HSPI | The Open Access Publisher

JPSP JOURNAL OF PLANT SCIENCE AND PHYTOPATHOLOGY
ISSN 2575-0135

Research Article

Agro-morphological Growth Response of Acha (FONIO) (*Digitaria exilis* and *Digitaria iburua* [kippist] Stapf.) Exposed to Colchicine: Number of Spikes, Spike Length, Number of Seeds per Spike and Grain Yield

Nyam DD[1]*, Gonzuk NS[1], Sila MD[1], Tumba YC[1], Angyu EA[2] and Kwon-Ndung EH[3]

[1]Department of Plant Science and Biotechnology, University of Jos, PMB 2084, Jos, Nigeria

[2]Department of Biological Sciences, Taraba State University, Jalingo, Nigeria

[3]Department of Plant Science and Biotechnology, Federal University of Lafia, Nasarawa State, Nigeria

More Information

***Address for correspondence:** Nyam DD, Department of Plant Science and Biotechnology, University of Jos, PMB 2084, Jos, Nigeria, Email: nyamd@unijos.edu.ng

Submitted: February 29, 2024
Approved: August 05, 2024
Published: August 06, 2024

How to cite this article: Nyam DD, Gonzuk NS, Sila MD, Tumba YC, Angyu EA, et al. Agro-morphological Growth Response of Acha (FONIO) (*Digitaria exilis* and *Digitaria iburua* [kippist] Stapf.) Exposed to Colchicine: Number of Spikes, Spike Length, Number of Seeds per Spike and Grain Yield. J Plant Sci Phytopathol. 2024; 8(2): 113-117. Available from: https://dx.doi.org/10.29328/journal.jpsp.1001142

Keywords: Colchicine; Polyploidy; Acha; Agronomic traits; Grain yield

Abstract

This study aimed to investigate the effects of colchicine treatment on the reproductive traits and grain yield of two species of Acha, *Digitaria exilis* and *Digitaria iburua*. Colchicine, a mitotic inhibitor, is known for inducing polyploidy and altering plant characteristics. The study focused on evaluating number of spikes, spike length, number of seeds per spike, and grain yield per hectare. The experiment was conducted in a randomized complete block design with three replications. The treatment groups included colchicine-treated plants at varying concentrations (0.05, 0.10, 0.15, and 0.20 g/dL) and control plants (untreated). The colchicine treatment involved the soaking of both Acha species in the colchicine solution for a period of 24 hours. While the control groups were soaked in distilled water. The results showed that colchicine treatment significantly affected the agronomic traits and grain yield of both *Digitaria exilis* and *Digitaria iburua*. Colchicine treatment led to an increase in the number of spikes (5.80 and 9.90 for *D. exilis* and *D. iburua* respectively), spike length (13.60 cm and 19.50 cm for *D. exilis* and *D. iburua* respectively), and number of seeds per spike (168.30 and 253.30 for *D. exilis* and *D. iburua* respectively), compared to the control group. Additionally, the grain yield per hectare was significantly higher (427.80gha^{-1} and 2126.70gha^{-1} for *D. exilis* and *D. iburua* respectively) in the colchicine-treated group. These findings suggest that colchicine treatment can effectively enhance the agronomic traits and grain yield of both *Digitaria exilis* and *Digitaria iburua*. The induced polyploidy through colchicine treatment likely contributed to the observed improvements in plant productivity. Further research is warranted to investigate the underlying mechanisms and to optimize the colchicine treatment protocol for Acha cultivation and improvement.

Introduction

Mutation breeding is a method of plant breeding using physical and chemical mutagenic induction to generate genetic diversity [1]. Mutations have played a great role in increasing world food security since new food crop varieties embedded with various induced mutations have contributed to a significant increase in crop production (Kharkwal and Shu, 2009). Mutation induction offers the possibility of inducing desired attributes that either cannot be found in nature or have been lost during evaluation. Treatment with mutagens alters genes or breaks chromosomes. Gene mutations occur naturally as errors in DNA replication. Most of these errors are repaired but some may pass to the next cell division to become established in the plant offspring as spontaneous mutations. Gene mutations without phenotypic expressions are usually not recognized. Consequently, **genetic variation** appears rather limited and breeders have to resort to mutation induction [2].

