

Response of Pearl Millet (*Pennisetum Glaucum*L.) to Experimental Mutagenesis in the Guinea Savannah Agro-Ecology of Ghana

Isaac K. Addai

*Department of Agronomy, University for Development Studies, Tamale, Ghana
ikaddai2014@gmail.com*

and

Baba Salifu

*Faculty of Agriculture and Social Sciences, Anglican
University College of Technology, Ghana*

DOI//<http://dx.doi.org/10.4314/gjds.v15i1.2>

Abstract

*Irradiation techniques were applied to investigate the effect of gamma irradiation on growth and yield of pearl millet (*Pennisetum glaucum* L.) during the cropping seasons of 2014 to 2016 in Nyankpala, Ghana. Seeds of pearl millet were irradiated with gamma rays at 100, 200 or 300 Gy. The irradiated and some unirradiated control seeds were planted in 2014 in a randomized complete block design with four replications. At harvest, all M_1 seeds for respective gamma ray doses were harvested and advanced to M_2 generation during the 2015 cropping season. Mutant lines with desirable agronomic traits from the M_2 generation were advanced to M_3 during the 2016 season. Result of screening the M_3 mutant lines indicated that mutagenesis followed by selection produced desirable agronomic characteristics. Number of productive tillers was the yield component mostly associated with total grain yield. The mutant lines especially those from the 100 and 200 Gy doses of gamma rays recorded significant improvement in earliness, number of productive tillers, seed weight and total grain yield. The early maturing and high yielding mutant lines are being evaluated in multilocational trials for possible release as varieties for northern Ghana.*

Keywords: Pearl Millet, Growth, Grain Yield, Gamma Irradiation, Induced Mutation

Introduction

Millet is widely grown around the world as human food or as feed for livestock. The crop has 97 % its production in the developing countries (McDonough et al., 2000). The most widely grown millet cultivar is pearl millet which is an important crop in India and parts of Africa (Kalaisekar et al., 2017). Millet provides about 75% of total caloric intake for the poor people living in the semi-arid tropics and sub-humid drought-prone areas. Millets alone provide 13.40 kg/yr per capita food use. They are nutritionally equivalent or superior to other cereals. They generally contain high protein (up to 9.5 g/100g), ash, calcium (up to 344 mg/100g), phosphorus and potassium (up to 250 mg/100 g and 314 mg/100 g respectively) as well as iron and zinc (Obilana and Manyasa, 2000).

Millet is widely perceived as a crop in terminal decline. It is a neglected and under-utilized crop whose yields are low under the local environmental conditions (Salifu, 2015). The crop is distinctive in its adaptability to adverse agro-ecological conditions and requires minimal agronomic inputs with good nutritional properties (Bashir et al., 2011; Subi and Idris, 2013). It is therefore an important crop for household food security, and its resilience to drought can help offset the effects of climate change. Between 1981 and 2012, worldwide production of millets grew by 0.4% per year and in Africa over the same period, the production of this crop grew by 1.8% per year (Orr et al, 2016).

Exploitation of natural and induced genetic diversity is the basic requirement for plant breeding in developing plant varieties for sustainable food production (Jain, 2010). More often than not, plant breeders are handicapped due to lack of availability or non-existence of desired genotypes. However, they have successfully recombined certain desired genes from the available gene pool and the related plant species by sexual hybridization. This has successfully helped in developing new cultivars with desirable traits such as high yield, abiotic and biotic stress resistance (Huang et al., 2002).

Induced mutation is one of the best alternatives for improvement of crops as it can help to create and regenerate the variability, which is generally lost in the process of natural selection and adaptation of crops to various stresses (Khan and Goyal, 2009). The frequency of spontaneous mutations is rather very low and difficult to exploit by the plant breeder (Jain, 2010). Thus breeders normally resort to mutagenesis in creating variation during breeding programmes. The purpose of induced mutation is to enhance the mutation frequency in order to select appropriate variants for evaluation and possible release as varieties. Gamma rays have proven to be economical and effective mutagen as compared to other ionizing

radiations because of its easy availability and relatively high penetration power. The penetration power of gamma irradiation helps in their wide application for the improvement of various plant species (Moussa, 2011). The present study was designed to create genetic variation in pearl millet through mutagenesis and select mutants with improved grain yield and other desirable agronomic traits for release as varieties in northern Ghana.

