MUTAGENESIS STUDY IN CASTOR
(*Ricinus communis* L.)

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BY

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ABSTRACT

Mutagenesis study in castor (*Ricinus communis* L.) was carried out to induce macro and micro mutational changes in two castor genotypes *i.e*., VP 1 (M) and SKI 215 using sole treatments of chemical and antibiotic *viz*., ethyl methane sulphonate (EMS) and streptomycin sulphate (S.S.). Laboratory study on M_1 generation was carried out at Department of Genetics and Plant Breeding, C. P. College of Agriculture, S. D. A. U., Sardarkrushinagar during the *Kharif* 2020-21 and the field study on M_1 and M_2 generations were conducted at Center for Oilseeds Research, S. D. A. U., Sardarkrushinagar during *Kharif* 2020-21 and *Kharif* 2021-22, respectively.

For mutagenesis, the germinating seeds of two genotypes of castor treated with EMS (50 and 60mM) and streptomycin sulphate (1000 and 1500 ppm) studied by comparing their respective untreated controls. Doses near to LD_{50} value of the mutagens were more effective for inducing more mutants as compared to higher concentration as well as untreated control. The expected LD_{50} values for VP 1 (M) was 65 mM solution of EMS and 1492 ppm solution of streptomycin sulphate. LD_{50} for SKI 215 was found 63 mM of EMS and 1460 ppm of streptomycin sulphate. These estimations were made on the basis of seed germination percentage.

Laboratory and field study in M_1 generation, indicated that germination percentage and plant survival percentage gradually decreased with increase in concentration of mutagens. Different morphological variants were frequently seen in the M_1 progenies of both the genotypes and pollen sterility percentage which ranged between 0.03-73.68 per cent among all the mutagenic treatments. It was also noticed that antibiotic mutagens appeared to cause relatively more sterility than chemical mutagens.

In M_2 generation, progenies of VP 1 (M) and SKI 215 genotype were evaluated in Compact Family Block Design and data of various 10 characters were analysed to study the extent of genetic variability for seed yield and its attributing traits. Evaluation of mutants

revealed that morphological variant like leaf colour, plant height and stem thickness were observed in both the genotypes in M_2 generation. Pollen sterile plants were observed in M_1 and M_2 generation. More sterile plants with higher pollen sterility were observed in M_2 progenies which were derived from partial pollen sterile rather than fully fertile plant of M_1 generation. Periodical observations indicated that increasing in temperature and decrease in humidity increases pollen sterility. Sterility range was found between 12.30-95.83 per cent during growing period in M_2 generation. Frequency of morphological mutants in both the genotypes increased with an increase in dose of mutagenic treatments. The efficiency of mutagenic treatments showed that antibiotic mutagen 1500 ppm streptomycin sulphate is most efficient followed by 1000 ppm solution of streptomycin sulphate and then by 60 mM solution of EMS on VP 1 (M) and SKI 215.

Analysis of variance for progenies within family in M_2 generation indicated that progeny mean squares were significant for all the characters. Family mean of different mutagenic treatments were found shifted toward positive direction for characters like days to flowering, days to maturity, number of node up to primary raceme, effective length of primary raceme, effective branch per plant, seed yield per plant, 100-seed weight and oil content, while toward negative direction for plant height. Both GCV and PCV were high as well as low among most of the characters studied and less differences between respective phenotypic and genotypic coefficient of variation indicated that most of the characters were less influenced by the environment and selection would be efficient.

High heritability with high genetic advance as per cent of mean was observed for plant height up to primary raceme, number of node up to primary raceme, effective length of primary raceme, number of effective branch per plant, number of capsule on primary raceme and seed yield per plant, which indicates that expression of these traits was governed by additive gene action and as a result there was a scope for improving these traits through adopting selection procedure during advancement of progenies of mutant generations.

Treatment of chemical mutagen EMS with concentration of 60 mM proved to be highly efficient on genotype VP 1 (M), while antibiotic streptomycin sulphate with concentration of 1500 ppm proved to be efficient on genotype SKI 215 for overall morphological mutations. Observations on pollen sterility in M_1 and M_2 generation and periodical observations on three pollen sterile plants of M_2 generation indicates that there is ample scope of development of male sterility system in castor crop that can be helpful for development of high purity commercial hybrids.

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This is to certify that the thesis entitled, **"MUTAGENESIS STUDY IN CASTOR (*Ricinus communis* L.)"** submitted for the degree of **DOCTOR OF PHILOSOPHY** in the subject of **GENETICS AND PLANT BREEDING** is a record of bonafide research work carried out by **PARMAR BHUMIKABEN RATNABHAI** under my guidance and supervision and that no part of this thesis has been submitted for any other degree, diploma, associateship, fellowship or other similar titles. The assistance and help received during the course of investigation have been fully acknowledged.

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LIST OF ABBREVIATIONS

%	Per cent
°C	Degree Celsius
$\overline{X}$	Mean
σ^2_g	Genotypic variance
σ^2_p	Phenotypic variance
σ^2_e	Error mean square
Anon.	Anonymous
SDAU	Sardarkrushinagar Dantiwada Agricultural University
CPCA	Chimanbhai Patel College of Agriculture
CD	Critical differences
cm	Centimetre
CV	Coefficient of variation
GA	Genetic advance
d.f.	Degree of freedom
GCV	Genotypic coefficient of variation
PCV	Phenotypic coefficient of variation
h^2_b	Heritability in broad sense
et al.	and others
etc.	Et cetera
Fig.	Figure
VP 1 (M)	Vijapur Pistillate line Modified
SKI 215	Sardarkrushinagar Intersperse
mM	Millimolar
ppm	Parts per million
Min.	Minimun
Max.	Maximum
g	Gram
NS	Non-significant
S	Significant
GM	General mean
Hrs	Hours
ml	Milliliter
i.e.	That is
SEm ±	Standard error of mean
LD_{50}	Lethal Dose at 50% mortality
M_1	Mutagenic generation one
M_2	Mutagenic generation two
MS	Mean sum of square
ANOVA	Analysis of variance
CFBD	Compact Family Block Design
No.	Number
t	Time
c	Concentration
EMS	Ethyl Methane Sulphonate
S.S.	Streptomycin sulphate
pp.	Pages
SA	Sodium Azide

Sr. No.	Serial Number
vs.	Versus
Via	Through
viz.	Namely
NG	Not germinated
NMF	No male flower
NS	Not survive

I. INTRODUCTION

Castor (*Ricinus communis* L., 2n = 2x = 20) is an industrially important non-edible oilseed crop widely cultivated in the arid and semi-arid regions of the world (Govaerts *et al.,* 2000). The genus *Ricinus* is monotypic and *R. communis* is the only species with the most polymorphic forms known. Several of these forms were designated as species (*R. communis, R. macrocarpus, R. microcarpus*) (Weiss, 2000), but they are inter crossable and fertile and are not true species. All the varieties investigated cytologically are diploids and it is presumed to be a secondary balanced polyploid with a basic chromosome number of x = 5 (Singh, 1976). Many of the morphological differences might be due to genic differences, cryptic inversions, duplications, *etc*., rather than changes in the whole chromosome complement (Perry, 1943).

Castor is believed to have most probably originated in Ethiopian-East African region. There are four centers of diversity for castor *viz*., Ethiopian-Eastern African, North-West, South-West and Arabian Peninsula and Sub-continent of India and China. In India, it is known from very early days and is referred in Susruta Samhita written over 2,000 years ago (Gangaiah, 2005). Its monoecious nature favours cross-pollination and it is up to the extent of 50 per cent. It is essentially a semi-tropical, intermediate perennial plant, but it has naturalized as annual/seasonal crop plant throughout the world in frost free zones. It has an ability to grow under low-rainfall and low-fertility conditions, and hence it is most suitable for dry land farming.

India is the world's principal producer of castor and ranks first both in area and production. Castor productivity in India is more than world average and ranks first among the major castor producing countries *viz*., India, China, Brazil and Thailand. In India, castor is being grown for oil under wide ranging environmental conditions. The area, production and productivity of castor in India during 2020-21 were 8.91 lakh hectares, 16.51 lakh tonnes and 1851 kg/hectare, respectively (Anon., 2021[a]). Gujarat, Andhra Pradesh, Rajasthan, Tamil Nadu, Karnataka, Madhya Pradesh, Uttar Pradesh, Maharashtra and Orissa are the main castor growing states in the country. Gujarat ranks first in area, production and productivity, contributing about 80 per cent of the country's area and production. In Gujarat, 13.46 lakh tonnes of castor seed were produced from an area of 6.52 lakh hectares with an average productivity of 2060 kg/hectare during 2020-21 (Anon., 2021[b]). In Gujarat, castor is mainly grown in nine

districts, among which Banaskantha, Mehsana and Sabarkantha are the major castor growing districts.

In Gujarat, real breakthrough in castor production has come with development and release of hybrids for commercial cultivation. This state was first in the development and release of commercial hybrid, wherein a series of hybrids, GCH 3, GAUCH 1, GCH 2, GCH 4, GCH 5, GCH 6, GCH 7, GCH 8, GCH 9, GNCH 1 and GCH 10 have been released for commercial cultivation.

Castor oil plant is a tall, branching perennial shrub that grows to 3 m high and occasionally higher. Castor plants can be grouped into tall and short types. The tall type has a large, well-developed tap-root which can reach several feet in length and has substantial laterals and secondary roots. Dwarf types roots always reflect peculiarity to particular variety or cultural system and show less apparent tap-root. The castor stem is round, sometimes covered with a waxy bloom which gives red or green stems a bluish appearance on the field. The stem colour may be green, red or purple and every graduations of the colour can be seen. The stem colour generally often turn grey-like colour at the base when the castor is old. The presence of plastids in the stem at juvenile stage gives opportunity for additional photosynthetic activity. Under natural environment, the stem is multi-branched, primary branches giving rise to secondary branches, a sequence that continues over the life of the plant. The stem of dwarf types generally becomes hallow with age, but it is usually solid to a considerable height in giant tree-like types. There are well-developed nodes, from each of which a leaf arises. The node at which the first racemes appear is an important agronomic characteristic, since it is associated with maturity. It has stout, hollow branches that are a dull pale green or red. Older branches and trunks turn greyish. Large leaves (10−60 cm across) are widely spaced on the branches and grow on long, stout, hollow stalks attached off-center to the bottom of the leaf. Each leaf is divided into 7−9 pointed triangular segments with toothed edges and conspicuous veins. Leaves are glossy, dark reddish-green when young and glossy green when mature. In some castors, the leaves start – off as dark reddish purple or bronze when young but gradually changing to a dark green, sometimes with a reddish tinge as they mature. The leaves of some others are green practically from the start, whereas in others a pigment masks the green colour of all the chlorophyll – bearing parts. Growth and expansion of castor leaves do not appear to be checked by prolonged sunlight provided there is ample moisture for transpiration. The flowers are crowded in stout,

erect spikes in the forks of the upper branches. Female flowers are in the upper part of the spikes and male flowers at the base. The male flowers shed most of the viable pollens between 1 to 2 days after opening. The pollens normally shed from 2 - 3 hours before sunrise until late afternoon, and there is frequently a peak at mid-morning. The pollens are shed readily between 26 – 29 ºC with a relative humidity of 60 per cent. Days between the opening of female flowers and that of male may varies from 3 to 7 days depending on genotypes. Female flowers develop into fruit about 2.5 cm across that are covered with soft green or red spines. The fruit have three segments, each segment containing one large, mottled, smooth seed. The seed has a tiny and brittle testa (seed coat) enclosing a white kernel. The seeds may be coloured white, dark brownish-red, brown, dark chocolate, red or black but usually several colours occur as very attractive mottle on the testa. The seeds vary greatly in size, from a few milli meters to nearly 25 mm long and in breadth from 5 to 16 mm. The fruit is a globular spiny capsule which becomes hard and brittle when ripe. The castor fruit is usually a schizocarp, typical regma; a capsular fruit with three cells each of which splits open at maturity into separate parts and then breaks away explosively, shattering the seeds. However, some castor varieties produce capsules with rudimentary spines, some produce soft, flexible and non – irritant spiny capsules while other produce spiny irritant. When ripe, the fruit explode violently and throw the seeds a distance of several meters.

Castor is a very ancient oilseed crop cultivated because of high oil content of the seeds, which ranges between 42 to 58 per cent. The castor oil is unique in the sense that 84-90 per cent of it is composed of a single fatty acid, *i.e.*, *ricinoleic* acid. The physical and chemical properties of castor oil are unique because of presence of this 12 hydroxy fatty acid with an 18-carbon backbone. Castor oil although well known for its medicinal properties, this area of utilization is now relatively minor compared with the numerous aspects of industrial uses of the oil. Castor oil has tremendous industrial value and is mainly utilized in the production of lubricants, greases, wax blends, plastics, nylon, hydraulic fluid, artificial leather etc. The refined oil also has a good domestic market as medicines and storage grains preservatives. The castor oil is different from other vegetable oils in the sense that it does not freeze even under adverse temperatures of -12ºC to -18ºC. It is, therefore, considered as the best lubricating agent particularly for both high speed engines and aeroplanes. Castor oil is the source of sebacic acid, which is used in the manufacture of nylon and vinyl resins

(Nagraj, 1996). The castor plants are also grown for rearing 'eri' silkworm for the production of ‘eri silk'. The castor cake is a valuable source of nitrogen (5.5 %) applied in seedbeds and fields to promote early growth of the plant. However, it is poisonous as animal feed because of the presence of a toxic alkaloid "ricinine".

Castor is generally long duration crop *i.e*., 240 days required to complete its life cycle. In current situation to take the advantage of more than one season per year, it is necessary to develop early maturing variety, hence farmers can take advantage of more than one season per year. In hybrid seed production programme, instability of pistillate line create problem in purity of hybrid seeds because instable pistillate line produce male in raceme so purity of hybrid seed will automatically degrade, Therefor, it is require to development of environmental insensitive pistillate line or there is urgent need of CGMS system for castor hybrid.

Mutation breeding requires handling of large population as chances of induction and detection of mutations in the desired genes are rare. That increases the cost of breeding and makes the selection procedure time consuming and tedious. Detection in mutagenic treated population at the early generations, particularly in M_1 generation would no doubt reduce the population load in subsequent generation and provide better scope for selection. However, study in this respect is limited and needs more investigation. For this molecular level can helps for early detection of mutations.

The success of mutation breeding lies in creating appropriate genetic variability without many associated deleterious effects in plant type and its performance in terms of productivity and nutritional alternations. This requires use of appropriate mutagens that could be physical or chemical. The dose of mutagen is equally important to realize desirable variability without deleterious impacts. Micro mutation are expected to be more effective in inducing higher proportion of desirable mutations and providing future base for selection through induction of enormous polygenic variability (Solanki and Sharma, 1999). It leads to changes involving many loci induced in a single genotype resulting from mutation specificity by modifying mutational sites (Prakash and Khansure, 1999). It also depends on effective and need based selection, observing the changes critically at plant level. Mutations are of two types spontaneous or natural and artificial or induced. Frequency of natural mutation is very low and hence, induced mutations are used to obtain genetic variability for qualitative and quantitative traits.

Induced mutagenesis is recognized as a potential tool for crop improvement. Mutants are produced by treating seeds, pollens or other plant parts by radiation or

chemical. Such mutants are either directly released as varieties or used in breeding programme to improve existing cultivars. Moreover, through mutagenic treatments new variants differing on morphological or quantitative characters are also produced. Thus, through this technique desired variability could be obtained with little alteration in whole genome. Proper screening in advance mutation generation may lead to identification of trait specific genotype (genetic variability) or agronomically suitable variety.

Various types of chemicals capable of inducing mutation in plants have been known. They are ethyl methane sulphonate (EMS), methyl methane sulphonate (MMS), diethyl sulphate (DES), ethylene imine (EI), hydroxyl amine (HA), n-nitroso-n-ethyl urea (NEU), nitrous acid (NA), sulphur mustard, 5-bromouracil, sodium azide (SA) etc. Among these, EMS is a potent mutagen belongs to the category of alkylating agents with a chemical formula $C_2H_5OSO_2CH_3$. Its potentiality in inducing mutations was confirmed in Drosophila, Neurospora, Bacteria and also in a number of higher plants species.

Antibiotics are defined functionally on the basis of their anti-microbial activity. This group of compounds includes a multitude of natural and synthetically synthesized substances, which according to their molecular structure, fall into very different classes of compounds. Some antibiotics, such as streptozotocin, mitomycin C or azaserine, can also be included in the group of alkylating compounds and streptomycin, neomycin, penicillin, rifampicin, erythromycin and tetracycline can be used in non-alkylating compound. Streptomycin sulphate is a potent mutagen belongs to the category of non- alkylating agents with a chemical formula $C_{21}H_{41}N_7O_{16}S$. This property of streptomycin in certain concentration was made use of for the purpose of sharply increasing the frequency of mutation of genes in the chromosome of the green algae chamydomonas. The efficiency of streptomycin to induce male sterile mutants was also proved in sugar beet, sorghum and pearl millet (Burton and Hanna, 1982).

Among the non-alkylating mutagenic compounds antibiotics have been the most extensively used in plant mutation breeding, with particular success in the induction of male sterile mutants in a number of plant species. Twenty-two cytoplasmic male sterile (CMS) and 7 nuclear male sterile (NMS) mutants were selected in sunflower (*Helianthus annus*) after treatments of seeds with mitomycin C and streptomycin. Streptomycin proved to be more effective in the induction of male sterility mutations as 18 of the CMS mutants were induced by this antibiotic. Six of these CMS lines have

been released by the USDA-ARS and the North Dakota AES (Jan and Vick, 2006). Athma and Reddy (1986) depicted mutagenic effect through gamma radiation in castor. Ganesan *et al*. (2001) found variation through chemical and gamma rays treatment in castor. Gothaliya and Madariya (2019) studied the effect of mutagens on quantitative characters in M_2 generation of castor.

Keeping all these facts in view, the proposed investigation was carried out using three genotypes of castor with the following objectives

1. To identify the mutagenic efficiency of different mutagens on castor
2. To detect morphological mutants from M_1 and M_2 generations
3. To estimate extent of variation within and between progenies in M_2 generations for different quantitative traits

II. REVIEW OF LITERATURE

The success of any breeding methodology for improving quantitative characters depends primarily on magnitude of usable genetic variability available and its efficient utilization. Therefore, while existence of genetic variability is essential for any crop improvement programme, if not present, then its creation and management becomes central to the crop breeding (Chopra, 1989). The induced mutations have been found quite effective in generating useful variation for polygenically controlled traits (Kumar, 1982). Mutation breeding can, thus, be a valuable supplement to conventional breeding methods in creating variability and even in minor modifications in traits particularly for seed yield and its component characters as well as to rectify the minor defects in otherwise agronomically superior variety including single gene mutations in desired directions.

The concept of induced mutation was developed by Hugo de Vries (1910) and its significance was subsequently demonstrated by Muller (1927) in Drosophila that X-rays mutation, breeder has available several types ionizing radiations namely, gamma rays, alpha and beta particles, protons and neutrons. (Co^{60}) and (Ce^{17}) are the main sources of gamma rays. The discovery of chemical mutagens during Second World War was another milestone in the history of induced mutations. Auerbach (1943) was the first, who clearly introduced the existence of powerful chemical mutagens. Subsequently, many chemical mutagens such as ethyl-methane sulphonate, methyl methane sulphonate, ethylene-imines, nitroso compounds, base analogs and several antibiotics *etc*. have been used in mutation studies. Various antibiotic like streptomycin, neomycin, penicillin, rifampicin, erythromycin and tetracycline can also be used in non-alkylating compound. Rice seeds were treated with streptomycin sulphate, an antibiotic known effect in chloroplast DNA (Sagar, 1972), ethidium bromide and acridine dye that inhibits nucleic acid synthesis and other chemicals that have some specificity for mitochondria and chloroplast but are little known for their nuclear mutagenic action.

2.1 Relative effectiveness and efficiency of mutagens

The mutagenic effectiveness and efficiency of mutagens and their doses are pre-requisite for induction and utilization of mutations. Effectiveness means the rate of mutations as related to dose, while efficiency usually refers to the mutation rate in relation to damage (Nilan, 1964). The usefulness of any mutagen for plant breeding

depends not only on its effectiveness but also up on its efficiency suggested by Konzak *et al.* (1965).

Burton and Hanna (1982) reported that stable cytoplasmic male-sterile lines are necessary for the commercial production of F_I hybrid seed of important crop plants such as sorghum (*Sorghum bicolor* L.) and pearl millet [*Pennisetum americanum* (L.) Leeke.]. The objective of their investigation was to ascertain if streptomycin and mitomycin could help to create stable CMS mutants. Seeds of 'Tift 23DB1' pearl millet were soaked in water solutions of 200 and 500 ppm of streptomycin, and 50 ppm of mitomycin at 5°C for 40 hours. Treated seeds were rinsed in tap water, surface dried, and planted in an isolated field along with a check of untreated seed. Head populations of 32,800, 22,300, 18,000, and 13,000 from seed treated with 0, 200, 500 ppm of streptomycin and 50 ppm of mitomycin contained progeny tested stable cytoplasmic male-sterile (CMS) mutants at frequencies of 1 in 16200, 5575, 4500, and 2600, respectively. The sterility or fertility of CMS mutants crossed with 2 sterility maintainers and 6 fertility restorer inbreds of pearl millet suggests that the induced mutants have sterility maintainer and fertility restorer requirements similar to CMS Tift 23DA, and are similar CMS mutants.

Athma and Reddy (1986) evaluated the mutagenic effects of gamma irradiation at different developmental stages in castor. In the present study the castor plants, at four ontogenetic stages, were exposed to acute doses of gamma rays with an objective to find a stage which gives maximum frequency and wider spectrum of beneficial mutations, besides quantum increases in polygenic variability. In this investigation, irradiation at gametic stage caused highest frequency of chlorophyll and viable mutants with widest spectra besides maximum levels of polygenic variability and M_1 generation observed that mean amount of pollen sterility was maximum at meiotic stage (38.5%) followed by gametic (31.6%), post-gametic (20.2%) and seedling stage (17.7%). Whereas, the seed sterility was maximum at meiotic stage (29.1%) followed by post-gametic (23.0%), seedling (20.8%) and gametic stage (18.1%), suggesting that gametic stage is the most suitable one for irradiation and recovery of useful mutants.

Rao *et al*. (1993) induced streptomycin-resistant mutations in *Solarium melongena* by exposing seeds to ethyl methane sulphonate (EMS). Seed mutagenesis resulted in a high frequency of chlorophyll-deficient mutations and a low frequency of resistant shoots, both of which retained their resistance on subsequent testing. Reciprocal crosses between streptomycin-resistant and -sensitive plants showed a non-mendelian

transmission of the resistance trait. Streptomycin resistance is the first selectable and maternally inherited organelle marker described in brinjal.

Pandey and Datta (1995) used γ rays with a view to mutation breeding in *J. curcas* and the effects of various γ ray doses on cotyledons were studied. Seedlings with 3 rather than the normal 2 cotyledons were observed at frequencies of 5.9, 7.5, 10.9 and 5.0 per cent following the 0, 6, 12 and 18 kR treatments. Changes in cotyledon position, shape and size and stomata number were also observed following irradiation. The results indicated that mutagenesis has the potential of inducing desirable variation in *J. curcas*.

Singh *et al*. (1999) observed the mutagenic effects of gamma rays (10, 20, 30 and 40kR) and ethyl methane sulphonate (0.01, 0.02, 0.03 and 0.04M) alone or in combination (10kR+0.02M, 20kR + 0.02M, 30kR + 0.02M and 40kR + 0.02M) on frequency and spectrum of chlorophyll and macro mutations in two cultivars, namely PDU and T-9 of urdbean. Conclusively, the combination treatments have yielded the higher frequency and spectrum of chlorophyll mutations; whereas the various doses of mutagenic agents have independent response towards macro mutations in both the cultivars.

Mensah *et al*. (2003) exposed seeds of rice (*Oryza sativa* L. cv. ITA 150) to varying concentrations of 0.063-1.00 per cent of hydroxylamine, streptomycin and urea for 24 hours at 28°C. The effectiveness of the three chemicals on rice is ranked as streptomycin> hydroxylamine> urea. They concluded that streptomycin was the most efficient mutagen by inducing high levels of mutation frequency in 1 per cent concentration (12.88%) in terms of morphological and chlorophyll deficiency and pooled sterility that either of the other mutagens used in this investigation. However, the highest concentration of 0.750-1.00 per cent were more efficient in inducing higher mutation frequencies than the lower concentration.

