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ANALYSIS OF GAMMA IRRADIATED POTATO GENOTYPES BASED ON SELECTED AGRONOMIC TRAITS

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ABSTRACT

The morphological traits of induced potato plants established from irradiated microtubers with Co^{60} gamma rays led to the identification of solid mutants with linear leaf shape and various chimerical mutants at the M1V1 stage. Potato breeding requires genetic variation of useful traits for crop improvement. The use of induced mutations is highly effective in enhancing genetic variability. The objectives of the study were to determine dose of mutagen and effects of induced mutation on morphological traits in potato. The study involved potato clones; Kenya Sherekea, Kenya Mpya and Asante (M1V0) improved varieties as parents. Populations of 300 potato mutants were developed by irradiation of microtubers with different dose rates (0, 3, 5, 6, 9, 10, 12, 15, 20 and 30 Gray (Gy)) of gamma rays of Co^{60} source at Seiberdorf laboratories in Vienna, Austria. The microtubers M1V0, M1V1, M1V2 and M1V3 were established at the University of Eldoret Greenhouse. Data collected on morphology observed was computed using SAS and means separated using Fisher's protected LSD at 95% significant level. The morphological traits results showed that, there were significant difference in genotypes and dose of mutagen at $p \leq 0.05$ for most traits studied. Exposure to higher doses of gamma irradiation (20 and 30 Gy) had significant influence ($p \leq 0.05$) on the stem number, number and weight of tubers. This suggest that mutation induction generates genetic variations from which desired mutants may be selected based on the needs and preferences and further assist breeders in developing appropriate breeding strategies to decipher potato production constraints.

Contribution/Originality: This study contributes to the existing literature on the application of induced mutation in generating genetic variations in potato where selections are done based on the desired traits.

1. INTRODUCTION

The cultivated potato (*Solanum tuberosum* L.) is the second most important staple food in Kenya after maize and the world's fourth major food crop after wheat, rice and maize (De Haan & Rodriguez, 2016; FAO, 2017; MoA, 2008). Potato farming in Kenya employs 3.3 million people at all levels of the value chain. Potato is grown by about 800 000 farmers on about 158 000 ha per season, with an annual production of about 1.6 million tonnes in two growing seasons. The annual potato crop is valued at KES 13 billion (USD 150 million) at farm gate level, and KES 40 billion (USD 362 million) at the consumer level (FAO, 2017; National Potato Council of Kenya (NPCK), 2014).

Potato breeding requires genetic variation of useful traits for crop improvement. Most often, desired variation is lacking due to its narrow genetic diversity and mostly grown vegetatively (tubers). The use of induced mutations creates new additional variation within the crop variety where natural genetic variation was limited and insufficient leading to desired mutants with agronomically important traits. Induced mutations have been used to generate variations to obtain desired mutants with agronomically important traits (Jain, 2005; Shu, Forster, & Nakagawa, 2012). Induced mutations have been used in the improvement of crops such as sweet potato (*Ipomea batatas* L. Poir), pineapple (*Ananas comosus* (L.) Merr), wheat (*Triticum spp.*), rice (*Oryza sativa*), barley (*Hordeum vulgare*) and cotton (*Gossypium hirsutum*) both vegetative and seed propagated among others (Ahloowalia & Maluszynski, 2001; Sleper & Poehlman, 2006).

Mutation induction a tool in plant breeding has been used to create variation to supplement and improve the limited genetic variability existing within the specific crop germplasm (Shu et al., 2012). Irradiation of plant material can result in positive or negative (lethal) change. A pre-test is necessary to prevent killing of all the planting material at various doses (radiosensitivity test). When half of the planting material survives (LD_{50}) the safe dose is noted as a reference dose (Brunner, 1995). Irradiation of planting material with suitable doses, though genetic differences could exist, can produce small effects with several important biosynthetic processes and morphological traits (Jankowicz-Cieslak, Mba, & Till, 2017; Mba, 2013). Mutation induction in potato has produced mutants with diverse characters (Al-Safadi, Ayyoubi, & Jawdat, 2000; Albiski, Najla, Sanoubar, Alkabani, & Murshed, 2012; Cieśla & Eliasson, 2002; Li et al., 2005; Muth et al., 2008). Therefore, the aim of the study was to determine the effects of induced mutation on morphological traits in potato.

