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SYNERGISTIC HORMESIS OF COMBINED GAMMA RAYS DOSES AND COLCHICINE CONCENTRATIONS IN DESIGNING HIGH YIELDING GENOTYPES OF FONIO (*DIGITARIA EXILIS* [KIPPIST] STAPF.)

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ABSTRACT

A research was conducted to study the synergistic hormesis of low dose of gamma rays in combination with low colchicine concentration in developing high yielding fonio (Digitaria exilis) genotypes with good seeds quality and high genetic variability. Seeds of five different accessions of fonio were irradiated with four different doses of gamma rays (100 Gy, 200 Gy, 400 Gy and 500 Gy) and then treated with four corresponding colchicine concentrations (0.1 mM, 0.5 mM, 1.0 mM and 2.0 mM). The experiment was conducted during 2014 to 2017 wet seasons and was laid out in Randomized Completely Block Design with three replications for four generations. The result obtained from the M_4 generation revealed highly significant difference ($P \leq 0.01$) in the effects of different treatments for all the selected agronomic traits of fonio indicating the presence of induced variability among the accessions. The result revealed that, the synergistic effect of low gamma rays and colchicine doses developed early maturing high yielding genotypes of fonio with larger grain sizes and high genetic variability. The LD_{50} value was genotype dependent and was fixed at 137 Gy+mM. The results for the estimation of genetic parameters revealed higher PCV and GCV values and that PCV values were slightly greater than GCV values for all the traits studied. However, moderate to high heritability among the mutants' traits indicates that the traits are primarily under genetic control. While, the predominance of moderate heritability estimates and high GAM in most of the traits revealed additive gene effects induced by the mutagens in controlling such traits indicating that selection for improvement might be effective.

Key words: Colchicine, fonio, gamma rays, hormesis

INTRODUCTION

Fonio (*Digitaria exilis* [Kippist] Stapf.) is popularly known as Acha (Jideani, 1999; Gyang and Wuyep, 2005). It is one of the world's fastest maturing cereals producing grains just 42 to 56 days after sowing for the extra early genotypes (Ibrahim, 2001). The late genotypes take up to 150 days to grow (CIRAD, 2004). Fonio is grown in commercial quantity in various parts of Nigeria (Maji *et al.*, 2005; Chukwu and Abdulkadir, 2008). It is a rich source of energy and the best tasting and nutritious of all grains (Vietmeyer *et al.*, 1996). Fonio grains are rich in methionine and cystine; which are the two vital amino acids almost deficient in sorghum, rice, wheat or barley (Barikmo and Ouattara, 2004). It is a useful diet for diabetic patients (Balde *et al.*, 2008;

Jideani and Jideani, 2011) due to its low carbohydrate contents and for delivering women due to its anti-clotting potential after delivery (Adoukonou-Sagbaja *et al*., 2006). Its porridge is also recommended for breast-feeding women to stimulate milk production (Vodouhe *et al*., 2003).

