaptation to climate change challenges cannot be overemphasized. The low yielding ability of the crop has been attributed to lack of varietal replacement through development of hybrid and persistent use of traditional practices coupled with the influence of environmental degradation (Chinedu et al., 2008). Increasing crop yields is a major demand for assuring food security and as such mutagenesis is an important tool to improve crops (Beyaz et al., 2017). As an alternative to natural mutation, which can take years, inducing mutations with different mutagens has greatly aided breeding projects in a variety of ways. Many studies have reported that genetic variability for numerous desired traits may be successfully created through mutations, and its application in plant development programmes is well known (Chopra, 2005). Because of its penetrating capabilities, gamma irradiation is one of the most successful techniques of creating genetic diversity in plants when compared to other ionising radiations (Moussa, 2006), as well as in the production of new varieties (Animasaun, 2014; Mohamad et al., 2006). Gamma-ray photons have the shortest wavelength in the electromagnetic spectrum, and therefore possess more energy which gives them the ability to penetrate deeper into the plant tissues (Amano, 2006). Accordingly, gamma irradiation has been used to induce mutation and still shows great potential for improving vegetative plants (Predieri, 2001). Mutation breeding is utilised in addition to traditional plant breeding because it has a stronger potential for enhancing plant architecture and resulting in improved crop development (Khin, 2006). Gamma rays are used in inducing mutations in seeds, and other planting materials such as cuttings, pollens or callus cultures (Ali et al., 2015). Gamma rays are also being widely used as mutation techniques in an attempt to improve morphological and plant growth characteristics. For example, gamma ray irradiation was used to extend the shelf life of tomatoes (Antaryami et al., 2016) and to improve potato storage capacity (Nouani et al., 1987) as well as the morphological traits in pepper (Abu et al., 2020). This can also be of great value and benefit for the improvement of eggplant. The improvement of eggplants through creation of variability using gamma rays would enable the selection of high yielding genotypes with improved agro-morphological characters and increase the crop's agricultural productivity. Thus, the objective of this study was to assess the effect of gamma irradiation on the growth and yield traits of three varieties of eggplants.

2 MATERIALS AND METHODS

2.1 SOURCE OF SEEDS

Seeds of three varieties of eggplants, African Beauty F_1 (*Solanum melongena* L.), Kotobi (*Solanum aethiopicum* L.) and Melina F_1 (*Solanum melongena* L.), were purchased from Technisem® (Longue-Jumelles, France).

2.2 IRRADIATION OF SEEDS

Protocol for the irradiation of eggplant seeds was followed according to the National Institute of Radiation Protection and Research at the University of Ibadan, Nigeria. The irradiator used was a Gamma-Photon Irradiator with model GammaBeam™ X200 (Best Theratronics Ltd., Canada). The samples were irradiated with 100 Gy of gamma rays.

2.3 EXPERIMENTAL SITE AND DESIGN

The study was conducted at the University of Calabar Teaching and Research Farm, Calabar in two phases – the screenhouse and the field. Completely randomised design with four replications was used for the potted experiment in the screenhouse comprising while randomised complete block design with three replications was used in the field.

2.3.1 Screenhouse experiment

The top-soil (15–20 cm depth) used for the screenhouse experiment was obtained from the earmarked experimental field site. The friable, humus-rich topsoil was properly sieved, uniformly mixed, weighed and then transferred into conically shaped base-perforated plastic pots with the following dimensions: 20 cm – height, 8 cm – base radius and 10 cm – rim radius. The total volume of each pot was 5108 cm^3. Three-quarters of the total volume of each pot was filled with the prepared topsoil (i.e., 3831 cm^3 of topsoil). The potted soil was sufficiently and uniformly wetted with 500 ml of irrigation water the after preparation of the seed bed. The seeds were primed in distilled water for 24 h prior to sowing on 2 March 2020. A total range of 30 seeds were sown in each pot. The total number of pots was 24. Seedlings of irradiated and unirradiated seeds were raised indoors in potted nursery in the screenhouse. Subsequent irrigation was done for 22 days: at germination (thrice, 50 ml at three days interval) and emergence (thrice, 100 ml at two days interval). At full emergence and growth (≥ 22 days after sowing), 500 ml of the irrigation water was applied at two days interval for three weeks. Transplanting of vigorous seedlings was done at six weeks after sowing (WAS). The seedlings were transplanted at a height of 10–15 cm on 13 April 2020 using the ball-of-earth method. The plant spacing was 0.6 m × 0.6 m and the gross treatment plot size was 2.4 m × 3.0 m (for 20 seedlings) giving a total plant population of 27,777 stands per hectare.