2. MATERIALS AND METHODS

2.1. Mutant Population Development

Three commercial potato varieties namely; Asante, Kenya Mpya and Kenya Sherekea were obtained from Kisima farm. The three potato varieties used had various characteristics as described by National Potato Council of Kenya (NPCK) (2013); Chepkoech et al. (2018); Chepkoech et al. (2019). A total of 30 tubers each of the three potatoes were sent to the Plant Genetics and Breeding Laboratories (PGBL) at IAEA/FAO Seibersdorf laboratories in Vienna, where they were grown at the greenhouse to initiate *in vitro* shoot cultures as described by Bado et al. (2016); Chepkoech et al. (2018); Chepkoech et al. (2019).

2.2. Irradiation Methods

A radio-active cobalt-60 (Co^{60}) (gamma source) were used to induce mutations with a low dose rate of 2 gray per minute (Gy/min). The susceptibility of each potato cultivar with regard to mutation induction, optimal dosage was determined at GR_{30} and GR_{50} (30 % and 50 % growth reduction respectively) as well as LD_{30} and LD_{50} (30 % and 50 % lethality dose) for each approach as described by Owoseni et al. (2006); Mba, Afza, Bado, and Jain (2010); Kodym et al. (2012); Bado et al. (2016). Two *in-vitro* radio-sensitivity tests were developed involving different tissues for irradiation of potato mutation induction as described by Bado et al. (2016). The irradiation dose rates performed on the two *in-vitro* radio-sensitivity tests for the three potato varieties were 0, 3, 6, 9, 12 and 15 gray (Gy) for Asante, 0, 5, 6, 10 and 15 Gy for Kenya Mpya and 0, 3, 5, 10, 12, 15, 20, and 30 Gy for Kenya Sherekea according to Bado et al. (2016); Chepkoech et al. (2018); Chepkoech et al. (2019).

2.3. Establishment of M1V1 and Coding of Surviving Putative Mutants in the Greenhouse

A total of 570 mutant microtubers (M1V1) were received and established at the University of Eldoret (UoE), Biotechnology Green House Research facility on autoclaved loam sandy soil. Each mutant at M1V1 generation individual microtuber was planted on 10 × 9 mm polythene bag as described by Chepkoech et al. (2018); Chepkoech

et al. (2019). The coding of the M1V1 plants were developed based on the number of irradiated stakes that survived as described by Chepkoech et al. (2018); Chepkoech et al. (2019).

2.4. Experimental Site

The experiment was carried out at the University of Eldoret (UoE) which is at an altitude of 2153 metres above sea level (masl), latitude of 0°34'N and longitude 35°18'E. The average annual rainfall is 1295 mm with a bimodal distribution. The mean air temperature ranges from 15 to 28 °C. The soil type is rhodic ferralsol (UNESCO, 1977).

2.5. Planting of M1V2 and M1V3 Mutants in the Field

The tubers obtained at M1V1 were advanced to M1V2 and M1V3 generations of mutants by planting at the University of Eldoret research field.

2.6. Experimental Design, Layout and Planting in Field Plots

In M1V2 and M1V3 generation five tubers per plot/mutant were planted replicated 3 times in alpha lattice design. The linear model for alpha design was:

$$y_{ijtl} = \mu + g_i + r_j + \alpha_t +, \alpha(r)_{jl} + \varepsilon_{ijtl}$$

Where; y_{ijtl} represent the observations, μ is the population mean, g_i the genotypic effects, r_j the resolvable replicate effects, α_t the latinized block effects, $\alpha(r)_{jl}$ the incomplete block effects within replicates and ε_{ijtl} the random errors.The experimental area was divided into fifteen blocks where each block consisted of 11 plots. Each plot consisted of a mutant selection from a single variety and were planted in 1 × 0.6 metre (m) spacing. This setup was set in 3 replicates and the distance between replicates was 3 m. All agronomic practices were carried out according to recommended practices (Kabira, Macharia, Karanja, & Muriithi, 2006) . The M1V2 generation was established in April to July 2015 and the M1V3 generation was planted between January to May 2016.

