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MUTAGENIC EFFICIENCY AND EFFECTIVENESS IN M_2 GENERATION OF FENUGREEK (*Trigonella foenum-graecum* L.)

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ABSTRACT

The present investigation was carried out in a set of of 270 M1 single plants of two genetically diverse genotypes of fenugreek with eight treatments and one control sown in three replications. The experimental material evaluated in Compact Family Block Design (CFBD). Its involves mutagen treatment in fenugreek genotype RMt1 and RMt 354 with physical Family-200 Gamma rays and Family-400 Gamma rays, chemical treatment Family-6 mM SA, Family-8 mM SA and Family-10 mM SA and their combinations. The maximum mutagenic frequency of morphological mutants viz., chlorophyll (chlorina and xantha), plant height (tall and dwarf) and pod (multiple pod) were observed in (Family 9-400 Gy + 10 mM SA) in both varieties of fenugreek while minimum mutagenic frequency of morphological were observed in (Family 2-200 Gy gamma rays) and (Family 4-6 mM SA) in both varieties of fenugreek. Mutagenic frequency showed increase with increase in the dose or concentration and combination of mutagens. Mutagenic efficiency and effectiveness showed decreasing trend with increase in the dose and combination of mutagens in both the varieties RMt 1 and RMt 354.
***Keywords* :** Gamma rays, Sodium azide, Treatment, Mutagenic efficiency and effectiveness.

Introduction

The fenugreek (*Trigonella foenum-graecum* L.) is an annual, diploid, dicotyledonous plant that self-pollinates. It is a member of the *Leguminaceae* order and family, *Fabaceae*. The crop's origins are in the Mediterranean region, and opinions on *Trigonella foenum graecum* likely ancestry vary. According to de Candolle (1964), Fazli and Hardman (1968) and Vavilov (1951), fenugreek is a native of the Mediterranean region known as the "Old World." These authors have traced fenugreek to Asian and South Europe origins. Known by most as "methi," this significant green vegetable and spice has branched stems, trifoliate ovate-orbicular leaves with white flowers, papilionaceous corolla, diadelphous stamens, ovary superior, and numerous ovules within pods that produce golden yellow seeds (Acharya *et al*., 2010).

One of the most ancient and significant medicinal, chemurgic, annual forage legumes in the world, fenugreek is also a well-known traditional spice crop with a variety of uses (Basu *et al*., 2009). This crop offers a range of advantages for the environment, economy, and society (Moyer *et al*., 2003; Acharya *et al*., 2011). Legumes like fenugreek, which have bacteria in their roots that bind nitrogen, have the ability to fix nitrogen from the atmosphere into the soil. It is a wise decision to include in crop rotation plans with short growing seasons, particularly when non-leguminous crops are involved. 45–60% of fenugreek seeds' composition is made up of carbohydrates, mainly fiber (galactomannans), 20–30% of which are proteins that are high in lysine and tryptophan, 5–10% of which are fixed oils (lipids), pyridine alkaloids, mainly trigonelline (0.38%), choline (0.5%), free amino acids, such as 4-hydroxyisoleucine (0.09%), arginine, histidine, and lysine, saponins and calcium and iron.

Mutagenesis is an effective approach that generally enhances and uplifts the genetic makeup of plants. They are beneficial for enhancing genetic variety. Although mutation may have negative effects. The unfavorable outcomes of the produced mutations that can lower the mutagens' efficiency are lethality, damage, and sterility. According to Gaul *et al*., 1972 and Wani, 2009, mutagenic efficiency quantifies the amount of genetic damage seen in the M_2 generation in relation to the biological damage induced in the M_1 generation, i.e., sterility, injury and lethality. Mutagenic effectiveness shows mutations induced by a unit dose of mutagen. To achieve desired plant mutations in a mutation breeding program, mutagenic effectiveness and efficiency are required (Smith, 1972). To achieve a high frequency, it is therefore essential to examine the mutation frequency, mutagenic effectiveness, and efficiency of a certain mutagen dose. Additionally, seed mutagenesis has been employed for inducing chlorophyll mutations, morphological mutations and yield parameters.