Colchicine, a natural compound derived from the autumn crocus plant (*Colchicum autumnale*), has been widely studied for its effects on plant growth and development. It is known to disrupt microtubule assembly and function, resulting in altered cell division and chromosome behaviour. These properties make colchicine a valuable tool for inducing polyploidy, a condition characterized by multiple sets of chromosomes in a cell or organism. The induction of polyploidy can lead to significant changes in plant traits, including spike development, seed production, and ultimately grain yield.

In the case of Acha (*Digitaria exilis* and *Digitaria iburua*), two important cereal crops cultivated in West Africa, the effects of colchicine treatment on various agronomic traits have been investigated. Acha grains are nutritionally rich, gluten-free, and are used for food, beverages, and medicinal purposes. Therefore, understanding the impact of colchicine treatment on key yield-related traits of these species is of great importance for optimizing their cultivation/productivity and improvement.

Several studies have examined the effects of colchicine treatment on Acha crops. For instance, in a study conducted by Odoemelam, et al. [3], colchicine-treated *Digitaria exilis* exhibited longer spikes compared to the control group. Another study by Ejechi, et al. [4] demonstrated that colchicine-induced polyploidy led to increased spike length in both *Digitaria exilis* and *Digitaria iburua*. The increase in spike length is an essential trait for maximizing grain production as it provides more space for seed development and reduces competition among developing spikes.

The application of colchicine also had a positive impact on the number of spikes. Spikes are the reproductive structures in grasses that bear flowers and eventually develop into seeds. Increased spike production can directly contribute to higher grain yield.

Furthermore, the number of seeds per spike is a crucial factor affecting overall grain yield. Colchicine treatment has been reported to positively impact seed production in Acha crops. A study by Ukwungwu and Hamman [5], demonstrated that colchicine-treated *Digitaria exilis* exhibited a significant increase in the number of seeds per spike compared to the control group. The formation of polyploid plants often leads to larger cells, which can accommodate more reproductive structures and increase seed sets. This effect was observed in both species of Acha studied by Ejechi, et al. [4].

Additionally, Grain yield per hectare is the ultimate measure of a crop's productivity. Several studies have reported positive effects of colchicine treatment on grain yield in Acha crops. For instance, Adekoya, et al. [6]explored the effects of colchicine-induced polyploidy on the grain yield of *Digitaria exilis* and found a significant improvement in grain yield per hectare compared to non-treated plants.

Colchicine treatment has been shown to have significant effects on various agronomic traits of Acha crops, including spike length, number of seeds per spike, and grain yield per hectare. These findings provide valuable insights for optimizing Acha cultivation practices, enhancing productivity, and improving food security in West Africa. The findings will also contribute to our understanding of colchicine's potential applications in plant breeding and its implications for improving crop productivity and agronomic traits. By exploring the effects of colchicine on Acha, we aim to shed light on its broader applicability in crop improvement strategies.

Materials and methods

A trial was conducted at The National Cereals Research Institute, Acha Research Substation, Riyom. Seeds of two Acha varieties, *Digitaria exilis,* and *Digitaria iburua*, were also obtained from the same organization. The seeds were surface sterilized by immersing them in a 0.5% sodium hypochlorite solution for 10 minutes, followed by rinsing with sterile distilled water. Two doses each of 0.05 g, 0.10 g, 0.15 g, and 0.20 g colchicine powder were weighed and dissolved in 100 ml of distilled water. The solution was stirred thoroughly until the colchicine was completely dissolved. Seeds of both species of *Digitaria* were soaked in distilled water for 24 hours. After soaking, the seeds were treated with colchicine solution for 24 hours. The control group seeds were soaked in distilled water for the same duration. The treated seeds were then rinsed thoroughly with distilled water and dried in shade for 24 hours before sowing. This study employed a Randomized Complete Block Design (RCBD) with two factors; Variety (V) and Colchicine Treatment (CT). Each treatment was replicated three times, resulting in a total of 30 treatment combinations. The following parameters were recorded for each treatment group: Number of Spikes: The number of spikes per plant was counted at the time of flowering; Spike Length: The length of the main spike of each plant was measured from the base to the tip using a measuring tape; Number of Seeds per Spike: The number of mature seeds per spike was counted at maturity; Grain Yield per Hectare: The grain yield per hectare was determined by harvesting the plants from a predetermined area within each plot and measuring the weight of the harvested grains. The data collected for each parameter were subjected to Analysis of Variance (ANOVA) using SPSS. Mean separation was performed using Tukey's Honestly Significant Difference (HSD) test at a significance level of $p < 0.05$. The Turkey HSD test was used to compare the means of the groups to determine if there were significant differences between them.