Materials and Methods

Description of Study Area

The studies were conducted at the experimental field of University for Development Studies in Nyankpala, Ghana during the 2014 – 2016 cropping seasons. The experimental sites lie on altitude 183 m, latitude 09° 25' N and longitude 0° 58'W. The area has a unimodal rainfall pattern of about 1000 mm which is evenly distributed from May to October with the peak in August and September. The total annual rainfall is about 1022 mm. The average minimum and maximum temperatures are 25°C and 35°C respectively (Lawson *et al.*, 2013). The area lies within the interior Guinea savannah of Ghana and is characterized with natural vegetation dominated by grasses with few shrubs. Soils of the area are moderately drained and are free from concretions. The soils are shallow with hardpan under the top few centimetres and were derived from Voltaian sandstone. The soils, according to FAO (1988), are classified as Nyankpala series or Plinthic Acrisol. The area has grassland vegetation and it is interspersed with short trees such as *Parkia biglobosa* and *Azadirachta indica*, and weed species such as *Centrosema pubescens*, *Cyperus difformis* and *Striga hermontheca*.

Irradiation and Planting of Seeds

Seeds of pearl millet (variety Naara) were obtained from Savannah seeds in Tamale, Ghana. The seeds were packed in brown paper envelopes and irradiated with 100, 200 and 300 Gy of gamma rays at the Radiation Technology Center (RTC) of Ghana Atomic Energy Commission (GAEC), Accra, Ghana in August 2014. Treated seeds were sown in the field along with some unirradiated control seeds in a randomized complete block design with four replications. All the treatments and the control were planted at a spacing of 25 cm x 75 cm in plots measuring 5 m x 5 m in order to raise the M₁ generation.

Handling the Mutagen Treated Populations

All seeds from individual heads per treatment in the M_1 generation were harvested and replanted for advancement to M_2 generation in 2015 in randomized complete block design. In the M_2 generation, plants were monitored and screened for superior characteristic using single plant selection procedure and desirable genotypes selected. The superior M_2 plants were planted to raise the M_3 generation in 2016. In M_3 , the desirable mutant lines were also selected using the same procedure as indicated in the M_2 generation.

Weed Control and Scaring of Birds

In all seasons, weed control was done by hoeing four and seven weeks after planting. Scaring of birds was done to reduce grain loss from seed filling stage up to harvesting.

Data Collection and Statistical Analysis

Data collected on vegetative and yield parameters at the M_1 , M_2 and M_3 generations included plant height, number of tillers and productive tillers, earliness in flowering, head length, head width, head weight, seed weight and total grain yield. The data were subjected to ANOVA using GENSTAT Statistical package (12th edition) and means separated using either Duncan's Multiple Range Test (DMRT) or Least Significant Difference (LSD) at 5% level of probability.

Results

Plant Height and Tiller Formation

Data on plant height is as shown in Table 1. Height of plants was significantly ($P < 0.05$) affected by gamma irradiation. In the M_1 generation, plants from 100 Gy plots recorded the highest height but were significantly similar to the height attained by the control whilst plants irradiated at 300 Gy of gamma irradiation had the least height. The control plots recorded the least plant height whilst those irradiated at 100 Gy were the tallest in the M_2 generation. In the M_3 , plants from the three mutant generations recorded significantly similar but higher height than those of the control.

Gamma irradiation had no significant ($P > 0.05$) effect on tillering in the M_1 generation (Table 1). Irradiation, however, significantly ($P < 0.05$) influenced this parameter in the M_2 and M_3 generations. Plants irradiated at 100 Gy recorded the highest number of tillers whilst the control and 300 Gy plots recorded the least

height in the M_2 generation. In the M_3 , plants from 100, 200 and 300 Gy plots performed significantly similar in terms of number of tillers formed (Table 1).