2.7. Data Collection

Data was collected at M1V1 mutants on: the number of irradiated shoots that survived and produced tubers; this was the number of mutant plants that produced tubers in each plot divided by the control (parent) as a percentage. Plant height is the average measure in centimeters from ground to tip of the main stem for 3 randomly selected plants in each plot. Stem number; was done by counting the number of main stems in each mutant for 3 randomly selected plants in each plot. Tuber number which is the average of total count of tubers from each plant for 3 randomly selected plants in each plot. Weight per mutant**,** this was the average weight for 3 randomly selected plants in each plot and converted into tons per hectare.

Data were also collected on each of the plants in M1V2 and M1V3 mutants. Standard potato descriptors according to International Union for the Protection of New Varieties of plants (UPOV, 2004) were used to describe the potato mutant selections in M1V2 and confirmed in M1V3.

2.8. Statistical Analysis

Data on the number of irradiated shoots that survived and produced tubers at M1V1 generation, plant height, stem number, tuber number and weight per mutant was calculated as the number of micro-tuber survived to produce tubers/ number of control micro-tubers sprouted x 100 and presented in graphic form. The morphological data of M1V2 and M1V3 generations was subjected to analysis of variance (ANOVA) using SAS software. The means were compared using Fisher's Protected Least Significance Difference (FPLSD) whenever effects were significant at 95 % confidence level. Principal component analysis of the qualitative and quantitative traits was evaluated to examine the percentage contribution of each trait to total genetic variation.

3. RESULTS

The total number of irradiated potato mutants that survived during planting after irradiation treatment were far much less than half of each respective potato mutants that were initially irradiated and varied with dosage rates across the three genotypes used Figure 1. The Asante mutants at dosage 15 Gy had higher percentage survival and tuber number compared the Kenya Mpya and Kenya Sherekea mutants. The total number of irradiated Asante, Kenya Mpya and Kenya Sherekea genotypes were 230, 160 and 180 mutants respectively but the number of survived to produce M1V2 plants were 73 (Asante), 44 (Kenya Mpya) and 48 (Kenya Sherekea) mutants Figure 1.