2.3.2 Field experiment

The net plot size of 1.2 m × 1.8 m, comprising of six tagged stands of eggplants, was earmarked for growth and yield data collection. Organic fertilizer, poultry manure (15 t ha^{-1}), was applied by broadcasting to the soil at two weeks before transplanting. Inorganic fertilizer, NPK 15:15:15 (120 kg ha^{-1}), was applied by ring method at 10 cm away from the base of the plants at two weeks after transplanting (WAT). Pest was controlled using a systematic pyrethroid insecticide, Fighter 35 EC (Lambda-Cyhalothrin 15 g l^{-1} + Acetamiprid 20 g l^{-1}). Foliar application at the rate of 640 ml ha^{-1} was done at two and four WAT; manual weeding (hand-hoeing and hand-rouging) was done concurrently. Manual harvesting of mature fruits was done between 65 and 95 days after transplanting (DAT) (Mahanta and Kalita, 2020). The fruits were hand-picked four times at 10 days intervals.

2.4 DATA COLLECTION

Growth and yield data were collected on the number of germinated seedlings that emerged in the screenhouse, plant height, number of fully-opened leaves per plant, number of branches (primary and secondary), leaf area according to Rivera et al. (2007), stem width, fruit load (i.e., number of mature fruits per plant), fruit volume based on water displacement method, fruit mass, and fruit yield (per plant and per hectare).

2.5 PROXIMATE ANALYSIS

Moisture, crude protein (Kjeldahl method), fat (Soxhlet method), crude fibre and ash contents of the harvested fruits (mean of the four harvests) were determined according to the standard procedures of Association of Official Analytical Chemists (AOAC) (2010). Content of carbohydrates was calculated by percentage difference between 100 % (accepted total value of nutritional status) and the sum of the moisture, fat, ash, crude protein and crude fibre (Ovenuga, 1986). Calorific value (Kcal 100 g^{-1}) was determined from crude protein, crude fat and carbohydrate values accordingly:

[(Crude protein × 4.0) + (Crude fibre × 9.0) + (Carbohydrate × 3.75)] (FAO, 2003).

2.6 DETERMINATION OF ESSENTIAL MINERALS

Analysis of essential minerals in fruit samples were performed in three replicates, and data are presented as mean ± SD. Iron was determined following the method of Pearson (1976). Phosphorus was determined by molybdate method as described by Onwuka (2005). Flame photometer was used to determine potassium by the procedure described by Osborne & Voogt (1978). Calcium (extracted by the titrimetric method with EDTA) and Zinc were determined by atomic-absorption spectrophotometry (David, 1958; David, 1959). Magnesium was determined with disodium ethylenediaminetetra-acetate (Smith & McCallcum, 1956) and sodium was determined using ion chromatography (Basta & Tabatabai, 1985).

2.7 DATA ANALYSIS

Treatments and replicates mean values of all the nursery and field data obtained were subjected to a two-way analysis of variance (ANOVA) using software GenStat 16th Edition (VSN International, 2013). Turkey's

Honest Significant Difference test (HSD) was used for significant treatment means separation at 95 % confidence limit.

3 RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 Soil physical and chemical properties

Soil properties for the two experiments are presented in Table 1. The screenhouse soil texture was sandy loam while the field had a loamy sand soil texture. Soil pH ranged from strongly acidic (4.9) to moderately acidic (5.9). Overall, screenhouse soil had higher cation-exchange capacity (CEC) and base saturation (BS) compared to the soil in the field. Both soils were suitable for the cultivation of eggplant.

3.1.2 Effects of irradiation (γ-ray) on growth of eggplants in the nursery

The effects of γ-ray radiation, eggplant variety and their interactions on seedling emergence, height and number of leaves were examined at two and four weeks after sowing (Table 2). At 2 weeks after sowing (WAS), the eggplant variety, Melina F_1 had the highest seedling emergence ($p \leq 0.05$) followed by Kotobi and African Beauty F_1 varieties. 'Kotobi' was shorter in height ($p \leq 0.05$) than 'Melina F_1' and 'African Beauty F_1'. There was no significant difference ($p > 0.05$) in the average number of leaves for the three eggplant varieties.