Rathod *et al*. (2004) treated the seeds of two varieties of soyabean (*Glycine max* L. Merrill) *viz*., Monetta and MACS-13 with ethyl methane sulphonate (0.3 and 0.6%) and gamma rays (20 and 25 kR) with the aim to induce mutation. Mutation frequency increased with increase in doses of EMS and gamma rays. The frequency of induced mutation was greater in Monetta than MACS-13. The economical mutants showing characters of early maturity, high oil content and high yield. Total of 78 progenies were isolated from Monetta and MACS-13 treated with 0.6 per cent ethyl methane

sulphonate. In general gamma rays showed higher mutagenic effectiveness than ethyl methane sulphonate in both the varieties.

Elkonin and Tsvetova (2007) studied treatment of sorghum callus cultures with 500–1000 mg/l streptomycin led to a high regeneration frequency of plants with partial or complete male sterility (MS), up to 100 per cent of all green regenerants. The induced MS mutation (ms-str) was preserved in the F_1 and BC_1 progenies and was genetically unstable: many families produced semi-sterile and fertile revertants, whose progenies again contained semi-sterile and sterile mutants. The ms-str mutation was maintained through eight generations *via* selection and self-pollination of semi-sterile plants. The mutation was inherited as a recessive nuclear mutation in test crosses of sterile plants segregated in the progenies of fertile and semi sterile revertants and was expressed only in single cases in a test cross for ms-str transfer through pollen of hybrids with restored male fertility. Recessive nuclear mutations determining a low plant height (dwarfness) and the lack of waxy bloom on the stem and leaves (bloomless) were found in male-sterile plants with the ms-str mutation.

Janila *et al*. (2007) reported three recessive mutants in castor using dry seed irradiation with gamma rays. The crinkled leaf mutant (cri) was identified in K-55-112 M, family and leafy mutant (lea) in H-55-577 M, family; both are recessive lethal and thus maintained as heterozygotes and studied germination and mortality percentage in both varieties. Ten treatment ranging 10 to 100 kR were used to determine the dose resulting in 50 per cent mutagen-caused mortality and the treatment 60 kR showed 50 per cent mortality in both the varieties. The number of leaf lobes is reduced in lea mutant and though it produced spikes, the male and female flowers are converted to leafy appendages. The third mutant, fused (fus) stem identified in H-55-617 M, family is a recessive mutant. The branches of which are fused at the base and though each branch terminates in to monoecious spike like normal plant, the spike is highly condensed. The three mutants under report are valuable genetic stocks for development of linkage maps in castor.

Ramkrishna (2008) studied both M_1 and M_2 generations of certain genotypes of seed spices (fenugreek, cumin, fennel and coriander) resulting from treatment of the mutagens in respect of yield and yield attributes and other phenotypic alterations (Chlorophyll and other 80 macro mutations). Fenugreek was found relatively most radio and chemo-resistant followed by cumin. Mutagenic efficiency also varied

noticeably between crops and mutagens; gamma rays were relatively more potent on cumin as compared to chemical mutagens whereas on fennel it was just reverse.

Kumar *et al*. (2009) exposed seeds (9% moisture content) of two mungbean varieties PS 16 and Sona to six doses (10 to 60 KR) of gamma rays or treated with four concentration of ethyl methane sulphonate (0.1 to 0.4%) alone or in various combination. EMS produced the highest frequency of mutations followed by gamma rays or their combinations.

Kumar and Ratnam (2010) studied single treatment with gamma-rays, sodium azide and combination treatments of gamma rays and sodium azide on seed germination, seedling survival, pollen fertility and seed set in sunflower (*Helianthus annuus* L.). M_2 generation was studied in the varieties of USH-430 and SHSF-333. There was gradual decrease of seedling survival and pollen fertility with an increase in the dose of mutagen in both varieties. The percentage of lethality and achene sterility gradually increased with an increased dose. In USH-430 variety, the seed set percentage was significantly increased at 6kR, 4 mM and 6 kR + 6 mM, respectively. Mutagenic effectiveness decreased with an increased dose or concentration of gamma-rays and sodium azide in both varieties. In combined treatments, mutagenic effectiveness gradually increased with an increased dose. Mutagenic efficiency increased with an increased dose in case of gamma-irradiated seeds in both varieties. Mutagenic efficiency decreased gradually with an increased dose in both varieties.

Pavadai *et al*. (2010) observed the effectiveness and efficiency for M_2, M_3 and M_4 generation of soybean using gamma rays treatment. Effectiveness and efficiency was recorded at increase for low concentration and decrease for high concentration level.

Bhat *et al*. (2011) studied the effect of ethyl methane sulphonate (EMS), sodium azide (SA) and hydrazine hydrate (HZ) on seed germination, pollen fertility and survival at maturity in two varieties *viz*., Avrodhi and BG- 256 of chickpea. A linear and dose dependant decrease on germination, pollen fertility and survival was observed in all the three mutagenic treatments in both the varieties. The maximum reduction in these parameters was observed to be induced by EMS treatments. Variety Avrodhi proved to be more sensitive to the mutagenic treatments than var. BG-256. Estimated values of LD_{50} for EMS, SA and HZ were observed to be 0.363, 0.045 and 0.052 for Avrodhi and 0.457, 0.058 and 0.070 for BG-256, respectively.

Anbarasan *et al*. (2013) irradiated the seeds of sesame genotype TMV3 with different dosages of gamma rays like 10 to 100 KR. The sensitivity of gamma irradiation was observed on different germination and growth parameters such as germination rate (%), seedling height (shoot length), root length, number of lateral branches per primary root and seedling vigour (Vigour index). The results showed that depressive effects were increased with increasing radiation dosages and 50 per cent reduction in germination and seedling size (Injury) was observed at 50 KR of gamma rays irradiated seedlings and it was considered as LD_{50} value (Optimum dose) for gamma rays in sesame.

Burghate *et al*. (2013) studied impact of mutagens, its efficiency and effectiveness in groundnut (*Arachis hypogaea* L.) seeds of TAG-24 variety. In M_1 generation, the germination percentage was reduced due to various mutagenic treatments under field as well as laboratory conditions. Reduction in germination was found maximum in higher dose and/or concentration of the mutagens. The pollen sterility was estimated during M_1 generation and it was found increased significantly with an increased in doses and/or concentrations. Day to 50 per cent flowering and mortality were also found increased with an increased in doses and/or concentrations of the gamma rays, ethyl methane sulphonate and their combinations. The mutagenic efficiency was found maximum in combined treatments of gamma rays with ethyl methane sulphonate followed by sole treatment of gamma rays and ethyl methane sulphonate.

Jahan *et al*. (2016) aimed to study a comparative mutagenic impact of two alkylating agents, ethyl methane sulfonate (EMS) and methyl methane sulfonate (MMS) on seed germination, pollen fertility and meiotic cell division. Seeds of tomato (*Lycopersicon esculentum* Mill.) were subjected to five different doses (0.02%, 0.04%, 0.06%, 0.08%, and 0.10%) of EMS and MMS. A dose dependent reduction in seed germination and pollen fertility was seen by them while an increase in meiotic abnormalities with increasing doses were noticed in mutagenic population of both mutagens in M_1 generation. Various types of abnormal pollen mother cells (PMCs) such as univalents, multivalents, bridges, stickiness, stray chromosomes, laggards, unequal separation, disturbed polarity *etc*., were also recorded at different stages of meiotic cell division. Study revealed that the lower doses of the two mutagens causes less pollen sterility and chromosomal damage as compared to the higher doses. However, MMS is found to be more toxic and effective than EMS treatments. Therefore, they recommended that the lower concentrations of the mutagens could be

used by breeders for inducing desirable mutations and to improve genetic base in tomato based on the above cytological studies.

Laskar and Khan (2017) reported the mutagenic effectiveness and mutagenic efficiency of physical mutagen (gamma rays) and chemical mutagen (hydrazine hydrates; HZ) on two cultivars of lentil (*Lens culinaris* Medik.), *viz*. DPL 62 (macrosperma) and Pant L 406 (microsperma). Dry and healthy seeds were treated with four doses of each gamma rays (100-400 Gy), HZ (0.1-0.4 %) and their combinations. Frequencies of the induced agro-morphological variations into different phenotypic categories were estimated in M_2 population that resulted into identification and isolation of wide range of mutants with altered phenotypes.

Goyal *et al*. (2019) evaluated induced mutant populations of widely recommended T-9 and Pant U-30 varieties of urdbean which were generated using single and combination treatments of gamma rays and ethyl methane sulfonate (EMS). Frequency of morphological mutants was the highest in combined treatments of gamma rays and EMS followed by individual treatments of EMS and gamma rays. Highest frequency (8.84%) was noticed in the combination treatment of gamma rays + EMS, whereas the lowest (6.30%) was witnessed with individual treatments of gamma rays. The spectrum of such mutant types was relatively wide in var. Pant U-30 as compared to the var. T-9.

Parthasarathi *et al*. (2020) recorded the effects of two mutagens, gamma rays and EMS on the phenotypes of two sesame varieties *viz*., TMV7 and SVPR1. A known quantity of dry, uniform and healthy seeds of TMV7 and SVPR 1 were irradiated using Co^{60} (Cobalt 60) with different doses (250, 300, 350, 400, 450 Gy) of gamma rays. For chemical mutagenesis, different concentrations of EMS @ 0.20 per cent, 0.40 per cent and 0.60 per cent was used and treated for 8 h. The dose-response curve of the probit analysis showed that the optimal lethal dose for SVPR1 was lower than TMV7. The expected LD_{50} values of gamma radiation for TMV7 and SVPR1 were 403.91Gy and 343.84Gy, respectively. Mutagenic effectiveness (ME) was maximum (0.68 & 0.72) at 250 Gy in both the varieties *viz*., TMV7 and SVPR1, respectively, while in EMS treatment, significant ME (0.85 & 0.83) was observed at 0.20 per cent concentration in both the varieties *viz*., TMV7 and SVPR1, respectively. Mutagenic effectiveness was higher at lower doses whereas mutagenic efficiency was observed higher at extremity doses in both the varieties. The current studies suggest gamma rays

as an efficient mutagen to induce essential mutations in TMV7 for the further crop improvement program.

Rohini *et al*. (2020) treated the seeds of *Sesamum Indicum* L. with various doses/ concentrations of gamma radiation (Gy-300 to 500Gy), ethyl methane sulphonate (EMS- 0.3 to 0.5%) and sodium azide (SA-0.15, 0.20, 0.25%). The physiological effects on seed germination and seedling height on 7^{th} day after sowing were investigated. Gradual reduction in seed germination and seedling height was recorded with increase in dose/concentration of mutagens. Almost all the mutagenic treatments caused decrease in seed germination, seedling height, seedling injury, pollen sterility and survival of plants at maturity.

Rajderkar and Sakhare (2021) studied the mutagenic effectiveness and efficiency of a physical mutagen *i.e*., gamma rays and chemical mutagen *i.e*., ethyl methane sulphonate in the soybean (*Glycine max* (L) Merill.) varieties JS-335 and JS-9560. The seeds of soybean varieties JS-335 and JS-9560 were mutagenized with the increasing doses of gamma rays (10kR, 20kR, 30kR and 40kR) and ethyl methane sulphonate (0.1%, 0.2%, 0.3% and 0.4%). The effectiveness and efficiency was determined by accounting lethality and seedling injury in M_1 generation of mutagenized seeds and frequency and spectrum of chlorophyll mutations in M_2 generation. The increasing doses of mutagens decreased plant survival and seedling height. It was observed that the frequency of mutations increased with increasing doses of mutagen. The higher mutation frequency was noticed in chemical mutagen than physical mutagen. The highest mutagenic effectiveness was recorded 2.5 per cent in 0.2 per cent EMS and lowest 0.02 per cent in 30kR dose of gamma rays. Whereas maximum mutagenic efficiency was recorded 0.23 per cent in 10kR and minimum 0.13 per cent in 40kR dose of gamma rays. Thus the lower doses of mutagen were effective and efficient than the higher doses in both varieties of JS-335 and JS-9560 and chemical mutagen EMS found more effective and efficient mutagen in soybean than physical mutagen gamma rays which may create genetic variability.

Raina *et al*. (2022) studied genetic diversity in M_2 mutants of cowpea and evaluates mutagenic effectiveness and efficiency of the single and combination doses of γ rays and SA. In M_0 generation, 7200 M_1 seeds obtained by SA treatment (0.01-0.1%) and γ irradiation (100-1000 Gy) at a dose rate of 11.58 Gy/min were sown to raise M_1 generation. A total of 57,620 M_2 seeds were generated from the M_1 generation of two varieties-Gomati VU-89 and Pusa-578, from which 47,650 seeds

germinated. Moreover, plants (38,749) that survived were screened for chlorophyll and morphological mutations. A wide range of morphological mutants affecting every growth stage was recorded with the highest frequency in 400 Gy γ rays + 0.04 per cent SA treatment. These morphological mutants with desirable agronomic traits represent a valuable genetic resource for future breeding programs.

2.2 Morphological mutations

Several induced morphological mutations have been reported in literature showing alterations in the morphology of various plant parts since long long ago.

Chauhan *et al.* (1990) investigated the effect of gamma rays as a source to induce male sterility in castor (*Ricinus communis* L.), an important oil seed crop. The application of spontaneous male sterility in hybrid seed production and the studies on mechanism of male sterility have received much attention during the past three decades. New sources of male sterility are expected to be obtained by interspecific crosses and induced mutations. All the plants raised from gamma-ray irradiated seeds exhibited a significant enhancement in the extent of pollen sterility, and the increase was directly proportional to the increase in the doses of gamma rays. The plants of the 12.5 kR gamma-rays treated population showed only 19.12 per cent pollen sterility, while the plants of the 150 kR gamma ray irradiation were 62.93 per cent pollen sterile.

Iqbal *et al*. (1994) treated socked seeds of *Gossypium hirsum* with gamma rays. From the segregating generations, a high yielding mutant was selected. This mutant has semi-hairy with a compact sympodial habit and medium height. It has 0-2 fruit bearing monopodial branches and has superior fiber quality characters.

Singh and Mohapatra (1997) reported induced mutation in blackgram using digitonin which applied as a pre-treatment chemical just before the treatment with the mutagen, ethyl methane sulphonate (EMS) to enhance the mutagenic effect of EMS through greater uptake of the mutagen into the cells. The M_2 populations were screened for macro-and micro-mutations. The frequency and spectrum of total macro-mutations were substantially increased by digitonin EMS treatment compared to EMS treatment alone. There was also an increase in micro-mutations by digitonin pre-treatment for almost all the quantitative characters except seeds per pod and single plant yield.

Gaur and Gaur (1999) induced in chickpea (*Cicer arietinum*) a fascinated mutant characterized by broad and flat stem, irregular leaf arrangement and clustering of pods

at the stem tip through mutagenesis with ethyl methane sulphonate (EMS). It was isolated in the M_2 derived 77 from seeds treated with 0.4 per cent EMS for 6h. The mutant had delayed maturity, larger seed size and yielded less as compared to its parental cultivar. It was designated as Jawahar gram mutant-2 (JGM-2). The fasciation was found to be governed by a single recessive gene which segregated independently of the loci slv (simple leaf), mlv (multipinnate leaf), blv (bronze leaf) and B (blue flower). The fasciation has been transferred to different genetic background.

Girhe and Choudhary (2002) treated the seeds of variety Pusa-24 of the pulse, *Lathyrus sativus* L. with various doses/concentrations of physical (gamma rays) and chemical (SA and EMS) mutagens. Various morphological mutations were recorded in the M_2 and M_3 generations. These morphological mutations were characterized on the basis of the part of the plant body affected, based on this, 21 different morphological mutants were isolated. Among them, the important mutants from the point of view of breeding were high yielding and early flowering; whereas the pink, peach and white flower colour mutants were important from the ornamental point of view.

Gaikwad and Kotheker (2003) treated the seeds of two lentil cultivars, L-4611 and L-4639 with 3 different concentrations of 2 chemical mutagens, ethyl methane sulphonate (EMS) and sodium azide (SA). Nine morphological mutants were isolated in M_2 and M_3 generations. These morphological mutants were named on the basis of the part of the plant body affected. Among them, 79 the early maturity, high yielding and bold seed type mutants having the potential that can be incorporated into breeding programs were isolated.

Solanki (2005) isolated twelve kinds of morphological mutants in lentil included changes for growth habit (compact, bushy, prostrate), foliage (narrow, broad, rogue, tendrillar), plant height (tall, dwarf), and maturity and flowering behaviour (early, late, sterile) by EMS and SA treatments. The mutations for growth habit and foliage were induced with higher frequency by EMS, whereas those for plant height, maturity and flowering behaviour were induced with higher frequency by SA. For induction of sterility SA was found more effective and efficient than EMS.

Kumar *et al*. (2009) exposed the seeds (9% moisture content) of two mungbean varieties PS 16 and Sona to six doses (10 to 60 KR) of gamma rays or treated with four concentration of ethyl methane sulphonate (0.1 to 0.4%) alone or in various combination. A wide range of chlorophyll and morphological mutants was observed in the M_2. The range was greater with EMS than with gamma rays or combined

treatments. The different types of morphological mutants were induced. The chlorophyll deficient and flower colour mutations are of hardly any economic importance, but the compact, dwarf, early, large pod size and synchronous maturity mutants are agronomically desirable which may be utilized in future breeding programme.

Rakszegi *et al*. (2010) studied the agronomic and morphological properties in mutant hexaploid wheat populations by growing generations M_3–M_6 in a 3-year field experiment. Most of the traits were scored according to UPOV TG/3/11, namely the time of ear emergence, plant height, ear glaucosity, shape, density and length, presence of awns and scurs, seasonal type, and grain colour. Other characters such as visible mutant phenotypes, ear sterility, heterogeneity of head rows, leaf colour and responses to powdery mildew and leaf rust were also studied. Variation in certain bread making quality parameters was also studied. The EMS mutant Cadenza lines studied showed wide diversity in terms of above morphological and agronomic properties.

Roychowdhury *et al*. (2012) used different chemical ethyl methane sulphonate (EMS), sodium azide (SA) and colchicine (COL) with three different concentrations (0.1%, 0.4% and 0.7%) to analyse their effect on seed germination behaviour, survivability and pollen sterility in both first (M_1) and second (M_2) mutant generations in *Dianthus*. It was noted that increase in the dose of EMS and SA, germination percentage and survivability were decreased; whereas colchicine doses were proportional to increase germination percentage at seedling stage, but they were not survived till maturity. In M_1 and M_2, higher lethality over control (44.3 and 32.89, respectively) was shown by 0.7 per cent of SA and EMS, respectively. Pollen sterility was also increased with increasing mutagenic doses. The maximum pollen sterility was 71.8 per cent and 61.1 per cent for 0.7 per cent COL in M_1 and M_2, respectively. So, the effect of chemical mutagenesis on biological parameters with SA (0.7%) treatment in M_1 and EMS (0.7%) treatment in M_2 were much more beneficial as compared to colchicine. For each studied parameter, chemical mutagenesis was higher in M_1 than M_2. Hence, for the first time in *Dianthus*, they reported that these mutagens can be used for improving the germination behaviour and the metrical traits in *Dianthus* cultivar.

Gnanamurthy and Dhanavel (2014) reported effect of EMS (ethyl methane sulphonate) on induced morphological mutants and chromosomal variation in cowpea. It was studied using five different doses of mutagen along with a control in

randomized blocked design with three replications. In respect to morphological mutants there were two types of viable and chlorophyll mutants. Viable mutant contains tall, dwarf, early maturity, late maturity, leaf mutants, pod mutants and flower mutants and maximum number of mutants was recorded at 25 mM of EMS treatment. EMS can damage or modify important components of plant cells and have been reported to affect the morphology, anatomy, biochemistry and physiology of plants differentially depending on the concentration level.

Mangaiyarkarasi *et al*. (2014) evaluated genotypes of periwinkle (C*atharanthus roseus*) using gamma rays and EMS treatment and they found that some of the morphological (viable) mutants were observed in M_2 generation with different dose of gamma rays and EMS treatment an increase in the number of viable mutants were realized in the present study. Dose of 50 mM of EMS produced more number of viable mutants than gamma rays treatments. Tall, dwarf mutants and leaf mutants were observed in different mutagenic treatments and maximum number of mutants were recorded at 50 kR of gamma rays and 50 mM of EMS.

More and Jagtap (2016) studied morphological leaf mutations in *Lablab purpureus* (L.) using chemical mutagens like ethyl methane sulphonate (10mM, 20mM, 30mM and 40mM), gamma radiations (100Gy,200Gy, 300Gy and 400Gy) and gamma rays and ethyl methane sulphonate combination treatment (100Gy + 40mM, 200Gy + 30mM, 300Gy + 20mM and 400Gy + 10mM). The morphological leaf variations were observed in the M_1 and M_2 generations. The variation was observed in the leaf lamina, leaf size, leaf apices, leaf shape *etc*. The normal leaf was with the acute apex but variation observed in the leaf apex with emarginated, acuminate apex. The bifurcated leaf, and aristate, lunate, elongated leaf lamina was also observed in the M_1 Generation.

Laskar and Khan (2017) studied mutagenic effectiveness and mutagenic efficiency of physical mutagen (gamma rays) and chemical mutagen (hydrazine hydrates; HZ) on two cultivars of lentil (*Lens culinaris* Medik.), *viz*. DPL 62 (macrosperma) and Pant L 406 (microsperma). Dry and healthy seeds were treated with four doses of each gamma rays (100-400 Gy), HZ (0.1-0.4 %) and their combinations. Phenotyping of the mutants revealed that growth habits was the most sensitive category to which most of the mutant, followed by leaf different mutation in growth habit like bushy, prostrate, erect *etc*., and in plat size like tall/semi-dwarf/dwarf and flower/pod/seed in both the cultivars studied.

Amin *et al*. (2019) exposed dry and healthy seeds of two varieties of black cumin to different doses of gamma rays and EMS singly and in combination. The observations were recorded on morphological, cytological and physiological parameters in M_1 and M_2 generations to evaluate the mutagenic potency and to induce the desirable genetic variability in the crop. A broad spectrum of morphological variations with different frequencies affecting different plant parts and chromosomal aberrations were screened out in both the varieties in M_1 generation.

Goyal *et al*. (2019) evaluated induced mutant populations of widely recommended T-9 and Pant U-30 varieties of urdbean which were generated using single and combination treatments of gamma rays and ethyl methane sulfonate (EMS). Investigation on induced phenotypic variations in individual plants of M_2 population of different treatments resulted in identification and isolation of sixteen morphological mutant types affecting plant height, growth habit, leaf morphology, growth period, pod and seed.

Purente *et al*. (2020) studied induce morphological mutants in *C. indicum* var. *aromaticum* using EMS treatments with different doses and to analyze the morphological and physiological traits of obtained mutants in expectation of finding favorable mutants. Results revealed significant effects of EMS doses on seed germination. The sample germination rate significantly decreased with increasing of EMS doses. The obtained morphological mutants were two viable types, containing leaf and stem mutants. Overall leaf size was significantly larger as a result of EMS treatments. And the height of mutant plants was significantly higher. Anatomical characteristics exhibited changes in both leaves and stems of the mutant plants. The puncture strength of the bent stem from the mutant plants was low, with weak penetration resistance. The total lignin and cellulose contents of mutant plants stem decreased significantly as a result of the EMS treatments. These results demonstrate the efficiency of EMS to induce mutations in *C. indicum* var. *aromaticum*, and this method can be useful in the future to assist breeding of this plant.

2.3 Effect of mutation on quantitative variations

Importance of genetic variability in any breeding programme is well known as it provides not only a basis for selection but also some valuable information regarding selection of diverse parents to be used in a hybridization programme. The most important function of heritability estimates in the genetic studies of quantitative characters is their predictive role. Possible advance through selection based on

phenotypic values can be predicted only from knowledge at the degree of correspondence between phenotypic and genotypic values. High heritability coupled with high genetic advance has been reported by several workers in mutagenesis population.

Sarkar and Sharma (1987) recorded increased variability over control in all the mutagenized populations in lentil. The characters like flowering duration, primary branches per plant, effective peduncle per plant, pods per plant and seed yield per plant exhibited more variability than seeds per pod and 1000 seed weight in M_2 generation. Among the mutagens, EMS and NED induced greater variability for most of the characters than gamma rays and sodium azide (SA). The interfamily analysis revealed a great deal of heterogeneity among different M_2 families in each mutagenized population using coefficient of variability as a selection parameter. It was possible to isolate the mutated families in each population, and taking coefficient of variability and mean together. A number of families were identified (out of the mutated families) as promising for multiple characters with the frequency: 80.6 per cent with NEU, 75.3 per cent with EMS, 72.2 per cent with SA and 64.0 per cent with gamma rays. Promising M_2 plants were selected for multiple characters through intra family selection in the exceptionally promising families with different mutagens in the order of NEU>EMS>SA> gamma rays.

Mahla *et al*. (1991) treated seeds of two mustard genotypes and their F_1 hybrids with 0.50, 0.75 and 1.0 per cent concentrations of EMS and 80, 100, and 120 kR gamma rays doses. In most of treated populations, the enhancement was more evident in EMS treatment. Induced variations of parents were greater than the induced variations of hybrid in F_2M_2. Thus it was suggested that mutagenesis of F_1 hybrid had no greater advantage for creating variability. The lower dose of 0.5 per cent EMS and 80 kR gamma rays induced as much variation than the higher dose of the mutagens.