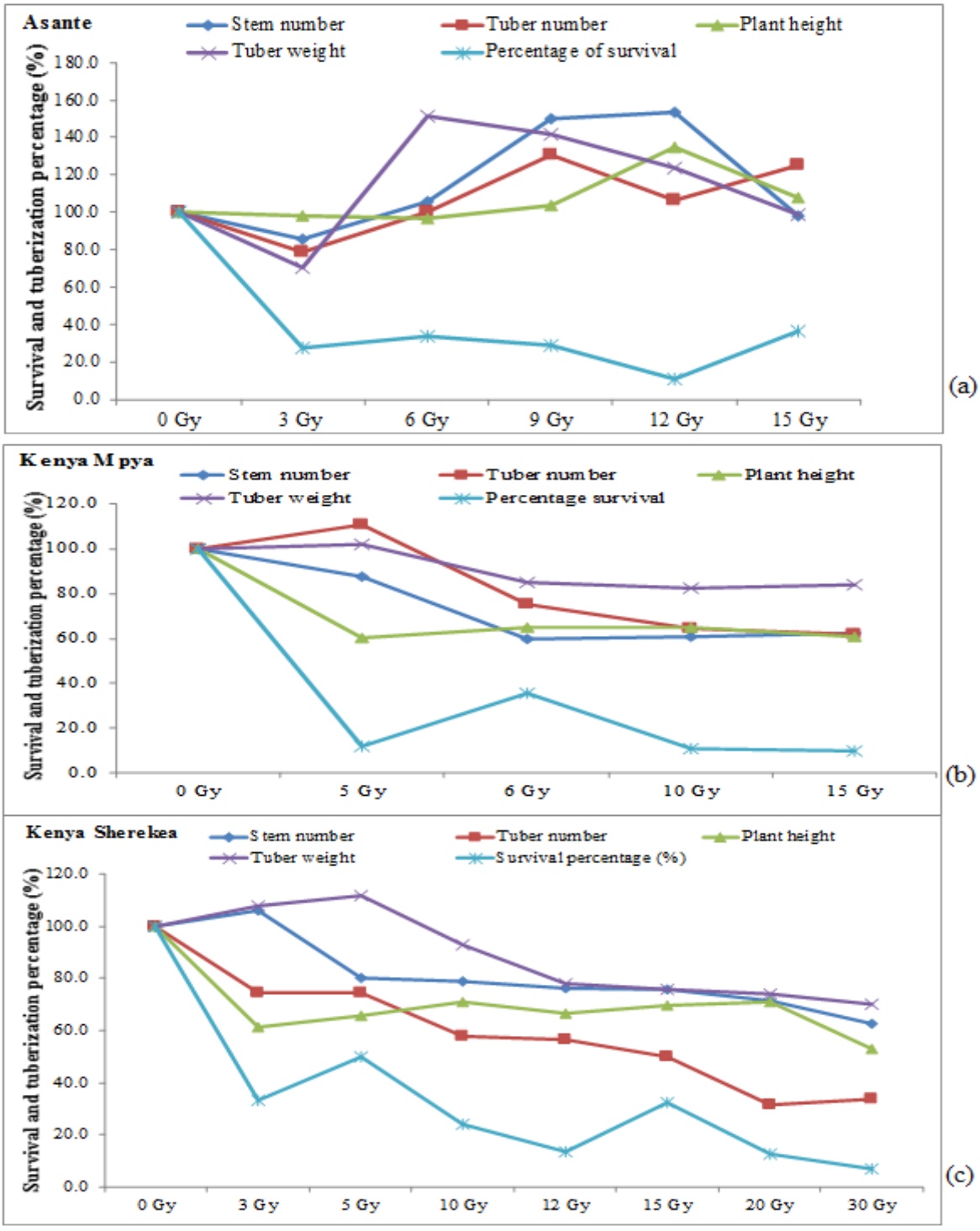

Figure 1. Effects of dosage rates on survival rate of irradiated (a) Asante, (b) Kenya Mpya and (c) Kenya Sherekea potato mutants at the first generation.

Figure 1, shows that the percentage of stem and tuber number of Asante mutants increased from 3 Gy to 9 Gy and reduced from 12 Gy to 15 Gy. The tuber number increased again at 15 Gy. The percent tuber weight was high at 6 Gy dose rate in Asante mutants. The percentage stem and tuber number, tuber weight and plant height were decreasing as the dosage rates increased in both Kenya Mpya and Kenya Sherekea mutants.

3.1. Effects of Dosage Rate on Various Agronomic Traits

The Asante mutants at M1V2 generation and M1V3 generation in Table 1 showed no significant difference between the different mean dose rates in the following traits; stem anthocyanin colouration (SAC), leaf outline openness (LOO), leaf presence of secondary leaflets (LPSL), leaf green colour (LGC) and flower corolla anthocyanin colouration (FCAC). Plant height (PH) and mean per plant tuber number (PTN) in M1V2 generation and mean plant tuber weight (PTW) in M1V3 generation were also not significantly different. There was significant difference at $p \leq 0.05$ in mean plant stem number (PSN) and mean plant tuber weight (PTW) in M1V2 generation and plant height (PH), mean plant tuber number (PTN) in M1V3 generation for the different mean dose rates Table 1.

Table 1. Effects of dosage rates on various morphological traits of Asante potato mutants at M1V2 and M1V3 generation.