In general, control (no irradiation) had significantly ($p \leq 0.05$) higher effect on seedling emergence and plant height, but no significant ($p > 0.05$) influenced on the number of leaves borne by each of the eggplant varieties. Following the interaction effect, un-irradiated Melina F_1 eggplant variety had a 100 % seedling emergence while irradiated 'African Beauty F_1' had the lowest seedling emergence (31.1 %). In terms of plant height, irradiated Melina F_1 eggplant variety was the tallest (4.85 cm) and significantly ($p > 0.05$) different from irradiated 'Kotobi', the shortest (2.98 cm) eggplant variety. There was no significant difference in the number of leaves for eggplant × γ-ray interaction effect at 2 WAS. At 4 WAS, single effects of eggplant and γ-ray radiation were significant ($p \leq 0.05$) for plant height. γ-ray radiation did not lead to a significant ($p > 0.05$) variation in the number of leaves. However, the eggplant × γ-ray interaction effect showed that un-irradiated and irradiated 'Melina F_1' plants were the tallest, similar to irradiated and un-irradiated 'African Beauty F_1', but significantly different ($p > 0.05$) from irradiated 'Kotobi'. Meanwhile, the number of leaves ranged from 3.72 (irradiated 'Kotobi') to 4.78 (un-irradiated 'Melina F_1'). All other eggplant × γ-ray effects, except 'Melina F_1', were similar ($p > 0.05$) to irradiated 'Kotobi' in terms of the average number of leaves per plant at 4WAS.

3.1.3 Effects of irradiation (γ-ray) on growth of eggplants in the field

The single effects of γ-ray radiation, eggplant variety and their interactions on plant height, stem width, number of branches, number of leaves and leaf area (upper, middle and lower canopies) were assessed at ten weeks after transplanting to field (Table 3). Varietal effect was only significant ($p \leq 0.05$) for leaf area of the upper canopy while radiation effect was significant ($p \leq 0.05$) for stem width and number of branches. 'African Beauty F_1' had the largest leaves (382.85 cm^2) and was not significantly ($p > 0.05$) different from those of 'Melina F_1' (339.75 cm^2). Plants from un-irradiated eggplant seeds had thicker stems and more leaves than its counterparts from irradiated seeds. The eggplant × γ-ray interaction only had significant influence on leaf area of the upper canopy of the eggplants. The largest upper canopy leaf area was obtained from irradiated 'African Beauty F_1' (429.54 cm^2) while irradiated 'Kotobi' had the lowest upper canopy leaf area (267.77 cm^2). The general observation was that all growth traits of un-irradiated 'Melina F_1' were consistently higher than its irradiated group. A similar trend was observed for un-irradiated 'Kotobi', except for leaf area of the middle canopy where the irradiated group led with larger leaves.

3.1.4 Effects of irradiation (γ-ray) on yield of eggplants at harvests

Four harvests were made and at each of these harvests, records were taken on several yield and yield-related characters of the three eggplants varieties obtained from their irradiated and un-irradiated seeds. There were highly significant ($p \leq 0.05$) variations observed for all the characters (Table 4). Fruit load (number of mature whole fruits per plant) ranged from 5.5 ('African Beauty F_1' and 'Melina F_1') to 51.5 ('Kotobi'). Up to the third harvest, with the exception of Melina F_1, all eggplant varieties from un-irradiated seeds had either similar or higher fruit load in comparison with the irradiated group. At fourth harvest, all irradiated varieties had higher fruit load, 'African Beauty F_1' recorded its highest. Volume and mass

Table 1: Soil physical and chemical properties

	pH in H_2O	Sand	Silt	Clay	OC	TN	Available P	K^+	Ca^{2+}	Mg^{2+}	Na^+	Al^{3+}	H^+	CEC	BS
	(1:25)		($g\ kg^{-1}$)			(%)		($mg\ kg^{-1}$)				($cmol\ (+)\ kg^{-1}$)			(%)
Screenhouse	5.9	690	150	160	2.89	0.24	82.50	0.13	6.2	2.2	0.10	1.16	0.56	10.15	83.00
Field	4.9	843	54	103	1.10	0.14	23.17	0.10	1.4	1.2	0.09	0.56	1.76	5.11	54.59

Table 2: Single and interaction effects of radiation (γ-ray) and variety on growth of eggplants at two and four weeks after sowing in the nursery

	Emergence (%)	Plant Height (cm)	Number of Leaves	Plant Height (cm)	Number of Leaves
Treatment	Two Weeks After Sowing			Four Weeks After Sowing	
Eggplant					
African Beauty F_1	46.4 b	4.64 a	2.28 a	7.66 a	4.03 b
Kotobi	54.2 b	3.41 b	2.09 a	5.34 b	3.97 b
Melina F_1	77.9 a	4.67 a	2.17 a	8.33 a	4.72 a
$HSD_{0.05}$	<0.01	<0.01	0.14	<0.01	<0.01
γ-ray					
Irradiation	36.67 b	4.00 b	2.13 a	6.44 b	4.15 a
No irradiation	82.32 a	4.49 a	2.22 a	7.78 a	4.33 a
$HSD_{0.05}$	<0.01	0.03	0.25	<0.01	0.18
Eggplant × γ-ray					
Irradiated African Beauty F_1	31.1 d	4.52 a	2.22 a	7.16 ab	4.06 bc
Un-irradiated African Beauty F_1	61.7 c	4.77 a	2.33 a	8.17 ab	4.00 bc
Irradiated Kotobi	25.6 d	2.98 b	2.07 a	4.44 c	3.72 c
Un-irradiated Kotobi	82.8 b	3.84 ab	2.11 a	6.24 bc	4.22 abc
Irradiated Melina F_1	53.3 c	4.49 a	2.11 a	7.72 ab	4.67 ab
Un-irradiated Melina F_1	100.0 a	4.85 a	2.22 a	8.93 a	4.78 a
$HSD_{0.05}$	0.01	<0.01	0.92	<0.01	<0.01