Despite the nutraceutical and pharmaceutical importance of fonio, it is still unimproved and its cultivation is not beyond subsistence level in Nigeria (Philip, 2011) due to low yields (Dachi and Barko, 2003; Maji *et al*., 2003; Ukwungwu *et al*., 2003; Kuta *et al*., 2005) and very small grain size of about 0.4–0.5 mm (Sulaiman *et al*., 2015). Research efforts to improve fonio are still at a low level. In consequence, the crop remains primitive facing diverse agronomical and technological problems; to the extent that, fonio cultivation relies only on traditional landraces which are, despites their adaptability to marginal farming system are less productive (Vietmeyer *et al*., 1996). Lack of information on the inheritance of agronomic traits also makes fonio germplasm analyses to depend on phenotypic traits that could easily be influence by the environment. Most of the researches (Aliero, 2000; Olorunmaiye and Aliero, 2000; Aliero and Morakinyo, 2001; Aliero and Morakinyo, 2005) were centered upon germplasm collection and morpho-agronomic characterization with the objective of broadening the crop gene pool. In order to bring fonio to prominence, extensive researches are needed to provide adequate information that can support and revive its mass cultivation (Philip and Isaac, 2012). This indicates the need to enhance the productivity of this crop by developing high yielding genotypes with larger grain size and high genetic variability possessing good grain quality. Induced mutagenesis is one of the tools used to enhance genetic variability in crops and facilitate development of improved varieties at a faster rate (Maluszynski, 1990). However, most studies have been conducted and designed to evaluate the biological response to high doses of radiation, while in relatively few studies have used low doses to stimulate physiological processes although the ionizing radiation hormesis has been widely supported (Luckey, 1980). Hormesis, which is the excitation or stimulation by small doses of any agent in any system (Luckey, 2003) has been well documented as beneficial in the improvement of plant species of agricultural importance (Zaka *et al*., 2004; Kim *et al*., 2005). Although little is known about the basic nature of this phenomenon, Vaiserman (2010) had indicated the possible correlation between the hormesis and epigenetic effects. The application of low-dose ionizing radiation produce in coniferous species hormetics radio-stimulants effects through genetic and epigenetic changes that manifest as adaptive responses (Iglesias-Andreu *et al*., 2015). Therefore, this study aimed at designing high yielding genotypes of fonio using synergistic hormesis of gamma rays and colchicine.

MATERIALS AND METHODS

The research was conducted at the Botanical Garden of the Department of Botany, Ahmadu Bello University, Zaria (Lat 11^o 11$'$ N; Long 7^o 38$'$E) during 2014 to 2017 wet seasons.

Treatment and experimental design

Seeds of five fonio accessions: Dinat, Jakah, Jiw 1, Jiw 2 and Nkpowas were obtained from the National Cereal Research Institute, Badeggi, Niger State, Nigeria. The seeds were first exposed to ^{60}Co gamma rays at four different doses (100 Gy, 200 Gy, 400 Gy and 500 Gy) at the Plant Breeding and Molecular Biology Laboratory, International Atomic Energy Agency (IAEA), Vienna, Austria. The irradiated seeds were then soaked in four corresponding colchicine concentrations (0.1mM, 0.5mM, 1.0mM and 2.0mM) for four hours after which the treated seeds were washed thoroughly in running tap water, allowed to dry over-night on Whatman No 1. filter paper at 27 ^{o}C. The control was soaked in distilled water. The treated seeds of all the accessions were sown along with respective controls to rise the M_1 generation. The field was laid out in a Randomized Completely Block Design (RCBD) with three replications and plots were spaced 10 m x 5 m. The seeds were sown at 20 cm intra row and 40 cm inter row spacing. All the recommended agronomic and cultural practices such as sowing, fertilizer application, weeding and thinning as well as harvesting were carried out according to the procedures described by National Agricultural Extension Research and Liason Services (NAERLS) Crops Production Guide (2012) for millets.

Seeds harvested from individual M_1 plants were advanced to M_4 generation via M_2 and M_3 generations. Ten progenies from each accession in each replication of the M_2 generation which showed significant deviation in mean values for tiller number, number of spikes, spikes length and number of seeds/spikelets in the positive direction from the mean values of control were selected as described by Singh (2011), Wani *et al*. (2013) and Chahal and Gosal (2014). Combined Lethal dose and concentration were determined for each treatment in the first mutant generation from random selection of mutants.