Generation	Dosage (Gray)	GH	SAC	LOO	LPSL	LGC	FCAC	PH	PSN	PTN	PTW
M1V2	0	3.7a	1.7a	3.0a	4.3a	3.7a	1.0a	72.3a	6.7b	17.0a	15.7a
	3	3.1a	2.1a	3.1a	4.6a	3.6a	1.1a	79.4a	4.6ab	22.5a	19.5ab
	6	3.0a	1.7a	3.1a	5.0a	3.1a	1.1a	78.7a	2.9a	25.3a	19.8ab
	9	3.0a	1.1a	3.1a	5.0a	3.0a	1.0a	84.8a	3.8ab	20.2a	22.0b
	12	3.0a	1.7a	4.0a	5.0a	3.0a	1.0a	83.0a	6.3ab	13.3a	17.3a
	15	3.0a	1.2a	3.6a	5.0a	3.0a	1.0a	86.7	5.1ab	14.8a	20.3ab
	Grand mean	3.1	1.6	3.2	4.8	3.2	1.03	80.8	4.9	18.9	19.1
	CV %	15.3	39.3	30.3	10.1	15	9.2	30.4	38.4	37.9	16.3
	EMS	ns	ns	ns	ns	ns	ns	ns	3.2*	ns	84*
Generation	**Dosage (Gray)**	**SAC**	**LOO**	**LPSL**	**LGC**	**FCAC**	**IAC**	**PH**	**PSN**	**PTN**	**PTW**
M1V3	0	1.7a	3.0a	4.3a	3.7a	1.7a	1.0a	113b	6.7a	46.3a	67.5a
	3	2.1a	2.5a	4.6a	3.6a	1.4a	1.3a	95.5a	5.8a	55.1b	53.5a
	6	1.7a	3.1a	5.0a	3.0a	1.0a	1.1a	87.8a	5.8a	51a	53.5a
	9	1.1a	3.1a	5.0a	3.0a	1.0a	1.0a	94.6a	5.7a	55.8b	59.3a
	12	1.7a	4.0a	5.0a	3.0a	1.0a	1.0a	88.3a	6.5a	53.0a	56.9a
	15	1.3a	3.6a	5.0a	3.0a	1.0a	1.0a	99.5ab	7.0b	52.0a	57.0a
	Grand mean	1.6	3.2	4.8	3.3	1.2	1.1	96.5	6.2	52.2	58.3
	CV %	9.2	15.2	10.1	14.7	18.3	13.4	9.2	13.2	24.1	14.6
	EMS	ns	ns	ns	ns	ns	ns	3.4*	5.4*	14.3*	ns

Note: ns= not significant, *=significant at $p \leq 0.05$, Growth habit (GH), Stem anthocyanin colouration (SAC), Leaf Outline openness (LOO), Leaf presence of secondary leaflets (LPSL), Leaf green colour (LGC), Flower corolla anthocyanin colouration (FCAC), Plant height in cm (PH), Average Plant stem number (PSN), Average Plant Tuber number (PTN), Average Plant Tuber weight in t/ha (PTW). Error mean squares (EMS), Coefficient of variation (CV), within each column, means having the same letters are not significantly different at $p \leq 0.05$.

In Table 2 Kenya Mpya mutants did not show significant difference between the different dose rates for leaf outline openness, leaf green colour, flower corolla anthocyanin colouration, plant height and plant tuber weight in t/ha. While growth habit, leaf anthocyanin colour midrib of upperside, in M1V2 generation and potato tuber number in M1V3 generation also did not differ significantly between the different mean dose rates. In M1V2 generation stem anthocyanin colouration and potato tuber number differed significantly a $p \leq 0.05$ while plant height, growth habit, stem anthocyanin colouration, leaf presence of secondary leaflets, leaf anthocyanin colour midrib of upperside and potato tuber number differed significantly in M1V3 generation.

The Kenya Sherekea mutants exposed to different dose rates at M1V2 generation and M1V3 generation Table 3 showed significant difference at $p \leq 0.05$ for leaf outline openness and plant tuber number and plant tuber weight (M1V3 generation) and at $p \leq 0.01$ for plant height and plant tuber weight (M1V2 generation). Most of the qualitative traits did not differ significantly among the different mean dose rates of this mutant.

Table 2. Effects of dose rates on various morphological traits of Kenya Mpya potato mutants at M1V2 and M1V3 generation.

