International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(8): 841-843
Received: 17-06-2025
Accepted: 19-07-2025

Mutagenic effectiveness and efficiency in M_2 generation of foxtail millet (*Setaria italica* (L.) Beauv)

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i8l.3655

Abstract
An experiment entitled "Mutagenic effectiveness and efficiency in M_2 generation of Foxtail millet (*Setaria italica* (L.) Beauve)" was carried out during Kharif 2024-25 at the Department of Agriculture Botany, VNMKV, Parbhani. The experiment was laid out in Randomized Block Design (RBD) with 11 Genotype and three replications to estimate the frequency and spectrum of chlorophyll and viable mutation in M_2 generation. For this purpose, seeds of Foxtail millet Siya 3156 seeds were treated with different doses of Gamma rays ranging from 100Gy, 200Gy, 300Gy, varying concentration of ethyl methane sulphonate (EMS) 0.1, 0.2, 0.3 and 0.4 and their combination of Gamma and EMS i.e 100Gy+0.1EMS, 100Gy+0.2EMS and 200Gy+0.1EMS. found of chlorophyll mutants and viable mutants like Xantha, Chlorina, Viridis, Xanthaviridis and viable mutants like Long, Loose, Compact panicle, bold Seeded panicle, pigmented glume panicle, Dwarf panicle. Among the all treatment mutagenic frequency and effectiveness maximum found in 100Gy+0.1 EMS followed by 200Gy+0.1EMS. Among all 12 characters like Days to 50% flowering, plant height, No. of productive tillers per plant, No. of tillers per plant, Internodal distance, Peduncle length, No. of ears per plant, Flag leaf area, Ear length, Grain yield per ear head, Grain yield per plant, 1000 grain weight.

Keywords: Foxtail millet, Chlorophyll mutants, mutagenic effectiveness and efficiency

Introduction
Foxtail millet (*Setaria italica* (L.) Beauv.) is a self-pollinated diploid species with a chromosome number of 2n = 2x = 18. It belongs to the Poaceae family, within the subfamily Panicoideae. It is one of the oldest cultivated millet in the world, is cultivated in about 23 countries in Asia, Africa and America. Foxtail millet ranks second among the millets production in the world and continues to have an important place in the world agriculture providing food to millions of people dependent on poor or marginal soils in southern Europe and in temperate, subtropical and tropical Asia. Foxtail millet is an ancient crop dating back to the Neolithic era, having been cultivated over 10,500 years ago in China. It holds significant importance in dryland agriculture. In India production of foxtail millets is estimated to be around 500,000 tons per year. The major states that produce Foxtail millet in India are Andhra Pradesh, Karnataka, Maharashtra, Rajasthan, Tamil Nadu, and Telangana. The states of Rajasthan, Karnataka, Maharashtra, Madhya Pradesh and Haryana account for more than 79.6% of the total millet production. The total production of foxtail millet in Maharashtra in 2023 is estimated to be 14.78 lakh tons. In 2024, the estimated production is 16.00 lakh tons. The average yield was 762 kg/ha. Foxtail millet is a minor cereal crop that can grow in variety of elevation, soil, and temperature.

Mutation breeding in Foxtail millet has gained attention as a tool for broadening the genetic base and improving yield potential. Mutagenic agents such as gamma rays, ethyl methane sulfonate (EMS), and fast neutrons have been widely used to induce genetic variability. These mutagens cause alterations in DNA sequences, resulting in new allelic variations that can be exploited for trait enhancement. The success of mutation breeding depends on the selection of desirable mutants with superior agronomic performance. Evaluating the induced mutants for yield and associated traits using appropriate biometrical techniques helps identify promising lines that can be utilized in breeding programs. Induced mutagenesis is a well-established and effective approach for generating variability within crop varieties, providing opportunities to introduce desirable traits that may not occur naturally or have been lost through conventional breeding.The targeted recombination without very much disturbing the yield and quality status in existing well adopted varieties can be achieved within shortest time by induced mutation. Mutations are of two types spontaneous natural and artificial or induced. Frequency of natural mutation is very low and hence, induced mutations are used to create genetic variability for qualitative traits. Therefore, the present experimental study was conducted to estimate spectrum of chlorophyll and viable mutants and to study variability, correlation, path analysis in foxtail millet.

Materials and Methods

The present study was conducted on Foxtail millet (*Setaria italica* (L.) Beauv) during the kharif season of 2024-25 at the Department of Agricultural Botany, Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani. The experimental site is located at 19° 24' N latitude, 76° 78' E longitude, and an altitude of 458.38 meters above mean sea level (MSL), characterized by shallow to medium black soils. Climatic data, including rainfall, minimum and maximum temperatures, and relative humidity during the crop growth period, were recorded at the Meteorological Department, VNMKV, Parbhani.

Table 1: Mutagens and their treatments.