The number of productive tillers were significantly ($P < 0.05$) affected by the irradiation treatment in all mutant generations. The highest number of productive tillers in the M_1 generation was recorded by plants from 100 Gy plots but it did not vary from the number recorded by plants from 200 Gy plots. Similar values of productive tillers were recorded by plants from 300 Gy and control plots. In the M_2 generation, the performance of plants from 100 Gy plots was at par with plants from the 200 Gy plots whilst in the M_3 , 100 Gy, 200Gy and 300 Gy plots recorded significantly similar but higher number of productive tillers than those from the control.

Earliness in Flowering

Days to flowering was significantly ($P < 0.05$) affected by the gamma irradiation treatment. Flowering response to irradiation was similar in M_1 and M_2 generations. In M_3 , plants from 100 Gy plots took the least number of days to attain 50% flowering and differed significantly from all other treatments, whilst plant from 200 and 300 Gy plots performed significantly similar as shown in Table 1.

Components of Yield and Total Grain Yield

Gamma irradiation had no significant ($P > 0.05$) effect on head length in the M_1 generation. Gamma irradiation, however significantly ($P < 0.05$) influenced head length in the M_2 and M_3 generations. Plants from 100 Gy plots recorded the highest head length in the M_2 , followed closely by plants from the 200 or 300 Gy plots. In the M_3 generation, plants from all gamma ray treated plots recorded significantly similar head lengths (Table 2).

The highest head width in the M_1 generation was recorded by plants from 100 Gy plots though these mutants recorded significantly similar values as plants from the unirradiated control plots. In the M_2 , head width recorded by plants from 100 Gy plots was highest and varied significantly from all other treatments, whilst plants from 200 and 300 Gy plots recorded significantly similar widths. In the M_3 generation, plants from 100, 200 and 300 Gy recorded significantly similar head widths but differed significantly from the control (Table 2).

No significant ($P > 0.05$) variation was observed for head weight in the M_1 generation, but the parameter varied significantly ($P < 0.05$) in the M_2 and M_3 generations. In the M_2 , plants from the control, 100 Gy, and 200 Gy plots recorded

significantly similar head weight. Similar pattern of distribution in head weight as in M_2 was also observed in the M_3 (Table 2).

Seed weight also varied significantly ($P < 0.05$) among populations. Plants from the control, 100 Gy and 200 Gy plots recorded significantly similar values of 100 seed weight in the M_1 generation. Seed weights recorded by plants from 100 Gy plots in the M_2 generations were similar to those from 200 Gy and 300 Gy plots. In the M_3 generation, the 200 Gy and 300 Gy plots also recorded similar seed weight. Seed weight recorded by 200 Gy plots was significantly higher than those from the 100 Gy and the control plots (Table 2).

Variation in total grain yield is shown in Figure 1. This parameter was significantly ($P < 0.05$) affected by the irradiation treatment. In the M_1 generation, similar grain yield were recorded by plants from 100 Gy and control plots, as were plants from 200 and 300 Gy plots. Pattern of total grain yield response to gamma irradiation was similar in the M_2 and M_3 generations. The overall highest grain yield was recorded by plants from 100 Gy plots in the M_2 and M_3 generations.