Generation	Dosage (Gray)	GH	SAC	LOO	LPSL	LGC	LACM	FCAC	PH	PSN	PTN	PTW
M1V2	0	2.3a	3.0b	4.7a	4.3a	3.7a	3.0b	4.7a	79.3a	3.7a	27.7a	27.7a
	5	3.0a	1.0a	4.8a	5.0a	3.3a	1.3a	5.0a	73.8a	3.8a	34.0b	30.8a
	6	3.0a	1.0a	5.0a	5.0a	3.0a	1.0a	5.0a	81.1a	3.3a	30.3a	30.0a
	10	3.0a	1.0a	5.0a	5.0a	3.0a	1.0a	5.0a	73.5a	3.0a	31.7a	30.0a
	15	3.0a	1.0a	5.0a	5.0a	3.0a	1.0a	5.0a	84.7a	3.2a	21.7a	31.0a
	Grand mean	2.9	1.4	4.9	4.9	3.2	1.5	5.49	78.5	3.4	29.1	30
	CV %	18	11.5	6.2	10.6	18.9	9.7	5.2	9.1	13.7	16.5	12.9
	EMS	ns	0.7*	ns	ns	ns	ns	5.7s	ns	ns	7.3*	ns
Generation	**Dosage (Gray)**	**GH**	**SAC**	**LOO**	**LPSL**	**LGC**	**LACM**	**FCAC**	**PH**	**PSN**	**PTN**	**PTW**
M1V2	0	1.7a	5.0b	4.7a	3.7a	3.7a	3.0b	4.6a	82.0b	5.0a	38.0b	43.1a
	5	3.0b	1.0a	4.7a	5.0a	3.3	1.3a	5.0a	68.7a	4.0a	33.7a	36.9a
	6	3.0b	1.0a	5.0a	5.0a	3.0a	1.0a	5.0a	70.3a	5.7a	34.0a	37.2a
	10	3.0b	1.0a	5.0a	5.0a	3.0a	1.0a	5.0a	88.3b	3.0a	21.3a	31.6a
	15	3.0b	1.0a	5.0a	5.0a	3.0a	1.0a	5.0a	88.0b	5.3a	33.7a	46.8a
	Grand mean	2.7	1.8	4.9	4.6	3.2	1.5	4.9	79.5	4.6	31.9	39.1
	CV %	18.9	6.1	6.9	10.9	18.9	9.7	5.2	17.2	17.8	16.7	24.3
	EMS	0.3*	2.4*	ns	0.3*	ns	0.8*	ns	1.2*	ns	0.2*	ns

Note: ns= not significant, *=significant at $p \leq 0.05$, Gray (Gy), Growth habit (GH), Stem anthocyanin colouration (SAC), Leaf Outline openness (LOO), Leaf presence of secondary leaflets (LPSL), Leaf green colour (LGC), Leaf anthocyanin colour midrib of upperside (LACM), Flower corolla anthocyanin colouration (FCAC), Plant height in cm (PH), Plant stem number (PSN), Plant Tuber number (PTN), Plant Tuber weight (PTW). Error mean squares (EMS), Coefficient of variation (CV), within each column, means having the same letters are not significantly different at $p \leq 0.05$.

Table 3. Effects of dose rates on various morphological traits of Kenya Sherekea potato mutants at M1V2 and M1V3 generation.

Generation	M1V2				M1V3			
Dosage (Gray)	**LOO**	**PH**	**PTN**	**PTW**	**LOO**	**PH**	**PTN**	**PTW**
0	3.4ab	97.7cd	55.3b	40.9bc	3.6ab	94/7bcd	51.3bc	38.4abc
3	3.8b	89.8bc	58.6b	41.1bc	3.8b	89.8bc	58.6c	37.6abc
5	3.6ab	85.4ab	59.0b	43.1bc	3.5ab	82.1ab	52.1bc	46.3bc
10	3.4ab	95.3bcd	54.0b	48.4c	3.4ab	92.3bcd	54.0c	49.0c
12	3.6ab	86.0abc	39.3a	38.7b	3.6ab	86.0abc	39.3ab	33.4ab
15	3.4ab	95.7bcd	49.6ab	39.3b	3.8b	95/7cd	49.6abc	41.8abc
20	3.7ab	102.5d	48.3ab	42.2bc	3.8b	103.8d	48.3abc	44.9abc
30	3.0a	74.7a	38.9a	22.6a	3.0a	74.7a	36.4a	30.0a
Grand mean	3.5	90.9	50.4	39.5	3.5	89.9	48.7	40.1
CV %	11.5	7.7	13.2	12.9	10.6	8.6	15.7	22.7
EMS	1.5*	40**	6.7*	1234**	0.14*	59.6**	58.4*	718*

Note: *=significant at $p \leq 0.05$, **=significant at $p \leq 0.01$, Gray (Gy), Leaf Outline openness (LOO), Plant height (PH), Average Plant Tuber number (PTN), Average Plant Tuber weight (PTW). Error mean squares (EMS), Coefficient of variation (CV), within each column, means having the same letters are not significantly different at $p \leq 0.05$.

3.2. Principal Component Analysis

The principal component analysis (PCA) in Table 4 showed that the quantitative traits had higher percentage of total variation compared to qualitative traits in all the three potato mutants in the two generations. The total percentage variation for the first three PC at M1V2 generation for both qualitative and quantitative traits accounted for 92.14 and 97.92 %, 90.76 and 99.96 %, 88.06 and 95.98 % in Asante, Kenya Mpya and Kenya Sherekea respectively.