Material and Methods

The experiment was conducted at the experimental farm, Department of plant breeding and Genetics, Sri Karan Narendra College of Agriculture, Jobner (SKNAU, Jobner-Jaipur). The material consists of 270 M_1 single plants of two genetically diverse genotype of fenugreek RMt 1 and RMt 354 (each genotype having 135 lines) with eight treatments and one control sown in three replications. The experimental material evaluated in Compact Family Block Design (CFBD) sown on 9th November during *rabi*, 2022-23. Each genotype was sown in a plot of single row, each of 3 meter length. Row to row and plant to plant distance maintained at 30 cm and 10 cm, respectively. The mutagenic treatment involves physical mutagens, chemical mutagen and their combination at different doses with the recommended package of practices.

The experiment consisted of nine treatments, including one control (Family 1) and eight mutagenic treatments. The physical mutagen treatments included 200 Gy gamma rays (Family 2) and 400 Gy gamma rays (Family 3). The chemical mutagen treatments involved sodium azide at three different concentrations, namely 6 mM (Family 4), 8 mM (Family 5) and 10 mM (Family 6). Combined treatments of gamma rays and sodium azide consisting of 400 Gy gamma rays + 6 mM sodium azide (Family 7), 400 Gy gamma rays + 8 mM sodium azide (Family 8) and 400 Gy gamma rays + 10 mM sodium azide (Family 9).

Estimation of mutagenic efficiency and effectiveness

Mutagenic effectiveness and efficiency of different mutagens were calculated according to the formulae suggested by (Konzak *et al*., 1965). The mutagenic effectiveness can be measured of the frequency of mutations induced by a unit dose of mutagen (kR or time × concentration) while mutagenic efficiency gives an idea of the proportion of mutations in relation to biological damage such as lethality, pollen sterility.

$$\text{Mutagenic Effectiveness (Physical Mutagens)} = \frac{\text{Mutation frequency on the basis of } M_2 \text{ population (Ms)}}{\text{Dose in kilo Roentgen (Gy)}}$$

$$\text{Mutagenic Effectiveness} = \frac{\text{Mutation frequency on the basis of } M_2 \text{ population (Ms)}}{\text{Dose in kilo Roentgen (Gy)} \times \text{Concentration of mutagen} \times \text{duration of treatment}}$$

$$\text{Mutagenic Effectiveness (Chemical Mutagens)} = \frac{\text{Mutation frequency on the basis of } M_2 \text{ population (Ms)}}{\text{Concentration of mutagen} \times \text{time of treatment}}$$

$$\text{Mutagenic Efficiency} = \frac{\text{Mutation frequency on the basis of } M_2 \text{ plant population (Ms)}}{\text{\% Pollen Sterility (Ps)}}$$

$$\text{Mutagenic frequency} = \frac{\text{No. of mutant plant}}{\text{No. of total plant}} \times 100$$

Morphological mutation

Morphological mutations were identified through careful screening of both control and treated populations to assess the response of fenugreek to different mutagenic treatments. Various macro-mutations were observed at different growth stages in the M_2 generation. Among chlorophyll mutants, two types namely chlorina and xantha were recorded based on seedling pigmentation. Chlorina mutants showed patches of bright green to yellowish colour on leaves, and some seedlings survived up to about 20 days, whereas xantha mutants were characterized by vivid yellow seedlings that survived only for 10–20 days. In addition, plant height mutants such as tall and dwarf types were observed. Pod mutants were also noticed in the form of multiple podding plants, indicating the effectiveness of mutagenic treatments in creating useful variability in fenugreek.

Result and Discussion

Mutation Frequency

In the present investigation the maximum mutagenic frequency observed at (Family 9-400 Gy +

10 mM Sodium Azide) and the minimum was observed at (Family 2-200 Gy) and (Family 6-10 mM Sodium Azide). The mutagenic frequency showed an increased with increase in the dose or concentration and their combination of mutagens for getting variability and could be further used in next generation. Mutagenic frequency followed similar pattern between progeny as like within families in both the variety. Similar result finding by Usharani and Ananda Kumar (2015) in Urdbean, Laskar *et al.* (2018) in lentil, and Goyal *et al.* (2020) in black gram and Yasmin *et al.* (2020) in cowpea.