Data analyses

Multivariate Analysis of variance (MANOVA) was used to analyze quantitative traits using SAS (2008) Version 9.1 with Duncan's multiple range tests (DMRT) used to separate the significant means. Probit analysis (Finney, 1978) was carried out to determine the lethal dose (LD_{50}) and lethal concentration (LC_{50}). The Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were estimated as described by Syukur *et al*. (2012):

$$\sigma^2_G = [(MSG) - (MSE)] / r$$
$$\sigma^2_P = [\sigma^2_G + (\sigma^2E/r)].$$

Where: σ^2_G = Genotypic variance; σ^2_P = Phenotypic variance; σ^2E = environmental variance (error mean square from the analysis of variance); MSG = mean square of genotypes; MSE = error mean square; r = number of replications.

$$GCV\ (\%) = \frac{\sqrt{(\sigma^2_G)}}{x} \times 100$$
$$PCV\ (\%) = \frac{\sqrt{(\sigma^2_P)}}{x} \times 100$$

Where: σ^2_G = Genotypic variance; σ^2_P = Phenotypic variance; x is grand mean of a character. The Broad Sense Heritability (H^2), Genetic Advance (GA) and Genetic Advance as percent of the Mean (GAM) were estimated according to the formula described by Singh and Choudhury (1985).

$$H^2\ (\%) = \frac{\sigma^2_G}{\sigma^2_P} \times 100$$
$$GA = k\sigma_P H^2$$

Where k is the selection differential in standard units in the present study and it was 2.06 at 5% level of selection, σ_P is standard deviation of the phenotypic variance and H^2 is Broad sense heritability. Genetic advance expressed as percentage of mean (GAM) was measured by the following formula:

$$GAM\ (\%) = \frac{GA}{x} \times 100$$

RESULTS

The result for the synergistic effects of different combinations of gamma rays and colchicines on individual accessions of fonio in the M_4 generation is presented in Table 1. The result showed highly significant differences ($P \leq 0.01$) in the effects of the synergistic hormesis in all the accessions for all the traits (except in plant height). It was shown that, the synergistic combinations of low gamma rays doses and colchicines concentrations produced mutants with higher germination rates of 57.66% in Jiw 1 to as high as 66.66% in Jakah. The synergistic hormesis developed mutants with high number of leaves (5-6 leaves) that were larger in size (11.70-12.80 cm^2). The mutants developed by the synergistic hormesis produced high number of tillers (7-12 tillers) with higher number of spikes (4-5 spikes) that were longer in size (9.46-10.00 cm) and which produced high number of seeds (107-112 seeds/spikelets). The mutants' seeds were larger in diameter (1.07-1.16 mm) and weighed However, the result for the synergistic effects of different combinations of gamma rays and colchicine on M_4 generation of fonio is presented in Table 2. The result showed that a combination of lower dose of gamma rays with lower colchicine concentration (100 Gy+0.1 mM) produced mutants with highest mean values in almost all the selected traits except plant height at maturity. The mutants showed 63.86% germination after two weeks of sowing. The mutants attained height of 70.66 cm at maturity. The mutants also produced 5 leaves that were 12.32 cm^2 in size, produced 10 tillers that possess 5 spikes that were 9.74 cm long and which bear 116seeds/spikelet. The 1000 seeds of the mutants weighed 0.62 g with diameter of 1.12 mm and attained maturity 97 days after sowing. More so, the result for the lethal dose and concentration of the mutagens is presented in Table 3. The result showed that, the lethal dose and concentration of gamma rays and colchicine were fixed between the ranges of 137 Gy+mM in accession Jiw 2 to 182 Gy+mM in accession Jakah.

Result for the genetic parameters estimates induced by a combination of different gamma rays doses with various colchicine concentrations is presented in Table 4. The result showed that the GCV values are slightly lower than the PCV values for all the traits studied. Moderate to high GCV and PCV values were found in terms of germination percents, leaf number and size, number of tillers and spikes, spikes length and number of seeds/spikelet. The highest GCV and PCV values were found among 500 Gy+2.0 mM treated mutants. However, the heritability values were found to be higher (>60%) among the mutants in all the traits studied. More so, the highest heritability values (>60%) were found among 100Gy+0.1mM treated mutants in terms of number of leaves (94.01%), number of tillers (79.04%), spikes length (78.75%) and number of seeds/spikelet (78.42%). The genetic advance and Genetic Advance as percent of the Means values were found to be higher (>20) among the mutants in all the traits studied.