Deshpande and Giriraj (1997) irradiated two restorer line of sunflower IV83 (non branching) and RLC 2 (branching) with gamma rays at 10 kR, 15 kR and 20 kR to induce variability for flowering, test weight and oil content. In the M_2 populations of both genotypes the mean values for oil content was increased but the test weight increase was observed only in IV83 genotypes. Shift in mean values was accompanied with increase in range, variance and coefficient of variation for all three traits in the M_2 populations of both genotypes. Increased variation for flowering, test weight and oil content in irradiated population enabled effective selection for desirable genotype.

Sathiyamurthy *et al*. (1998) carried out the genetic studies in okra by treating the two okra cultivars *viz*., Pusa Sawani and Parbhani Kranti with gamma radiation (20 to 80 kR). High heritability with genetic advance as per cent of mean was observed for nodes per plant, fruits per plant and yield per plant. The GCV was comparatively high for branches per plant, nodes per plant, fruits per plant, fruit weight and fruit yield indicated that these characters exhibited high genetic variability.

Singh *et al*. (1999) evaluated the extent of genetic variability in the four quantitative characters in M_2 generation following mutagenesis with gamma rays, ethyl methane sulphonate (EMS) and epichlorhydrin (ECH) in mungbean. The range of induced variability was assessed by basic statistics such as range, mean, variance and coefficients of variation, heritability and genetic advance. Estimates of heritability and genetic advance increased significantly in the treated populations and varied from trait to trait, combination of higher value of heritability and genetic advance were noticed for the characters like pods/plant, seeds/pods and yield/plant.

Kharkwal (2000) generated a wide range of induced polygenic variability in the form of micro mutations observed in M_2 and M_3 generations of chickpea. M_2 population showed a much greater range of variability for all the characters than the controls. High magnitude of increased ranges of variability towards positive side showed that some extremely useful variability has been induced due to followed mutagenic treatments. Mutagens were equally effective in generating variability for quantitative characters and showed a differential response to the different varieties. In general, chemical mutagens were found to be relatively more efficient than physical in generating variability in M_2 and M_3 generations. In M_3 the coefficient of variability was considerably lower than in M_2 for most of the characters suggesting that selection technique employed in M_2 was highly effective and played a key role in shifting useful variability in the positive direction in M_3 generation. The usefulness of induced variability was also evident from the higher estimates of heritability and genetic advance in M_2 and M_3 populations. The study also revealed that characters such as grain yield, number of pods and grains per plant, grain weight and biological yield showed a higher response to mutagenic treatments indicating that remarkable opportunities exist for marked improvement of these polygenic characters in chickpea.

Ganesan *et al*. (2001) created variability through mutation in two cultivars of castor 'TMV5' (maturing in 130-140 days) and 'CO1' (perennial type). Ten doses, from 100 to 1000 Gy were employed. For chemical mutagenesis five concentrations of

mutagens from 10 to 50 mM were tried. The following economic mutants were identified in the dose 300 Gy of gamma rays. Four mutants were identified from the variety TMV 5 with higher proportions of female flowers ranging from 80-90 per cent. These mutants in M_7 generation were identified as good combiners in the development of hybrid combinations.

Javed *et al*. (2003) treated homogeneous seeds of *Brassica campestris* L. cv. Toria with different doses of gamma rays (750, 1000 and 1250 Gy) to induce genetic variability for the selection of new genotypes with improved agronomic traits. After passing through different stages of selection, two promising mutants were selected for further studies. Two selected mutants along with 5 other entries including parent variety were evaluated for yield and yield components like plant height, primary branches, grain yield per plant, oil content *etc*., in yield trials for two consecutive years. The mutant TS96-752 was significantly ($P \leq 0.05$) superior to all other entries in grain yield but at par with FSD 86028-3.

Mensah *et al*. (2003) evaluated seeds of rice (*Oryza sativa* L. cv. ITA 150) which were exposed to varying concentrations of 0.063-1.00 per cent of hydroxylamine, streptomycin and urea for 24 hours at 28°C. Treatment effects on germination, survival, maturity time, number of leaves/plant, dry weight, yield/plant and 100 seed weight as well as polled viability and chlorophyll content have been evaluated. Streptomycin was a more efficient mutagen than hydroxylamine and urea in inducing chlorophyll deficiencies and male sterility. All the three chemicals induced increased spectrum of variability in the characters under study. ITA 150 variety treated grain with streptomycin solution lowest mean (1.60) compared to control (1.65) and high heritability (69.05%) with streptomycin solution. The viable materials possessing variability may, therefore, be used for the genetic improvement of rice. The genetic factors from a sporophytic male sterile plant isolated from streptomycin treatment are currently being transferred to other rice varieties to enhance production of hybrid seeds.

Sheeba *et al*. (2003) treated well filled dry seeds of 2 cultivars of sesame with five doses of gamma rays (30, 40, 50, 60 and 70 kR) and EMS (0.8, 1.0, 1.2, 1.4 and 1.6 %). The treated as well as control population were screened for polygenic variation by recording data on quantitative traits like, plant height, number of branches per plant, number of capsule per plant, number of seeds per capsule and seed yield per plant in the M_2 generation. GCV, heritability in broad sense and genetic advance as per cent of

mean were computed. The enhanced genetic variability for seed yield and its component characters in M_2 generation indicated the scope for effective selection to developed high yielding genotype.

Dwimahyani and Ishak (2004) concluded that induced mutation can be used for improving quality in term of seed production, oil content in seed and early maturity of Jatropha with the aim for bio-diesel in Indonesia. The doses of 10, 15, 20, and 25 Gy of gamma applied to cuttings was able to increase genetic variability in vegetatively propagated plants of Jatropha at M_1V_1 (mutant-l vegetative-1) generation. Selection for desirable trait was done at M_1V_2 (mutant-1 and vegetative-2) generation until homogenous plants obtained. Gamma rays at dose of 20 to 25 Gy damaged several genes controlling growth and development on Jatropha which was shown by dwarf and poor plant growth compared to control (plant without irradiation). Irradiation with the dose of 10 Gy raised genetic variability on plant development which was identified with early maturity, 100 seeds weight was 30 per cent over control, and the number of branch growth was good.

Giriraj *et al*. (2004) treated two restorer lines of sunflower, *viz*., RHA 265 (non-branching) and 6D-1 (branching) with ethyl methane sulphonate (EMS) at 0.5 per cent and 1.0 per cent concentrations to induce variability for days to flowering and test weight. Early flowering mutant lines as flowering ranged from 54 to 75 days in the mutant population 6D-1 genotype at 0.5 per cent EMS treatment observed against 65 to 81 days in the untreated population. In general a wide range of variability in the M_3 generation was observed for flowering and test weight in both the genotypes. Favourable mutant lines for the traits were recovered at 0.5 per cent concentration in comparison with 1.0 per cent concentration. Pedigree selection enabled isolation of early flowering and high test weight mutant genetic stock in both the restorer lines. In the RHA 265 mutant population, high estimates of heritability (86%) were accompanied by moderate genetic advance (16.50) for flowering in contrast to test weight which was accompanied by high genetic advance. In 6D-1, a low to medium heritability estimate was observed for the traits studied.

Patil *et al*. (2004) conducted an irradiation experiment in Indian soybean variety, MACS-450 using various dose of gamma rays, EMS and combination of both. Observations on percentage germination, percentage leaf abnormalities, percentage survival, days to maturity, plant height, pods per plant, seed weight per plant and yield kg/ha were recorded in M_1 generation. Likewise percentage reduction in various

quantitative characters through various treatments were also recorded. The results indicated dose related effect of mutagenic treatments on quantitative traits. Dose of 20 to 25 KR γ rays and 0.10 to 0.20 per cent EMS dose may be optimum to obtain maximum variations in qualitative as well as quantitative traits in M_2 population.

Khatri *et al*. (2005) treated homogeneous seeds of *Brassica juncea* L. cv. S-9 with different doses of gamma rays (750 and 1000 Gy) and EMS (0.75% and 1.0%) to induce genetic variability for the selection of genotypes with improved quantitative and quality traits. After passing through different stages of selection, 17 promising mutants were selected for further studies. Seventeen mutants and its parent were evaluated for yield and yield components like days to maturity, plant height, 1000 seed weight and oil content in the preliminary yield trials for two consecutive years. Three mutants S 97-75/36, S 97-1.0E/20 and S 97-1.0E/21 were significantly ($p \leq 0.05$) superior to all other entries in grain yield and these were also found early in maturity, short stature and having high seed index.

Mensah and Obadoni (2007) investigated the mutagenic effects of different concentrations of sodium azide (0.01 to 0.05%) on groundnut (*Arachis hypogaea* L. cv SS1145B and RMP 91). They found that survival percentage decreased with progressively as the dosage increased in both varieties (25, 6.5%) respectively. The characters studied include; plant height, number of branches per plant, pods/plant, seeds/pod, seeds/plant and 100 seed weight in the M_1 and M_2 generations. Both negative and positive shifts in mean values were recorded as a result of the chemical treatment. They observed that phenotypic variance (2.26, 2.16), genotypic variance (1.41, 1.40) and heritability (62.49%, 74.80%) in both the cultivars, respectively for the number of primary branches per plant. The most effective dosage for inducing mutation/morphological aberration was established at 0.03 per cent. Increases in genetic parameters of variation, heritability and genetic gain under the chemical treatment indicated the possibility of evolving higher yield variants through proper crop selection. Thus, economic traits like pods/plant, seeds/plant with high heritability and genetic gain values in the M_3 generation offer good scope for selection and improvement.

Mishra *et al*. (2007) conducted an experiment to study the macro and micro mutations, in gamma rays induced populations of okra. The dry seeds of okra variety Arka Anamika were treated with gamma rays dose of 15, 30, 45, 60 and 75 kR. Under 30 kR the mean fruit number per plant, fruit length and fruit yield per plant were

increased as compared to control. The estimates of range, environmental, genotypic and phenotypic variance with their coefficients and heritability and genetic advance were higher under 30 and 60 kR but lower in other doses than those of control. 30 kR was emerged as the best treatment with 75 kR to have drastic effect.

Sarwar and Chaudhry (2008) evaluated nineteen M_4 generations of castor mutants obtained by gamma irradiation (100 to 1000 Gy) on DS-30 castor seeds along with this as reference variety over 2006-07 for their possible use in the improvement of castor seed yield. The number of main spike capsule showed the high GCV and PCV (41.71%, 46.45%), respectively with high heritability and genetic advance as per cent of mean (80.60, 66.04%) for number of capsule on primary raceme spike length and number of spike. Traits such as the number of capsule, spike length and number of spike showed strong heritability and good genetic advance. These traits are therefore governed by additive genes and for the improvement of seed yield, selection may be based directly on these attributes.

Dhakshanamoorthy *et al*. (2010) performed mutation studies on *Jatropha curcas* by exposing the healthy and dry seeds to gamma rays *viz*., 5, 10, 15, 20 and 25 KR doses and ethyl methane sulphonate (EMS) *viz*., 1, 2, 3 and 4 per cent. The observations were made for seed germination percentage, growth and yield characters such as root length, shoot length, seedling length and vigour index, plant height, petiole length, days to first flowering, days taken for flowering to fruiting, days taken for fruiting to maturity, total number of flowers per inflorescence, number of fruit bunches per plant and number of fruits per bunch in the treated plants. A minimum decrease in days to first flowering (255), days taken for flowering to fruiting (6) and fruiting to maturity (49) were recorded in 5 KR dose when compared to control. Seeds treated with 5 KR dose of gamma rays and 1 per cent EMS revealed a stimulatory effect, while 25 KR dose of gamma ray except seed germination and 4 per cent EMS treatment showed an inhibitory effect for all the characters studied when compared to other treatments. Minimum seed germination percentage was recorded in the higher dose/concentration of gamma rays/EMS (37% and 24.66% in kR and 4 % EMS respectively). Data obtained in this study were statistically significant at 5 per cent level. The results concluded that treatments of gamma rays were found to be greater compared to those of EMS treatments.

Pavadai *et al*. (2010) studied the yield parameters like plant height, number of branches per plant, number of pods per plant and yield per plant of M_2, M_3 and M_4

generation in soybean using gamma rays treatment. The statistical analysis such as variability, heritability and genetic advance as per cent of mean was high in treated plants than the untreated plants for all the generations. For plant height 50 kR gamma rays produced the highest PCV, GCV, h^2 and GA as per cent of mean in (13.71, 11.68, 72.53, 20.45%, respectively) and maximum mean value for number of branch per plant recorded (4.87) at 50 kR treatment as compared to control (4.27) in M_1 generation and PCV, GCV, h^2 and GA as per cent of mean were recorded in 50 kR gamma rays (9.24, 5.19, 31.54, 6.00%, respectively) for number of branch. So, they concluded that 50 kR of gamma rays treatment was effective than the other doses compared to control.

Srivastava *et al*. (2011) soaked 100 genetically pure seeds of wheat in distilled water for 6 hours, blotted dry and treated with freshly prepared mutagenic solution of 0.02 per cent, 0.04 per cent and 0.06 per cent concentration of sodium azide. In laboratory germination, root length and shoot length were observed. Among the different concentration of sodium azide, highest germination was recorded at control (99.55%) followed by 0.02 per cent concentration (97.11%), 0.04 per cent concentration (95.55%) and lowest at 0.06 per cent concentration (85.77%). Higher concentration of sodium azide reduces the germination percentage, root length and shoot length; however, at low concentration it was at par with control. The magnitude of genotypic & phenotypic variability, heritability and genetic gain for various polygenic traits were also decreases with the increases in concentration of sodium azide. However, yield attributing characters showed both positive and negative shift in mean than those of control. Some of the mutant lines (eight progeny for earliness, one for plant height, three for spike length and grain yield each, two for tillering and four for test weight) were found desirable. These lines were either comparable to or better than control for yield and its components. They found that high PCV (8.43%), GCV (7.05%) and heritability (69.97%) for spike length in family II. It is concluded that sodium azide with 0.02 per cent concentration appear to be most effective mutagenic treatment for induction of micro-mutation in yield component traits and selection in M_2 populations of these treatment would be effective in rectification of simply inherited morphological deficiencies and bringing out lines with yield improvement.

Ahmed *et al*. (2012) recorded morphological data pertaining to different attributes in M_4 and M_5 generations of gamma irradiated castor bean to study correlations, path analysis and some genetic parameters. Number of capsules of main spike, main spike length and number of spikes per plant showed high heritability coupled with high

genetic advance which revealed the preponderance of additive genes and seed yield could be improved via these traits. Among this, highest heritability was observed for days to mature (89.80%). However, length of spike and 100-seed weight may also be considered for improvement in seed yield. They found that GCV (6.54) and PCV (6.61%) value while highest heritability with moderate GAM (89.80%, 11.37%) were observed for days to mature, high heritability for plant height observed maximum (96.3%) in CBM line of castor, length of main spike had high GCV (27.04%), PCV (33.83%), h^2 (68.90%) and GAM (38.04%), and high GCV and PCV value (20.35, 37.42%) and low heritability with moderate GAM (29.60%, 19.49%) was observed for seed yield per plant in M_5 generation of CBM line castor. Moderate PCV (11.17%), GCV (13.08%) and high heritability (72.90%) found for 100 seed weight. On contribution of different morphological traits, 16 mutants yielded higher than the check, however, the maximum seed yield per plant (mean of 02 years) was gained by CBM-7 (209.54 g) followed by CBM-17 (183.35 g) as against the check DS-30 (126.75 g). These prospective mutants can be tested for genetic stability and adaptability over different locations for variety release programme in the country.

Emrani *et al*. (2012) investigated the variability induced by gamma rays for plant height, days to flowering, days to maturity, number of fruits/plant, number of seeds/fruit, 1000-seed weight and seed yield/plant. Seeds of two canola cultivars ('RGS003' and 'Sarigol') were treated with 0, 800, 1000, 1200 Gy of gamma rays and the resultant M_2 and M_3 lines were grown under field conditions. Heritability, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) and genetic advance of mean (GAM) were estimated. Results of analysis of variance indicated highly significant effect of mutagenic doses, genotypes and genotype × dose interaction on the traits, indicating the differential response of genotypes to mutagenic treatments in terms of inducing genetic variations. The results revealed a higher variation in the treated populations than the control for all of the traits, with the highest GCV, PCV and GAM belonging to seed yield per plant. They found that treatment with 1200 Gy mutagen induced the highest heritability of flowering date (96.43%, 93.32%) in both cultivars, respectively, while treatment with 1000 Gy showed the highest values for GCV, PCV and GAM in RGS003 and Sarigol both cultivars. Early maturity in 'Sarigol' cultivar having days to maturity reduction of 5.64 per cent and 10.49 per cent in M_2 and M_3 generations, respectively, while 1200 Gy gamma rays also induced the highest values of GCV (5.04%), PCV (5.12%) and GAM (13.08%) in

M_3 lines of RGS003-1200 and Sarigol-1200 (5.91%, 5.98%, 15.40%), respectively and also high heritability observed 1200 Gy gamma rays in both the cultivar (95.13%, 89.78%, respectively) and the highest phenotypic and genetic coefficients of variation (21.84%, 23.27%) while heritability and genetic advance (88.09%, 54.13%) for plant height were obtained at mutagenic treatment 1000 Gy in 'RGS003'. Whereas these were obtained for 'Sarigol' at 800 Gy-treatment (19.85%, 21.17%, 87.86%, 49.11%, respectively). For seed yield per plant in 1000 Gy gamma rays caused the highest heritability (88.21%), genotypic coefficient of variation (34.61%) and genetic advance (85.81%) in M_2 lines of 'RGS003' ,while 800 Gy treatment lead to the highest amount of these parameters in 'Sarigol' mutant lines (86.53%, 36.41%, 89.43%). The highest variations induced with treatment of 1000 Gy gamma rays in most of the traits in 'RGS003' cultivar, while 800 Gy gamma rays induced similar conditions in 'Sarigol' cultivar.

Ibrahim and El-Degwy (2013) treated the seeds of rice with gamma irradiation and studied its effect in M_1 and M_2 generation. They observed that 15 kR dose recorded the highest mean value of heading date and plant height in both the generations and number of panicles/plant in M_1 generation. The dose of 20 kR recorded significantly higher fertility percentage and number of branches/panicle in M_2 generation and number of panicles/plant in M_1 generation. The dose of 25 KR produced the highest number of panicles/plant and number of spikelets/panicle in M_2 generation with in-significance difference with the control. Among all treatments, the dose of 25 kR gamma radiation produced the highest variations. Mutagenesis has proved to be the handy tool to enhance the natural mutational rate, thereby enlarging the genetic variability and increasing the scope for obtaining desired selections.

Reddy and Dhaduk (2014) treated seeds of two popular okra varieties *viz*., GO-2 and GJO-3 with 20, 30 and 40 kR of gamma rays and 0.15 and 0.25 per cent EMS to raise M_1 generation and the seed obtained from all of the M_1 competitive plants were used to raise M_2 in progeny rows of each of the treatments including control. In M_2 generation, increase in GCV, heritability and genetic advance was considerable under different mutagenic treatments for most of the traits observed in both varieties. In GO-2 genotype the highest genotypic coefficient of variability (GCV) was (8.83) and highest GAM was (13.55%) in 40 kR treatment for number of nodes on main stem and high heritability found (58.55%) in 0.25 per cent EMS

dose and high heritability and moderate genetic advance was observed for the characters number of branches (57.22, 34.06%), respectively. In GO-2, high heritability and genetic advance was observed for some important yield contributing characters like fruit length at 40 kR and 0.25 per cent EMS; fruit weight at 20 kR and 40 kR; and fruit yield per plant at 20, 30, 40 kR and 0.15 per cent EMS. While 40 kR treatment was highest GCV (19.57%), heritability (81.44%) and genetic advance as per cent of mean (36.38%) in character fruit yield per plant. Similarly in GJO-3, high heritability coupled with high genetic advance was observed for fruit length at 30 kR of gamma rays and fruit yield per plant at 20 kR. Thus selection for these characters at specific mutagenic treatments will be effective for improvement in okra.

Gunasekaran and Pavadai (2015) treated groundnut (*Arachis hypogia*) variety VRI-2 with different concentration of physical and chemical mutagen namely gamma rays (10, 20, 30, 40, 50 and 60 kR) and ethyl methane sulphonate (EMS) (0.1, 0.2, 0.3, 0.4, 0.5 and 0.6%). For inducing mutation various concentration of EMS for six hours were applied to 200 seed sample of each concentration and one respective control. The LD_{50} value was observed in 50 kR of gamma rays and 0.5 per cent of EMS. The increasing doses/concentration of gamma rays and EMS decreased variations in phenotypic and yield characters in M_1 generation. The mutagenized populations showed significantly higher variability in the M_2 generation. Maximum kernal yield/plant was recorded at 50 KR gamma rays treatment (30.15 g), while the minimum kernal yield/plant was recorded at 0.1 per cent EMS treatment (23.54 g) when compared to untreated plant (25.64 g), while maximum oil content (50.88%) was observed at 50 KR gamma rays treatment. The minimum oil content (45.25%) was observed at 0.2 per cent EMS treatment when compared to control (49.12%). Mutant lines showing higher yield per plant than the respective parents and checks were isolated in M_2 and subsequent generation having significantly more pod yield and yield components like number of kernel per plant, kernel yield per plant and 100 seed weight *etc*., than the untreated plants.

Ravichandran and Jayakumar (2015) studied the mutagenic effects of different dose/concentrations of gamma rays (30, 40 and 50 KR) and ethyl methane sulphonate (1.0, 1.5 and 2.0 mM) on sesame (*Sesamum indicum* L.) varieties VRI-1. The characters studied include; days to first flower, plant height, number of branch per plant, number of capsule per plant, number of seed per capsule and seed yield

per plant in M_2 and M_3 generations. The treatment at EMS 2.0 mM took more number of days to first flower (42.00 days), while the minimum number of days to first flower (38.00 days) was observed at 40 KR of gamma rays. Plant height was increased in all the mutagenic treatments in this genotype than the control. The maximum plant height was recorded at 40 KR of gamma rays (90.10 cm), while the minimum plant height was recorded at 50 KR of gamma rays (81.75 cm). Maximum number of branches (9.00) was observed at 40 KR of gamma rays. The minimum number of branches (4.00) was observed at 2.0 mM of EMS, while the maximum mean was observed at 40 KR of gamma rays (38.00) and the minimum mean was observed at 2.0 mM of EMS (25.00) for number of capsule per plant. Both negative and positive shifts in mean values were recorded as a result of the physical and chemical treatments. The results indicated the possibilities of evolving higher yield variants through proper selection. Thus, economic traits like number of capsule per plant, number of seed per capsule and hundred seed weight in M_3 generation offer scope for selection and improvement.

The investigation of Wani *et al*. (2017) was aimed to enhance the genetic variability for three quantitative traits *viz*., pod length, number of seeds per pod and 100-seed weight in M_2 and M_3 generations of mungbean following mutagenesis with ethyl methane sulphonate (EMS), hydrazine hydrate (HZ) and sodium azide (SA). Mean pod length did not differ significantly in most of the mutagenic treatments in M_2. However, significant improvement for the trait was exhibited with lower and moderate concentrations in M_3 generation. The mean number of seeds per pod and 100-seed weight increased with lower and moderate concentrations of the mutagens in M_2, whereas M_3 generation showed a complete positive trend of shift. Long pod and bold seeded mutants may be exploited to increase the number of seeds per pod and seed size leading to increased yield potential. The genotypic coefficient of variation, heritability and genetic advance increased manifold in the treated population for all these traits suggesting that mutagen induced variability has the substantial scope to improve the mungbean crop.

Amin *et al*. (2019) exposed dry and healthy seeds of two varieties of black cumin to different doses of gamma rays and EMS singly and in combination. Observations on quantitative traits including plant height, number of fertile branches, number of capsules per plant, number of seeds per capsule and 1000 seed weight showed significant inter-treatment variations at different mutagenic doses. The findings of the present study are encouraging, and showed that significant genetic variability had been induced by the mutagens, thus the rigorous selection of

the desirable mutants may result in the development of improved and high yielding mutants of *Nigella sativa* in subsequent generations.

Deshmukh *et al*. (2018) irradiated sorghum cultivar 'Parbhani Moti' with gamma rays and EMS. The experimental material comprised of 8 different mutagenic treatments of gamma rays and EMS *viz*., 10 kR, 20 kR and 30 kR were gamma rays treatments and 0.1 per cent, 0.2 per cent, 0.3 per cent and 0.4 per cent EMS treatments and 10kR + 0.1 per cent EMS of sorghum cultivar 'Parbhani Moti' with two control treatments *viz*., wet control and dry control. They reported that highest mean value for ear head length was found in treatment T_1 (16.3 cm) and T_4 (15.76 cm) while lowest mean value for ear head length was found in T_3 (15.03 cm) and T_6 (15.23 cm) among Gamma rays and EMS, respectively. The treatments10 kR, 0.1 per cent and 10 kR + 0.1 per cent were superior as compared to control treatments for days to panicle initiation, days to maturity, plant height, ear head length, number of grains per primary, grain yield per plant, 100 seed weight and harvest index.