Mutation efficiency

The mutagenic efficiency was determined based on lethality and injury of the seedling in the M_2 population. The mutagenic efficiency based on the lethality was highest mutagenic efficiency for chlorina, xantha, tall, and multiple pod mutants was noted at (F 4-6 mM Sodium Azide). However, in variety RMt 1, dwarf mutants (F 2-200 Gy, F 4-6 mM Sodium Azide, and F 9-400 Gy + 10 mM Sodium Azide) showed the highest mutagenic efficiency. Lowest mutagenic efficiency of chlorina and tall mutants were observed at (F 3-400 Gy) in both the varieties. The lower mutagenic efficiency of xantha studied in (F 6-10 mM Sodium Azide) in variety RMt 1 and in (F 3-400 Gy) in RMt 354 and lowest mutagenic efficiency of dwarf mutant studied in (F 3-400 Gy, F 5-8 mM Sodium Azide, F 6-10 mM Sodium Azide, F 7-400 Gy + 6 mM Sodium Azide and F 8-400 Gy + 8 mM Sodium Azide) in variety RMt 1 and (F 6-10 mM Sodium Azide) in RMt 354. For multiple pod mutant, it was lowest in (F 7-400 Gy + 6 mM Sodium Azide) in both the varieties RMt 1 and RMt 354 within the family, between progeny, mutagenic efficiency a similar pattern has been followed by within family in varieties RMt 1 and RMt 354. The higher efficiency of mutagens at lower dose/conc. is due to the increase in seedling injury and pollen sterility along with increases in mutagenic concentration at a rate faster than the mutations frequency (Blixit, 1964). The higher efficiency obtained at lower and intermediate doses of mutagens might be due to the fact that the sterility increases with mutagen concentration at a rate faster than the frequency of mutations Similar result findings were obtained by Wani (2009) in chickpea, Bhosle and Kothekar (2010) in cluster bean and Kousar and Babu (2010) in black gram, Parchin *et al.* (2021) and Jyothsna *et al.* (2022) in Fenugreek.

Mutagenic effectiveness

Within the family, the maximum mutagenic effectiveness of chlorina was found at (F 2-200 Gy), whereas the maximum mutagenic effectiveness of xantha, dwarf, and tall mutants was found at (F 4-6 mM) in both the RMt 1 and RMt 354 types. The maximum mutagenic effectiveness of multiple pod mutants was found in (F 4-6 mM) in RMt1 and (F 5-8 mM) in RMt 354. The minimum mutagenic effectiveness of chlorina, tall and dwarf mutant was observed in (F 9-400 Gy + 10 mM) in both the varieties and dwarf mutant showed minimum mutagenic effectiveness in (F 7-400 Gy + 6 mM) in RMt 1. Variety RMt 354 showed minimum effectiveness at (F 9-400 Gy + 10 mM). The minimum mutagenic effectiveness of multiple pods was found in (F7-400 Gy + 6 mM) in both the varieties RMt 1 and RMt 354 of fenugreek. Between progeny, mutagenic effectiveness a similar pattern has been followed by within family in varieties RMt 1 and RMt 354. The effectiveness of mutagenic treatments differed considerably depending upon the dose/conc. of mutagens. The mutagenic effectiveness showed a trend, which shows negative correlation to the increasing dose/conc. of mutagenic treatments up to a level and beyond declined in both the varieties RMt 1 and RMt 354. The mutagenic efficiency and effectiveness were estimated on the basis of frequency of progenies segregating for chlorophyll mutation. The decrease in mutagenic effectiveness of morphological mutants *viz*., chlorophyll (chlorina and xantha), plant height (tall and dwarf) and pod (multiple pod) at higher doses/conc may be attributed to the failure in proportional increase of mutagenic frequency induced at higher treatments, drop in the auxin level (Gordon sand Webber, 1955), inhibition of auxin synthesis, inhibition of the formation of meristematic cells which influence plant growth (Skoog, 1935). Double pod mutants obtained in the present study are of special interest since these mutants resulted in improvement in seed yield. Double or twin pods are an indication of high diosgenin content in the seed. Similar result findings were obtained by Singh and Chaturvedi (1980) in *Vigna radiata*, Wani (2009) in chickpea, Bhosle and Kothekar (2010) in cluster bean and Kousar and Babu (2010) in black gram, Goyal *et al.* (2012) in Urdbean, Bashir *et al.*(2013) and Rajariya *et al.* (2015) in Fenugreek, Umavathi. and Mullainathan (2018) in Chickpea and Yasmin *et al.* (2020) in cowpea, Parchin *et al.* (2021) and Jyothsna *et al.* (2022) in Fenugreek.