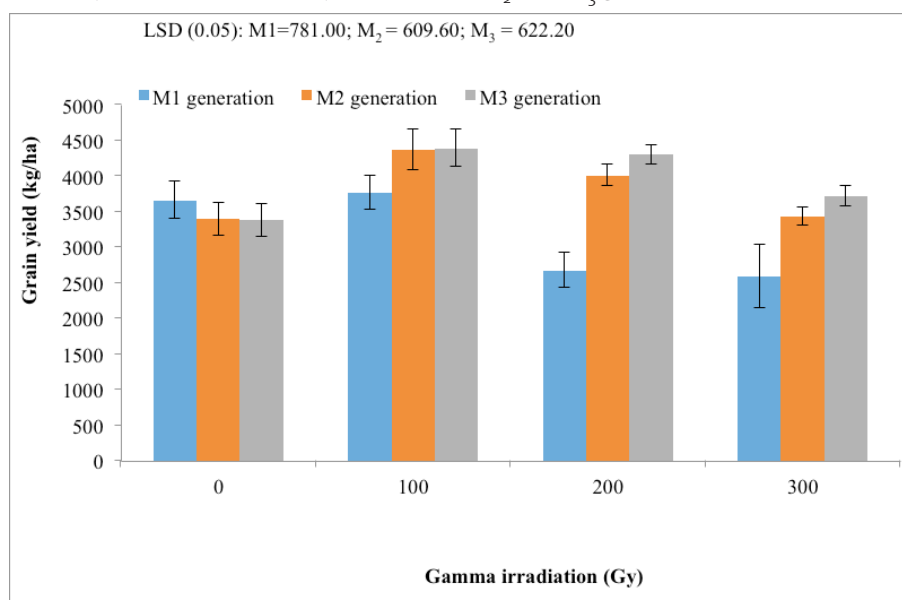


Figure 1: Effect of gamma irradiation on grain yield of millet.
Bars indicate mean \pm standard error of the means.

Progress Made in Selection of Agronomic Traits

Table 3 shows that whilst characters such as plant height and number of productive tillers exhibited high percentage improvements, earliness to maturity and total grain yield recorded lower percentage improvements. Plant height was

observed to have decreased from M_2 to M_3 in plants irradiated at the 100 Gy dose, but increased in plants irradiated at 200 and 300 Gy doses of gamma irradiation. Genetic advancement or gain in selection of important agronomic traits such as plant height, tillering, earliness in maturity period and total grain yield at the M_2 and M_3 generations was highly variable. For instance, mutants obtained from plants irradiated at 100, 200 and 300 Gy of gamma ray recorded 37.85%, 102.81% and 125.64% gain in plant height at the M_2 generation. Similarly, the number of productive tillers also increased by 89.66%, 96.43% and 25.00% whilst total grain yield increased by 16.10%, 50.19% and 32.21% at the M_2 when plants were irradiated at 100, 200 and 300 Gy of gamma rays, respectively. In general, improvements in agronomic traits at the M_3 generation were higher than those in the M_2 .

Table 1: Effect of gamma irradiation on plant height, number of tillers, productive tillers and earliness to flowering

Irrad. Levels	Plant height (cm)			Tillers			Productive tillers			Earliness in flowering (days)		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
Control	71.90ab	97.70a	83.90a	6.03	3.66ad	3.62a	1.05b	1.50b	1.38a	45.75a	50.00a	46.25a
100 Gy	90.20a	124.10b	118.20b	8.35	7.15b	5.50ab	.45a	2.75a	2.97b	41.75b	45.00b	33.00b
200 Gy	56.90bc	115.40bc	126.90b	7.04	5.40c	6.03b	1.40a	2.75a	2.81b	47.50a	50.00a	40.25c
300 Gy	47.20c	106.50c	119.20b	6.45	4.90cd	6.09b	1.20b	1.50b	2.59b	48.75a	50.25a	42.75ac
LSD (0.05)	22.40	9.86	23.17	5.00NS	1.39	2.27	0.18	1.08	1.03	3.52	3.90	4.35

Irrad. = irradiation; NS = Not significant; Means followed by the same letter (s) in each column are not significantly different

Table 2: Effect of gamma irradiation on head length, width, weight and 100 seeds weight