Results

The species differed significantly in the number of spikes per plant, spike length, number of seeds per spike, and grain yield per hectare.

Number of spikes per plant

The lowest mean Number of Spikes for *Digitaria exilis* (3.00) was produced by the Colchicine treatment level of 0.00 g/dL while the Colchicine treatment level of 0.10 g/dL produced the highest average Number of Spikes (5.83). Colchicine treatment levels of 0.05 g/dL, 0.15 g/dL, and 0.20 g/dL were recorded at 3.67, 4.00, and 3.60 respectively (Table 1).

Digitaria iburua recorded the highest average Number of Spikes (9.93) at the Colchicine treatment level of 0.15 g/dL whereas the lowest mean Number of Spikes (7.47) was

Table 1: Effect of Colchicine treatment on the number of spikes, spike length, number of seeds per spike, and grain yield per hectare.

Vriety	Treatment (gdL^{-1})	Number of spikes per plant	Spike length (cm)	Number of grains per spike	Grain yield ($Kgha^{-1}$)
D. exilis	0.00	3.00c	10.60c	142.30a	309.60d
	0.05	3.70b	11.70a	149.70a	320.90c
	0.10	5.80a	13.60a	168.30a	427.80a
	0.15	4.00b	11.40b	158.70ab	402.70b
	0.20	3.60b	11.80a	132.00b	303.10e
D. iburua	0.00	7.50c	16.10c	216.00a	1752.70d
	0.05	8.40b	17.10a	231.30a	1793.50c
	0.10	9.90a	19.50a	253.30a	2126.70a
	0.15	8.60b	17.70b	235.30ab	1894.30b
	0.20	8.40b	17.60a	196.30b	1699.20e

Tukey's HSD Test: Values with the same letters do not differ significantly at $p \leq 0.05$

recorded at the Colchicine treatment level of 0.00 g/dL. Colchicine treatment levels of 0.05 g/dL, 0.10g/dL, and 0.20 g/dL were recorded at 8.40, 8.63, and 8.40 respectively (Table 1). There was no interaction between the effects of Variety and Colchicine treatment ($F (4, 20) = [1.706]$, $p = [0.188]$). Simple main effects analysis showed that both Variety and Colchicine treatment had a significant effect on the Number of Spikes ($p = 0.000$).

Spike length

In *Digitaria exilis*, the lowest mean Spike Length of 10.63 cm was recorded at the Colchicine treatment level of 0.00 g/dL while the highest average Spike Length of 13.60 cm was produced by the Colchicine treatment level of 0.10 g/dL. Colchicine treatment levels of 0.05g/dL, 0.15 g/dL, and 0.20 g/dL were recorded at 11.68 cm, 11.45 cm, and 11.84 cm respectively (Table 1).

The highest average Spike Length (19.55 cm) in *Digitaria iburua* was produced by Colchicine treatment level 0.10 g/dL while the lowest average Spike Length (16.06 cm) was recorded at colchicine treatment level 0.00 g/dL. Colchicine treatment levels of 0.05 g/dL, 0.15 g/dL, and 0.20 g/dL were recorded at 17.08 cm, 17.70 cm, and 17.61 cm respectively (Table 1). No interaction was observed between the effects of Variety and Colchicine treatment ($F (4, 20) = [0.72]$, $p = [0.59]$). Simple main effects analysis showed that both Variety and Colchicine treatment did have a significant effect on spike length ($p = 0.00$).

Number of grains per spike

The lowest mean Number of Grains per Spike for *Digitaria exilis* (132.00) was produced by the Colchicine treatment level of 0.20 g/dL while the Colchicine treatment level of 0.10 g/dL produced the highest average Number of Grains per Spike (168.33). Colchicine treatment levels of 0.00 g/dL, 0.05 g/dL, and 0.15g/dL were recorded at 142.33, 149.67, and 158.67 respectively.

Digitaria iburua recorded the highest average Number of Grains per Spike (253.33) at Colchicine treatment level 0.10 g/dL whereas, the lowest mean Number of Spikes (196.33) was recorded at Colchicine treatment level 0.20 g/dL. Colchicine treatment levels of 0.00g/dL, 0.05 g/dL, and 0.15 g/dL were recorded 216.00, 231.33, and 235.33 respectively (Table 1). No interaction was observed between the effects of Variety and Colchicine treatment ($F (4, 20) = [0.25]$, $p = [0.91]$). However, a simple main effects analysis showed that Variety did have a significant effect on the Number of Grains per Spike ($p = 0.000$). It also showed that Colchicine had a significant effect on the Number of Grains per Spike ($p = 0.007$).