Table 1 : Mutagenic frequency of morphological mutants between families in M_2 generation of fenugreek in varieties RMt 1 and RMt 354

	Chlorina		Xantha		Tall		Dwarf		Multiple pod	
Families	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**
F1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F2	2.15	2.16	0.54	0.80	0.82	0.80	2.39	2.14	0.00	0.00
F3	2.31	2.34	0.83	1.16	0.86	0.87	2.60	2.60	1.74	1.76
F4	2.56	2.58	0.16	2.54	2.77	2.81	2.53	2.52	3.04	2.78
F5	2.61	2.70	2.35	3.57	1.77	1.79	2.70	2.71	3.62	4.22
F6	3.33	3.58	0.81	1.97	3.53	3.57	3.24	3.59	3.48	3.44
F7	2.96	2.98	0.56	1.46	1.74	1.74	2.67	2.67	0.89	0.90
F8	3.81	3.83	1.86	2.77	3.17	3.11	2.81	2.80	2.16	1.85
F9	5.61	5.98	3.75	3.70	7.92	7.77	6.40	6.71	5.59	5.60

Table 2 : Mutagenic efficiency of morphological mutants between families in M2 generation of fenugreek in varieties RMt 1 and RMt 354

	Mutagenic Efficiency of families									
	Chlorina		**Xantha**		**Tall**		**Dwarf**		**Multiple pod**	
Families	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**
F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F2	0.020	0.021	0.005	0.008	0.008	0.008	0.020	0.021	0.000	0.000
F3	0.009	0.009	0.003	0.005	0.003	0.004	0.010	0.011	0.007	0.007
F4	0.022	0.024	0.015	0.022	0.025	0.025	0.020	0.023	0.027	0.027
F5	0.013	0.011	0.011	0.015	0.009	0.007	0.010	0.012	0.017	0.018
F6	0.011	0.010	0.002	0.006	0.011	0.010	0.010	0.010	0.011	0.010
F7	0.013	0.013	0.003	0.006	0.008	0.008	0.010	0.012	0.004	0.004
F8	0.014	0.013	0.007	0.010	0.012	0.011	0.010	0.010	0.008	0.007
F9	0.013	0.014	0.008	0.009	0.019	0.018	0.020	0.016	0.013	0.013

Table 3 : Mutagenic effectiveness of morphological mutants between families in M2 generation of fenugreek in varieties RMt 1 and RMt 354

	Mutagenic effectiveness of families									
	Chlorina		**Xantha**		**Tall**		**Dwarf**		**Multiple pod**	
Families	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**	**RMt 1**	**RMt 354**
F1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F2	0.0234	0.0234	0.0000	0.0088	0.0088	0.0088	0.0234	0.0263	0.0000	0.0000
F3	0.0117	0.0117	0.0088	0.0058	0.0044	0.0044	0.0117	0.0132	0.0088	0.0088
F4	0.0167	0.0167	0.0204	0.0167	0.0185	0.0185	0.0167	0.0167	0.0204	0.0185
F5	0.0125	0.0125	0.0167	0.0167	0.0083	0.0083	0.0125	0.0125	0.0167	0.0194
F6	0.0100	0.0100	0.0100	0.0056	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100
F7	0.0004	0.0004	0.0001	0.0002	0.0002	0.0002	0.0004	0.0004	0.0001	0.0001
F8	0.0004	0.0004	0.0002	0.0003	0.0003	0.0003	0.0004	0.0003	0.0003	0.0002
F9	0.0003	0.0003	0.0003	0.0002	0.0003	0.0004	0.0003	0.0003	0.0003	0.0003

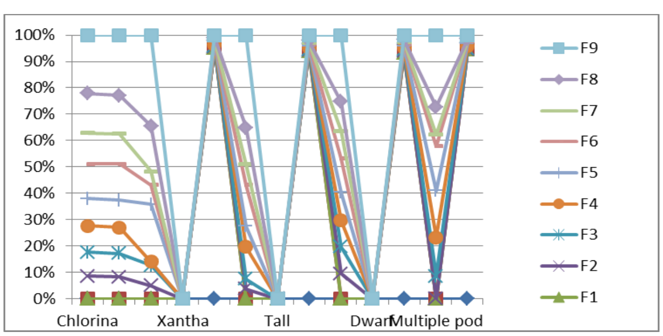

Fig. 1 : Mutagenic frequency of morphological mutants between families in M_2 generation of fenugreek in varieties RMt 1 and RMt 354.