DISCUSSION

Artificial induction of mutation through the synergistic hormesis in fonio using physical and chemical mutagens had proved vital in the cultivars improvement. The high rate of germination induced by synergy of low doses of gamma rays and colchicine in fonio revealed the significance of the two mutagens in stimulating germination process at low doses. This is in line with the findings of Hemavathy (2015) who reported decreased germination rate of mung bean (*Vigna radiata*).

Table 1: M_4 Generation effect of combined gamma rays and colchicine concentrations on agronomic traits of fonio accessions

Accession	Dose+ Concentration (Gy+mM)	% Germination (2WAS)	Height at Maturity (cm)	Number of Leaves	Leaf Area (cm^2)	Number of Tillers	Number of Spikes	Spikes Length (cm)	Number of Seeds/Spikelets	1000 Seeds Weight (g)	Seeds Diameter (mm)	Days to Maturity
Dinat	0	61.00^{c*1}	73.65^{a}	3.66^{d}	4.63^{d}	5.67^{c}	3.00^{d}	7.90^{d}	71.67^{d}	0.58^{c}	0.90^{d}	125.66^{a}
	100+0.1	65.00^{b}	69.33^{b}	5.67^{a}	12.07^{a}	7.33^{a}	4.33^{a}	9.46^{a}	109.00^{a}	0.62^{a}	1.14^{a}	97.00^{e}
	200+0.5	66.67^{a}	67.00^{c}	4.67^{b}	10.80^{b}	6.33^{b}	3.67^{b}	9.07^{b}	105.67^{b}	0.60^{a}	1.03^{c}	98.67^{d}
	400+1.0	55.00^{d}	67.33^{c}	4.00^{c}	9.63^{c}	6.00^{b}	3.33^{c}	8.27^{c}	86.33^{c}	0.60^{a}	1.05^{b}	99.33^{c}
	500+2.0	51.00^{e}	58.67^{d}	3.00^{e}	9.10^{c}	4.33^{d}	3.33^{c}	6.63^{e}	52.33^{e}	0.59^{b}	0.91^{d}	100.67^{b}
	Means	59.73	67.20	4.20	9.25	5.93	3.33	8.27	85.00	0.60	1.01	104.27
Jakah	0	53.54^{d}	73.67^{a}	3.66^{d}	7.36^{d}	4.67^{d}	2.66^{c}	7.23^{d}	70.66^{d}	0.58^{d}	0.90^{e}	122.00^{a}
	100+0.1	66.66^{a}	72.66^{b}	5.00^{a}	12.33^{a}	9.40^{a}	4.67^{a}	10.00^{a}	112.33^{b}	0.62^{a}	1.14^{a}	96.33^{e}
	200+0.5	63.00^{b}	70.33^{c}	4.33^{b}	11.16^{b}	7.33^{b}	4.33^{b}	9.36^{b}	118.00^{a}	0.61^{b}	1.09^{b}	98.67^{d}
	400+1.0	57.00^{c}	64.67^{d}	4.00^{c}	8.33^{c}	5.00^{c}	2.67^{c}	7.80^{c}	87.66^{c}	0.59^{c}	1.05^{c}	105.00^{c}
	500+2.0	46.33^{e}	65.66^{d}	3.00^{e}	6.60^{e}	4.00^{e}	2.33^{d}	6.30^{e}	41.33^{e}	0.57^{e}	1.01^{d}	108.67^{b}
	Means	57.31	69.40	3.99	9.16	6.08	3.33	8.14	86.00	0.59	1.04	106.13