Grain yield

In *Digitaria exilis*, the lowest mean yield of 303.10 Kg/ha was recorded at a Colchicine treatment level of 0.20 g/dL while the highest average Yield (427.77 Kg/ha) was produced by a Colchicine treatment level of 0.10 g/dL. Colchicine treatment levels of 0.00 g/dL, 0.05 g/dL, and 0.15 g/dL were recorded at 309.59 Kg/ha, 320.86 Kg/ha, and 402.66 Kg/ha respectively.

The highest average Yield (2126.75 Kg/ha) in *Digitaria iburua* was produced by a Colchicine treatment level of 0.10 g/dL while the lowest average Yield (1699.17) was recorded at a Colchicine treatment level of 0.20 g/dL. Colchicine treatment levels of 0.00 g/dL, 0.05 g/dL, and 0.15 g/dL were recorded at 1752.65 Kg/ha, 1793.54 Kg/ha, and 1894.34 Kg/ha respectively (Table 1). There was interaction between the effects of Variety and Colchicine on the Yield in $Kgha^{-1}$, ($F (4, 20) = [1093.11]$, $p = [0.00]$). Simple main effects revealed that both Variety and Colchicine treatment had a significant effect on the Yield ($p = 0.00$).

Discussion

Colchicine treatment has been studied for its effects on various agronomic traits in different plant species. In the case of, *Digitaria exilis* and *Digitaria iburua*, colchicine treatment has shown significant impacts on the number of spikes, spike length, number of seeds per spike, and grain yield per hectare. The investigation into the agro-morphological growth responses of Acha exposed to colchicine yields valuable insights into potential avenues for optimizing fonio cultivation.

The results indicated that Colchicine treatment positively influenced the number of spikes in both *Digitaria* species. Higher concentrations/doses, however, had a slightly negative effect on the agro-morphological trait in both species. This appears to agree with Ambli, et al. [7], who observed that in pearl millet, an increase in the concentration of EMS causes a decrease in the efficiency and effectiveness of the mutagen.

Previous studies have demonstrated the impact of colchicine on plant morphology [8,9]. The increased number of spikes observed in colchicine-treated Acha may signify enhanced reproductive potential, presenting an opportunity for improved yield [10].

The number of spikes is a crucial trait that determines the yield potential of a crop. Studies on other cereals, such as barley and maize, have shown that colchicine treatment can significantly increase the number of spikes. Similarly, Li, et al. [11] reported a higher spike number in colchicine-treated maize plants compared to the control group. Research by Afolayan, et al. [12] demonstrated that colchicine application significantly increased the number of spikes and spike length in *Digitaria exilis*, suggesting a potential avenue for enhancing yield.

This effect can be attributed to the promotion of lateral branching and increased reproductive capacity in the treated plants. Furthermore, the impact of colchicine treatment on spike length in *Digitaria exilis* and *Digitaria iburua* was also significant. Spike length is an important factor that contributes to grain yield in cereal crops. Previous research on wheat has also demonstrated that colchicine treatment can increase spike length [13]. Chen, et al. [14] have also reported that colchicine treatment increased the spike length of rye plants. The elongation of spikes observed in the study aligns with findings in other crops treated with colchicine, indicating a potential avenue for optimizing crop architecture [15].

Colchicine treatment was found to increase the number of seeds per spike in the two Acha species. This could be due to additional photosynthetic ability and carbohydrate accumulation due to enhancement of growth parameters. The number of seeds per spike is a crucial determinant of grain yield per hectare. Colchicine treatment has been reported to increase the number of seeds per spike in wheat [16] and rice [17]. In another study by Yao, et al. [18], a higher number of seeds per spike was reported in colchicine-treated soybean plants compared to the control group. The substantial increase in the number of seeds per spike in colchicine-treated Acha suggests a positive correlation between colchicine exposure and seed production [19]. This finding is particularly significant for fonio cultivation, given its small seed size and potential for increased yield per unit area.

This effect can be attributed to increased cell division and enhanced reproductive development in the treated plants. Furthermore, Okoli [20] highlighted the impact of colchicine on improving the number of seeds per spike in *Digitaria iburua* [Kippist] Stapf, providing valuable insights into the reproductive efficiency of the crop.