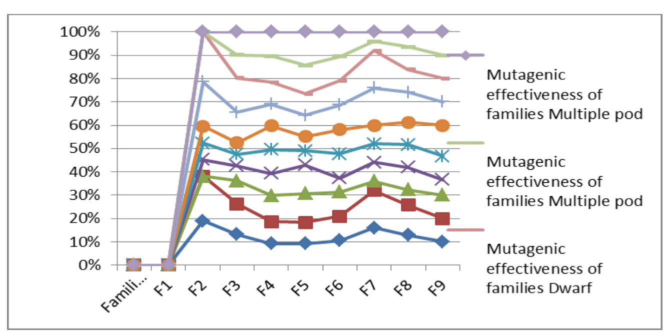

Fig. 2 : Mutagenic effectiveness of morphological mutants between families in M2 generation of fenugreek in varieties RMt 1 and RMt 354.

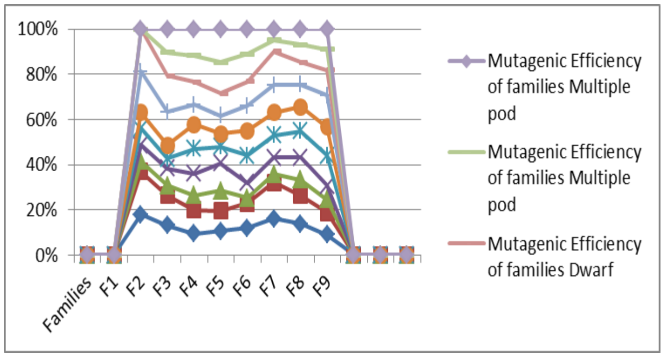

Fig. 3 : Mutagenic efficiency of morphological mutants between families in M2 generation of fenugreek in varieties RMt 1 and RMt 354.

Plate 1 : Morphological mutants viz., Chlorina and Xantha in M2 generation of fenugreek

Plate 2 : Morphological mutants viz., Tall and Dwarf in M2 generation of fenugreek

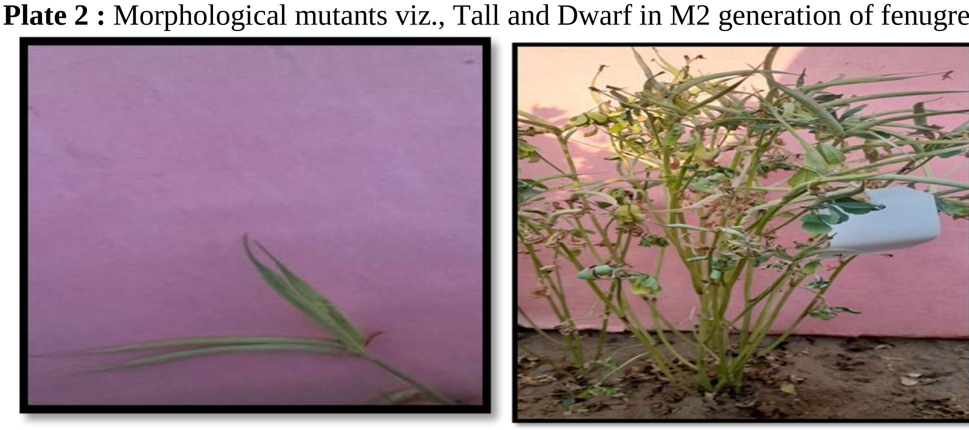

Plate 3 : Morphological mutants viz., multiple pods in M2 generation of fenugreek