Maibam *et al*. (2018) tested three sesame entries *viz*., Gujarat Til-4 (GT-4), Gujarat Til-10 (GT-10) and Patan-64 with 0.5 per cent, 1.0 per cent, 1.5 per cent, 2.0 per cent and 2.5 per cent doses of ethyl methane sulphonate (EMS). In M_1 generation, the mutagenic effect of EMS on seed germination with respect to different doses was studied. In M_2 generation, analysis of variance, estimation of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic advance (GA) were undertaken. Characters like plant height, number of pods per plant, 1000 seed weight and yield per plant exhibited high values of GCV and PCV. Whereas number of capsule per plant treatment V_2D_3 (1.5% EMS) recorded high values (32.37) suggesting their superiority than control which was a positive result from mutagenesis. High PCV (41.02%), GCV (38.26%), heritability (87%) and genetic advance as per cent of mean (73.49%) was observed for number of capsule per plant and genotype GT-10 with control dose (D_5) recorded maximum yield per plant, while Patan 64 with dose D_4 *i.e*. 2.00 per cent EMS recorded the least yield per plant. High PCV, GCV (105.00%, 104.26%) and heritability with genetic advance as per cent of mean (98%, 21.84%) observed in yield per plant. High heritability coupled with high genetic advance as per cent of mean were observed for plant height, number of capsules per plant and yield per plant.

Gothaliya and Madariya (2019) studied the mutagenic effects of two different

doses of gamma rays (500 and 750 Gy) on three castor (*Ricinus communis* L.) genotypes JP-94, JI-444 and GP-15-1. The quantitative characters studied include; days to 50 per cent flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of node up to primary raceme, length of primary raceme, effective length of primary raceme, number of effective branch per plant, number of capsule on primary raceme, shelling out turn, seed yield per plant, 100-seed weight and oil content. In JP-15 mean number of the days to maturity of primary raceme for both the treatments is lower than control (140.66). Early variants were observed in 500 Gy (128.70) treatment. In GP 15-1 short variants were observed in 750 Gy (76.44 cm) and tall variants were observed in 500 Gy (83.06 cm) treatment. Mean values for plant height were shifted in both directions in JP-96 and GP-15-1 indicated good variability present for this character. GP-15-1 recorded number of node lower in both the treatments than control and lowest value was observed in 750 Gy (16.74) treatment while it was highest in 500 Gy (89.86) treatment for number of capsule on primary raceme and mean values for 100-seed weight were decreased in JP-96 and GP-15-1 in both the treatments as compared to control. GP-15-1 genotype had highest in control (48.43%) and 750 Gy (48.43%) treatment in oil content. Both negative and positive shifts in mean values were recorded as a result of the physical treatments. The results indicated the possibilities of evolving higher yield variants through proper selection.

Hasan *et al*. (2020) studied the responses of *C. annum*, to the chemical mutagens MMS and EMS (0.1%, 0.25%, 0.50%, 0.75% and 1.0%). The qualitative and quantitative traits were observed from the seedling stage to maturity of chili plant, which includes plant height, leaf size and leaf shape, branch per plant, fruit size, number of pods per plants, weight of 1000 seeds in gram, yield per plant and root length. Statistical analysis of the traits showed the induction of signifcant variations at diferent concentrations of the mutagen treatments. Quantitative traits including plant height and yield per plant showed useful variations for further selection and advancement in the subsequent generations. The observed morphological variations provided valuable genetic resources which will be helpful in improving the agronomic characters in chili breeding program.

III. MATERIAL AND METHODS

The present experiment entitled "Mutagenesis study in castor (*Ricinus communis* L.)" was carried out during *Kharif* 2020-21 and *Kharif* 2021-22. Details of experimental procedure adopted, materials used and techniques followed during the course of present investigation are described as under in this chapter.

3.1 EXPERIMENTAL SITE

3.1.1 Location and experimental site

Laboratory work was conducted at Department of Genetics and Plant Breeding, C. P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat and Field work was conducted at Center for Oilseeds Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat. Geographically; Sardarkrushinagar is situated at 24^0 12' North latitude and 72^0 12' East longitude with an altitude of 154.5 m above mean sea level, which is located in North Agro Climatic Zone-IV of Gujarat state.

3.1.2 Climatic condition

According to agro-climatic conditions of Gujarat state, Dantiwada falls under Agro Ecological Situation II of North Gujarat Agro Climate Zone IV with arid and semi-arid region. The mean annual rainfall of this region is 540 mm. The soil of experimental field was sandy loam with pH 7.5. In general, monsoon is warm and moderately humid; winter is cool and dry, while summer is very hot. The soil of research station is placed into alluvial plane geomorphic unit. The meteorological data on maximum and minimum temperature, relative humidity and rainfall for 2020-21 and 2021-22 were obtained from the Meteorological Observatory, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar and are presented in Appendix-A.

3.2 EXPERIMENTAL MATERIALS

3.2.1 Genotypes

The basic experimental materials consisted of two genotypes of castor *viz*., Pistillate inbreed line: VP 1 (M) and Intersperse staminate inbreed line: SKI 215. The genotype VP 1 (M) and SKI 215 obtained from Center for Oilseeds Research, S. D. Agricultural University, Sardarkrushinagar. The salient features of the genotypes are given in Table 3.1.

Table 3.1: Salient features of two castor genotypes used in the experiment

Sr. No.	Salient features	VP 1 (M)	SKI 215
1	Branching pattern	Convergent	Divergent
2	Days to maturity	70-80 days	110-120 days
3	Plant height (cm)	53	85
4	Stem colour	Green	Mahogany
5	Leaf shape	Deep cup	Flat
6	Bloom	Triple bloom	Double bloom
7	Capsule feature	Spiny	Non-Spiny
8	Spike type	Compact	Semi compact
9	Inflorescence spike types	Pistillate	Interspersed
10	Plant type	Dwarf	Tall
11	Seed shape	Oval	Oval

3.2.2 Mutagens

One chemical and one antibiotic mutagens namely ethyl methane sulphonate (EMS) and streptomycine sulphate were employed for different mutagenic treatments.

Table 3.2: The source and mode of action of mutagens used

Sr. No.	Mutagens	Source	Mode of action
1)	**Chemical mutagen**		
a)	Ethyl Methane Sulphonate (EMS) $C_2H_5OSO_2CH_3$	Eastman Kodak Chemical Rochester, New York 14650 USA Loba Chemicals, India	Alkylation
2)	**Antibiotic mutagen**		
a)	Streptomycin sulphate $C_{21}H_{41}N_7O_{16}S$	Duchefa-Postbus 809, 2003 RV Haarlem, The Netherlands	Non- alkylating

Solutions of mutagens were prepared in double distilled by dissolving appropriate amount of these chemicals at room temperature as given in Table 3.3.

Application of chemical and antibiotic treatments were performed at Department of Genetics and plant Breeding, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar in three sets of treatments and each having hundred seeds of respective genotype. For every experimental set the solutions for treatment of streptomycin sulphate and EMS were prepared fresh. Before giving the chemical treatment to the seeds of both varieties were presoaked in distilled water for 24 hrs than

Table 3.3: Solution preparation for mutation treatments

Sr. No	Treatment	Treatment concentration	Molecular weight (g)	Amount of chemical	Volume (ml)
1	Double distilled water	100%	18.00	50 ml	50
2	EMS	25 mM	124.16	155 mg	50
3	EMS	50 mM	124.16	310 mg	50
4	EMS	60 mM	124.16	372 mg	50
5	EMS	75 mM	124.16	465 mg	50
6	EMS	100 mM	124.16	620 mg	50
7	EMS	125 mM	124.16	776 mg	50
8	Double distilled water	100%	18.00	50 ml	50
9	Streptomycin sulphate	500 ppm	679.70	25 mg	50
10	Streptomycin sulphate	1000 ppm	679.70	5 mg	50
11	Streptomycin sulphate	1500 ppm	679.70	75 mg	50
12	Streptomycin sulphate	2000 ppm	679.7	100 mg	50
13	Streptomycin sulphate	2500 ppm	679.7	125 mg	50

after immersed in mutagen solution for overnight with intermittent shaking. After completion of incubation period, the treated seed samples were surface dried on a blotting paper. Seeds of both the genotypes only presoaked in distilled water were used as controls for respective genotype. The set of treatment were grown in germination paper at laboratory condition and same was also grown in field condition as second set and then germination percentage was counted after 15 days.

3.3 STDIES IN M_1 GENERATION

3.4 EXPERIMENTAL METHODS

First set of experiment to study effect on germination by different concentration of EMS and streptomycin sulphate treatments (Table 3.4) seed was conducted at Laboratory of Department of Genetics and Plant Breeding, C. P. College of Agriculture, S. D. Agricultural University during *kharif*-2020. Using fresh hundred seeds per treatment of both the genotypes namely VP-1 (M) and SKI- 215 were treated with chemical and antibiotic mutagens germinated in germination paper.

Table 3.4: Details of mutagenic treatments for first and second set

Treatment	Genotypes	Mutagens	Concentration	Number of seed treated
T_1	VP 1 (M)	Control (Water)	Distilled Water	100
T_2	VP 1 (M)	EMS	50 mM	100
T_3	VP 1 (M)	EMS	60 mM	100
T_4	VP 1 (M)	Streptomycin sulphate	1000 ppm	100
T_5	VP 1 (M)	Streptomycin sulphate	1500 ppm	100
T_6	SKI-215	Control (Water)	Distilled Water	100
T_7	SKI-215	EMS	50 mM	100
T_8	SKI-215	EMS	60 mM	100
T_9	SKI-215	Streptomycin sulphate	1000 ppm	100
T_{10}	SKI-215	Streptomycin sulphate	1500 ppm	100

Second set treated as in first set (Table 3.4) were also surface dried and immediately sown in the soil at Center for Oilseeds Research, S. D. Agricultural University, Sardarkrushinagar during *kharif*-2020 in field condition. Different concentration were evaluated by counting their germinated healthy seedlings of both genotypes.

Third set of the experiment was formulated immediately on the basis of results obtain from first and second set. The aim of this experiment was to identify LD_{50} dose of concentration of mutants on the basis of germination. (Table 3.5). Experiment was conducted using germination papers in the laboratory at Department of Genetics and Plant

Breeding, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar during *kharif*-2020.

Table No. 3.5: Details of mutagenic treatments for third set

Sr. No.	Treatment	VP 1(M)	Treatment	SKI-215
1.	LD T_1	(Water) 0	LD T_{12}	0
2.	LD T_2	EMS 25 mM	LD T_{13}	EMS 25 mM
3.	LD T_3	EMS 50 mM	LD T_{14}	EMS 50 mM
4.	LD T_4	EMS 75 mM	LD T_{15}	EMS 75 mM
5.	LD T_5	EMS 100 mM	LD T_{16}	EMS 100 mM
6.	LD T_6	EMS 125 mM	LD T_{17}	EMS 125 mM
7.	LD T_7	S.S 500 ppm	LD T_{18}	S.S 500 ppm
8.	LD T_8	S.S 1000 ppm	LD T_{19}	S.S 1000 ppm
9.	LD T_9	S.S 1500 ppm	LD T_{20}	S.S 1500 ppm
10.	LD T_{10}	S.S 2000 ppm	LD T_{21}	S.S 2000 ppm
11.	LD T_{11}	S.S 2500 ppm	LD T_{22}	S.S 2500 ppm

3.5 OBSERVAIONS RECORDED IN M_1 GENERATION

3.5.1 Macro mutations / Morphological variants

(i) Plant height (Tall or Dwarf)

(ii) Stem thickness

(iii) Flower morphology

(iv) Pollen characteristic: Pollen sterility/fertility

Pollen sterility study under light microscope

Fresh and young male flower buds of individual plants from field were taken each and every plant of the treatment as well as control. The pollen grains from freshly dehisced anthers were spread in a drop of stained (1% aceto-carmine) on glass slides and observed under microscope at 10X and 40X. Pollen grains stained as uniform deep red colour were counted as fertile and others as sterile. Pollen sterility was determined by counting sterile pollen from total pollen under light microscope from individual plants per treatment along with control.

Aceto-carmine test

Materials:

Carmine powder - 1g

Glacial acetic acid - 45 ml

Distilled water - 55 ml

Ferric acetate – 2 drops

Procedure:

a. Add 55 ml of distilled water to 45 ml glacial acetic acid to form 45 % acetic acid solution.
b. Heat a conical flask up to boiling and add one gram carmine powder slowly to the boiling solution.
c. Cool the solution at room temperature for 12 hours and filter the same using filter paper.
d. Add two drops of saturated aqueous solution of ferric acetate to increase the keeping quality of the stain.
e. Store the solution in a glass stopper bottle or dropping bottle in dark place, preferably in a refrigerator.

Pollen sterility counts:

Pollen grains stained dark red color were counted as fertile and the pollen grain stained with light or not stained at all were counted as sterile.

$$\textbf{Pollen sterility (\%)} = \frac{\text{No. of unstained pollens}}{\text{Total no. of pollens}} \times 100$$

(v) Leaf: Shape, colour (chlorotic leaves or non-chlorotic leaves)

3.5.2 Germination

The number of seeds germinated were recorded at final count for each treatment was recorded on 15th day as after sowing to estimate germination and as presented in percentage over the control.

Germination percentage was calculated by using the following formula:

$$\textbf{Germination (\%)} = \frac{\text{Total no. of seeds emerged}}{\text{Total no. of seeds sown}} \times 100$$

3.5.3 Plant survival

All such plants which reached up to flowering were counting. The survival percentage was calculated as the proportion of seedlings reached at flowering to the total seeds germinated.

Survival percentage was calculated by using the following formula:

$$\textbf{Plant survival (\%)} = \frac{\text{Total no of plants survived}}{\text{Total no. of plants emerged}} \times 100$$

3.6 STUDIES IN M_2 GENERATION

3.6.1 Raising of M_2 generation

M_2 generation were raised during *Kharif* 2021-22 at Center for Oilseeds Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. Gujarat in a Compact Family Block Design with three replications. The experiment consisted of 10 main treatments (families). Ten progenies selected randomly from each treatment of M_1 and they were self-fertilized using paper bags enclosed with 'U" pins. Self-seeds of those 10 plant considered as progenies of respective family were utilized for growing M_2 generation in a plant to progeny manner from respective treatments which were considered as families. All the treatments including untreated controls of both the genotypes was consisted to families and randomly selected ten plants to progenies which have sufficient seed that were grown to three replication *i.e.*, ten dibbled of each progeny grown in compact family block design per replication (10 family × 10 progenies × 10 dibble per replication × 3 replication = 3000 dibbles).

Table 3.6 Experimental details of M_2 generation

Experimental design	CFBD (Compact Family Block Design)
Treatment (as family)	Mutagen (EMS 50 mM, EMS 60 mM, streptomycin sulphate1000 ppm, streptomycin sulphate1500 ppm) = 10 (Mutation Treatment)
No. of progeny	10 (plant to row)
Replication	Three
Genotype	Two genotypes (VP 1 (M) and SKI 215)
Spacing	120 cm × 60 cm
Plot size	Single row of 6 m length
Cultural practices	As per standard package of practices

Seeds were dibbled by hand, at a spacing of 120 cm between rows and 60 cm between plants within row. The crop was irrigated as and when required; other cultural and agronomical practices were followed as per recommendation for raising castor crop in this region.

3.6.2 Observations recorded in M_2 generation

A. Estimation of mutagenic effectiveness and efficiency

Mutagenic effectiveness is defined as a measure of frequency of mutation induced

by a unit of mutagen while mutagenic efficiency is the proportion of mutation in relation to the other associated undesirable effects such as lethality injury, which estimated using the formula suggested by Konzak *et al.* (1965).

Formula:

(1) Mutation Frequency $= \frac{\text{Number of mutated seedling}}{\text{Total number of } M_2 \text{ plants}} \times 100$

Mutagenic effectiveness: Mutagenic effectiveness is the ratio of mutagenic frequency to the dose of mutation.

(2) Mutagenic effectiveness $= \frac{\text{Mutation frequency}}{\text{Concentration of mutagen x time of treatment (hrs)}} \times 100$

(3) Mutagenic efficiency $= \frac{\text{Mutation frequency}}{\text{Lethality (L)}}$

(4) Lethality (L) = 100-Germination percentage

(5) Correlation coefficient (r) $= \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2}\sqrt{(Y-\bar{Y})^2}}$

3.6.3 Macro mutations

Observations were recorded as mentioned as above in M_1 generation as 3.5.1.

3.6.4. Micro mutations

Observations in M_2 generation were recorded on all the survived plants in each progeny and mean were calculated for all the characters. Methods of recording observations in M_2 generation (including the control progenies) are described as under.

(i) Days to flowering of primary raceme

Number of days taken from sowing to initiation of flowering in primary raceme of the plants were recorded during the flower initiation period.

(ii) Days to maturity of primary raceme

Number of days from sowing to maturity of 50 per cent of the capsules in primary raceme of plants were recorded.

(iii) Plant height up to primary raceme (cm)

The height of the plant from the base of plant to the base of primary raceme were measured in centimeters at the time of maturity.

(iv) Number of node up to primary raceme

The total number of nodes from cotyledonary node to the base of primary raceme

were counted at the time of maturity.

(v) Effective length of primary raceme (cm)

The length of capsule bearing portion of primary raceme were measured in centimeters at the time of maturity and considered as effective length of primary raceme.

(vi) Number of effective branch per plant

The total number of raceme bearing branch were counted and recorded at the time of maturity.

(vii) Number of capsule on primary raceme

The total number of capsule born on primary raceme were counted at the time of maturity.

(viii) Seed yield per plant (g)

All the capsules bearing racemes from individual plant were threshed and cleaned and dried seeds were weighed in grams on an electronic balance.

(ix) 100-seed weight (g)

Random sample of 100-seeds were taken from individual plants and were weighed in grams.

(x) Oil content (%)

The oil content of random bulk seed sample of the plant were estimated by Nuclear Magnetic Resonance (N.M.R.) technique.

3.7 ANALYSIS OF VARIANCE FOR EXPERIMENTAL DESIGN

M_2 generations field data were analyzed in Compact Family Block Design (CFBD) as per Panse and Sukhatme (1995).

3.7.1 Analysis of induce variability

The relative effects of mutagenic treatments in inducing variability for different quantitative traits were estimated as per the method suggested Panse and Sukhatme (1995) for Compact Family Block Design. This was done by determining the following components of variance. The analysis was carried out in two stages, first between family and secondly between progenies within family.

(a) First from the data of main plots, the variance between treatment and corresponding pooled error were calculated by treating the experiment as one in a simple randomized block design. The structure of ANOVA for families is given below:

Source	d.f.	M.S	E.M.S
Replications	(r-1)	M_r	$\sigma^2_e + f\,\sigma^2_f$
Families	(f-1)	M_f	$\sigma^2_e + r\,\sigma^2_g$
Error	(r-1)(f-1)	M_e	σ^2_e

(a) The analysis for progenies within family was done separately for each character using the data of sub plots to give the variance between different selection procedures and corresponding error. The structure of ANOVA for progenies within families is given below:

Source	d.f.	M.S	E.M.S
Replications (r)	(r-1)	M_r	$\sigma^2_e + p\,\sigma^2_f$
Families (f)	(f-1)	M_f	$\sigma^2_e + r\,\sigma^2_g$
Error	(r-1)(f-1)	M_e	σ^2_e
Progenies within the family (f)	f (p-1)	M_p	$\sigma^2_e + r\,\sigma^2_g$
Error (b)	f (r-1)(p-1)	M_e	σ^2_e

Where,

r = Number of replications

f = Number of families within treatment

p = Number of progenies within family

M_f = Mean sum of square due to families within each treatment

M_r = Mean sum of square due to replication

M_p = Mean sum of square due to progenies within families

Me = Mean sum of square due to error

(1) Standard error of mean (S.Em.) = $\sqrt{\frac{\sigma^2_e}{r}}$

Where, σ^2_e = Error mean square

r = Number of replications

(2) Critical difference (C.D.)

The critical difference (C.D.) to compare the mean of any two genotypes was calculated using following formula;

C.D. = S. Em. x $\sqrt{2}$ x t at error df (P = 0.05)

Where,

t = Table value of 't' at 5 % level of significance at error degree of freedom

The coefficient of variance (CV) was calculated by using the following formula

$$CV\ (\%) = \frac{\sqrt{\sigma_e^2}}{\bar{x}} \times 100$$

Where,

CV% = Coefficient of variation

Me = Error mean sum of square

$\bar{x}$ = General mean

(3) Mean

It is computed by dividing the sum of all observation in a sample by their number. Thus,

$$\bar{x} = \frac{\sum x_{ijn}}{N}$$

3.7.2 Estimation of variance components

The mean squares due to genotypes and error were used for calculation of variance components by manipulation of expected mean squares as shown below.

3.7.2.1 Estimate of genotypic and phenotypic Variances

Genotypic and Phenotypic variances were calculated as suggested by Johnson *et al*. (1955).

(a) Genotypic variance $(\sigma^2_g) = (M_g - M_e)/r$

(b) Phenotypic variance $(\sigma^2_p) = \sigma_g^2 + \sigma_e^2$

3.7.2.2 Genotypic and phenotypic coefficient of variation

GCV and PCV were calculated as per the formula suggested by Burton (1952).

(a) Genotypic coefficient of variation (GCV)

$$GCV\ (\%) = \frac{\sqrt{\hat{\sigma}^2_g}}{\bar{x}} \times 100$$

(b) Phenotypic coefficient of variation (PCV)

$$PCV\ (\%) = \frac{\sqrt{\hat{\sigma}^2_p}}{\bar{x}} \times 100$$

Where, σ^2_p = Phenotypic variance

σ^2_g = Genotypic variance

$\bar{x}$ = General mean of the character under study

GCV and PCV are classified as suggested by Johnson *et al.* (1955) as following

Range	Class name
0-10 %	Low
10-20%	Moderate
More than 20%	High

(c) Phenotypic range

It is the difference between maximum and minimum value in a particular trait.

Range = Maximum value – Minimum value

3.7.2.3 Heritability in broad sense (H^2_b)

It is the proportion of phenotypic variability that is due to genetic reasons. It was computed in per cent using the formula given by Allard (1960).

$$h^2 = \frac{\hat{\sigma}^2_g}{\hat{\sigma}^2_p} \times 100$$

The heritability was classified as suggested by Johnson *et al.* (1955) as following:

Range	Class name
0-30 %	Low
30-60 %	Moderate
More than 60 %	High

3.7.2.4 Genetic advance (Gs)

The expected genetic advance under selection (Gs) was estimated as per the formula described by Allard (1960).

$$Gs = k \times \sigma_p \times h^2$$

Where,

K = Selection differential (value of k at 5% selection intensity = 2.06)

σ_p = Phenotypic variance

h^2 = Heritability fraction

3.7.2.5 Genetic advance as per cent of mean (GA %)

The formula given by Johnson *et al*. (1955) was followed for estimating the genetic advance as per cent of mean.

$$\text{GA (\% of mean)} = \frac{GA}{\bar{X}} \times 100$$

Genetic advance as per cent of mean classified as suggested by Johnson *et al*. (1955) as following:

Range	**Class name**
0-10 %	Low
10-20 %	Moderate
More than 20 %	High

IV. RESULTS AND DISCUSSION

Mutation breeding is a useful technique for creation and selection of desirable variability in a crop. Physical, chemical and antibiotic mutagens provide handy tools to enhance natural mutation rate, thereby enlarging the genetic variability and increasing the scope of obtaining desired mutants. Genetically mutant varieties shows maximum yield and good quality of the crop. Macro mutation can be used as a variety or a donor for bringing desirable traits into the well adapted cultivars. The possible cause of these macro mutations may be due to chromosomal aberrations, small deficiencies or duplications and most probably gene or point mutations (Vairam and Ibrahim, 2014).

The presence of genetic variability for economic traits is a key point for improving the locally adapted varieties with regard to specific traits. The present investigation on "Mutagenesis study in castor (*Ricinus communis* L.)" was carried out to study the effect of chemical and antibiotic mutagens on germination, plant survival, morphological variants, macro mutations and induced variability in quantitative characters. Two generations *viz*., M_1 and M_2 of two varieties of castor VP 1 (M) and SKI 215 were studied. The results obtained are presented as below.