Irrad. Levels	Head Length (cm)			Head Width (cm)			Head Weight (g)			100 Seed Weight (g)		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
Control	16.15	13.10c	12.18a	2.72ac	2.36a	2.14a	12.29	25.1a	20.86ab	1.41a	0.85b	0.74a
100 Gy	16.64	16.74a	17.45b	2.78a	2.67b	2.84b	16.16	22.40ab	22.81ab	1.29ab	1.07a	1.56ac
200 Gy	16.23	15.32b	15.43ab	2.57bc	2.52c	2.74b	12.62	20.50ab	23.55a	1.29ab	1.01a	1.96b
300 Gy	15.74	14.30bc	16.60b	2.45b	2.48c	2.71b	15.09	16.3b	20.83b	1.24b	0.95ab	1.66bc
LSD (0.05)	1.02NS	1.21	3.84	0.17	0.13	0.34	6.00NS	6.46	2.94	0.16	0.13	0.85

Irrad. = irradiation; NS= Not significant; Means followed by the same letter (s) in each column are not significantly different

Table 3: Improvements made in some agronomic traits of Pearl millet through mutagenesis using gamma irradiation

Irrad. levels	Character	M ₁	M ₂	M ₃	M ₂ -M ₁	M ₃ -M ₁	M ₃ -M ₂	[(M ₂ -M ₁)/M ₁] ₁₀₀	[(M ₃ -M ₁)/M ₁] ₁₀₀	[(M ₃ -M ₂)/M ₂] ₁₀₀
100 Gy	Plant height	90.20	124.1	118.2	33.90	28	-4.75	37.85	31.04	-4.75
	Productive tillers	1.40	2.75	2.97	1.30	1.52	0.22	89.66	104.83	8.00
	Earliness	41.70	45.00	33.00	3.25	-8.75	-12.00	8.89	-0.21	26.67
	Grain yield	3758.00	4363.00	4381.0	605.00	623.00	18.00	16.10	16.58	0.41
200 Gy	Plant height	56.90	115.40	126.90	58.50	70.00	11.50	102.81	123.02	9.97
	Productive tiller	1.40	2.75	2.81	1.35	1.41	0.06	96.43	100.71	2.18
	Earliness	47.50	50.00	40.25	2.50	-7.25	-9.75	5.26	-15.26	19
	Grain yield	2668.00	4007.00	4296.0	1339.0	1628.0	289.00	50.19	61.02	7.21
300 Gy	Plant height	47.20	106.5	119.20	59.30	72.00	12.7	125.64	152.54	11.92
	Productive tiller	1.20	1.50	2.59	0.30	1.39	1.09	25.00	115.83	72.67
	Earliness	48.75	50.25	42.75	1.50	-6.00	-7.50	3.08	12.31	14.93
	Grain yield	2589.0	3423.0	3717.0	834.00	1128.0	294.00	32.21	43.68	8.59

Discussion

Data obtained from the present studies revealed that mutagenesis using gamma irradiation created genetic variation that served as basis for selecting mutants with desirable agronomic traits in millet. Yıldız and Ceylan (2015) also demonstrated that mutagenesis using gamma rays could increase the nutritional value of barley. Values of genetic advancement or gain in selection as recorded in the present study are in conformity with the results obtained for sesame and groundnut by Mathur et al. (2000). There was a stimulatory effect on plant height in this study, and this was observed especially with the lower doses of gamma irradiation. This agrees with the finding by Wi et al. (2007) that low doses of gamma irradiation may induce growth stimulation in plants. These authors explained that stimulation of plant growth by low doses of gamma rays occur through changes in the hormonal signaling network or by increasing the anti-oxidative capacity of the cells to overcome stress factors such as fluctuations in light intensity and temperature during the period of plant growth and development. According to Zaka et al. (2004), the stimulatory effect on plant growth is attributed to changes in the rates of cell division as well as activation of growth hormones such as auxin in the treated populations. In the present study, the high irradiation dose (300 Gy) resulted in growth inhibition particularly at the M_1 generation. The inhibition of growth according to Preussa and Britta (2003) might have been caused by the cell cycle arrest at the G₂/M phase during somatic cell division and/or various damages in the entire genome of the plants following irradiation.