$HSD_{0.05}$ = Tukey's honestly significant difference test at 95 % confidence level

Table 3: Single and interaction effects of radiation (γ-ray) and variety on growth of eggplants at ten weeks after transplanting in the field

Treatment	Plant Height (cm)	Stem Width (mm)	Number of Branches	Number of Leaves	Leaf Area (Upper Canopy) (cm²)	Leaf Area (Middle Canopy) (cm²)	Leaf Area (Bottom Canopy) (cm²)
Eggplant							
African Beauty F_1	63.72 a	17.85 a	16.26 a	42.23 a	382.85 a	300.34 a	327.08 a
Kotobi	63.00 a	16.95 a	16.51 a	44.56 a	278.65 b	241.82 a	266.44 a
Melina F_1	61.93 a	15.00 a	12.53 a	30.56 a	339.75 ab	262.79 a	256.35 a
$HSD_{0.05}$	0.94	0.11	0.12	0.14	0.02	0.24	0.19
γ-ray							
Irradiation	60.23 a	15.31 b	13.17 b	33.97 a	339.08 a	275.06 a	277.98 a
No irradiation	65.53 a	17.89 a	17.04 a	44.26 a	328.42 a	261.57 a	288.60 a
$HSD_{0.05}$	0.22	0.03	0.04	0.10	0.67	0.62	0.74
Eggplant × γ-ray							
Irradiated African Beauty F_1	65.35 a	18.02 a	12.50 a	34.46 a	429.54 a	336.85 a	324.50 a
Un-irradiated African Beauty F_1	62.08 a	17.69 a	20.02 a	50.00 a	336.15 ab	263.84 a	329.67 a
Irradiated Kotobi	56.16 a	14.38 a	15.06 a	38.43 a	267.77 b	251.25 a	256.61 a
Un-irradiated Kotobi	69.85 a	19.51 a	17.95 a	50.68 a	289.53 ab	232.38 a	276.27 a
Irradiated Melina F_1	59.19 a	13.53 a	11.94 a	29.03 a	319.93 ab	237.08 a	252.84 a
Un-irradiated Melina F_1	64.67 a	16.46 a	13.13 a	32.08 a	359.57 ab	288.50 a	259.85 a
$HSD_{0.05}$	0.28	0.14	0.29	0.65	0.01	0.21	0.98

$HSD_{0.05}$ = Tukey's honestly significant difference test at 95 % confidence level

Table 4: Effects of radiation (γ-ray) × variety × harvest interval on yield of eggplants

Treatment Combination		Fruit Load	Fruit Volume (ml^3)	Fruit Mass (g)	Fruit Yield (kg $plant^{-1}$)	Fruit Yield (t ha^{-1})
First Harvest	Irradiated African Beauty F_1	5.50 i	9.35 ab	505.05 a	2.30 cd	62.55 e
	Un-irradiated African Beauty F_1	5.50 i	8.15 d	320.05 f	1.55 e	41.72 i
	Irradiated Kotobi	23.50 d	3.85 j	17.41 r	0.42 ijkl	10.23 q
	Un-irradiated Kotobi	46.64 b	3.68 jkl	18.23 q	0.69 hi	17.91 n
	Irradiated Melina F_1	5.50 i	4.92 gh	241.72 n	1.05 f	27.83 k
	Un-irradiated Melina F_1	7.90 hi	5.31 ef	296.48 k	1.79 e	48.38 g
Second Harvest	Irradiated African Beauty F_1	5.50 i	9.25 ab	490.05 b	2.45 c	66.71 c
	Un-irradiated African Beauty F_1	5.50 i	8.85 c	450.05 d	2.15 d	58.38 f
	Irradiated Kotobi	13.30 f	3.85 j	17.22 r	0.23 l	5.05 t
	Un-irradiated Kotobi	51.50 a	3.78 jk	15.76 u	0.75 gh	19.49 m
	Irradiated Melina F_1	11.50 fg	5.05 fg	277.55 l	2.15 d	58.38 f
	Un-irradiated Melina F_1	5.50 i	4.65 hi	271.30 m	1.03 fg	27.13 l
Third Harvest	Irradiated African Beauty F_1	5.50 i	9.15 b	450.05 d	2.15 d	58.38 f
	Un-irradiated African Beauty F_1	9.50 gh	8.81 c	384.05 e	2.95 b	80.60 b
	Irradiated Kotobi	18.00 e	3.45 l	15.46 v	0.28 kl	6.30 s
	Un-irradiated Kotobi	36.83 c	3.45 l	16.12 t	0.55 hijk	13.94 p
	Irradiated Melina F_1	5.50 i	4.95 g	305.05 h	1.15 f	30.60 j
	Un-irradiated Melina F_1	11.50 fg	4.53 i	186.72 o	1.75 e	47.27 h
Fourth Harvest	Irradiated African Beauty F_1	17.50 e	8.32 d	318.38 g	4.55 a	125.05 a
	Un-irradiated African Beauty F_1	8.50 h	9.47 a	480.05 c	4.55 a	125.05 a
	Irradiated Kotobi	36.17 c	3.51 kl	16.41 s	0.58 hij	14.86 o
	Un-irradiated Kotobi	21.32 d	3.71 jkl	21.30 p	0.40 jkl	9.90 r
	Irradiated Melina F_1	11.50 fg	5.37 e	298.18 j	2.38 cd	64.63 d
	Un-irradiated Melina F_1	10.00 gh	5.52 e	303.26 i	2.15 d	58.38 f
	$HSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