Jiw1	0	57.00^{b}	75.00^{a}	3.33^{d}	8.66^{e}	8.00^{c}	2.66^{d}	7.73^{c}	88.00^{d}	0.59^{c}	0.89^{e}	121.00^{a}
	100+0.1	57.66^{b}	70.00^{b}	4.67^{a}	11.70^{a}	12.33^{a}	4.67^{a}	9.93^{a}	112.00^{a}	0.62^{a}	1.12^{a}	97.67^{e}
	200+0.5	58.00^{a}	67.00^{c}	4.33^{b}	10.67^{b}	9.33^{b}	3.67^{b}	9.16^{b}	103.33^{b}	0.61^{b}	1.09^{b}	101.00^{d}
	400+1.0	53.66^{c}	63.00^{d}	3.67^{c}	9.03^{c}	7.33^{d}	3.33^{c}	7.56^{c}	89.00^{c}	0.59^{c}	1.00^{c}	103.66^{c}
	500+2.0	48.33^{d}	61.33^{e}	2.67^{e}	7.07^{e}	5.33^{e}	2.33^{d}	5.97^{d}	63.66^{e}	0.57^{d}	0.98^{d}	108.33^{b}
	Means	54.93	67.27	3.73	9.43	8.46	3.31	8.07	91.20	0.60	1.02	106.33
Jiw 2	0	60.33^{c}	65.33^{c}	3.67^{c}	8.76^{d}	5.67^{d}	2.66^{d}	7.47^{d}	74.33^{d}	0.58^{d}	0.87^{e}	122.00^{a}
	100+0.1	66.00^{a}	70.33^{a}	5.33^{a}	12.80^{a}	9.33^{a}	4.67^{a}	9.80^{a}	109.66^{a}	0.62^{a}	1.07^{b}	100.67^{e}
	200+0.5	63.33^{b}	69.33^{b}	4.33^{b}	11.87^{b}	8.66^{b}	3.67^{b}	8.93^{b}	103.00^{b}	0.61^{b}	1.11^{a}	103.00^{d}
	400+1.0	55.00^{d}	61.33^{d}	3.67^{c}	8.83^{c}	6.00^{c}	3.33^{c}	8.73^{c}	82.33^{c}	0.59^{c}	1.02^{c}	107.00^{c}
	500+2.0	48.00^{e}	57.00^{e}	2.67^{d}	7.47^{e}	4.33^{e}	2.67^{d}	6.27^{e}	43.00^{e}	0.58^{d}	0.99^{d}	108.67^{b}
	Means	59.40	64.66	3.93	9.95	6.80	3.40	8.24	82.46	0.60	1.01	108.27
Nkpowas	0	58.33^{b}	64.67^{c}	3.00^{d}	9.43^{d}	6.00^{d}	2.67^{d}	7.36^{d}	78.33^{d}	0.58^{d}	0.97^{d}	120.66^{a}
	100+0.1	64.00^{a}	71.00^{a}	5.33^{a}	12.70^{a}	10.66^{a}	4.67^{a}	9.50^{a}	107.33^{a}	0.62^{a}	1.16^{a}	94.33^{e}
	200+0.5	58.66^{b}	66.67^{b}	4.33^{b}	10.33^{b}	8.00^{b}	3.33^{b}	8.63^{b}	103.66^{b}	0.61^{b}	1.09^{b}	98.67^{d}
	400+1.0	54.33^{c}	63.00^{d}	3.33^{c}	9.80^{c}	7.00^{c}	3.00^{c}	7.80^{c}	93.67^{c}	0.59^{c}	1.04^{c}	100.00^{c}
	500+2.0	43.66^{d}	50.00^{e}	3.00^{d}	8.93^{e}	4.67^{e}	2.33^{d}	6.16^{e}	44.00^{e}	0.58^{d}	0.97^{d}	105.33^{b}
	Means	55.80	63.07	3.80	10.24	7.27	3.20	7.89	85.40	0.60	1.05	103.80

N.B: *1 Means within the column with the same superscript(s) for each accession are not significantly different ($P \leq 0.05$)

Table 2: M_4 Generation combined effect of doses of gamma rays and colchicine on agronomic traits of fonio