In plant production, the formation and development of buds occur at an early stage of growth. Available evidence (Koli et al., 2002) indicates that an increase in kinetin/auxin ratio may increase the formation of buds, leaves and shoots. Kinetin is known to increase the proliferation of tillers. Gamma irradiation might have influenced the biochemical processes that are known to regulate the rate and pattern of apical differentiation and this could have had a direct effect on production and proliferation of tillers. The low gamma ray doses might have played a pivotal role in maintaining this hormonal balance in the irradiated plants. Reduction in tillering at higher doses as observed in this study might have resulted from reduced mitotic activities in the meristematic tissues of pearl millet which resulted from low moisture content in the seeds of the irradiated plants prior to planting (Muhammad and Afsari, 2001). Reduction in number of tillers of crops planted after irradiation at high gamma ray doses has also been reported by Al-Salhi et al. (2004), Token et al. (2005) and Kon et al. (2007). Norfadzrin et al. (2007) also noticed that high gamma ray doses had negative effect on morphological characteristics of tomato and okra.

The study has demonstrated that irradiation using gamma rays can change the number of days to flowering in plants. Karim et al. (2008) also reported that gamma irradiation has the potential to change flowering dates of plants. Mutagenesis using gamma irradiation may create variability in flowering dates of plants and this will assist breeders in selecting early or late flowering plants for crop improvement. In this study, the low dose of gamma irradiation (100 Gy) was capable of stimulating early flowering in millet especially at the M_2 and M_3 generations whilst the high doses were not. Jan et al. (2012) explained that biological damage resulting from seedling injury, lethality and sterility in crops may occur with increases in doses of gamma irradiation during mutagenesis and that the suppressive effect on flowering by high doses of gamma rays may have been related to the combined effects of auxin and DNA biogenesis in a relationship. Decreases in root and shoot growth by high doses of gamma rays have also been observed in finger millet (Ambavane et al., 2015).

The beneficial effect of gamma rays on grain yield has been reported by Kon et al. (2007) who observed an increase in yield at low doses of gamma irradiation and a decrease at higher doses in long bean. Maman et al. (2010) observed that yield differences in agronomic crops are associated with variations in yield components. In the present study, the low doses of gamma rays (100 Gy and 200 Gy) enhanced the formation of productive tillers, head weight, and 100 seed weight more than the high dose (300 Gy) and the control and this reflected in the relatively high grain yield of the former as compared with the latter. The observation made in this study is in agreement with the findings of Majeed et al. (2010) who reported that reduction in grain yield at higher doses of irradiation was as a result of reduced plant stature or reduced moisture contents in shoot due to radiation effect. The data presented in the present work indicated that plants that were high yielding were also tall and those that were short due to their exposure to high irradiation dose were low yielding.

Conclusion

Mutagenesis using gamma irradiation created genetic variability in pearl millet that served as basis of selection of mutants with improved agronomic traits. Among the gamma ray treatments, 100 Gy and 200 Gy predominantly enhanced growth and yield parameters in all the generations as compared to the unirradiated control. Though, 200 and 300 Gy gamma ray treatments performed less than the control in some of the parameters measured in the M_1 generation, the performances of plants irradiated at 200 Gy or 300 Gy were significantly better than the unirradiated control in the M_2 and M_3

generations. Gamma – induced mutagenesis enhanced earliness in flowering. Mutants derived from all gamma treatments plants flowered earlier than the unirradiated control especially in the M₃ generations, among which 100 Gy was outstanding. The high yielding and early flowering mutant lines especially those from 100 Gy or 200 Gy doses when released as varieties will play a major role in breaking the yield constraints in pearl millet and improve the economic status of farmers in the study area.

Acknowledgement

The authors of this study are most grateful to the Faculty of Agriculture of UDS for providing funds for land preparation prior to planting. Sincere thanks also go to all technicians of the Department of Agronomy, UDS for their help in data collection, weeding and other cultural practices.