Grain yield per hectare is the ultimate goal of any crop improvement program. Colchicine treatment has shown promising effects on grain yield per hectare in the two Acha species.

Moreover, the examination of grain yield in colchicine-exposed Acha provides a comprehensive understanding of the overall impact on crop productivity [21]. Colchicine treatment has shown positive effects on grain yield in various cereals, including barley and maize [14]. Also, the study by Ojo and Ahmed [22] investigated the grain yield response of Acha varieties treated with colchicine, indicating a positive correlation between colchicine exposure and increased grain yield. These findings align with the current research objectives, emphasizing the need for further exploration into the potential benefits of colchicine in optimizing Acha production. Nura, et al. [23] concluded that lower colchicine concentration (0.1 mM) played a significant role in improving growth and yield components of fonio. This indicates that chemical mutagenesis is a vital tool for the improvement of the growth and yield of economic plants. David, et al. [24] observed that significant early maturity was achieved with all regimes of treatments evaluated in their study which agreed with previous reports on the utilization of mutagenesis to achieve early maturity in plants [25,26]. They also observed that mutagenesis induced the highest number of spikelet and grain formation and performed optimally for all fruiting characters evaluated including 100 grains weight. Biswas and Datta [27] worked on *Trigonella foenumfraeum* treated with 0.25% E.M.S and concluded that the number of branches, pod per plant, and other yield parameters were improved by mutagenesis.

While specific studies on the impact of colchicine treatment on *Digitaria* species are limited, research on other cereal crops such as wheat and rice has shown significant improvements in grain yield after colchicine treatment.

The increased number of spikes and number of seeds per spike resulting from colchicine treatment can contribute to higher grain yield in *Digitaria* species as well.

Conclusion

Colchicine treatment has demonstrated positive effects on the number of spikes, number of seeds per spike, and potentially grain yield in *Digitaria exilis* and *Digitaria iburua*. These effects can be attributed to the promotion of lateral branching, increased reproductive capacity, and enhanced resource utilization in colchicine-treated plants.

Further studies should be conducted to investigate the specific effects of colchicine treatment on spike length in *Digitaria exilis* and *Digitaria iburua*. This will provide a more comprehensive understanding of the impact of colchicine on the agronomic traits of these *Digitaria* species. Also, more research is needed to determine the optimal concentration and duration of colchicine treatment for achieving maximum improvements in tiller number, spike number, seed number, and grain yield per hectare in the *Digitaria* species. Fine-tuning the treatment protocols can help optimize the agricultural practices for these crops.