4.1 STUDIES IN M_1 GENERATION

Preliminary experiment was conducted using two genotypes of castor *viz*., the pistillate inbred line VP 1 (M) and intersperse staminate inbreed line SKI 215 using different levels of doses of EMS and streptomycin sulphate as mention in methodology-3.4. The experiment grown was having two sets. One set was conducted in laboratory using hundred seeds of each castor genotype treated by respective treatment and were grown in germination papers. The germination percentage were recorded after 15 days. The germinated seeds (seedling) were further grown in field by taking all care. For survival count second set was grown directly in field. Per cent plant survival of seedling obtained from germinated seeds of seedlings in first set of experiment and both germination and plant survival were recorded second set of experiment.

4.1.1 Estimation of LD_{50} based on germination

On the basis of result of per cent germinations in preliminary experiments another set of treatments were formulated to estimate LD_{50}. LD_{50} values for both the genotypes determined based on seed germination in laboratory using germination paper and observations taken after 15 days. The value for germination were presented in Table 4.1.

The genotypic differences for both the mutagenic treatments were observed. The

genotype VP 1 (M) was more sensitive to both the mutagens. Concentration response curve were drawn and depicted in Fig. 4.1, 4.2, 4.3 and 4.4 for both genotypes with different treatments. Preliminary observations and trend of observed data along with actual graph indicating that LD_{50} value of EMS was found to be in between 50 mM and 75 mM whereas in case of streptomycin sulphate treatments, it was in between 1000 ppm and 1500 ppm for both the genotypes. Considering all these the trend equation was established by using Ms-office Excel file by using trend command. The LD_{50} (*i.e.*, for 50% germination) was computed using respective equations in which value of Y was kept 50 and value of X (*i.e.*, concentration of mutation) was calculated. By this estimated LD_{50} concentration for EMS was 65 mM and 1492 ppm in case of streptomycin sulphate. These concentrations are ideal for mutagenic treatment in case of castor genotype VP 1(M). Whereas 63 mM for EMS and

Table 4.1: Germination percentage of different treatments calculated on germination of respective controls

Sr. No.	Mutagen	Concentration	No. of seed germinated out of 200	VP 1 (M)	No. of seed germinated out of 200	SKI 215	Pooled
1	Control	0	182	100	186	100	100
2	EMS	25mM	158	86.81	160	86.02	84.41
3	EMS	50mM	98	53.85	98	52.69	49.42
4	EMS	75mM	74	40.66	71	38.17	39.41
5	EMS	100mM	38	20.88	40	21.50	21.19
6	EMS	125mM	18	9.89	12	6.45	8.17
7	Control	0	188	100	190	100	100
8	Streptomycin sulphate	500 ppm	161	85.64	164	86.32	85.98
9	Streptomycin sulphate	1000 ppm	112	59.57	115	60.53	60.05
10	Streptomycin sulphate	1500 ppm	72	38.30	70	36.84	37.57
11	Streptomycin sulphate	2000 ppm	59	31.38	58	30.53	30.95
12	Streptomycin sulphate	2500 ppm	38	20.21	32	16.84	18.52

Note: Germination for respective treatments are expressed as per cent over the respective control in lab condition

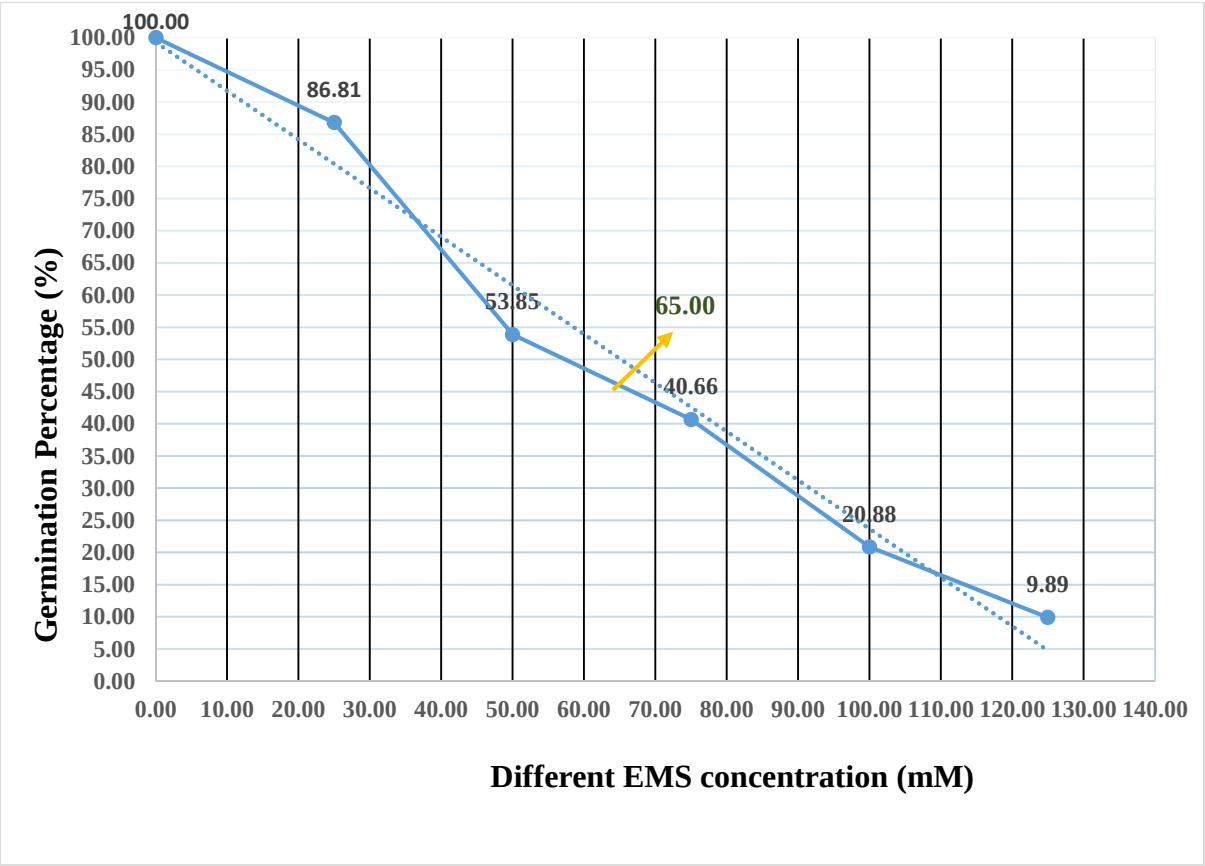


Fig. 4.1 Germination percentage of castor genotype VP 1 (M) EMS treatment

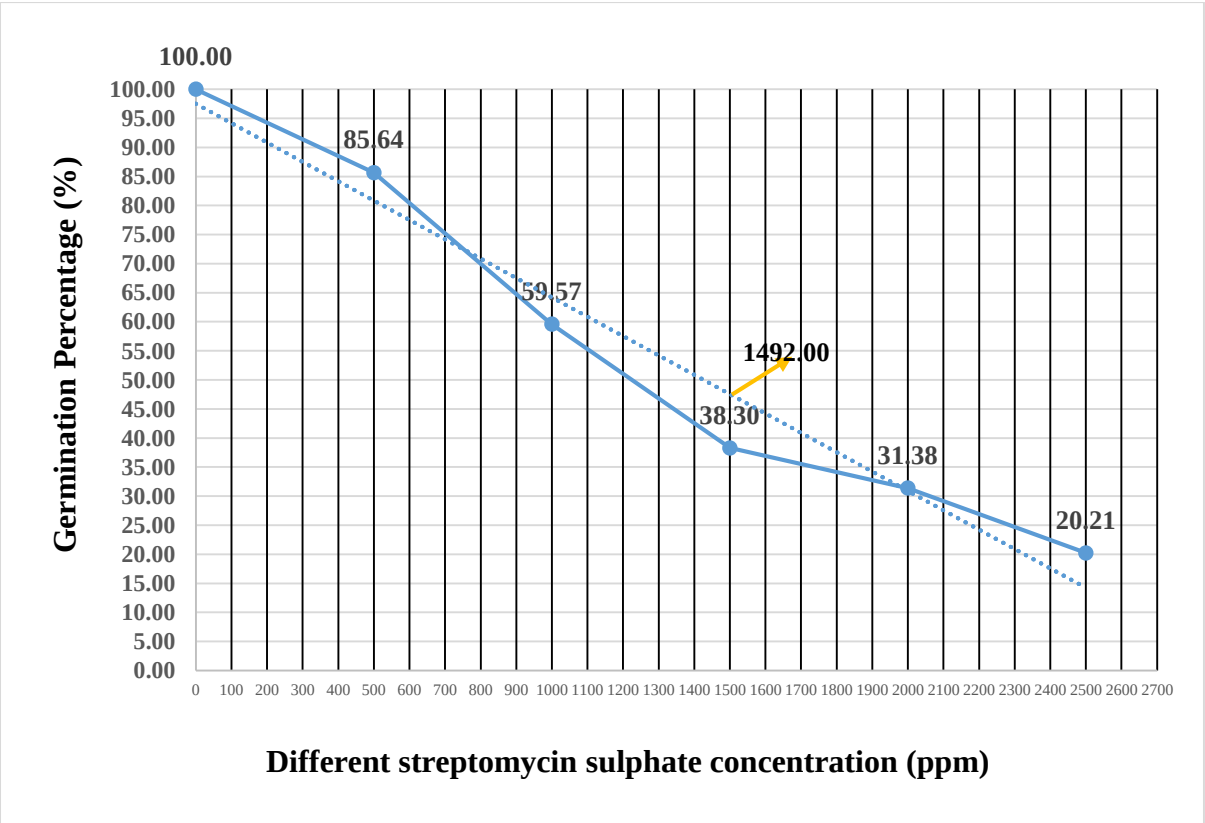


Fig. 4.2 Germination percentage of castor genotype VP 1 (M) streptomycin sulphate

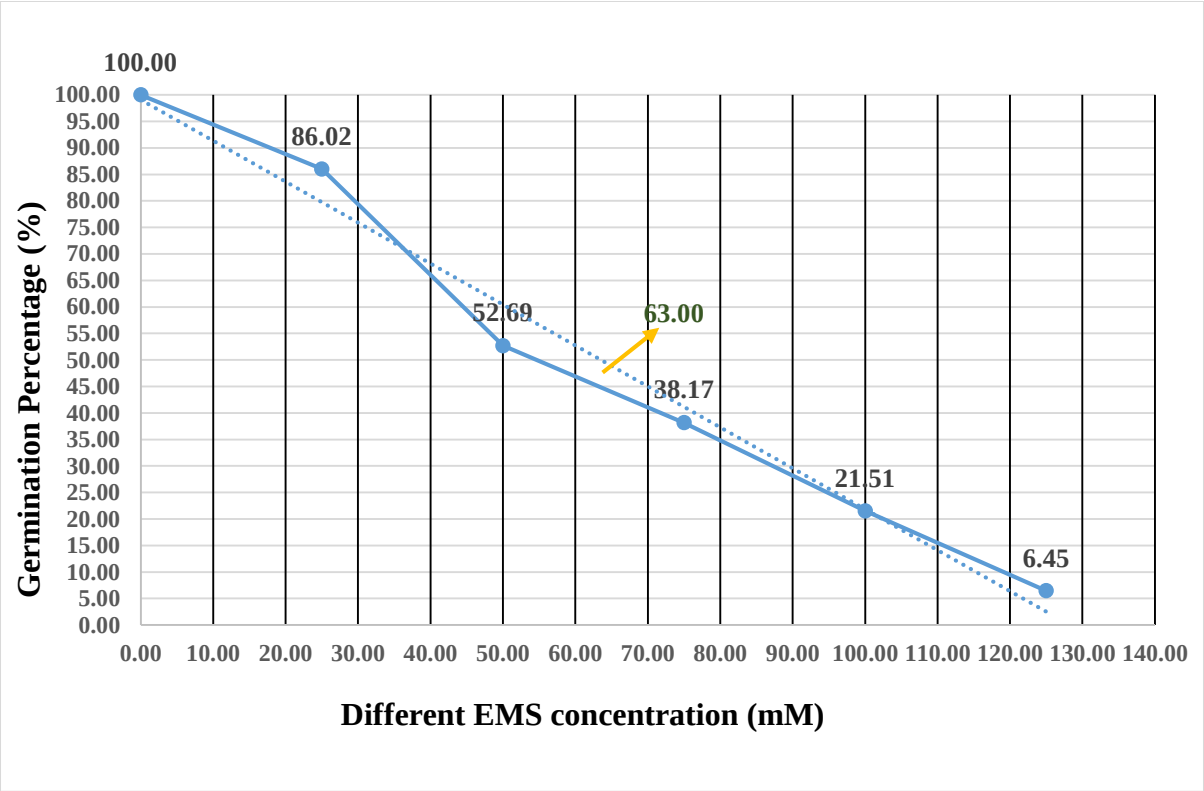


Fig. 4.3 Germination percentage of castor genotype SKI 215 EMS treatment

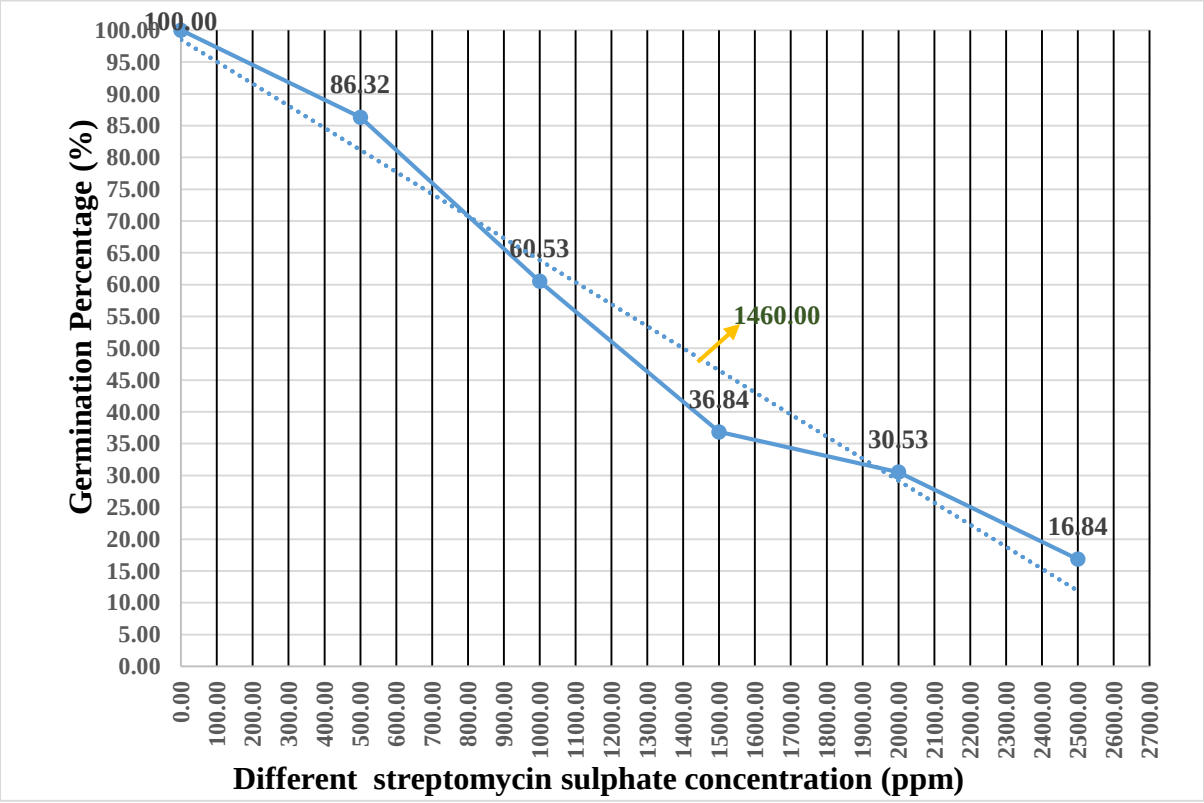


Fig. 4.4 Germination percentage of castor genotype SKI 215 streptomycin sulphate

1460 ppm for streptomycin sulphate in case of SKI 215. Based on the reduction of germination to 50 per cent, LD_{50} value was also determined by Parthasarathi *et al*. (2020) in sesame. They found that expected LD_{50} values of gamma radiation for TMV 7 and SVPR1 varieties were 403.91Gy and 343.84Gy, respectively. Similarly, Bhat *et al*. (2011) also in chickpea estimated values of LD_{50} for EMS, sodium azide and hydrazine hydrate and were observed to be 0.363 per cent, 0.045 per cent and 0.052 per cent for Avrodhi and 0.457 per cent, 0.058 per cent and 0.070 per cent for BG-256, respectively.

The data recorded on the basis of observations revealed that among mutant treatments germination per cent was higher in EMS concentration of 25 mM and 500 ppm of streptomycin sulphate in both the genotypes, *i.e*., VP 1 (M) (86.81%, 85.84%) and SKI 215 (86.02%, 86.32%), whereas lower germination per cent recorded in EMS concentration of 125 mM and 2500 ppm streptomycin sulphate in both the genotypes, *i.e*., VP 1 (9.89%, 20.21%) and SKI-215 (6.45%, 16.84%), respectively. On pooled basis, higher germination was observed in 25 mM EMS (84.41%) and 500 ppm streptomycin sulphate (85.98%) concentration, whereas lower germination was observed in concentration of 125 mM EMS (8.17%) and 2500 ppm streptomycin sulphate (18.52%).

4.1.2 Mutagenic sensitivity in M_1 generation

4.1.1.1 Germination

The effect of different doses of ethyl methane sulphonate (EMS) and streptomycin sulphate on germination of both the varieties was studied during M_1 generations in lab condition as well as in field condition. The results are presented in Table 4.2 and Table 4.3.

The data recorded on the basis of observation revealed that the germination per cent of VP 1 (M) and SKI 215 was reduced in all the mutagenic treatment as compared untreated control. The maximum reduction in the germination per cent was observed in EMS followed by streptomycin sulphate. EMS concentration of 60 mM recorded the lowest germination per cent in lab condition as well as in field condition (76%, 66%) followed by 1500 ppm streptomycin sulphate (84%, 70%) in variety VP 1 (M). The higher germination per cent were observed in 1000 ppm streptomycin sulphate (90%, 78%) followed by 50 mM EMS (82%, 72 %) among all the mutation treatments in variety VP 1 (M) respective to lab as well as field condition.

The effect of different mutagenic treatments on germination per cent in genotype SKI-215 was studied and the lowest germination per cent was observed in lab and field condition of (79%, 67%) was recorded in 60 Mm EMS dose followed by 1500 ppm streptomycin

sulphate (87%, 80%), respectively.

Among two set of population, the highest germination per cent (92%, 88%) was observed in 1000 ppm concentration of streptomycin sulphate in SKI 215 genotype which was lowest as compared to control SKI 215 (97%, 95%) in lab as well as in field conditions, respectively. Seed germination per cent decreased with increase in concentration of treatment. The results are in accordance with the finding of Dhakshanamoorthy *et al*. (2010) in jatropha using gamma rays and EMS treatment at different doses or concentration. They found that in both treatments, minimum seed germination percentage was recorded in the higher dose/concentration of gamma rays 15 kr dose and 4 per cent EMS (37% and 24.66%), respectively. Amin *et al*. (2019) in black cumin also reported seed germination in the var. NRCSSAN-1 was recorded as 90.00% in the control; however it decreased with increasing the concentrations of EMS, gamma rays and their combination. Purente *et al*. (2020) in chilli using EMS different doses for analyze the physiological traits of obtained mutants. Results revealed significant effects of EMS doses on seed germination. The sample germination rate significantly decreased with increasing of EMS doses. Rohini *et al*. (2020) in sesame seeds using various doses/ concentrations of gamma radiation (GR-300 to 500Gy), ethyl methane sulphonate (EMS- 0.3 to 0.5%) and sodium azide (SA-0.15%, 0.20%

Table 4.2: Effect of different mutagens on germination and survival in M_1 generation of castor in lab condition

Sr. No.	No. of seed treated	Treatment		No. of germinated seed	No. of seedling survived	Germination %	Survival per cent of germinated seed
		Genotype	Mutagen				
1.	100	VP 1 (M)	Control	95.00	88.00	95.00	92.63
2.	100	VP 1 (M)	EMS (50 mM)	82.00	64.00	82.00	78.04
3.	100	VP 1 (M)	EMS (60 Mm)	76.00	56.00	76.00	73.68
4.	100	VP 1 (M)	S.S (1000 ppm)	90.00	75.00	90.00	83.33
5.	100	VP 1 (M)	S.S (1500 ppm)	84.00	66.00	84.00	78.57
6.	100	SKI 215	Control	97.00	92.00	96.00	94.84
7.	100	SKI 215	EMS (50 mM)	84.00	68.00	84.00	81.00
8.	100	SKI 215	EMS (60 Mm)	79.00	60.00	79.00	76.00
9.	100	SKI 215	S.S (1000 ppm)	92.00	82.00	92.000	89.13
10.	100	SKI 215	S.S (1500 ppm)	87.00	74.00	87.00	85.06

0.25%). Per cent seed germination was decreased with the increase in doses/ concentrations of the mutagens. The per cent seed germination was 95.21 per cent in control while in 100Gy, 0.2 per cent EMS and 0.15 per cent SA, it was 78.39 per cent, 81.51 per cent and 77.26 per cent, respectively. The per cent seed germination decreased from 78.39 per cent to 52.16 per cent in gamma radiation, 81.51 per cent to 53.43 per cent in EMS and 77.26 per cent to 48.62 per cent in SA. The maximum (50%) decrease in per cent seed germination was observed with gamma radiation treatment 500Gy (52.16%), EMS 0.5 per cent (53.43%) and in SA 0.25 per cent (48.62%). Thus 0.25 per cent SA treatment was very effective in reducing per cent seed germination in sesame to almost 50 per cent.

4.1.1.2 Plant survival

The data with respect to survival is presented in Table 4.2 and Table 4.3. Both EMS and streptomycin sulphate treatments were effective in reducing the survival in both the sets.

Table 4.3: Effect of different mutagens on germination and survival in M_1 generation of castor in field condition

Sr. No.	No. of seed treated	Treatment		No. of germinated seed	No. of seedling survived	Germination %	Survival per cent of germinated seed
		Genotype	Mutagen				
1.	100	VP 1 (M)	Control	92.00	84.00	92.00	91.30
2.	100	VP 1 (M)	EMS (50 mM)	72.00	49.00	72.00	68.05
3.	100	VP 1 (M)	EMS (60 Mm)	66.00	42.00	66.00	63.63
4.	100	VP 1 (M)	S.S (1000 ppm)	78.00	58.00	78.00	74.35
5.	100	VP 1 (M)	S.S (1500 ppm S.S)	70.00	47.00	70.00	67.14
6.	100	SKI 215	Control	95.00	90.00	95.00	94.73
7.	100	SKI 215	EMS (50 mM)	76.00	55.00	76.00	72.37
8.	100	SKI 215	EMS (60 Mm)	67.00	44.00	67.00	65.67
8.	100	SKI 215	S.S (1000 ppm)	88.00	74.00	88.000	84.10
10.	100	SKI 215	S.S (1500 ppm S.S)	80.00	63.00	80.00	78.75

The data revealed that, plants death increased with an increase in concentrations of EMS and streptomycin sulphate in M_1 generation. The higher survival in M_1 generation

mutations treatment were obtained in 1000 ppm streptomycin sulphate (83.33%, 74.35%) in VP 1 (M) population and (89.13%, 84.10%) in SKI-215, respectively in both lab and field conditions which was lower as compared to control VP (M) (92.63%, 91.30%) and SKI 215 (94.84%, 94.73%), respectively. Similarly, the minimum survival rate of (73.68%, 63.63%) was obtained for VP 1 (M) and (76.00%, 65.67%) for SKI 215 in 60 mM EMS treatments. This results are supported by finding of Mensah and Obadoni (2007) in groundnut using different concentrations of sodium azide (0.01 to 0.05%) in SS1145B and RMP 91 varieties. They found that survival per centage decreased with progressively as the dosage increased in both the varieties (25%, 6.5%) respectively. Kumar and Ratnam (2010) in sunflower also found that reduction in percentage of seedling survival with an increased gamma-ray doses on sunflower varieties of USH-430 and SHSF-333.