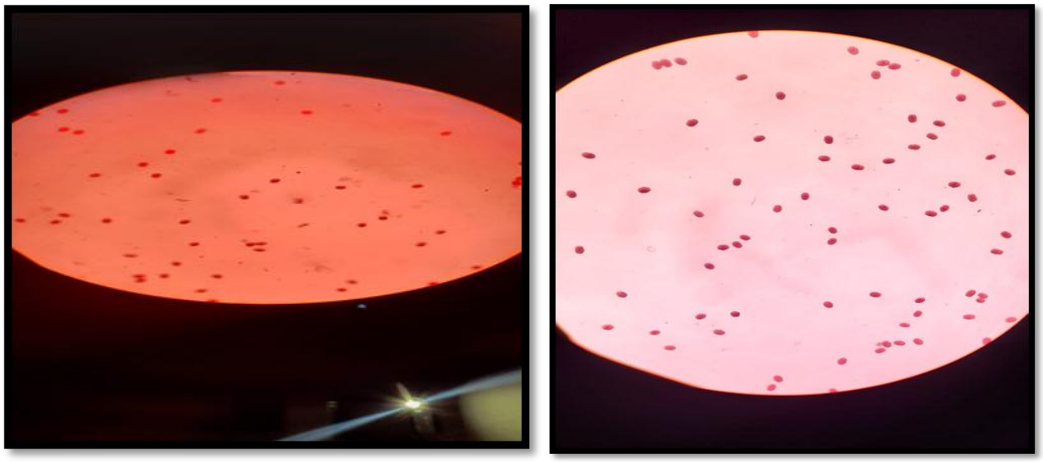

Plate 4 : Viable pollens of mutants in M2 generation of fenugreek

Conclusion

The present investigation was carried out to study the mutagenic efficiency and effectiveness in M_2 generation of fenugreek genotype RMt 1 and RMt 354. Among the gamma rays, sodium azide and their combinations. Sodium azide and their combination treatments were found to be more effective in mutagenicity. The combined treatments with both physical and chemical mutagens are found highly efficient with low biological damage. The effectiveness and efficiency of the mutagens were found to be declining with an increase in the mutagen dose/conc. and their treatment. The longer treatment duration recorded the maximum biological damage and the lower effectiveness and efficiency. The efficiency of mutagenic treatment was determined on the basis of pollen sterility. The mutagenic frequency showed increased with increase in dose or concentration and their combination for getting mutagenic variability and could be further used in next generation. The determination of mutagenic frequency, efficiency and effectiveness enables appropriate decisions on the mutagenic doses for the future works.

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References

Acharya, S. N., Basu, S. K., Acharya, K., Paul, S., Banik, S. D. and Prasad, R. (2011). In *Spices, The Elixir of Life*: De. A. K. (edition.). *Originals, New Delhi*, *India*, **7**, 129-150

Acharya, S. N., Basu, S. K., Banik, S. D. and Prasad, R. (2010). Genotype x environment interactions and its impact on use of medicinal plants. *The Open Nutraceuticals Journal*, **3**(1), 47-54.

Bashir, S., Wani, A. A. and Nawchoo, I. A. (2013). Mutagenic effectiveness and efficiency in Fenugreek (*Trigonella foenum-graecum L.). African journal of biotechnology*, **12**(18), 2437-2440.

Basu, S. K., Acharya, S. N., Bandara, M. S., Friebel, D. and Thomas, J. E. (2009). Effects of genotype and environment on seed and forage yield in fenugreek (*Trigonella foenum-graecum* L.) grown in western Canada. *Australian Journal of Crop Science*, **3**(6), 305-314.

Blixt, S. (1964). Studies on induced mutations in peas. VIII. Ethylene imine and gamma rays treatment of the variety Witham wonder. *Agric Hortique Genetica*, **22**, 171-183.

Bhosle, S. S. and Kothekar, V. S. (2010). Mutagenic efficiency and effectiveness in cluster bean (*Cyamopsis tetragonoloba* (L.) Taub.). *Journal of Phytology*, **2**(6), 21-27.

de Candolle, A. (1964). Origin of cultivated plants. *Hafner, New York***. 7**(4), 272-272.

Fazli, F. R. Y. and Hardman, R. (1968). The spice fenugreek (*Trigonella foenum-graecum* L). Its commercial varieties of seed as a source of diosgenin, *Tropical Science*, **10**, 66-78.

Gaul, H., Frimel, G., Gighner, T. and Ulonska, E. (1972). Efficiency ofmutagenesis. In Induced mutation and plant improvement. *Vienna International Atomic Energy Agency*. **4**(1), 121-139.

Gordon, S.A. and R.P. Webber (1955). Studies on the mechanism of phytohormone. *Plant Physiology*, **30**(3), 200-210.