Mutagens	Treatment
Gammy rays	100Gy
	200Gy
	300Gy
EMS	0.1%
	0.2%
	0.3%
	0.4%
Gamma + EMS	100Gy + 0.1%
	100Gy + 0.2%
	200Gy + 0.1%
Control	Untreated

The experimental material for present study consists of M_2 population of Foxtail millet variety Siya 3156 derived from self seed of M_1 generation from Department of Genetics and Plant breeding, VNMKV, Parbhani. The seeds are sown with the row ration of 2.40 × 3 meter plots with 8 lines in each plot. The spacing between the accessions is 30 × 10 cm. various traits were observed including days to 50% of flowering, plant height, No. of productive tillers per plant, No. of tillers per plants, internodal distances, peduncle length, ear length, No. of ears per plant, flag leaf area, 1000 grain weight, grain yield per ear head, grain yield per plant were observed.

Results and Discussion

Chlorophyll mutations, a visible outcome of mutagenic treatments, were recorded in the M2 generation of the Foxtail millet population. In Siya 3156, mutation frequency increased linearly with higher doses of both mutagens. The highest frequency was 1.99% at 300 Gy, followed by 2.25% at 200 Gy. For chemical treatment, 0.3% EMS showed 2.09%, while the combination 200 Gy + 0.1% EMS recorded the highest at 2.46%. Similar results found in Anittha (2018) [3], JD Deshmukh *et al*., (2024) [6].

Estimates of mutagenic effectiveness and efficiency in the M_2 generation of Siya 3156 Foxtail millet showed that combination treatments were more effective than individual gamma ray or EMS treatments. The highest effectiveness was in 100 Gy + 0.1% EMS (17.7%), followed by 200 Gy + 0.1% EMS (12.3%). Among individual treatments, 100 Gy gamma rays (11.1%) and 0.1% EMS (10.63%) were highest. Efficiency, calculated as per Konzak *et al*. (1965) [11], was also greater in combinations, with 200 Gy + 0.1% EMS (12.13%), 0.1% EMS (11.79%), and 100 Gy + 0.1% EMS (10.47%) performing best. Lower doses generally produced higher chlorophyll mutation frequencies, and combinations consistently outperformed single mutagens, aligning with earlier findings in barley and sorghum. Similar results found in Ambavane A. R *et al*., (2014) [2], Aviya (2018) [4].

Gamma rays, EMS, and their combinations induced a range of viable mutations in Siya 3156 Foxtail millet, affecting plant habit, leaf morphology, ear size, and seed traits. A wider mutation spectrum was observed in 0.3% EMS, 0.4% EMS, and 200 Gy + 0.1% EMS treatments. Notable mutants included dwarf types (200 Gy, 300 Gy), early maturing types (all treatments), compact ear (100 Gy, 300 Gy, various EMS doses, and combinations), loose ear (200 Gy, higher EMS doses, and combinations), long ear (all treatments, especially 100 Gy + 0.2% EMS and 0.4% EMS), short ear (100 Gy, 200 Gy, 300 Gy), spared awns (100 Gy, EMS doses, combinations), awnless ear (300 Gy, 0.1% EMS, 100 Gy + 0.1% EMS), straw-colored glumes (0.1% and 0.2% EMS), pigmented glumes (0.3% and 0.4% EMS), and bold-seeded ear (200 Gy, 0.1% EMS, 100 Gy + 0.1% EMS). Similar results found in Kalpande H. V *et al*., (2021) [13], Karthikeyan M *et al*., (2021) [12], Neethu Francis *et al*., (2021) [14].

Table 2: Frequency, Mutagenic effectiveness and efficiency of chlorophyll mutation.

Treatment	No. of seedling scored	No. of mutant	Frequency of chlorophyll mutant	Mutagenic effectiveness %	Mutagenic efficiency %
100Gy	718	8	1.11	11.1	3.57
200Gy	683	10	1.46	7.32	9.82
300Gy	652	13	1.99	6.64	8.28
0.1%EMS	677	9	1.32	10.63	11.79
0.2%EMS	671	11	1.639	8.19	7.08
0.3%EMS	668	14	2.09	8.38	6.93
0.4%EMS	656	13	1.98	5.94	8.72
100Gy+0.1% EMS	675	12	1.77	17.7	10.47
100Gy+0.2% EMS	665	15	2.25	8.5	9.87
200Gy+0.1% EMS	650	16	2.46	12.3	12.13
Control	720	-	-	-	-

Conclusion

In the M_2 generation of Siya 3156 Foxtail millet, chlorophyll mutation frequency increased with higher doses of mutagens, peaking at 2.46% in 200 Gy + 0.1% EMS. Combination treatments showed greater mutagenic effectiveness and efficiency than individual gamma ray or EMS treatments, with the highest effectiveness in 100 Gy + 0.1% EMS (17.7%) and highest efficiency in 200 Gy + 0.1% EMS (12.13%). Gamma rays, EMS, and their combinations induced diverse viable mutations affecting plant habit, leaf traits, ear size, and seed characteristics, with a broader mutation spectrum in 0.3% EMS, 0.4% EMS, and 200 Gy + 0.1% EMS.

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