Dose + Concentration (Gy+mM)/	% Germination (2WAS)	Height at Maturity (cm)	No. of Leaves	Leaf Area (cm^2)	No. of Tillers	No. of Spikes	Spikes Length (cm)	No. of Seeds Spikelets	1000 Seeds Weight (g)	Seeds Diameter (mm)	Days to Maturity
0	59.80^{b*1}	71.67^{a}	3.53^{c}	7.96^{d}	6.06^{c}	2.8^{c}	7.54^{d}	76.80^{d}	0.59^{c}	0.91^{e}	122.27^{a}
100+0.1	63.86^{a}	70.66^{a}	5.20^{a}	12.32^{a}	9.80^{a}	4.60^{a}	9.74^{a}	115.66^{a}	0.62^{a}	1.12^{a}	97.20^{e}
200+0.5	62.33^{ba}	66.86^{ba}	4.40^{b}	10.96^{b}	7.93^{b}	3.73^{b}	9.03^{b}	106.73^{b}	0.61^{b}	1.08^{b}	100.00^{d}
400+1.0	54.40^{c}	63.87^{b}	3.66^{c}	8.93^{c}	6.20^{c}	3.00^{c}	8.02^{c}	87.60^{c}	0.59^{c}	1.03^{c}	103.00^{c}
500+2.0	47.46^{d}	58.53^{c}	2.87^{d}	7.83^{d}	4.53^{d}	2.40^{d}	6.27^{e}	48.86^{e}	0.58^{d}	0.97^{d}	106.33^{b}
Mean	57.57	66.32	3.93	9.60	6.91	3.32	8.12	87.13	0.59	1.02	105.76
S.E (±)	4.92	8.83	0.87	0.69	1.29	0.62	0.62	7.45	0.02	0.04	1.64

N.B: *1 Means within the columns with the same superscript letter(s) are not significantly different ($P \leq 0.05$)

The observed synergistic hormesis agrees with the findings of Yadav *et al*. (2016) who reported significant improvements in growth and yield attributes among low doses induced-mutants of maize (*Zea mays*). High doses of gamma rays reduced the germination percent of fonio probably by inducing damage to the germinating seeds. Similar finding is reported by Rajapandian and Dhanam (2017) among mutants of maize. The increased in plant height at maturity and foliar attributing traits under low doses synergistic effects of the mutagens is due to the effect of low doses of gamma radiations and colchicine concentrations on plant growth and development probably by stimulating cell division and/or cell elongation at meristems. .

The significant improvement in fonio seed yield and quality due to synergistic hormesis of low gamma rays dose and colchicine concentration reported by the present study is in conformity with the previously reported work of Deshmukh *et al*. (2018) in sorghum, Kate *et al*. (2018) in proso millet

(*Panicum miliaceum* L.) and Bhave *et al*. (2016) in proso millet. Similar findings were reported in other crops by Suresh *et al*. (2017) in lima bean (*Phaseolus lunatus* L.) and Kara *et al*. (2016) in soy bean (*Glycine max*). It therefore implies that it is possible to improve yield components of economic plants using a synergy of gamma dose of 100 Gy and 0.1 mM colchicines concentration. However, these findings were contrary to the work of Zeerak (1990) who observed reduced yield in combined treatments of gamma rays and EMS in eggplant (*Solanum melongena* L.).

The genetic parameters estimates revealed that PCV values were slightly greater than GCV values for all the traits studied which indicates the presence of high contribution of genotypic effect for phenotypic expression of the selected traits and that there is high genetic variability for the traits which may facilitate selection based on phenotypic performance as reported by Islam *et al*. (2009). This finding is in conformity with that of Yohannes *et al*. (2015) who reported similar finding in sorghum. Moderate to high heritability, G.A and GCV estimates coupled with high genetic advance as percent of the mean explained the influence of additive gene effect as reported by Ibrahim and Hussein (2006) in roselle (*Hibiscus sabdariffa*) and that heritability is a property of a character in the population, environment and the conditions of the genotypes as stressed by Yadav *et al*. (2011). The moderate to high heritability, GA and GAM estimates reported by this research on the number of tillers, number of spikes, spikes length, number of seeds/spikelet and 1000 seeds weight conforms to the earlier reports by Wolie *et al*. (2013) in finger millet, Ogunbayo *et al*. (2014) in rice and Shrimali *et al*. (2017) in barley that these yield parameters were important for selection.