4.1.3 Morphological variants in M_1 generation

In the present investigation, some of the morphological (viable) mutants were observed in M_1 generation with different concentration of EMS and streptomycin sulphate. An increase in the number of mutants by increase in dose of mutagen were realized in the present study. EMS produced more number of viable mutants than streptomycin sulphate treatments. Mostly tall and dwarf mutants were observed in different mutagenic treatments. Among the concentration of maximum number of such mutants were recorded at 60 mM of EMS in VP 1 (M) and SKI 215 genotype. Only single leaf shape variant was observed in VP 1 (M) treated

Table 4.4: Different morphological variants observed in M_1 generation

Sr.no	Genotype	Treatment	Plant growth		Leaf shape	
			Tall	Dwarf	Shape	Colour
1	VP 1 (M)	50 mM EMS	1	3	-	-
2		60 mM EMS	2	5	-	-
3		1000 ppm (S.S)	-	1	-	-
4		1500 ppm (S.S)	2	-	1	-
5	SKI 215	50 mM EMS	2	4	-	-
6		60 mM EMS	-	1	-	-
7		1000 ppm (S.S)	1	-	-	-
8		1500 ppm (S.S)	-	3	-	-

with 1500 ppm streptomycin sulphate. No more varients except tall/dwarf and leaf shape were observed in M_1 generation throughout the growing season. Similar results obtained by Solanki (2005) in lentil, where twelve kinds of morphological mutant included changes for

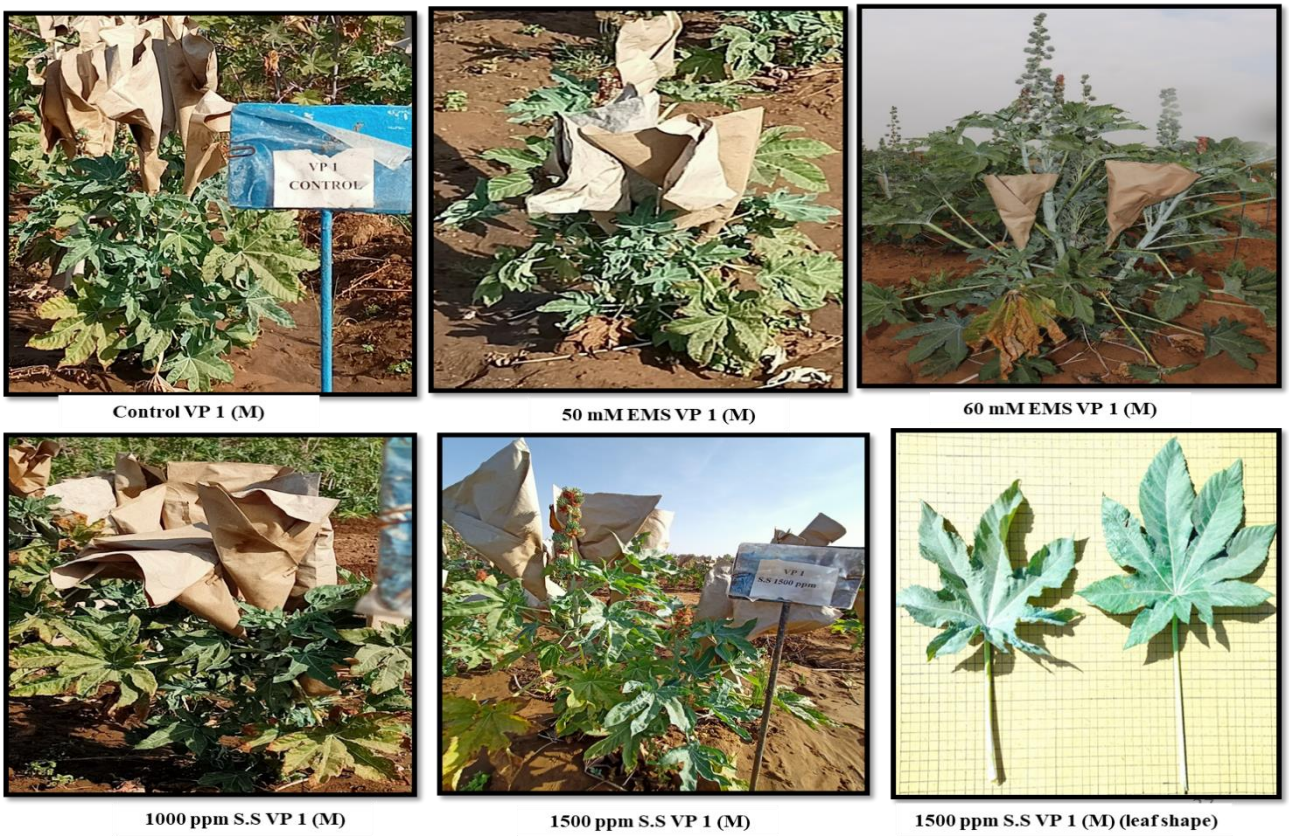


Plate I: Morphological variation observed in M_1 generation

growth habit (compact, bushy, prostrate), foliage (narrow, broad, rogue, tendrillar), plant height (tall, dwarf), and maturity and flowering behaviour (early, late, sterile) by EMS and SA treatments. Mangaiyarkarasi *et al*. (2014) treating dry and dormant seeds of the periwinkle for gamma rays and EMS treatments they found tall mutant, dwarf mutant and leaf mutant such as long leaf in different mutagenic treatments. Among the concentrations maximum number of mutants were recorded at 50 kR of gamma rays and 50 mM of EMS. Purente *et al*. (2020) in chilli using EMS treatments with different dose found two viable morphological mutants containing leaf and stem. Overall leaf size was significantly larger as a result of EMS treatments and the height of mutant plants was significantly higher in chilli plant.

The M_1 generation was advanced by taking selfed seed from each and every plants of treatment. Selfing was done by removing all the open flowers on raceme and covered by paper bag using U pin and some racemes were covered before flower open.

4.1.4 Pollen study in M_1 generation

The present investigation was carried out to induce mutations through different concentrations of EMS and streptomycin sulphate in castor. The individual plants raised from treated seeds were selfed and conducted pollen studies on those M_1 plants. In Table 4.5 listed different doses in both the genotype in individual plant to identify the pollen sterile or fertile. Under light microscope smear of crushed anther were stained using 1 per cent aceto carmine. The present study revealed that, all the plants found almost fertile in different concentration in SKI 215 except in case of EMS treatment 50 mM (11.90%), 60 mM (42.46%) and in case of 1500 ppm S.S (73.68%), partial pollen sterile plants were observed. Maximum mean value were observed in 1500 ppm streptomycin sulphate in both the genotype VP 1 (M) (0.52%) and SKI 215 (0.85%) compared to control (0.01%,0.02%), respectively. Minimum mean value was observed in concentration of EMS 50 mM in VP 1 (M) (0.05%) while in SKI 215 (0.04%) in 1000 ppm streptomycin sulphate. Looking to the results of control treatments for both the genotypes ranged from 0.00 to 0.02 per cent in VP 1 (M) and 0.00 to 0.03 per cent for SKI 215. Whereas higher range observed in 1000 ppm streptomycin sulphate in VP 1 (M) (0.00-61.54%) and in SKI 215 (0.00-73.68%) observed in 1500 ppm streptomycin sulphate. Similar results were obtained by Chauhan *et al*. (1990) in castor using gamma rays treatment for inducing male sterility. They found that the plants of the 12.5 kR gamma-ray treated population showed only 19.12 per cent pollen sterility, while the plants of the 150 kR gamma ray irradiation were 62.93 per cent pollen sterile. Increase in pollen sterility percentage was directly proportional to the increase in the doses

Table 4.5: Pollen study in different genotypes in M_1 generation

Plant No.	VP 1(M) family					SKI 215 family				
	Control	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**	**Control**	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**
1	0.00	0.00	0.17	NG	0.60	0.03	11.90	NG	0.15	0.50
2	0.02	NG	0.14	0.43	0.49	0.03	NG	0.27	NG	0.50
3	NFM	0.07	NG	**63.72**	0.46	0.02	0.08	0.28	0.04	NG
4	0.02	0.03	0.13	0.06	NG	0.01	0.01	42.46	0.01	0.49
5	0.01	NG	0.00	NG	NG	0.03	NG	NG	0.19	18.83
6	0.01	0.02	NG	0.21	**68.96**	0.01	29.82	0.10	0.24	NG
7	NFM	0.04	0.04	0.42	0.38	0.00	NG	0.15	NG	22.28
8	0.02	NG	0.35	NG	0.64	0.03	0.06	NG	0.09	0.01
9	0.01	0.05	0.15	0.33	NG	0.01	0.05	0.20	0.33	**77.55**
10	0.01	NG	NG	0.35	0.06	0.00	NG	0.48	0.11	0.11
11	NFM	0.10	0.01	0.36	0.24	0.03	NG	NG	0.55	0.04
12	0.01	0.09	0.03	0.02	0.30	0.03	0.01	NG	NG	0.07
13	NG	0.04	0.12	0.26	0.13	0.02	0.07	NG	0.03	0.32
14	0.00	NG	NG	0.07	0.00	0.01	NG	0.06	0.49	0.10
15	NFM	NG	0.16	NFM	NG	0.01	0.05	0.30	0.52	0.43
16	0.01	0.06	0.13	0.37	NG	0.03	NG	0.05	NG	0.02
17	NFM	0.07	NFM	0.19	0.00	0.01	0.05	0.37	0.23	0.09
18	0.02	0.08	NG	0.09	0.71	0.02	0.02	0.12	0.01	0.06
19	0.02	0.08	0.08	0.35	0.00	0.01	NG	0.04	0.31	0.13
20	NG	0.09	0.17	0.34	0.08	0.01	0.05	NG	0.18	0.02
21	0.01	NG	0.02	0.04	0.32	0.03	0.02	NG	NG	0.01
22	0.01	NFM	NG	NFM	NG	0.01	NG	0.03	0.16	0.00
23	0.01	0.05	0.00	NFM	0.39	0.02	0.07	0.05	0.16	0.26
24	NFM	0.06	0.12	0.12	0.35	0.01	0.09	0.37	NG	0.58
25	0.02	0.07	NG	0.53	0.31	0.01	0.06	0.10	0.45	0.29
26	NFM	NG	NFM	0.25	0.23	0.02	NG	0.08	0.18	0.39
27	0.00	0.08	NG	0.13	NG	0.02	0.06	0.26	0.06	NG
28	0.00	NFM	0.30	0.19	NG	0.01	NG	NG	0.23	0.40
29	NFM	0.04	0.08	0.27	NFM	0.01	0.10	0.46	0.09	0.08
30	0.02	NFM	NG	NFM	NFM	0.02	NG	NG	NG	NG
31	0.02	NFM	0.16	NG	NG	0.02	0.08	0.10	0.19	0.38
32	0.02	NG	NFM	0.46	0.12	0.00	0.10	NG	0.19	0.12
33	NFM	0.08	0.47	0.00	0.25	0.01	NG	0.19	0.02	0.25
34	0.01	0.04	NG	NG	0.07	0.03	0.08	NG	0.10	0.40
35	0.01	0.05	NG	0.45	0.04	NG	NG	NG	0.54	NG
36	0.00	0.04	NG	0.19	0.02	0.03	0.05	0.00	0.04	0.69
37	0.01	NG	0.16	0.00	0.07	0.02	0.03	0.14	0.04	0.06
38	NFM	0.00	NG	0.04	0.11	0.00	0.01	NG	0.11	0.19
39	0.00	0.05	0.06	NG	NG	0.03	NG	NG	0.10	0.31
40	0.01	NG	0.11	0.35	NG	0.02	0.01	NG	0.03	0.42
41	0.02	0.03	NG	0.00	0.37	0.02	0.03	0.00	0.02	NG
42	0.02	NFM	0.29	0.07	0.72	0.00	0.07	0.23	0.49	0.15
43	0.00	0.10	0.22	NG	NG	0.00	0.10	NG	NG	0.23
44	0.00	NG	NG	0.07	0.31	0.02	NG	NG	0.06	0.66
45	0.00	NG	0.17	0.57	0.52	0.00	0.05	0.16	0.13	0.47
46	NFM	0.07	NFM	NFM	0.41	0.01	0.06	NG	0.54	0.17
47	NFM	0.06	0.21	0.37	NG	0.02	NG	0.14	NG	0.43
48	0.01	0.06	0.10	0.16	0.21	0.03	NG	NG	0.60	NG
49	0.01	NG	0.31	0.40	NFM	0.01	0.04	0.06	0.20	0.20
50	0.02	0.03	NFM	0.41	0.14	0.02	0.10	NG	NG	0.25
51	NFM	NFM	NFM	NFM	NG	0.03	0.08	NG	0.00	0.46
52	0.02	0.03	0.14	0.13	NG	0.00	0.03	0.22	NG	NG

Table 4.5: Conti…

Plant No.	VP 1 (M) family					SKI 215 family				
	Control	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**	**Control**	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**
53	0.02	NG	0.00	0.01	0.17	0.01	0.01	0.13	0.31	0.01
54	0.01	0.02	0.25	0.04	NG	0.03	0.05	0.06	0.27	0.21
55	0.01	0.04	NG	0.48	0.32	0.03	0.08	NG	0.30	NG
56	NMF	NG	0.14	NG	NMF	0.00	NG	0.22	0.20	0.14
57	0.00	NMF	0.06	0.40	NMF	0.00	0.04	NG	0.01	NG
58	0.02	NG	NG	NG	NG	0.01	0.06	0.32	0.09	NG
59	NMF	0.09	NMF	NMF	NG	0.03	NG	0.00	0.03	0.54
60	0.02	0.05	0.07	0.07	NG	0.01	0.02	0.15	0.28	0.09
61	0.01	NG	NG	0.04	0.11	0.02	NG	NG	0.15	0.46
62	0.02	0.02	0.46	0.01	NG	0.03	0.04	0.19	0.04	0.14
63	NMF	0.01	0.18	NG	0.49	0.02	0.05	0.10	0.07	0.04
64	0.01	NG	0.01	0.00	NMF	0.02	0.04	NG	NG	0.64
65	0.02	0.01	NG	0.12	NG	0.02	0.09	0.01	0.45	0.53
66	NMF	0.05	0.32	0.01	NG	0.03	NG	0.15	0.50	NG
67	0.00	0.09	NG	NG	0.08	0.01	NG	0.17	0.05	0.18
68	NMF	0.05	0.17	0.28	NMF	0.01	0.05	NG	0.30	0.69
69	NMF	NG	0.27	0.51	0.60	0.00	0.07	0.01	0.09	0.06
70	0.02	0.08	0.09	0.34	NG	0.03	0.02	0.25	0.08	0.29
71	0.00	NG	NG	NG	0.70	0.03	0.07	NG	0.40	NG
72	0.02	NMF	0.19	NMF	0.37	0.03	NG	0.10	0.01	0.33
73	0.01	NG	0.24	0.17	NG	0.01	NG	0.15	0.06	NG
74	NMF	NG	0.21	NG	0.64	0.01	0.02	NG	0.00	NG
75	NMF	0.06	NG	0.01	NG	0.00	0.08	0.02	0.17	NG
76	0.01	0.04	NG	0.64	0.32	0.03	0.08	0.10	0.00	0.02
77	0.00	NG	0.40	NG	0.17	0.01	0.08	0.30	NG	0.47
78	0.01	0.10	0.33	NG	NMF	0.02	0.02	NG	0.22	NG
79	0.00	NMF	NG	0.06	0.18	0.03	0.08	NG	0.18	NG
80	0.01	0.09	0.36	0.31	NG	0.01	NG	NG	0.48	0.19
81	NMF	0.08	NG	0.20	0.25	0.00	0.08	NG	0.23	0.40
82	0.01	NG	0.06	NG	NG	0.02	0.08	0.13	0.00	0.20
83	0.00	0.07	NG	0.20	0.24	0.01	NG	0.23	0.09	0.14
84	NG	NMF	0.09	NG	NMF	0.03	0.05	0.24	0.47	NG
85	0.02	0.08	NG	NG	NG	0.00	NG	NG	0.11	0.28
86	NMF	0.09	0.41	0.00	0.07	0.02	0.10	NG	0.42	NG
87	0.02	NG	NMF	0.43	0.24	0.02	0.04	NG	0.06	0.69
88	0.01	0.00	0.44	NG	NG	0.03	0.05	0.06	0.01	0.29
89	0.01	0.02	NG	0.00	NMF	0.03	NG	0.00	0.12	0.54
90	NMF	NG	0.30	NG	0.19	0.00	0.02	NG	0.01	NG
91	0.02	0.07	NG	NMF	0.33	0.03	0.05	0.18	0.12	NG
92	NFM	0.09	0.16	0.20	NG	0.01	NG	NG	0.42	0.04
93	0.01	0.04	0.14	NG	0.24	0.01	0.07	0.04	0.40	0.18
94	NG	NG	0.00	0.42	0.65	0.02	0.04	0.00	0.25	0.06
95	0.00	0.07	NFM	0.37	0.54	0.00	0.05	NG	NG	NG
96	0.02	0.09	0.32	NG	0.37	0.00	0.09	0.23	0.01	0.38
97	NMF	NFM	0.07	0.30	0.03	0.03	NG	0.16	0.03	NG
98	0.02	0.09	0.05	NG	0.09	0.03	0.05	NG	0.27	NG
99	0.02	NG	0.44	0.24	NG	0.01	0.03	NG	0.31	0.07
100	0.00	0.00	0.26	0.22	NG	0.03	NG	0.38	0.17	0.26
101	0.02	0.06	0.05	NFM	0.69	0.01	0.01	NG	0.12	NG
102	NMF	0.02	NG	0.45	0.17	0.02	0.01	0.13	NG	NG
103	0.00	NG	0.38	NMF	0.16	0.03	0.09	0.36	0.06	0.23
104	NG	0.00	0.47	0.12	NG	0.03	NG	NG	0.06	0.02
105	NFM	0.09	NG	NMF	0.30	0.01	0.10	0.12	NG	NG
106	0.02	NFM	0.06	0.40	NG	0.01	NG	NG	0.19	NG

Table 4.5: Conti…

Plant No.	VP 1 (M) family					SKI 215 family				
	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S
107	0.02	NG	0.47	0.41	0.03	0.01	0.07	NG	0.47	NG
108	NFM	0.07	NG	0.22	NG	0.02	0.02	0.49	0.46	0.46
109	NFM	0.08	0.22	NG	0.23	0.02	NG	0.04	NG	0.09
110	0.02	0.03	0.26	0.13	NG	0.02	0.08	0.31	0.30	NG
111	0.01	NG	NG	NG	0.08	0.01	0.01	NG	0.37	0.39
112	0.00	NFM	NFM	0.49	0.20	0.00	NG	0.24	0.02	NG
113	NFM	NG	0.22	0.32	NG	0.03	0.09	NG	0.23	0.00
114	0.00	0.02	NG	0.33	0.08	0.03	0.05	0.03	0.05	0.01
115	0.01	0.01	0.00	NFM	0.12	0.00	NG	NG	0.05	0.39
116	0.01	0.07	0.17	NG	0.46	0.01	0.03	0.41	0.33	NG
117	NG	NG	NG	0.60	NG	0.01	0.09	NG	0.64	0.35
118	0.01	0.08	0.06	0.04	NG	0.01	NG	0.29	0.17	0.08
119	0.00	0.04	NG	NG	0.21	0.02	0.06	NG	0.07	0.52
120	NFM	0.09	0.21	0.42	NG	0.03	0.09	0.04	0.01	0.16
121	0.00	NG	0.19	0.30	0.36	0.02	NG	0.08	0.23	NG
122	0.01	0.00	NFM	NG	NG	0.03	0.10	NG	0.21	0.21
123	NFM	0.08	NG	0.20	0.00	0.02	0.10	NG	0.00	NG
124	0.02	NG	NFM	0.07	NG	0.01	0.03	0.04	0.10	0.58
125	0.01	0.07	0.20	NG	0.69	0.01	0.07	0.14	0.43	0.56
126	0.02	0.06	0.29	0.22	0.49	0.02	0.00	NG	0.21	NG
127	NFM	0.08	0.21	0.00	NG	0.01	NG	0.03	0.06	NG
128	NG	0.08	NFM	NG	NFM	0.02	0.01	NG	0.36	0.34
129	0.00	0.07	0.19	0.29	0.46	0.03	0.03	0.12	0.30	0.23
130	0.00	NG	0.35	0.05	NG	0.03	0.07	0.20	0.25	0.32
131	0.01	0.06	NFM	0.13	0.26	0.02	0.00	0.09	0.10	NG
132	NG	NG	0.01	NG	0.48	0.03	0.08	0.07	0.23	0.20
133	0.02	0.04	0.38	0.12	0.36	0.03	NG	NG	NG	0.13
134	0.00	0.05	0.04	NG	NG	0.02	0.06	NG	0.16	0.43
135	0.01	0.04	0.30	0.37	NG	0.01	0.02	0.19	0.07	0.48
136	0.01	NG	0.10	0.07	NG	0.00	NG	0.12	0.18	0.12
137	0.01	0.09	0.04	NG	0.30	0.01	0.08	0.06	0.29	0.05
138	0.02	NG	0.07	0.02	0.35	0.01	0.09	0.03	NG	0.05
139	0.00	0.06	0.17	0.34	0.29	0.01	0.05	NG	0.18	0.22
140	0.00	0.06	0.33	NG	NG	0.00	0.07	0.10	0.31	0.11
141	0.02	0.08	0.04	0.27	0.20	0.01	0.09	0.13	0.45	NG
142	0.01	NG	0.12	0.09	0.32	0.03	NG	0.10	NG	NG
143	0.00	0.07	NG	NG	NG	0.03	0.03	NG	NG	0.00
144	NFM	NG	0.30	0.23	0.11	0.03	0.06	0.04	0.11	0.04
145	NFM	0.09	0.23	0.41	NG	0.02	0.09	0.12	0.37	0.19
146	NFM	0.03	0.00	0.00	0.05	0.02	NG	NG	0.25	NG
147	0.02	NG	NG	0.03	NG	0.03	0.05	0.40	0.07	0.05
148	0.02	0.08	0.06	0.06	NG	0.01	0.02	0.31	0.00	0.16
149	0.00	0.06	NG	NG	0.69	0.02	0.09	0.14	0.13	NG
150	0.00	NG	0.23	0.29	0.60	0.01	NG	NG	0.02	NG
151	0.02	0.03	NFM	NFM	0.41	0.00	0.08	NG	0.01	0.07
152	NFM	0.03	0.21	0.21	NG	0.02	NG	0.12	0.01	0.11
153	NFM	0.08	NG	0.47	NG	0.02	0.05	0.01	0.02	0.09
154	0.00	NG	0.22	NG	0.04	0.02	0.06	NG	NG	NG
155	0.02	0.08	0.42	0.44	0.12	0.02	0.06	0.00	0.06	0.00
156	0.01	0.10	NG	NFM	NG	0.03	NG	NG	0.22	0.12
157	0.00	NG	0.25	0.57	0.53	0.00	0.04	0.41	0.17	0.30
158	NG	0.10	NFM	0.24	0.27	0.01	0.02	NG	0.20	0.23
159	0.01	0.07	NFM	0.21	NG	0.01	NG	NG	0.03	NG
160	0.00	0.05	0.02	NFM	0.65	0.00	0.09	0.03	0.14	0.19

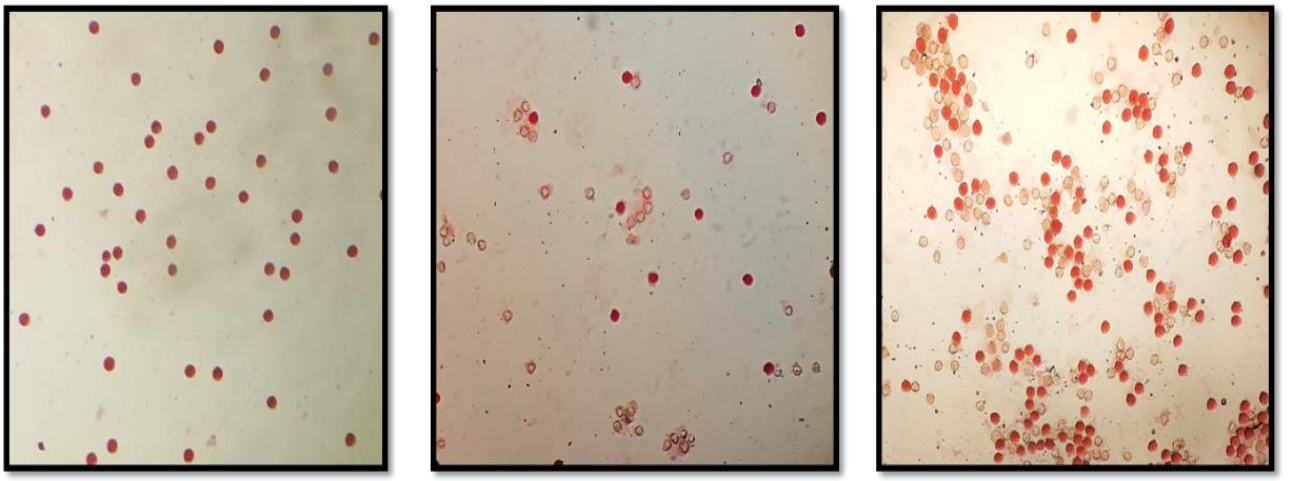


Plate II: Pollen sterility studies M_1 generation

Table 4.5: Conti…

Plant No.	VP 1 (M) family					SKI 215 family				
	Control	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**	**Control**	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**
161	0.01	0.07	0.22	0.33	NG	0.00	0.03	NG	0.11	0.13
162	0.01	0.05	NFM	NG	NFM	0.02	0.06	0.04	0.07	0.35
163	0.01	NG	0.16	NG	NG	0.01	NG	NG	0.28	0.53
164	NFM	NFM	0.16	NFM	0.26	0.03	0.09	0.07	NG	NG
165	0.00	0.01	NFM	NG	NG	0.00	0.06	NG	0.04	0.00
166	0.01	0.03	NG	0.01	0.59	0.00	0.10	0.01	0.27	0.02
167	0.00	NG	0.35	NFM	NFM	0.02	NG	0.17	0.32	0.02
168	0.00	NFM	0.04	0.12	0.44	0.03	0.06	NG	0.04	NG
169	NFM	0.07	NG	NG	NG	0.03	0.08	0.30	0.14	0.19
170	0.01	0.09	0.31	NG	NG	0.00	NG	0.26	0.05	0.25
171	0.01	0.09	0.02	0.27	0.24	0.01	0.06	0.27	0.08	0.58
172	0.01	NG	0.36	NG	0.23	0.03	NG	0.16	NG	0.00
170	NFM	0.07	0.27	NFM	0.41	0.02	0.06	NG	0.37	NG
174	0.01	0.07	NG	NG	NG	0.03	0.07	0.00	0.21	0.33
175	NG	NG	NFM	0.30	NFM	0.02	NG	0.07	0.04	0.00
176	0.01	NFM	0.34	0.23	0.26	0.02	0.09	NG	0.20	NG
177	0.02	0.09	0.11	0.40	NG	0.01	0.10	0.50	NG	0.52
178	NFM	NG	NG	NG	0.40	0.02	0.03	NG	0.10	0.39
179	0.00	0.00	NFM	0.37	NFM	0.01	NG	0.17	0.00	NG
180	0.01	NFM	0.18	NFM	NG	0.03	0.09	0.17	0.11	0.65
181	0.00	0.04	NFM	0.38	0.08	0.00	0.07	NG	0.09	NG
182	0.01	0.06	0.24	NG	NFM	0.01	NG	NG	0.05	0.69
Total	1.76	8.67	25.20	90.06	94.53	3.01	48.99	69.40	34.79	154.44
Rang: (Min-Max)	0.00-0.02	0.00-0.10	0.00-0.49	0.00-61.54	0.00-57.90	0.00-0.03	0.00-29.82	0.00-42.46	0.00-0.60	0.00-73.68
Mean	0.01	0.05	0.14	0.49	0.52	0.02	0.27	0.38	0.19	0.85

***Pollen sterility (%): (**No. of unstained pollens /Total no. of pollens) x 100

of gamma ray. In case of VP 1 (M) due to absent of male flower pollen study not taken during winter. Only M_1 generation was advanced when high environmental temperature was raised and male flower produced in selfing bags at that time bags were not opened to avoid cross pollination.