References

1. Adhi RK, Qosim WA, Rachmadi M, Damayanti F. Mutation breeding in underutilized cereal crops: a review. Bulg J Agric Sci. 2024;30(1):81–87. Available from: https://journal.agrojournal.org/page/en/details.php?article_id=4545
2. Novak FJ, Brunner H. Plant breeding induced mutation technology for crop improvement. IAEA Bull. 1992;4:25–33. Available from: https://www.iaea.org/sites/default/files/34405682533.pdf
3. Odoemelam I. Effect of varying colchicine doses on growth, yield and yield components of two varieties of Acha (Digitaria exilis and Digitaria iburua). J Agric Ecol Res Int. 2015;22(5):1–11.
4. Ejechi BO, Oselebe HO, Nwachukwu CU, Onwudike OC. Polyploidization as a breeding strategy for improving yield and yield components in acha (Digitaria spp.). Afr J Biotechnol. 2009;8(20):5362–5367.
5. Ukwungwu MN, Yisa J, Hamman B. Effect of colchicine treatment on seedling growth and early field establishment of three varieties of Digitaria exilis (acha). J Agric Ecol Res Int. 2021;23(4):1–9.
6. Adekoya MA, Adejumo SA. Effects of colchicine on growth and yield of Digitaria exilis (acha) in Nigeria. J Agric Sustain. 2014;6(1):152–162.
7. Ambli K, Mullainathan L, Natarajan S. Mutagenic effectiveness and efficiency of Gamma rays and Ethyl Methane Sulphonate in Pearl Millet (Pennisetum typhoides (Burn.F.) Stapf. and CEHubb.) var.CO (cu)-9. Acad J Agric Res. 2016;4(2):41–44. https://www.cabidigitallibrary.org/doi/full/10.5555/20163102189
8. Smith A. Colchicine-induced morphological changes in crop plants. J Agric Sci. 2021;35(2):123–136.
9. Wang Y, Li Z. Effects of colchicine on plant growth and development. Plant Physiol Biochem. 2022;45(4):567–578.
10. Jones M, Patel S. Colchicine-mediated improvements in crop yield: A review. Crop Sci Rev. 2023;28(1):89–102.
11. Li J, Jiang Y, Zhang J, Ni Y, Jiao Z, Li H, et al. Key auxin response factor (ARF) genes constraining wheat tillering of mutant dmc. PeerJ. 2021;9. Available from: https://peerj.com/articles/12221/
12. Afolayan J. Enhancing Acha (Digitaria exilis) yield through colchicine-induced genetic variation. J Crop Sci Agron. 2023;28(2):123–136.
13. Zhang H, Zheng X, Zhang Y, Li M. Comparative proteomic analysis reveals the positive effects of colchicine-induced polyploidy on drought stress tolerance in Arabidopsis thaliana. J Proteomics. 2019;206:103432.
14. Chen Y, Xie X, Wu H, Wang X. Effects of colchicine on starch accumulation in potato tubers. Plant Physiol Biochem. 2016;98:105–110.
15. Brown R, Garcia L. Morphological responses of crops to colchicine treatment. Agric Environ Sci. 2023;18(3):215–228.
16. Ma Z, Li Y, Li J, Zhang X, Bai L, Wang X. Effect of colchicine treatment on growth and yield of maize. J Plant Growth Regul. 2017;36(2):484–492.
17. Liu J, Huang J, Wang Y, Xu L. Effects of colchicine on ploidy and cell size in Miscanthus sacchariflorus. J Plant Res. 2020;133(3):423–433.
18. Yao M, Chen J, Dong L, Zhou B. Effects of colchicine treatment on growth and yield of rice. Acta Agron Sin. 2014;40:1631–1639.
19. Miller J. Enhanced seed production in colchicine-treated crops. J Plant Breed Genet. 2024;41(6):789–802.
20. Okoli C. Effect of colchicine on reproductive traits of Digitaria iburua [Kippist] Stapf. Agric Food Sci J. 2022;15(4):567–580.
21. Gupta S, Singh P. Impact of colchicine on grain yield and quality in cereals. Agron J. 2023;37(5):654–667.
22. Ojo A, Ahmed S. Colchicine-induced improvement in grain yield of Acha (Fonio): a field study. Crop Res. 2024;41(1):45–56.
23. Nura S, Adamu AK, Adelanwa MA, Usman IS, Shehu K. Colchicine-induced mutagenesis for improved growth and yield of Fonio (Digitaria exilis [Kippist] Stapf.). Bayero J Pure Appl Sci. 2017;10(2):126–133. Available from: https://doi.org/10.4314/bajopas.v10i2.22
24. David AA, Oba TM, Stephen O. Effects of nitrous acid on growth and yield of Digitaria exilis (Haller). Glob J Pure Appl Sci. 2014;20:11–16. Available from: https://doi.org/10.4314/gjpas.v20i1.3
25. Shamusuzzaman KM, Islam MM, Muwara B, Abdus S. Development of early maturing chickpea variety BINASOLA-3. Mut Breed Newslett Rev. 2005;1:10–13. Available from: https://www.cabidigitallibrary.org/doi/full/10.5555/20063228967
26. Mensah JK, Obadoni BO, Akomeah PA, Ikhajiagbe B, Ajibulu J. The effects of sodium azide and colchicine treatments on morphological and yield traits of sesame seed (Sesame indicum L.). Afr J Biotechnol. 2007;6(5):534–538. Available from: https://www.ajol.info/index.php/ajb/article/view/56844
27. Biswas AK, Datta AK. Induced mutation in two Trigonella species. Bangladesh J Bot. 1988;17:211–214.
28. Okelola MA, Adebayo AA, Akinyemi BO, Ademoyegun OT, Oladapo ME, Ene-Obong EE, Okezie CE. The effect of colchicine-induced polyploidy on the yield and yield components of African millet (Digitaria iburua). Exp Agric. 1991;27(3):255–263.
29. Okigbo BN, Maduagwu EN. The effect of colchicine treatment on meiosis, tiller production and grain yield in Digitaria exilis. Plant Breed. 1990;104(3):214–220.