Table 4. Principal component analysis of Asante, Kenya Mpya and Kenya Sherekea potato mutants for M1V2 and M1V3 generations showing the qualitative and quantitative traits contribution to the total percentage (%) variation.

Generations		M1V2		M1V3	
Mutants	**PCA**	**Qualitative %**	**Quantitative %**	**Qualitative %**	**Quantitative %**
Asante	1	74.23	82.01	67.12	84.67
	2	12.54	10.54	18.41	11.21
	3	5.37	5.37	3.41	0.11
	Total	92.14	97.92	88.94	95.99
Kenya Mpya	1	72.64	81.44	72.41	76.41
	2	14.2	17.23	12.2	18.2
	3	3.92	1.29	4.36	1.36
	Total	90.76	99.96	88.97	95.97
Kenya Sherekea	1	70.56	80.33	72.54	78.68
	2	15.12	12.32	5.15	9.87
	3	2.38	3.33	0.28	2.11
	Total	88.06	95.98	77.97	90.66
All mutants	1	71.54	78.56	70.3	74.56
	2	13.41	11.15	11.41	9.15
	3	2.24	4.28	1.66	4.28
	Total	87.19	93.99	83.37	87.99

The total percentage variation at M1V3 generation for both qualitative and quantitative traits accounted for 88.94 and 95.99 %, 88.97 and 95.97 %, 77.97 and 90.66 % in Asante, Kenya Mpya and Kenya Sherekea respectively Table 4. The traits that did not contribute to the variation are inflorescence anthocyanin colouration in Kenya Mpya, flower corolla anthocyanin colouration and leaf anthocyanin colour midrib of upperside in Asante and Kenya Sherekea and stem anthocyanin colouration in Kenya Sherekea mutants.

4. DISCUSSION

The study showed that the parents (M1V0) were significantly different from the mutants in terms of stem number (M1V1) and plant height (M1V2) in Asante mutants and stem anthocyanin colouration, leaf anthocyanin colour midrib of upperside, growth habit, plant height and tuber number in Kenya Mpya mutants. This demonstrates that induced mutations are highly effective in enhancing natural genetic resources and efficient tool to rectify or amend certain characters without altering other traits of the crop plants (Mba, 2013). Induced mutation has been used successfully to develop improved cultivars in cereals, fruits, Dolichos and other crops (Kamau, Kinyua, Kiplagat, & Gohole, 2011; Kinyua, Maluszynski, & Karanja, 2000; Kinyua, 2014; Kumar, Ghawade, & Shivaputra, 2018; Ulukapi & Nasircilar, 2015). The study showed that the total number of potato tubers that survived to produce tubers at the first generation was lower (approximately 50 % of irradiated) compared to the total (original) number of microtubers that were initially irradiated. The high mortality rates observed on potato mutant plants after transplanting in the glasshouse could be as a result of poor adaptability, effects of irradiation or environmental conditions (temperature). This results agrees with those of Malebana (2014) who observed uniform death on Monate mutant sweetpotato plants after transplanting the plantlets in the glasshouse from both single and re-irradiated treatments. Similarly, Kumar et al. (2018) in dolichos reported increased mortality at M1 generation with increasing doses of gamma radiations.

The findings also showed that the survival and tuberization rate of M1V1 was much lower than that of M1V2 plants. The low survival rate and decreased vigour of M1V1 plants could be because they were directly acquired from minitubers exposed to acute irradiation and the lingering effects of the genotypes. This might have suppressed the enzymatic activity and membrane integrity minitubers leading to reduced metabolic activity and failure of germination and tuberization. The induced M1V1 plants that survived the irradiation effects gave rise to induced M1V2 plants and were advanced to subsequent generations. The higher survival rate of M1V2 plants is because they had already stabilized and selection had favoured them. This finding agrees with the observations made by Bado et al. (2016) and Ahloowalia (1994) in their research on the effects of irradiation on tuberization capacity.