$HSD_{0.05}$ = Tukey's honestly significant difference test at 95% confidence level

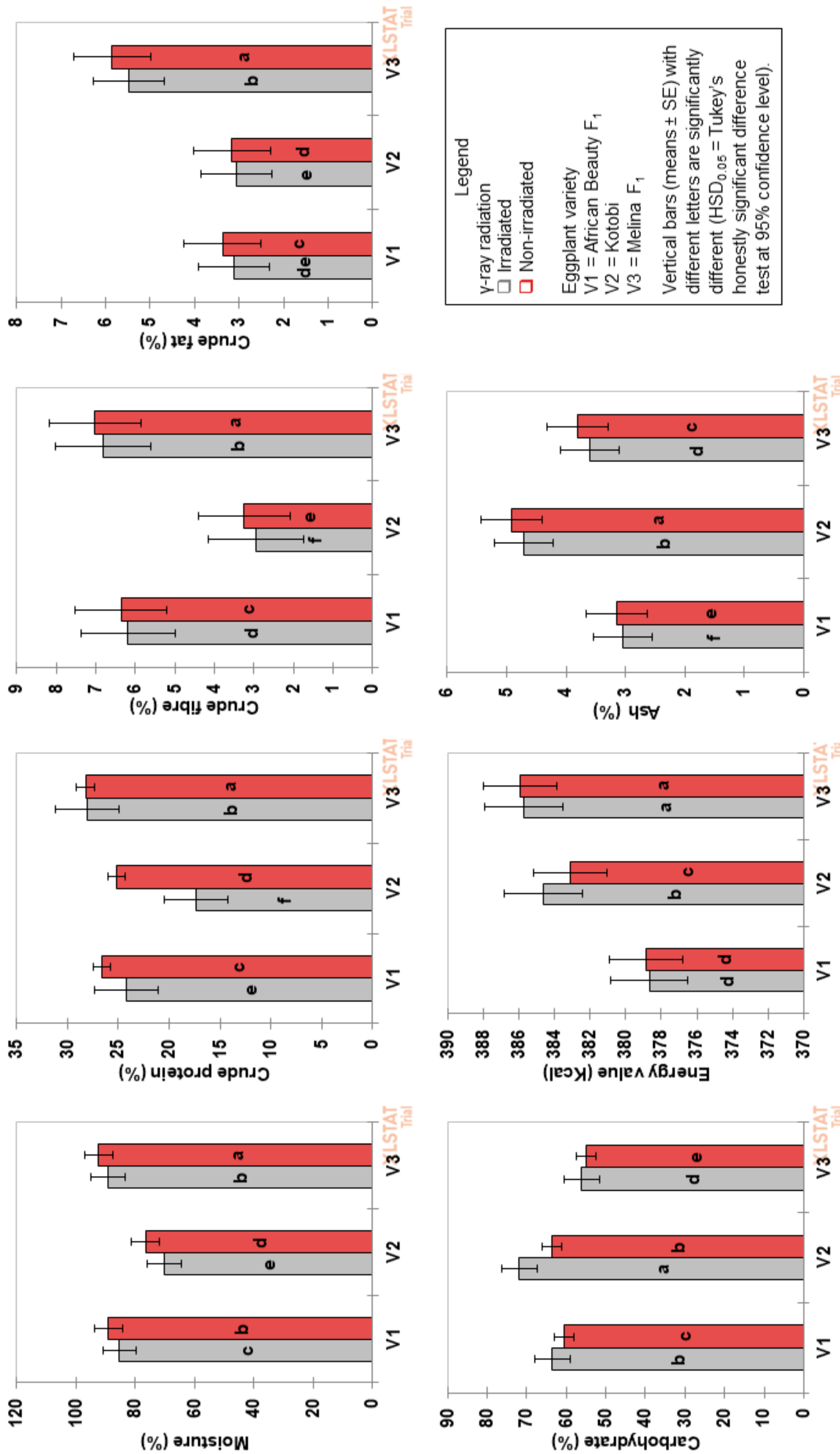

Figure 1: Comparative proximate compositions of γ-ray irradiated and un-irradiated eggplants

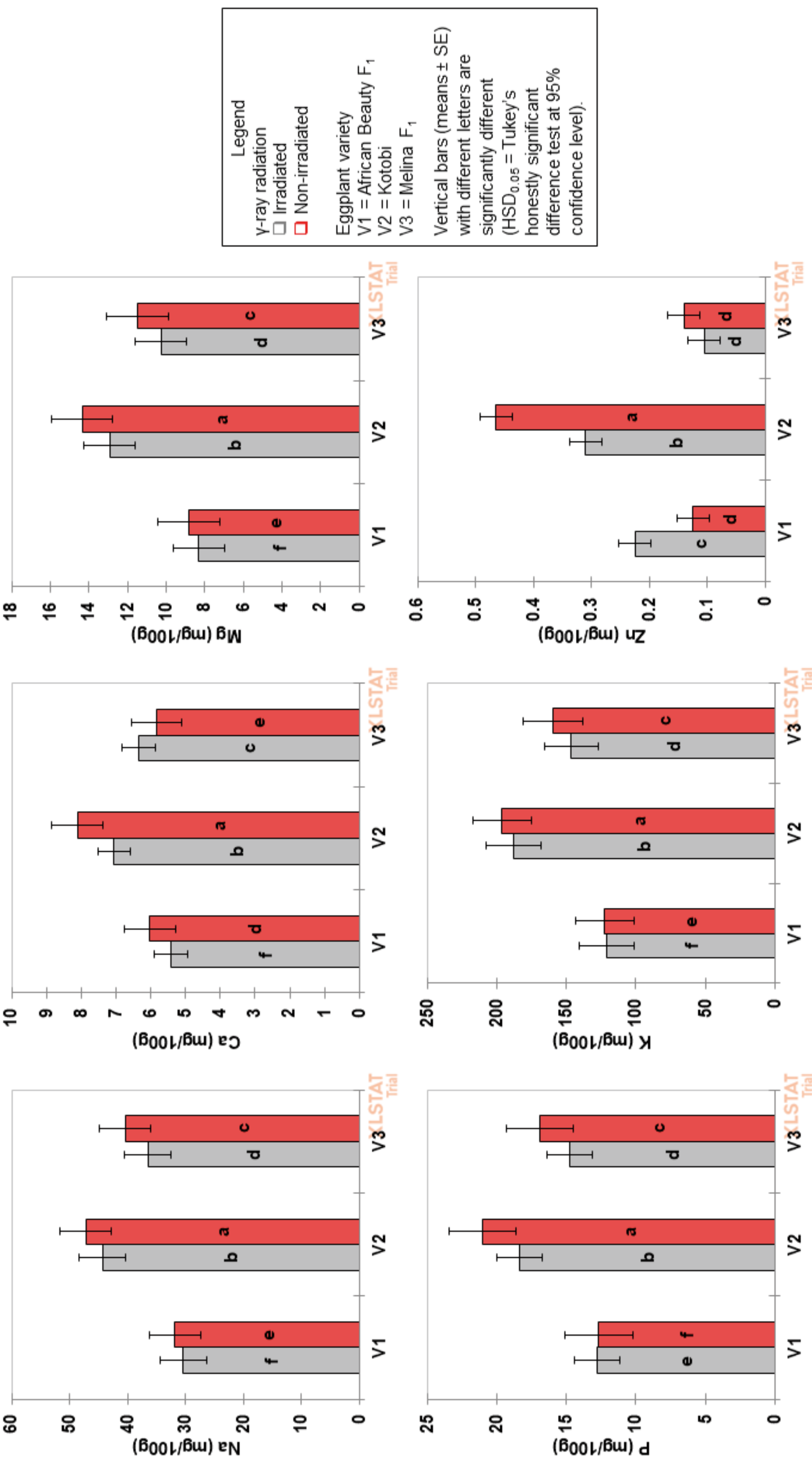

Figure 2: Comparative micronutrient profiles of γ-ray irradiated and un-irradiated eggplants

of eggplant fruits from irradiated seeds were the highest for 'African Beauty F_1' up to the third harvest. Fruits of 'Melina F_1', from both irradiated and un-irradiated seeds, were significantly ($p \le 0.05$) lighter in mass and smaller in volume than 'African Beauty F_1'. Characteristically, 'Kotobi' had higher fruit bearing attribute indicated by its high fruit load but with smaller fruit volume and lighter mass. The average fruit yield per plant ranged from 0.23 kg to 4.55 kg.