Thus, mutants with such characters need to be selected for improvement. Broad sense heritability (H^2) therefore represents the relative strength of the traits and indicates the efficiency of selection systems as reported by Hugar and Savithramma (2015). The LD_{50} and LC_{50} are very important parameters to understand the sensitivity of various genotypes to the critical dose of mutagens creating 50 per cent mortality as stressed by Usharani *et al*. (2017). One fundamental tenet in mutation breeding experiments is the evaluation of the effect of mutagens on the M_1 generation. The variation in the LD_{50} and LC_{50} reported by the present study indicated the differences in the response of the accessions to various doses and concentrations. Similar finding was reported in chick pea by Umavathi and Mullainathan (2015) and in butter bean by Suresh *et al*. (2017). This result showed that the LD_{50} and LC_{50} values are genotype dependents and is in line with the findings of Ramachander *et al*. (2015) in rice varieties.

Table 3: LD_{50}/LC_{50} of combined gamma rays and colchicine on agronomic traits of Fonio

Accession	Dose (Gy) + Concentration (mM)	Log_{10} of Dose + Concentration	%Germination (2 WAS)	% of Control	% Reduction over Control	Observed % Mortality	Empirical Probit Unit	LD_{50}/LC_{50} Value
Dinat	0	-	56.83[a]	0	-	-	-	
	100+0.1	2.00	55.30[b]	97.31	2.69	45	4.87	
	200+0.5	2.30	49.37[c]	86.87	13.13	51	5.03	143
	400+1.0	2.60	48.93[c]	86.09	13.91	51	5.03	
	500+2.0	2.70	41.40[d]	72.85	27.15	59	5.23	
Jakah	0	-	60.30[a]	0	-	-	-	
	100+0.1	2.00	58.66[b]	97.28	2.72	41	4.77	
	200+0.5	2.30	51.63[c]	85.62	14.38	48	4.95	182
	400+1.0	2.60	44.97[d]	74.58	25.42	55	5.13	
	500+2.0	2.70	37.20[e]	61.69	38.31	63	5.33	
Jiw 1	0	-	58.57[a]	0	-	-	-	
	100+0.1	2.00	56.17[b]	95.90	4.09	44	4.85	
	200+0.5	2.30	54.26[c]	92.64	7.36	46	4.90	155
	400+1.0	2.60	50.30[d]	85.88	14.12	50	5.00	
	500+2.0	2.70	41.56[e]	70.96	29.04	58	5.20	
Jiw 2	0	-	62.00[a]	0	-	-	-	
	100+0.1	2.00	60.20[b]	97.09	2.90	40	4.75	
	200+0.5	2.30	55.96[c]	90.26	9.74	44	4.85	137
	400+1.0	2.60	50.03[d]	80.69	19.31	50	5.00	
	500+2.0	2.70	47.73[e]	76.98	23.02	52	5.05	
Nkpowas	0	-	56.36[a]	0	-	-	-	
	100+0.1	2.00	55.30[a]	98.12	1.88	45	4.87	
	200+0.5	2.30	50.50[b]	89.60	10.39	50	5.00	156
	400+1.0	2.60	43.30[c]	76.83	23.17	57	5.18	
	500+2.0	2.70	38.03[d]	67.48	32.52	62	5.31	

Table 4: Genetic parameters estimates induced by combination of gamma rays and colchicine on agronomic traits of Fonio