The Asante mutants showed increased tuberization parameters (plant height, tuber weight, stem and tuber number) as the dosage rates increased from 3 Gy to 12 Gy and decreased at 15 Gy except tuber number at 12 and 15 Gy compared to Kenya Mpya and Kenya Sherekea mutants that were at a decreasing rate. The variation in response of potato genotypes to increasing gamma dose rates could be due to the sensitivity (Kenya Mpya and Kenya Sherekea) or persistence of the genotypes to irradiation methods used which affects plant growth and development. Higher doses of radiation can cause chromosomal damage in plant meristematic cells, cell cycle deceleration and mitotic delay, which might have brought down the rate of cell division, hence considerably influence general plant regeneration and development. Similar trends were observed in *Crossandra infundibuliformis* var. Danica (Hewawasam, Bandara, & Aberathne, 2004) potato (Bado et al., 2016; Yaycili & Alikamanoğlu, 2012) and dolichos (Kumar et al., 2018).

Regarding the relationship between the gamma ray's dosage and morphological traits, it was found that relatively low doses of gamma irradiation (3 to 9 Gy) had a positive effect in plant height, plant tuber number and plant tuber weight in all the three mutant populations at M1V2 and M1V3 generations. This is consistent with the observations made by Li et al. (2005) and Roy, Gruel, and Vaurijoux (2009) whose reports indicated that low doses of gamma irradiation stimulate plant growth through enhanced physiological activity. Bado et al. (2016) reported that low dose gamma irradiation (3 and 6 Gy) increased tuberization rate of potato cultivars; BP1, Mpya, Mondial, and Basotho Pink *in vitro*. Other studies on different potato genotypes have also shown that gamma irradiation stimulated micro-tuber induction (Al-Safadi et al., 2000; Al-Safadi & Arabi, 2003; Mahfouze, Esmael, & Mohasseb, 2012).

At relatively higher doses of gamma irradiation, (6 to 15 Gy for Asante and 10 to 30 Gy Kenya Sherekea mutants), there was an observed decline in the trends of stem number, tuber weight and tuber number with increased dosage. This can be attributed to the inhibitory effect of gamma radiation on physiological and physical properties that lead to reduced cell division and elongation of the plant. Reports by other researchers indicate the higher gamma irradiation can cause chromosomal damage in plants and therefore have significant effects on plant development (Bado et al., 2016; Yaycili & Alikamanoğlu, 2012). Abdul, Khan, Habib, and Zahir (2010) working with yams reported a decline in stem number with increasing doses of gamma irradiation. Similar trends were observed by Ellyfa, Ahmed, Shaharudin, and Abdul Rahman (2007) in snap bean, Khan and Goyal (2009) green beans, Gnanamurthy and Dhanavel (2014) cowpea and Anchalee (2011) Wishbone Flower (*Torenia fournieri*).

The potato mutants showed significant differences in stem number (Asante), stem anthocyanin colouration and tuber number (Kenya Mpya) and leaf outline openness, plant height, tuber number and tuber weight (Kenya Sherekea) mutants at M1V2 and M1V3 generation. The genetic variation observed within genotypes and generations may be due the effects of mutation induction on the physical and biochemical tissue contents such as DNA size, water content, DNA content, nuclear volume. Various reports showed that different genotypes of the same crop respond differently to different irradiation dosages due to genotypic effects (Owoseni et al., 2006). Several authors have reported variation in yield contributing traits due to different doses of mutagens used in different crops such as green gram (Khan & Wani, 2006) sweet potato (Shin et al., 2011) and African wrinkled pepper (*Capsicum annuum* var *abbreviatum* Fingerh) (Falusi, Daudu, Thomas, Mohammed, & Muhammad, 2013).

The first principal component analysis was effective in discrimination of potato mutants as it showed positive correlation in most of the traits studied. The highest correlation value of plant tuber weight (0.9) across the three mutants and generations indicated that the trait was the most reliable for phenotypic discrimination of the accessions under study. The first PCA across all the mutants contributed more than 60 % variation and can be interpreted to mean the reliability in discrimination based on the trait that contributed more to the variation.

5. CONCLUSION

This study aimed at investigating the relationship between the dosage rates and the agronomic traits of the potato mutants can be concluded that the optimum dosage rates are 9 Gy in Asante mutants, 15 Gy in Kenya Mpya mutants and 10 Gy in Kenya Sherekea mutants at M1V2 and M1V3 generation with respect to tuber weight.

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