References

- Al-Salhi, M., Ghannam, M. M., Al-Ayed, M. S., El – Kameesy, S. U. and Roshdy, S.** (2004). Effect of gamma irradiation on the biophysical and morphological properties of corn. *Nahrung*, Vol. 48, pp. 95 – 98.
- Ambavane, A.R., S.V. Sawantdesai, S.A., Gokhale, N.B.** (2015). Studies on mutagenic effectiveness and efficiency of gamma rays and its effect on quantitative traits in finger millet (*Eleusine coracana* L. Gaertn). *Journal of Radiation Research and Applied Sciences*, Vol. 8, No. 1, pp. 120-125.
- Bashir E., Haussmann B., Ali A., Ismail M., Abdalla E., Bakhit O., Sabeel S., Muth P. and Parzies H.** (2011). Genetic analysis and biofortification of pearl millet for nutritional values. Conference of Development on the margin, Tropentag 2011, October 5 – 7, Bonn, Germany.
- FAO** (1988). Soil Map of the World, Revised Legend, Reprinted with corrections. World Soil Resources Report 60, FAO, Rome.
- Huang, J., Rozell, S., Pray, C. and Wang, Q.** (2002). Plant biotechnology in China. *Science*, Vol. 295, pp. 674-677.
- Jain, S. M.** (2010). Mutagenesis in crop improvement under the climate change. *Romanian Biotechnological Letters*, Vol. 15, No. 2, pp. 88-106.
- Kalaisekar, A., Padmaja, P.G., Bhagwat, V.R. and Patil, J. V.** (2017). Systematics, Bionomics, and Management. In: *Insect Pests of Millets*, ISBN: 978-0-12-804243-4, Academic press, pp. 1-25.

- Jan, S., Parween T., Siddiqi, T.O. and Uzzafar, M.** (2012). Effect of gamma radiation on morphological, biochemical and physiological aspects of plants and plant products. *Environment Review*, Vol. 20, pp. 17-39.
- Karim, K.M.R., Islam, A.K.M.R., Hossain, M.M., Azad, H.M.S. and Rahman, W.M.** (2008). Effect of gamma rays on yield attributes of large seeded chickpea. *Journal of Soil Nature*, Vol. 2, No. 2, pp. 19-24.
- Khan, S. and Goyal, S.** (2009). Mutation genetics studies in mungbean IV: Selection of early maturing mutants. *Thai Journal of Agricultural Science*, Vol. 42, No. 2, pp.109-113.
- Koli, N.R., Sharma, Y. and Sharma, Y.** (2002). Gamma rays induced variation in cumin (*Cuminum cyminum*, L.). *Annals of Agriculture and Biology Research*, Vol. 7, No. 2, pp. 161-164.
- Kon, E., Ahmed, O.H., Saamin, S. and Majid, N.M.** (2007). Gamma radiosensitivity study in Long Bean (*Vigna sesquipedalis*). *American Journal of Applied Science*, Vol. 4, No. 12, pp. 1090-1093.
- Lawson, I.Y.D., Issahaku, A., Acheampong, S.K., Adams, B. and Tuffour, V.** (2013). Time of planting and weed suppression abilities of some legumes intercropped with maize in the Guinea savanna zone of Ghana. *Agriculture and Biology Journal of North America*, Vol. 4, pp. 358-363.
- Majeed, A., Rehman, K.A.U., Habib, A. and Zahir, M.** (2010). Gamma irradiation effect on some growth parameters of *Lepidium sativum* L. ARPN. *Journal of Agriculture and Biological Science*, Vol. 5, No. 1, pp. 39-42.
- Maman, N., Mason, S., Lyon, D.J. and Dhungana, P.** (2010). Yield components of pearl millet and grain sorghum across environments in the Central Great Plains. *Panhandle Research and Extension Center*. Paper III.
- Mathur, R.K., Manivel, P., Samder, M.Y., Gor, H.K. and Chikani, B.M.** (2000). Creation of genetic variability through mutation breeding in groundnut. Proceedings of the DAE-BRNS symposium on the use of nuclear and molecular techniques in crop improvement. December 6-8, 2000. Bhabha Atomic Research Centre, Mumbai, India. pp. 203-213.
- Muhammad, R. and Afsari, S.** (2001). Quantitative variations induced by gamma irradiation and gibberellic acid in M_1 generation of chick pea. *Sarhad Journal of Agriculture*, Vol. 17, No. 3, pp. 367-372.
- Moussa, H.R.** (2011). Low dose of gamma irradiation enhanced drought tolerance in soybean. *Acta Agronomica Hungarica*, Vol. 59, pp. 1-12.