Dose+ Concentration	Parameter	%Germination (2WAS)	Height at Maturity (cm)	Number of Leaves	Leaf Area (cm^2)	Number of Tillers	Number of Spikes	Spikes Length (cm)	Number of Seeds/Spikelets	1000 Seeds Weight (g)	Seeds Diameter (mm)	Days to Maturity
Control	GCV	10.47	1.86	11.63	12.57	10.65	6.35	10.67	7.07	0.96	3.72	1.45
	PCV	13.38	2.86	12.38	16.54	13.48	9.69	13.56	9.02	1.24	4.24	1.71
	H^2	78.25	65.03	93.94	75.99	79.01	65.53	78.69	78.38	77.41	87.74	84.79
	GA	589.63	226.55	680.89	636.64	597.58	420.21	596.92	484.93	177.57	372.18	228.40
	GAM	1250.28	312.61	20447.15	9779.42	6270.51	15392.31	7452.18	642.04	31152.63	46522.50	184.39
100Gy+0.1mM	GCV	9.03	2.05	8.95	10.76	8.56	4.99	8.97	5.67	0.89	3.26	1.73
	PCV	11.54	3.16	9.52	14.15	10.83	7.62	11.39	7.23	1.16	3.72	2.04
	H^2	78.25	64.87	94.01	76.04	79.04	65.49	78.75	78.42	76.72	87.63	84.80
	GA	547.59	237.55	597.53	589.23	535.83	372.41	547.49	434.37	170.22	348.17	249.50
	GAM	1001.08	362.12	13799.77	7742.83	4510.35	10732.28	.5744.91	461.46	27904.92	35893.81	240.37
200Gy+0.5mM	GCV	9.42	2.22	10.38	12.36	10.15	5.41	9.65	5.89	0.91	3.33	1.70
	PCV	12.04	3.42	11.05	16.27	12.85	8.26	12.27	7.51	1.18	3.79	2.00
	H^2	78.24	64.91	93.94	75.97	78.99	65.49	78.65	78.42	77.12	87.86	85.00
	GA	559.25	247.28	643.28	631.25	583.29	387.73	567.53	442.70	172.57	352.35	247.63
	GAM	1066.66	407.58	17246.11	9535.49	5832.90	12116.56	6412.77	488.25	28761.67	37089.47	233.90
400Gy+1.0mM	GCV	12.29	2.56	11.84	14.29	11.89	6.35	10.98	7.07	0.93	3.68	1.67
	PCV	15.71	3.95	12.61	18.79	15.06	9.69	13.96	9.02	1.19	4.19	1.97
	H^2	78.23	64.81	93.89	76.05	78.95	65.53	78.65	78.38	78.15	87.83	84.77
	GA	638.75	265.34	686.82	679.09	631.15	420.21	605.35	484.92	175.62	370.35	245.09
	GAM	1590.12	505.12	21003.67	11851.48	7399.18	15392.31	7780.85	642.53	29766.10	43063.95	227.65
500Gy +2.0mM	GCV	16.49	3.18	14.89	16.81	13.97	7.22	13.89	8.77	0.98	4.00	1.66
	PCV	21.07	4.91	15.86	22.12	17.69	11.02	17.66	11.19	1.26	4.56	1.95
	H^2	78.26	64.77	93.88	75.99	78.97	65.52	78.65	78.37	77.78	87.72	85.13
	GA	740.01	295.65	770.18	736.23	684.22	448.06	680.87	540.05	179.85	385.88	244.89
	GAM	2470.82	699.43	29622.31	15117.66	9424.52	18669.17	11071.06	887.36	32116.07	48845.57	225.77

N.B: PCV and GCV: 0 – 10 % = Low, 10 – 20 % = Moderate and >20 % = High H^2: 0 – 30 % = Low, 30 – 60 % = Moderate and >60 % = High GA: 0 – 10 % = Low, 10 – 20 % = Moderate and >20 % = High

CONCLUSION

The synergistic effects of lower colchicine concentration (0.1 mM) and lower dose of gamma rays (100 Gy) improved the yield and seeds sizes in fonio. The LD_{50} and LC_{50} of the mutagens were fixed at 137 Gy+mM. Moderate to high heritability GA and GAM estimates were found in almost all the traits studied signifying the additive gene effects induced by the mutagens in controlling such traits indicating that selection for improvement might be effective.

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