Goyal, S., Kozgar, M. I. and Khan, S. (2012). Effectiveness and efficiency of gamma rays, ethyl methane sulphonate and their combinations in *Vigna mungo* (L.) Hepper. *Biorem. Biodiv. Bioavail*, **6**, 113-115.

Goyal, S., Wani, M. R., Laskar, R. A., Raina, A., Khan, S. and Raina, A. (2020). Mutagenic effectiveness and efficiency of individual and combination treatments of gamma rays and Ethyl Methane sulphonate in black gram [*Vigna mungo* (L.) Hepper]. *Advances in Zooology and Botany*, **8**(3), 163-168.

Jyothsna, J., Nair, R., Pandey, S. K. and Mehta, A. K. (2022). Determination of Mutagenic Effectiveness and Efficiency of Gamma Rays and EMS in Fenugreek cv. Rmt-1.

In *Biological Forum–An International Journal*, **14**(2), 517-523.

Konzak, C. F., Nilan, R. A., Wagner, J. and Foster, R. J. (1965). Efficient chemical mutagenesis in the use of induced mutations in plant breeding. *Radiation Botany*, **5**, 49-70.

Kousar, M. and Babu, G. S. (2010). Mutagenic effectiveness and efficiency of gamma rays, sodium azide and their synergistic effects in urd bean (*Vigna mungo* L.). *World Journal of Agricultural Sciences*, **6**(2), 234-237.

Laskar, R. A., Laskar, A. A., Raina, A., Khan, S. and Younus, H. (2018). Induced mutation analysis with biochemical and molecular characterization of high yielding lentil mutant lines. *International Journal of Biological Macromolecules*, **109**, 167-179.

Moyer, J. R., Acharya, S.N., Mir, Z. and Doram, R.C. (2003). Weed management in irrigated fenugreek grown for forage in rotation with other annual crops. *Canadian Journal of Plant Science*, **83**, 181-188.

Parchin, R. A., Ghomi, A. A. N., Badi, H. N., Navabpour, S., Mehrafarin, A., & Eskandari, A. (2021). Investigation effect of ethyl methane sulfonate (EMS) on some of morphophysiological and phytochemical traits of fenugreek (*Trigonella foenum-graecum* L.). *Industrial Crops and Products*, **162**, 113239.

Rajoriya, C. M., Rayees, A., Rawat, R. S. and Jat, B. L. (2016). Studies on induction of mutation in fenugreek (*Trigonella fonum-graecum)*. *International Journal for Research in Applied Science and Engineering Technology*, **4**(10), 333-37.

Singh, V. P. and Chaturvedi, S. N. (1980). Mutagenic efficiency of EMS, NMU, gamma-rays and their combined treatments in *Vigna radiata* (L.) Wilczek. *Genetica Agraria*, **34**(4), 331-348.

Skoog, F. (1935). The effect of x-irradiation on auxin and plant growth. *Journal of Cellular and Comparative physiology*, **7**(2), 227-270.

Smith H. H. (1972). Comparative genetic effects of different physical mutagens in higher plants. In Induced mutations and plant improvement, *Vienna-International Atomic Energy Agency*, **3**(1), 75-93.

Umavathi, S. and Mullainathan L. (2018). Mutagenic effectiveness and efficiency of gamma rays and ems on chick pea. *International Journal of Current Research in Life Sciences*, 7(4) , 1426-1428.

Usharani, K. S. and Kumar, C. A. (2015). Mutagenic efficiency and effectiveness of gamma rays and EMS and their combination in inducing chlorophyll mutations in M2 generation of Urdbean (*Vigna mungo* (L.) Hepper). *Electronic Journal of Plant Breeding*, **6**(1), 210-217.

Vavilov, N. (1951). The origin, variation, immunity, and breeding of cultivated plants. *Chronica Botanica*, **13**, 1-364.

Wani, A. A. (2009). Mutagenic effectiveness and efficiency of gamma rays, ethyl methane sulphonate and their combination treatments in chickpea (*Cicer arietinum* L.). *Asian Journal of plant sciences*, **8**(4), 318-322.

Yasmin, K. and Arulbalachandran, D. (2022). Gamma irradiation effects on crop plants. *Research Journal of Biotechnology*, **17**(8), 126-135.