- McDonough, C.M., Rooney, L.W. and Serna-Sadivar, S.O.** (2000). The millets. *Food science and Technology: Handbook of cereal science and technology*, CRC Press, 2nd edition, pp. 117-210.
- Norfadzrin, F., Ahmed, O.H., Shaharudin, S. and Rahman, D.A.** (2007). A preliminary study on gamma radio-sensitivity of tomato (*Lycopersicon esculentum*) and okra (*Abelmoschus esculentus*). *International Journal of Agricultural Research*, Vol.2, No. 7, pp. 620-625.
- Obilana, A.B. and Manyasa, E.** (2002). Millets. In Pseudocereals and less common cereals: grain properties and utilization potential, P.S. Belton and J.R.N. Taylor (eds), Springer-Verlag, Berlin Heidelberg New York, pp. 177-217.
- Orr, A., Mwema, C., Gierend, A. and Nedumaran, S.** (2016). Sorghum and Millets in Eastern and Southern Africa. Facts, Trends and Outlook. Working Paper Series No. 62. ICRISAT Research Programme, Markets, Institutions and Policies. Patancheru 502 324, Telangana, India: International Crops Research Institute for the Semi-Arid Tropics. 76 pp.
- Preussa, S.B. and Britta, A.B.** (2003). A DNA-damage – induced cell cycle checkpoint in Arabidopsis. *Genetics*, Vol. 164, pp. 323-334.
- Salifu, B.** (2015). Effects of Cobalt – 60 gamma irradiation on growth and yield of pearl millet (*Pennisetum Glaucum* L.) in the Guinea Savannah Agroecological Zone of Ghana. Master of Philosophy Thesis, Department of Agronomy, Faculty of Agriculture, University For Development Studies, Ghana, pp. 99.
- Subi, M.I.M. and Idris, A.E.** (2013). Genetic variability, heritability and genetic advance in pearl millet (*Penisetum glaucum* [L.] R. Br.) genotypes. *British Biotechnology Journal*, Vol. 3, No. 1, pp. 54-65.
- Token, C.B., Uzun, H. and Canci, C.F.O.** (2005). Effects of gamma irradiation on the shoot length of cicer seeds. *Radiation Physics and Chemistry*, Vol. 73, No. 6, pp. 365-367.
- van Oosterom, E.J., O’Leary, G.J., Carberry, P.S. and Craufurd, P.Q.** (2002). Simulating growth, development, and yield of tillering pearl. *Field Crops Research*, Vol. 79, pp. 85-106.
- Wi, S.G., Chung, B.Y., Kim, J.H., Baek, M.H., Yang, D.H., Lee, J.W. and Kim, J.S.** (2007). Effects of gamma irradiation on morphological changes and biological responses in plants. *Micron*, Vol. 38, pp. 553-564.
- Yıldız, T. and Ceylan, N.** (2015). The Effects of using gamma irradiated wheat and barley in layer diets on egg production and quality. *Turkish Journal of Agriculture – Food Science and Technology*, Vol. 3, No. 9, pp.742-747.

Zaka, R., Chenal, C. and Misset, M.T. (2004). Effect of low doses of short-term gamma radiation on growth and development through two generations of *Pisum sativum*. *Science of the Total Environment*, Vol. 320, pp. 121-129.