The highest fruit yield on plant basis was recorded from 'African Beauty F_1' (irradiated and un-irradiated seeds) at fourth harvest. Fruit yield (plant^{-1} and hectare^{-1}) of 'Kotobi' was generally lower than other eggplant varieties across the four harvest intervals. 'African Beauty F_1' maintained the same trend for fruit yield on per hectare basis.

3.1.5 Effects of irradiation (γ-ray) on comparative proximate composition of eggplants

Proximate analysis of freshly harvested fruits of the three eggplants varieties in our study showed that fruits obtained from plants grown from γ-ray irradiated seeds had significantly ($p \le 0.05$) lower moisture content, crude protein, crude fibre, crude fat and ash content (Figure 1). In the other hand, all eggplants fruits from un-irradiated seeds had lower carbohydrate across the three varieties. Fruits of Kotobi variety had the lowest moisture content (70–77 %) followed by African Beauty F_1 (85–89 %) and Melina F_1 (89 – 92 %). Crude protein ranged from 17 % (irradiated 'Kotobi') to 28 % (un-irradiated 'Melina F_1'). Irradiated 'Kotobi' also had the lowest crude fibre (2.95 %) and crude fat (3.06 %), but had a significantly higher carbohydrate content (71.88 %). Although un-irradiated 'Melina F_1' had the lowest carbohydrate content (55.09 %), its energy value was the highest (385.9 Kcal 100 g^{-1}) which was not significantly ($p > 0.05$) different from the un-irradiated 'Melina F_1' (385.72 Kcal 100 g^{-1}). Irradiated (378.68 Kcal 100 g^{-1}) and un-irradiated (378.88 Kcal 100 g^{-1}) fruits of 'African Beauty F_1' had the lowest energy values ($p > 0.05$). Overall, 'Kotobi' had the highest ash content (4.72–4.92 %) followed by 'Melina F_1' (3.61–3.81 %) and 'African Beauty F_1' (3.04–3.15 %).

3.1.6 Effects of irradiation (γ-ray) on macro- and micro-nutrients profile of eggplants

There were significant ($p \le 0.05$) differences among the three eggplant varieties in micronutrient profiles of fruits obtained from γ-ray irradiated and un-irradiated seeds (Figure 2). In general, un-irradiated Kotobi eggplant variety had the richest nutrient contents: sodium (47.18 mg 100 g^{-1}), calcium (8.11 mg 100 g^{-1}), magnesium (14.36 mg 100 g^{-1}), phosphorus (21.02 mg 100 g^{-1}), potassium (196.15 mg 100 g^{-1}) and zinc (0.47 mg 100 g^{-1}). With exception of zinc (varieties: Kotobi > African Beauty F_1 ≥ Melina F_1), the micronutrient profile richness followed the varietis order: Kotobi > Melina F_1 > African Beauty F_1. It was observed that Na, Mg and K contents followed the same trend in the eggplant fruits for grown from both irradiated and un-irradiated seeds.

4 DISCUSSION

The use of gamma ray irradiation on eggplant varieties has helped in recent years to induce favourable mutation and improve agronomic attributes of the crop. There are reports that gamma ray could affect the growth and yield of eggplant. Contrary to Zanzibar and Sudrajat (2016) report that gamma ray irradiation could improve seed metabolism and stimulate seed germination, our results consistently showed that seedling emergence in the nursery was however higher from un-irradiated (100 Gy) eggplant seeds of African Beauty F_1, Kotobi and Melina F_1 varieties. In comparison, Rozman (2014) found that the percentage of germination of barley (*Hordeum vulgare* L.) seeds irradiated with 100 Gy did not differ from the un-irradiated in the first year, it was significantly higher in the fifth year. Also, Suparno (2018) conducted a study on the phenotypic diversity of eggplant (*S. melongena* L.) resulting from various doses of gamma-ray irradiation (0, 100, 150 and 200 *Gy*). The results showed that gamma ray irradiation resulted in high significant differences in seedling growth, 100 Gy giving the highest percentage of seedlings emergence (77.5 %) and contrary to our report where we had a range of 31.1 to 53.3 %. However, our results on the effect of gamma ray on plant height of eggplant (14 and 28 days after planting) grown from irradiated seeds was in consonant with Suparno (2018) who reported taller plants from un-irradiated seeds (4.19–10.45 cm) over 100 Gy irradiated seeds (3.99–10.38 cm). Another study conducted by David et al. (2018) on the effects of gamma irradiation on the agromorphological traits of two eggplant (*S. aethiopicum* L.) accessions conforms with our findings which showed reductions in germination percentage (in the nursery) and plant height (nursery and field) at irradiation dose of 100 Gy when compared with plants grown from un-irradiated seeds (control). Although David et al. (2018) had reported that irradiation doses of 40 Gy and 60 Gy were appropriate in creating beneficial agronomic traits in *S. aethiopicum* L. accessions, these were not consistent between the eggplant accessions. In support of our findings, Muhammad et al. (2021) reported that the growth, development, and survival rate of Bambara groundnut (*Vigna subterranea*