4.2 STUDIES M_2 GENERATION

4.2.1 Morphological mutant in M_2 generation

Any mutagenic event may bring large or small changes in the phenotype. In treated genotypes a viable mutants *i.e.*, tall, dwarf, thick stem, thin stem and leaflet variation were observed in M_2 generation in field condition (Table 4.6). In M_2 generation higher frequency of mutant was observed with increase in concentration or dose of EMS and streptomycin sulphate. In both VP 1 (M) and SKI 215 genotypes, tall and dwarf mutants were observed in both the mutagens. Leaflet variation was observed in SKI 215 genotype in 50 mM EMS treatment whereas leaf colour variation was observed in 60 mM EMS in VP 1 (M) genotype (Plate III). Difference in stem *i.e.*, thick and thin stem were also observed in both genotypes

in different concentration (Plate III). Pollen sterility of each and every plant in M_2 progeny were screened using selfing bags in field. The plants showing male flower in bagged raceme were critically observed which have not set capsules and also observed periodical fertile and sterile pollen counts under light microscope. Plants having above 50 per cent sterile pollen producing plants were considered as sterile. Looking to the results, two plants were found female sterile in VP 1 (M) when treated with 1000 ppm and 1500 ppm streptomycin sulphate as well as in progeny of SKI 215 treated with 1500 ppm streptomycin sulphate a single plant was observed sterile. This result supported by Laskar and Khan (2017) in lentil using gamma rays and chemical mutagens in two cultivar of lentil *viz*., DPL 62 and Pant L 406. They reported different mutation in growth habit like bushy, prostrate, erect *etc*., and in plant size like tall, semi-dwarf and dwarf in M_2 generation of both the cultivars and treatments. Gnanamurthy and Dhanavel (2014) in cowpea using EMS (ethyl methane sulphonate) for induced morphological mutants in CO-7 variety observed tall and dwarf mutants in different mutagenic treatments and maximum number of mutants was recorded at 25 mM of EMS treatment. Morphological variant in M_2 generation of both the castor genotypes and their frequencies are presented Table 4.6.

4.2.2 Mutation frequency

Mutation frequency increased with increase in doses of EMS and streptomycin sulphate except in VP 1 (M) genotype. In case of VP 1 (M) mutagenic frequency range was high in 1500 ppm streptomycin sulphate (5.91%) followed by 60 mM EMS (3.50%) and 1000 ppm streptomycin sulphate (3.17%). The least mutagenic frequency was seen with 50 mM EMS (1.67%) whereas genotype SKI 215 also observed mutagenic frequency range was high in 1500 ppm streptomycin sulphate (4.92%) followed by 60 mM EMS (4.20%) and 1000 ppm streptomycin sulphate (3.11%). The least mutagenic frequency was seen with 50 mM EMS (2.39%). These results are in accordance with the finding of Mensah *et al*. (2003) in rice using ITA 150 seeds of variety exposed to varying concentrations of 0.063-1.00 per cent of hydroxylamine, streptomycin and urea for 24 hours at 28°C. They concluded that streptomycin was the most efficient mutagen by inducing high levels of mutation frequency in 1 per cent concentration (12.88%) in terms of morphological and pooled sterility that either of the other mutagens used in this investigation. Goyal *et al*. (2019) in black gram using gamma rays and EMS treatment for T-9 and Pant U-30 varieties found that frequency of morphological mutants varied both within the mutagenic treatments as well as within the varieties. Highest frequency (8.84%) was noticed in the combination treatment of gamma rays + EMS, whereas the lowest (6.30%) was witnessed with individual treatments of gamma

SKI 215 1500 ppm leaf shape

VP 1 (M) 60 mM EMS leaf colour

SKI 215 control leaf shape

VP 1 (M) 1500 ppm leaf shape

VP 1 (M) 50 mM EMS plant

VP 1 (M) 60 mM EMS plant

VP 1 (M) 1500 ppm plant

VP 1 (M) 1000 ppm plant

Plate III: Morphological variation observed in M_2 generation

ray. Athma and Reddy (1986) in castor observed that frequency of viable mutants was maximum at gametic (0.33%) stage and least at post-gametic (0.03%) stage while using different gamma rays doses.

Table 4.6: Frequency of morphological mutant in M_2 generation

Plant characters	Mutagenic treatment	EMS (mM)		Streptomycin sulphate (ppm)		EMS (mM)		Streptomycin sulphate (ppm)		Total
	Genotype	VP 1 (M)		VP 1 (M)		SKI 215		SKI 215		
	Doses	50 mM	60 mM	1000 Ppm	1500 ppm	50 mM	60 mM	1000 ppm	1500 ppm	
	No of M_2 plants	240	228	252	237	251	238	257	244	1947
Plant height	Tall	2	4	3	5	2	5	3	4	28
	Dwarf	1	3	2	3	1	2	4	2	18
Stem Thickness	Thick			1	3		1		3	7
	Thin	1		1	2	2	2	1	1	10
Leaflet variation	Shape					1			1	2
	Colour		1							1
Pollen sterile plant				1	1				1	3
Total		4	8	8	14	6	10	8	12	70
M_2 mutation frequency %		1.67	3.50	3.17	5.91	2.39	4.20	3.11	4.92	28.87

4.2.3 Mutagenic effectiveness and efficiency

Employing the results of mutation frequency on population basis and lethality, two quantities *i.e.*, mutagenic effectiveness and mutagenic efficiency were calculated for the two genotypes of castor (Table 4.7). In case of VP 1 (M), the mutagenic efficiency was maximum with 1500 ppm streptomycin sulphate (0.28%) followed by 1000 ppm streptomycin sulphate (0.19%) and 60 mM EMS (0.14%). The least mutagenic efficiency was seen with 50 mM EMS (0.08%). In VP 1 (M) genotyp both the treatments mutagenic efficiency increased with increasing doses of mutagens. In SKI 215 genotypes, also 1500 ppm streptomycin sulphate appeared most efficient (0.26%) followed by 1000 ppm streptomycin sulphate treatment (0.22%) and 60 mM EMS (0.20%). Least mutagenic efficiency was seen in 50 mM EMS

Table 4.7: Mutagenic effectiveness and efficiency in inducing morphological mutation in castor genotype

Genotype	Treatment	Mutagenic frequency (Mf)	Mutagenic effectiveness (%) Mf/t × c	Lethality (L) (%)	Mutagenic efficiency (%) Mf/L
VP 1 (M)	EMS (50 mM)	1.67	0.14	20.00	0.08
	EMS (60 mM)	3.50	0.24	24.00	0.14
	S.S (1000 ppm)	3.17	8.98	16.67	0.19
	S.S (1500 ppm)	5.91	11.14	21.00	0.28
SKI 215	EMS (50 mM)	2.39	0.20	16.34	0.15
	EMS (60 mM)	4.20	0.29	20.67	0.20
	S.S (1000 ppm)	3.11	8.81	14.33	0.22
	S.S (1500 ppm)	4.92	9.28	18.67	0.26

Note: t×c stands for product of treatment duration in hrs and concentration of mutagen, respectively; L stands for Lethality

(0.15%). Results of mutagenic effectiveness were not consistent from one mutagen to another.

Mutagenic effectiveness can be compared between the doses of same mutagen but not between the doses of different mutagens, therefore, on the basis of effectiveness it was observed that linearly increased effectiveness in both treatments in VP 1 (M) and SKI 215 genotypes. In both treatments, mutagenic effectiveness were found higher in 1500 ppm streptomycin sulphate in VP 1 (M) (11.14%) and SKI 215 (9.28%) genotypes. These results are in accordance with the finding of Rathod *et al*. (2004) using ethyl methane sulphonate (0.3 and 0.6%) and gamma rays (20 and 25 kR) in soybeen seeds of two varieties *viz*., Monetta and MACS-13. They recorded gamma rays showed higher mutagenic effectiveness than ethyl methane sulphonate in both the varities. Burghate *et al*. (2013) in groundnut using gamma rays and EMS for TAG-24 variety found that maximum mutagenic efficiency in combined treatments of gamma rays with ethyl methane sulphonate followed by sole treatment of gamma rays and then by ethyl methane sulphonate. More specifically it was recorded highest in combined treatment of 200 Gy gamma rays + 0.2 per cent EMS. While, the effectiveness was reported maximum at lower concentration of 0.1 per cent EMS. Parthasarathi *et al*. (2020) using two mutagens, gamma rays and EMS on the phenotypes of two sesame varieties *viz*., TMV7 and SVPR1 found that mutagenic effectiveness (ME) was maximum (0.68% & 0.72%) at 250 Gy in both the varieties *viz*., TMV7 and SVPR1 respectively, while in EMS treatment, significant ME (0.85% & 0.83%) was observed at 0.20 per cent concentration in both the varieties *viz*., TMV7 and SVPR1, respectively. Mutagenic effectiveness was higher at lower doses whereas mutagenic efficiency was observed higher at higher doses in both the genotypes.

4.2.4 Pollen study in M_2 generation

Selfed plants from M_1 generation were considered as progeny and the progenies were grown in M_2 generation and labelled. The pollen fertility or sterility was conducted at on set of flowering of those each and every plants. The pollen sterility is presented in Table 4.8. All ten progenies in control treatment of VP 1 (M) showed 0.00 to 0.02 per cent pollen sterility whereas SKI 215 showed 0.00 to 0.05 per cent. Higher amount of sterile pollens were observed in most of the mutant treatment for both the genotypes in all the progenies except very few plants showing similarity to the control.

Looking to the sterility status under microscope, the highest pollen sterility was observed (95.83%) in plant No. 21 of 6^{th} progeny of 1500 ppm streptomycin sulphate treated VP 1 (M) genotype followed by plant No. 28 of 3^{rd} progeny of VP 1 (M) (84.61%) treated with

Table. 4.8: Per cent of Pollen sterility study in M_2 generation

Progeny-Plant No.	VP 1 (M) family					SKI 215 family				
	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S
1-1	0.01	0.14	NG	0.22	0.21	0.04	0.00	0.63	0.16	NG
1-2	0.01	0.07	0.06	0.69	NG	0.02	0.03	NS	0.01	0.08
1-3	NMF	NG	0.02	NG	NMF	0.02	NG	0.45	0.07	0.35
1-4	0.01	0.10	NS	0.16	0.02	0.02	0.01	0.33	NG	NG
1-5	NMF	NG	0.15	NG	0.16	NG	0.08	0.36	0.38	0.53
1-6	NG	0.06	0.25	0.84	NMF	0.05	0.00	0.19	NS	0.21
1-7	0.01	0.04	0.39	0.56	0.12	0.04	0.11	NG	0.16	0.03
1-8	0.01	NG	NMF	NMF	0.34	0.03	NG	0.30	0.20	0.07
1-9	NS	0.15	NG	0.08	NMF	0.04	0.12	0.06	0.12	0.05
1-10	0.01	0.17	0.42	0.24	0.43	0.02	0.00	0.64	0.03	0.08
1-11	0.01	NG	0.08	0.17	0.26	0.04	0.10	0.12	0.14	0.04
1-12	0.01	0.16	NS	0.38	NG	0.02	0.09	NS	0.44	0.36
1-13	0.02	0.08	0.19	0.19	0.30	0.01	NG	0.35	0.01	NG
1-14	0.02	0.07	0.32	0.02	0.21	0.01	0.09	0.41	NG	0.02
1-15	NMF	NG	0.50	NG	0.24	0.02	0.05	0.03	0.35	0.13
1-16	0.01	0.06	NG	0.50	0.17	0.03	0.06	0.06	0.03	0.19
1-17	0.02	0.04	0.18	0.06	0.13	0.00	0.04	0.05	0.10	0.17
1-18	NMF	0.04	0.20	NG	0.33	0.04	0.10	0.24	0.04	0.02
1-19	0.01	0.07	0.06	0.30	0.00	0.02	0.02	0.21	0.10	0.27
1-20	0.01	0.09	0.24	0.14	NG	0.04	0.04	0.48	0.15	0.13
1-21	NMF	NS	NG	0.61	0.14	0.03	0.07	NG	0.05	0.09
1-22	0.01	0.12	NMF	0.57	0.24	0.03	NG	0.15	NS	0.03
1-23	0.01	NG	0.11	NG	0.20	0.02	0.06	0.25	0.07	NG
1-24	0.00	0.05	0.01	0.08	NMF	0.03	0.12	0.11	0.11	NG
1-25	0.01	NMF	NS	0.63	0.07	0.03	0.09	0.28	0.48	0.20
1-26	NMF	0.15	0.14	NMF	0.04	0.03	0.01	0.17	0.06	0.09
1-27	0.01	0.04	0.04	0.39	0.08	0.04	0.03	0.05	0.04	0.12
1-28	0.00	0.06	0.01	0.50	NMF	0.02	0.04	0.05	0.04	0.08
1-29	NG	NMF	0.10	0.12	0.31	0.04	0.06	0.27	0.01	0.02
1-30	0.01	0.16	0.15	0.43	0.20	0.02	0.11	0.10	0.02	0.07
2-1	0.02	0.09	0.31	0.57	0.02	0.04	NG	NG	0.24	0.14
2-2	0.02	NG	NG	0.07	NG	0.02	0.02	NG	0.01	NG
2-3	NMF	0.18	0.24	NG	0.20	0.03	0.10	0.01	NG	0.09
2-4	0.01	0.08	0.44	0.15	0.07	0.03	0.00	0.12	0.06	NG
2-5	NG	0.11	NS	0.21	0.06	0.02	0.12	NG	0.03	0.31
2-6	0.02	0.17	0.51	0.31	NMF	0.01	0.06	0.00	0.00	0.09
2-7	0.02	NG	0.03	NG	0.06	0.02	0.04	0.06	0.17	0.50
2-8	NMF	0.06	NG	0.63	0.16	0.04	NG	0.02	0.19	0.01
2-9	0.01	0.17	0.01	0.45	NG	0.05	0.01	0.14	0.00	0.22
2-10	NMF	0.19	NMF	0.01	0.01	0.01	0.04	0.12	0.25	0.21
2-11	0.02	0.19	0.14	0.06	0.03	NG	0.04	0.02	0.23	0.02
2-12	0.01	0.16	0.10	0.74	0.09	0.02	NG	0.03	0.02	0.14
2-13	0.00	NG	0.15	0.68	0.06	0.04	0.06	0.24	0.29	0.11
2-14	0.01	0.10	NG	0.39	NG	0.02	0.01	NG	NG	NG
2-15	0.02	NMF	0.42	NG	NMF	0.01	NG	0.43	0.05	0.00
2-16	NG	NG	0.16	0.30	0.08	0.03	0.08	0.26	0.23	0.11
2-17	0.02	0.20	0.04	NG	0.13	0.04	0.08	NG	0.03	0.02
2-18	0.01	0.13	0.17	0.26	0.04	0.03	0.04	0.26	0.23	0.26
2-19	0.01	0.12	NMF	0.03	NS	0.03	0.09	0.04	0.14	0.19
2-20	0.01	NMF	0.53	0.02	0.35	0.02	0.12	0.02	0.17	0.06

Table. 4.8: Conti…

Progeny-Plant No.	VP 1 (M) family					SKI 215 family				
	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S
2-21	0.00	0.13	0.05	0.09	0.05	0.05	0.06	0.21	0.34	0.12
2-22	0.02	0.09	0.02	NMF	0.19	0.04	0.04	0.14	0.05	0.01
2-23	0.01	0.18	0.06	0.10	0.37	0.05	NG	NG	0.07	0.39
2-24	0.02	NG	NS	0.44	0.02	0.03	0.05	0.31	0.02	0.51
2-25	NMF	0.04	0.01	0.21	0.12	0.04	0.01	0.04	NG	NG
2-26	0.00	0.06	NG	NG	0.09	0.04	NG	0.02	NG	0.12
2-27	NMF	NS	0.04	0.34	0.28	0.01	0.09	NG	0.07	0.37
2-28	0.01	0.14	NMF	NMF	0.03	0.02	0.07	0.23	0.21	0.01
2-29	0.01	0.01	NG	NG	0.25	0.04	0.07	0.53	0.02	0.01
2-30	0.01	0.02	0.31	0.27	0.02	0.01	0.04	0.45	0.05	0.06
3-1	0.02	0.04	0.00	12.80	0.13	0.01	0.05	0.02	NG	0.13
3-2	NG	NG	NS	26.50	0.07	0.02	0.10	0.33	0.05	0.01
3-3	0.02	0.13	0.35	NG	0.01	0.02	NG	0.07	0.07	NG
3-4	0.02	0.09	0.04	9.80	0.18	0.02	0.06	NG	0.07	0.14
3-5	NMF	0.14	NMF	32.40	0.16	NG	0.08	NG	NG	0.01
3-6	0.01	NG	0.29	18.75	NG	0.03	NG	0.04	0.28	0.04
3-7	0.01	NMF	0.04	45.30	0.22	0.02	0.01	0.12	0.14	NG
3-8	0.01	0.09	NG	NG	0.02	0.00	0.08	0.11	0.08	0.13
3-9	NG	0.08	0.02	22.40	0.03	0.03	0.12	NG	0.01	0.23
3-10	0.02	0.07	0.17	NMF	NG	0.04	0.05	0.14	0.18	0.31
3-11	NMF	0.15	NMF	NMF	0.04	0.04	0.04	0.61	0.06	0.28
3-12	0.00	0.05	NG	48.50	0.20	0.03	0.04	NG	0.04	0.10
3-13	0.02	NG	0.17	16.50	NG	0.04	0.04	0.10	NG	0.01
3-14	NG	0.08	NG	NG	0.22	0.01	0.05	0.11	0.00	0.38
3-15	0.02	NS	0.27	52.30	0.43	0.04	0.01	0.22	NG	NG
3-16	0.02	0.10	0.26	NMF	NG	0.01	0.00	0.39	0.10	0.06
3-17	0.02	0.06	NG	60.75	0.06	0.05	NG	NG	0.01	0.05
3-18	NMF	0.04	NMF	23.56	0.11	0.05	0.05	0.06	0.01	0.17
3-19	0.02	0.18	0.05	NMF	0.01	NG	0.02	0.06	0.24	0.08
3-20	0.01	0.13	0.01	59.24	0.34	0.04	0.12	0.02	0.26	0.36
3-21	0.02	0.15	0.11	37.12	NMF	0.01	0.08	0.23	0.20	NG
3-22	NMF	0.06	0.14	18.54	0.38	0.05	0.10	NG	0.03	0.03
3-23	NMF	0.15	0.57	NG	0.02	0.03	0.10	0.06	0.14	NG
3-24	0.02	0.09	NMF	65.42	0.03	0.02	NG	0.13	0.06	0.07
3-25	NG	NMF	NG	24.54	0.16	NG	0.10	NG	0.17	0.03
3-26	0.02	NG	0.30	43.25	0.00	0.00	0.06	0.14	NG	0.03
3-27	0.01	0.01	0.20	NG	0.24	0.02	0.06	0.16	0.02	0.39
3-28	0.02	0.11	NG	**84.61**	0.10	0.05	0.10	0.07	NG	0.04
3-29	0.02	0.08	0.03	20.66	0.02	0.01	0.02	0.17	0.27	0.22
3-30	0.01	0.05	0.35	35.55	0.03	0.04	0.01	0.11	0.01	0.02
4-1	NMF	0.18	0.36	0.60	0.23	0.04	0.04	0.01	0.05	0.33
4-2	0.01	0.18	NG	0.15	NG	0.04	0.08	0.03	NG	0.35
4-3	0.01	NG	0.12	0.06	0.08	0.00	0.09	NG	0.00	0.21
4-4	0.02	0.02	0.30	NG	0.15	0.03	NG	0.46	0.04	NG
4-5	NG	0.03	NG	0.04	NG	0.04	NG	0.00	0.27	0.02
4-6	0.00	NMF	0.21	0.05	0.27	NG	0.07	0.11	NG	0.10
4-7	NMF	0.03	0.00	0.49	NMF	0.02	0.12	0.62	0.01	0.39
4-8	0.01	0.06	NG	0.05	0.34	0.02	0.09	0.06	0.02	0.24
4-9	0.02	0.03	0.01	0.42	0.07	0.00	NG	0.00	0.05	0.05
4-10	0.01	0.17	0.04	NMF	0.38	0.03	0.05	0.06	0.27	0.14