(L.) Verdc.) increased with a decrease in gamma-irradiation. In our study, we also observed similar varietal differences for 'Kotobi' (*S. aethiopicum* L.) in terms of stem width, number of branches, number of leaves and leaf area at different canopy heights in the field. Eggplant fruits have high contents of carbohydrates, proteins and some minerals such as Ca, Mg, and P (Kowalski et al., 2003; El-Nemr et al., 2012) and have low calories (25 kcal 100 g^{-1}) (Aly et al., 2019). We reported higher amount of mineral composition in the un-irradiated eggplants group over the irradiated ones. Aly et al. (2019) reported that eggplant growth increased when using a dose of 50 Gy gamma rays while increasing irradiation dose level to 100 Gy reduced phenyl alanine ammonia-lyase (PAL) enzyme and polyphenol oxidase enzyme activities which influences plant growth and invariably its accumulation of some active compounds. Additionally, these enzymes could also have a role in mineral accumulation. Gamma rays are one type of ionising radiation that interact with atoms or molecules to produce free radicals in cells, according to Aly et al. (2019). These radicals can change essential constituents of plant cells. In contrast to Hussein et al. (2012) that treating seeds before sowing by gamma radiation (40–80 Gy) generally increased Na and K in growing damsisa plant (*Ambrosia maritima* L.) compared by its corresponding un-irradiated control, our Na and K contents were higher in un-irradiated eggplants. Also, our results on Ca content in fruits of plants produced from irradiated seeds (except for 'Melina F_1') was similar to Hussein et al. (2012) for Ca in *A. maritima* at fruiting even under salinity stress. It was reported that exposure of red radish (*Raphanus sativus* L.) seeds to gamma irradiation before cultivation improved the root contents of the elements (N, K, S, P, Ca, and Mg) (El-Beltagi et al., 2022). In the study, it was clear that the dose of 100 Gy had different effects on the fruit characteristics of eggplants according to the genotypes. For example, while 100 Gy increased the amount of carbohydrate and energy in 'Kotobi' genotype, Ca content increased in Melina F_1 genotype, Zn content increased in African Beauty F_1 genotype. Our research clearly shows that gamma-ray irradiation of eggplant is genotype dependent as a technique of producing variation for the generation of new genotypes. Our findings correspond with those of Ulukapi et al. (2015), who discovered inconsistencies in determining optimal gamma radiation dose in eggplant mutation breeding. The preservation, decrease, or increase in agromorphological traits, mineral and nutrient compositions of plants grown from irradiated eggplant seeds compared to the control plants made it a problematic task to clearly highlight the behaviour of eggplants in response to gamma ray irradiation. Consistent with our study, studies in different plants show that variations in growth and yield traits in response to gamma ray irradiation is dependent on the crop variety as well as the radiation dose (Rozman, 2014; Majeed et al., 2018; Aparecida Costa Nobre et al., 2022; Puripunyavanich et al., 2022; Saibari et al., 2023) and as such it is difficult to establish a standard dose for mutation breeding in eggplants.

5 CONCLUSIONS

Though variations were created, gamma ray irradiation dose of 100 Gy had inconsistent influences on the agromorphological traits and nutritional profile M_1 generation of 'African Beauty F_1' (*Solanum melongena* L.), 'Kotobi' (*Solanum aethiopicum* L.) and 'Melina F_1' (*Solanum melongena* L.) eggplant varieties. Plants grown from irradiated eggplant seeds were negatively affected in terms of the following fruit characteristics: fruit load, fruit volume, fruit mass and fruit yield compared to eggplants grown form un-irradiated seeds. These differences could be partly attributed to their genetic make-up and gamma radiation dose. Hence, either higher or lower dose of gamma ray treatment could be suggested for use in subsequent studies depending on the following: (1) eggplant genotype and (2) the goal of the mutation breeding programme in view.

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