Table. 4.8: Conti…

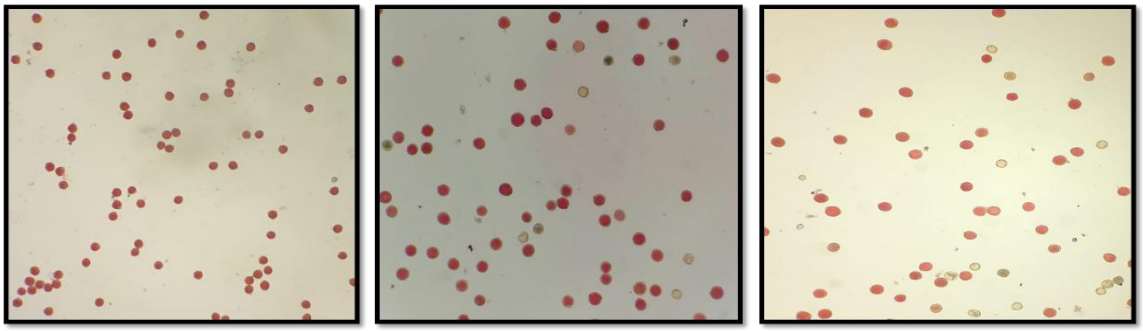
Progeny No.	VP 1 (M) family					SKI 215 family				
	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S
4-11	0.01	0.05	NG	0.24	0.06	0.02	0.02	0.02	0.21	0.26
4-12	0.01	0.19	NG	0.16	0.09	0.01	0.09	0.12	0.29	0.18
4-13	0.02	NS	0.57	0.01	NG	0.02	NG	0.44	0.03	0.02
4-14	NMF	0.04	0.22	0.46	NMF	0.03	0.04	NG	0.33	0.02
4-15	0.01	NG	0.46	NG	0.12	0.05	0.10	0.01	NG	0.16
4-16	NG	0.12	0.17	0.29	0.50	NG	0.05	NG	0.23	NG
4-17	0.01	NG	0.11	NG	NMF	0.01	NG	0.26	0.02	0.10
4-18	0.01	0.09	0.44	0.49	0.10	0.02	0.09	0.39	NG	NG
4-19	NMF	0.05	0.08	NMF	NG	0.03	NG	0.00	0.02	0.07
4-20	0.02	0.13	0.30	0.18	0.01	0.03	0.04	0.15	0.14	0.16
4-12	0.01	0.20	0.10	0.09	0.04	0.02	0.01	0.59	0.13	0.00
4-22	NMF	0.06	NMF	0.18	0.02	0.01	NG	0.01	0.19	0.17
4-23	0.01	0.19	NG	0.71	0.02	0.03	0.12	0.18	0.29	0.18
4-24	NMF	NG	0.22	0.23	NS	0.00	NG	NG	NG	NG
4-25	0.02	NG	NG	NG	0.03	0.05	0.07	0.27	0.11	0.47
4-26	NG	0.13	0.02	0.29	NG	0.03	0.04	0.44	0.03	NG
4-27	0.02	0.10	0.18	0.20	0.05	0.01	0.06	NG	0.06	0.03
4-28	0.02	0.09	0.21	0.03	0.01	0.04	0.10	0.51	0.03	0.00
4-29	NMF	0.17	NMF	0.08	NMF	0.01	0.02	0.44	0.02	0.12
4-30	0.02	NMF	0.03	0.07	0.45	0.05	0.04	0.13	0.06	0.06
5-1	0.01	0.06	0.08	0.69	0.26	0.03	0.11	0.12	0.01	0.16
5-2	NMF	0.02	0.23	0.22	0.10	0.05	0.07	0.08	NG	0.13
5-3	0.02	NG	NS	NG	NS	0.00	NG	0.16	0.14	0.10
5-4	NG	0.02	0.13	0.09	0.04	0.04	0.03	0.26	0.36	NG
5-5	0.01	0.18	0.05	0.06	0.20	0.05	0.11	NG	0.08	0.25
5-6	0.01	0.11	NG	0.02	0.26	NG	0.11	0.28	0.45	0.13
5-7	NMF	0.10	0.38	NG	NG	0.00	NG	0.01	NG	NG
5-8	0.02	0.07	0.09	0.04	0.38	0.03	0.12	NG	0.38	0.03
5-9	NMF	NS	0.46	0.18	NG	0.01	0.07	0.09	0.01	0.09
5-10	0.01	0.15	0.02	0.21	0.46	0.03	0.07	0.13	0.00	0.11
5-11	0.01	0.12	0.05	0.08	0.11	0.04	0.12	0.03	0.09	NG
5-12	0.00	NG	0.37	0.25	0.30	0.02	0.04	0.19	0.16	0.13
5-13	0.00	0.15	0.42	0.12	NG	0.02	0.02	NG	NG	NG
5-14	0.02	0.04	NG	0.30	0.00	0.00	0.06	0.14	0.45	0.10
5-15	0.01	0.18	0.54	0.70	0.01	0.00	0.11	NG	NG	NG
5-16	NG	0.04	0.00	NS	NG	0.00	0.02	0.33	0.12	0.48
5-17	0.01	0.08	NG	0.66	0.03	NG	0.05	0.00	0.02	0.32
5-18	0.01	0.11	0.28	0.29	NG	0.05	0.07	0.41	0.01	0.19
5-19	0.01	0.07	0.07	NG	0.02	0.02	0.04	0.31	0.01	0.40
5-20	0.02	NMF	NG	0.08	0.03	0.00	0.03	0.40	0.26	0.03
5-21	0.01	NG	0.10	0.08	0.18	0.01	0.05	0.04	0.18	0.16
5-22	0.02	0.16	0.01	0.39	NMF	0.04	0.01	0.18	0.08	0.22
5-23	0.02	0.04	0.29	0.07	0.13	0.02	0.11	0.06	0.03	0.03
5-24	0.02	0.04	0.15	NG	NG	0.03	0.01	NG	0.07	0.08
5-25	0.01	NG	NG	0.01	0.13	0.03	0.05	0.00	NG	0.12
5-26	0.02	0.01	NS	0.04	NG	0.01	NG	0.38	0.21	0.25
5-27	NMF	0.10	0.01	0.17	0.38	0.03	0.08	NG	0.03	NG
5-28	0.01	0.07	0.23	NG	0.31	0.02	NG	0.69	NG	NG
5-29	0.02	0.16	NG	0.18	0.30	0.05	0.05	0.30	0.05	0.15
5-30	0.02	NMF	0.00	0.34	0.00	0.01	0.09	0.02	0.24	0.25

Table. 4.8: Conti…

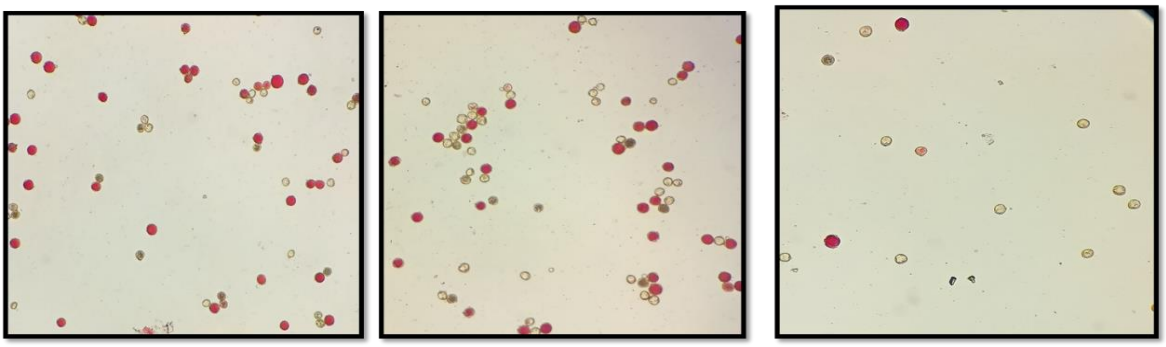
Progeny No.	VP 1 (M) family					SKI 215 family				
	Control	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**	**Control**	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**
6-1	0.02	0.12	0.49	0.33	30.10	0.03	0.02	0.50	0.07	0.43
6-2	0.01	NG	0.25	0.03	15.28	0.03	0.09	NG	0.16	0.08
6-3	0.01	0.04	0.08	0.81	NG	0.01	NG	0.28	0.04	NG
6-4	NMF	NG	NS	0.29	NMF	0.04	0.03	0.33	NG	0.08
6-5	0.02	0.18	NMF	0.40	NMF	0.05	0.00	NG	0.02	0.45
6-6	NS	0.16	0.13	NG	34.32	0.04	0.07	0.07	0.02	0.26
6-7	0.02	0.15	0.66	0.07	NG	NG	0.11	0.20	0.09	0.33
6-8	0.00	0.19	NG	0.22	40.15	0.02	0.03	0.56	0.00	0.28
6-9	NMF	0.13	0.05	NG	NG	0.00	0.06	0.16	0.30	0.25
6-10	0.02	NMF	0.66	0.15	58.60	0.04	0.07	0.33	0.06	0.06
6-11	0.02	0.18	NS	0.07	11.33	0.03	0.00	NG	0.14	0.50
6-12	0.01	NG	0.26	NG	61.32	0.05	NG	0.35	NG	0.09
6-13	0.02	NMF	0.02	0.01	NG	0.04	0.08	0.32	0.11	NG
6-14	0.01	NG	0.16	0.18	NMF	0.03	0.09	NG	0.25	0.01
6-15	NMF	0.02	NS	NG	NMF	0.04	NG	0.24	NG	NG
6-16	NG	0.03	0.12	0.18	24.30	0.02	0.05	0.02	0.06	0.23
6-17	0.00	0.09	0.00	0.01	NG	0.00	0.04	0.03	0.07	NG
6-18	0.00	0.11	0.27	0.23	16.65	0.04	0.02	0.33	0.02	0.00
6-19	NMF	0.16	0.06	0.19	38.40	0.02	0.02	0.26	0.25	0.29
6-20	0.01	0.09	0.26	0.21	NMF	0.04	0.04	0.27	0.02	0.11
6-21	0.01	0.06	NMF	0.06	**95.83**	0.05	0.04	0.10	NG	0.39
6-22	0.00	0.02	NG	0.31	40.10	NG	NG	0.11	0.41	NG
6-23	NMF	0.11	0.12	NG	22.42	0.01	0.03	0.21	0.07	0.01
6-24	0.02	NG	NG	0.20	11.68	0.02	0.06	0.26	0.05	NG
6-25	0.00	0.02	0.37	0.05	NG	0.04	0.07	NG	0.18	0.04
6-26	NMF	NG	0.05	0.70	70.75	0.00	0.05	0.19	0.06	0.03
6-27	0.01	0.04	0.29	0.31	15.12	0.04	0.07	NG	0.21	0.28
6-28	0.02	0.14	0.38	0.18	NG	0.05	NG	0.05	0.28	0.23
6-29	NG	0.17	0.04	0.52	28.26	0.02	0.03	0.18	0.01	0.18
6-30	0.02	0.15	0.28	0.20	39.58	0.02	0.10	0.03	0.00	0.01
7-1	0.00	NG	0.21	0.11	0.03	0.00	NG	0.02	0.15	0.01
7-2	0.02	NG	NG	0.65	0.24	0.04	0.09	NG	0.36	0.16
7-3	0.02	0.19	0.00	0.62	0.02	0.01	0.05	0.47	NG	NG
7-4	NG	0.20	0.23	NG	0.46	0.03	NG	0.47	0.41	0.08
7-5	0.01	NMF	NG	0.08	NG	0.03	0.11	0.16	0.02	0.16
7-6	0.01	0.10	0.08	0.10	0.62	0.04	0.09	NG	0.20	NG
7-7	0.01	0.19	0.13	NG	0.44	0.04	0.11	NG	NG	0.16
7-8	NMF	0.02	0.57	0.08	NG	0.02	0.04	0.45	0.07	0.08
7-9	0.01	0.11	0.45	0.51	0.36	0.00	0.02	0.08	0.03	0.03
7-10	0.01	0.12	0.18	0.44	0.17	0.01	0.08	0.05	0.07	0.08
7-11	0.02	NG	0.13	0.54	NMF	0.01	0.07	NG	0.10	0.09
7-12	0.01	0.11	NMF	0.03	NG	0.04	0.03	0.35	0.23	0.01
7-13	NG	NG	NG	0.11	0.39	0.03	0.12	0.32	0.07	0.05
7-14	0.00	NMF	0.19	NG	0.15	NG	NG	0.11	0.15	NG
7-15	NMF	0.08	0.16	0.01	0.18	0.01	0.08	NG	0.01	0.19
7-16	0.02	NG	NG	0.30	NG	0.04	0.08	0.11	NG	0.38
7-17	0.00	0.19	0.34	0.20	0.02	0.04	0.07	0.04	0.05	NG
7-18	0.00	0.11	NG	NG	0.13	NMF	0.02	0.21	0.02	0.12
7-19	0.02	0.00	0.20	0.00	0.19	0.01	0.05	0.34	0.02	0.37
7-20	0.02	NMF	0.35	NMF	NMF	NMF	0.05	0.09	0.15	0.09
7-21	NMF	0.10	NG	0.52	0.28	0.03	0.09	0.17	0.14	NG
7-22	0.02	NG	NG	0.54	0.06	0.00	0.05	NG	0.01	0.21

Table. 4.8: Conti…

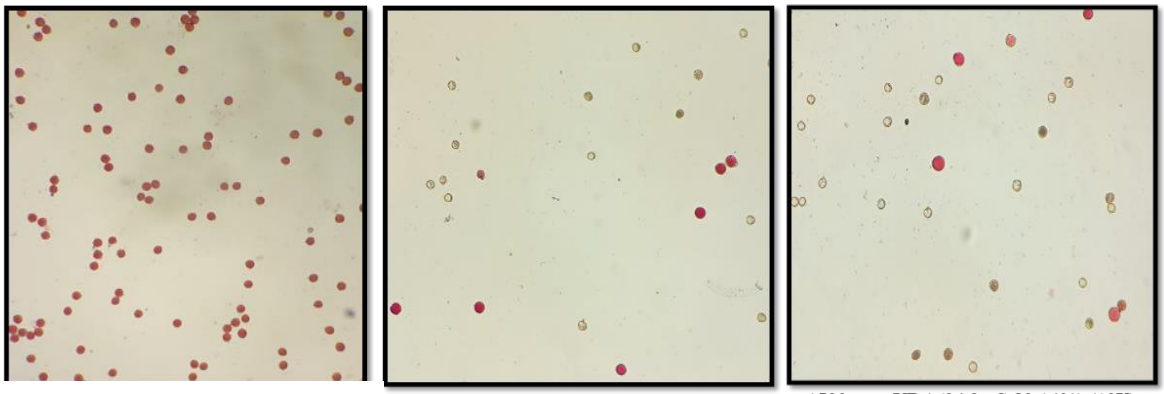
Progeny No.	VP 1 (M) family					SKI 215 family				
	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S	Control	50 mM EMS	60 mM EMS	1000 ppm S.S	1500 ppm S.S
7-23	0.01	0.06	0.03	0.10	0.03	0.01	0.06	0.43	0.05	0.29
7-24	0.02	0.18	0.10	NMF	NG	0.05	0.04	0.27	0.19	0.04
7-25	0.01	0.05	0.08	0.67	0.12	0.03	NG	NG	0.25	0.32
7-26	0.02	NG	NG	NG	0.35	0.00	0.10	0.42	NG	NG
7-27	0.00	NMF	0.36	0.13	0.04	0.04	0.07	0.02	0.00	0.09
7-28	NMF	0.12	0.35	0.35	0.30	0.03	0.04	0.08	0.13	0.15
7-29	NMF	0.16	0.19	NG	0.13	0.01	0.05	0.01	0.07	0.02
7-30	0.02	NMF	0.56	0.66	NMF	0.04	0.12	0.08	0.07	0.45
8-1	0.02	0.05	0.00	NMF	0.09	NG	0.11	NS	0.28	0.00
8-2	0.02	0.17	0.16	0.56	0.08	0.03	0.10	0.08	NG	NG
8-3	0.02	NG	0.23	0.02	NG	0.00	0.00	0.33	0.19	0.08
8-4	0.00	0.07	0.25	NG	0.22	0.04	NG	0.66	0.07	NG
8-5	NMF	NG	0.12	0.13	NMF	0.03	0.07	0.19	0.11	0.08
8-6	NG	0.03	NG	0.49	NG	0.04	NG	0.17	0.04	0.42
8-7	0.02	0.04	NMF	NG	NMF	0.04	0.08	NS	0.01	0.20
8-8	0.00	0.11	0.17	0.41	0.20	0.04	0.07	0.01	0.18	0.09
8-9	0.00	0.10	NS	0.37	0.35	0.04	0.03	0.10	0.02	0.10
8-10	0.00	0.12	0.04	0.29	0.00	0.04	0.09	0.00	0.06	0.10
8-11	0.00	0.02	NMF	0.01	NMF	0.03	0.03	0.22	0.01	0.13
8-12	NG	NS	0.28	0.03	0.19	NG	0.07	NG	NG	0.04
8-13	0.00	0.13	NG	0.20	NG	0.02	0.06	0.00	0.07	NG
8-14	NMF	0.19	0.27	0.06	0.47	0.04	0.10	0.27	NG	NG
8-15	0.02	NG	NMF	0.41	0.06	0.04	0.09	0.01	0.27	0.04
8-16	0.01	0.19	NG	0.51	0.28	0.02	NG	NG	0.03	NG
8-17	NMF	0.10	NMF	NG	NG	0.00	0.09	0.01	0.20	0.14
8-18	0.00	0.14	0.00	0.10	0.45	0.03	NG	0.33	0.03	0.00
8-19	0.02	0.18	0.23	0.13	0.00	0.00	0.06	NG	0.18	0.00
8-20	0.00	0.03	0.07	0.51	0.19	0.05	0.04	0.18	0.06	0.34
8-21	NMF	0.13	NMF	0.15	0.35	0.03	0.02	0.12	0.07	NG
8-22	0.02	0.16	0.09	0.10	0.17	0.04	0.05	0.06	NG	0.39
8-23	0.00	NMF	NG	0.00	0.04	0.01	0.09	0.46	0.03	0.13
8-24	0.02	0.14	0.15	0.03	NG	0.02	NG	0.08	0.08	0.00
8-25	0.02	NG	NG	0.16	0.51	NG	0.12	0.13	0.03	0.04
8-26	NG	0.07	0.05	0.09	0.40	0.04	0.06	0.13	0.01	0.14
8-27	0.02	NG	0.15	NG	0.01	0.00	0.12	NG	0.34	0.02
8-28	NMF	0.04	NMF	0.45	NG	0.04	0.05	0.09	0.14	0.26
8-29	0.01	0.11	0.48	NG	0.00	0.05	0.05	NG	0.31	0.06
8-30	0.01	0.10	0.68	0.01	0.33	0.03	0.05	0.00	0.22	0.11
9-1	0.01	0.09	0.19	0.67	0.01	0.03	NG	0.34	0.07	29.56
9-2	NMF	0.12	0.17	0.33	NG	NG	0.04	0.02	0.09	34.70
9-3	0.02	NG	0.08	0.38	0.52	0.02	0.02	0.41	NG	20.00
9-4	0.01	0.19	0.01	0.83	NG	0.03	0.05	NG	0.02	17.40
9-5	NG	0.04	NG	NMF	0.38	0.02	0.06	0.14	0.07	NG
9-6	0.02	0.14	0.02	NG	NG	0.04	0.05	0.27	0.06	23.46
9-7	0.02	0.07	0.45	0.05	0.05	0.01	0.10	NG	0.00	NG
9-8	0.01	NS	NS	0.40	0.08	0.03	0.11	0.01	0.04	NG
9-9	NMF	0.05	0.04	0.14	0.09	0.04	0.02	0.54	0.01	13.44
9-10	0.01	0.16	0.05	0.35	0.01	0.03	0.01	0.38	0.14	28.56
9-11	0.01	NG	0.21	0.55	0.23	0.04	0.08	0.04	0.32	NS
9-12	0.02	0.07	0.16	0.25	0.06	0.04	0.08	0.11	0.00	64.66
9-13	NMF	NS	0.37	0.45	NG	0.03	NG	0.19	NG	52.44



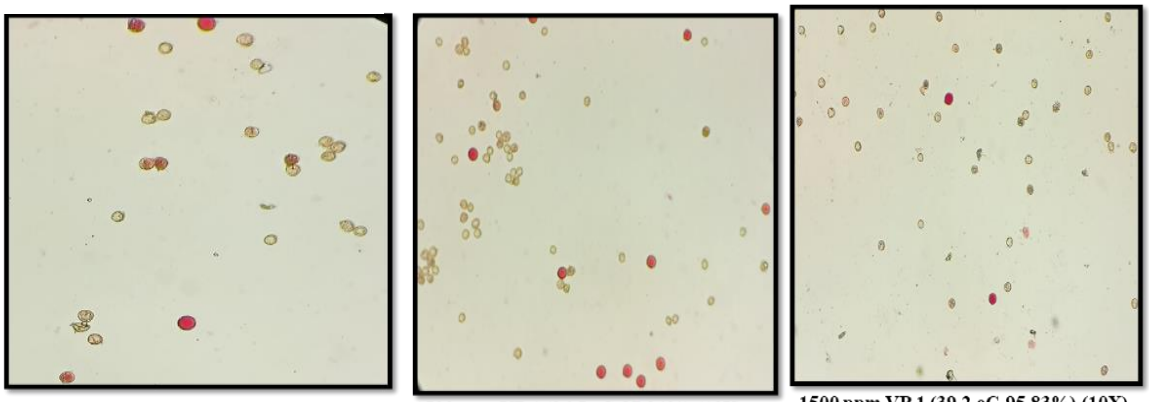
Control VP 1 (39.2 oC) (10X) | 1000 ppm VP 1 (21.9 oC- 12.30 %) (10X) | 1000 ppm VP 1 (24.9 oC- 21.42%) (10X)



1000 ppm VP 1 (26.5 oC- 43.48%) (10X) | 1000 ppm VP 1 (28.1 oC- 55.34 %) (10X) | 1000 ppm VP 1 (39.2 oC-84.61%) (10X)



VP 1 (M) 50 mM EMS plant | 1500 ppm VP 1 (21.9 oC-66.66%) (10X) | 1500 ppm VP 1 (24.9 oC-82.14%) (10X)



1500 ppm VP 1 (25.2 oC-83.33%) (10X) | 1500 ppm VP 1 (26.5 oC-87.34%) (10X) | 1500 ppm VP 1 (39.2 oC-95.83%) (10X)

Plate IV: Response of sterile plants for pollen sterility on metrological parameter

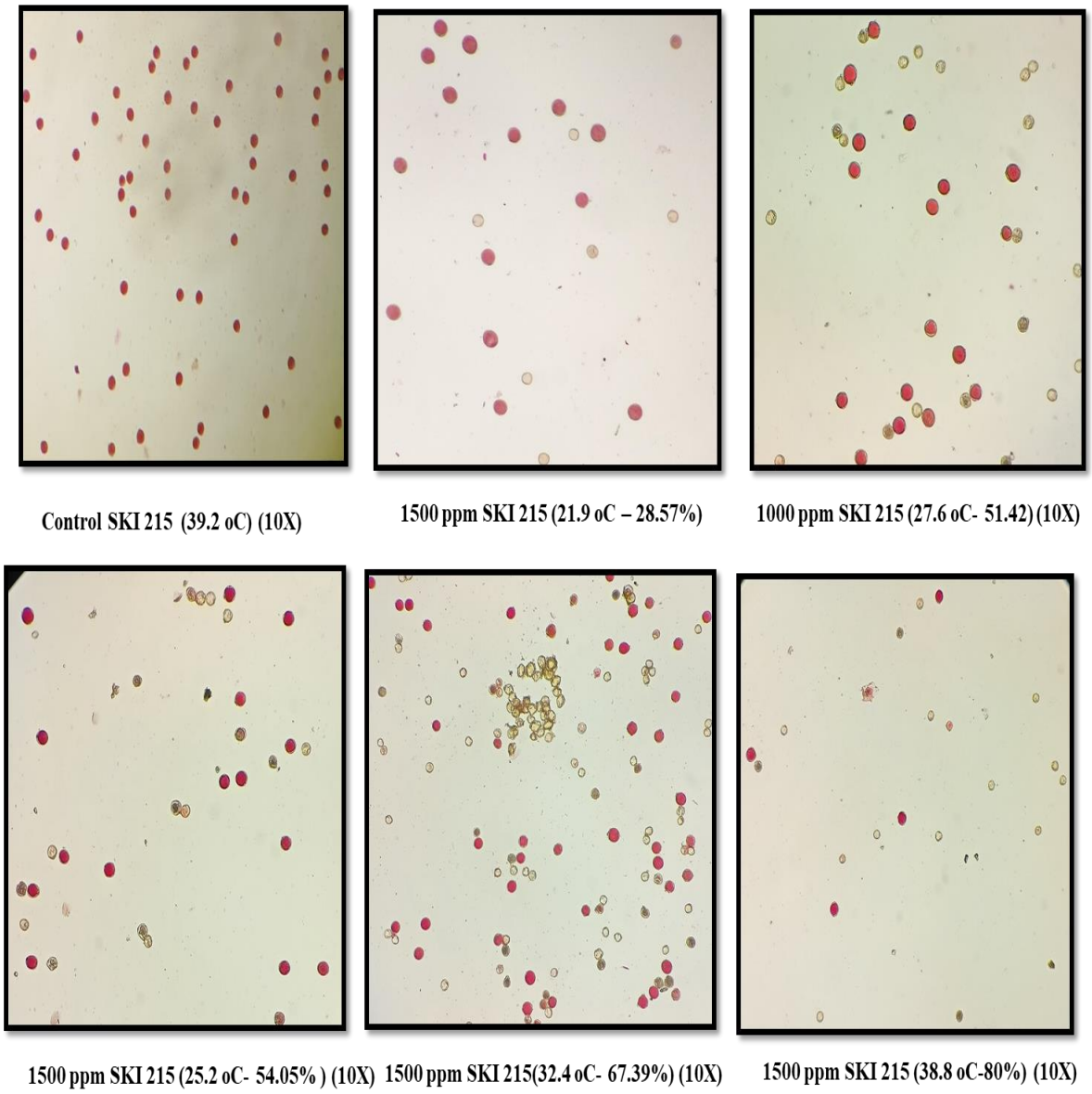


Plate IV: Response of sterile plants for pollen sterility on metrological parameter

Table. 4.8: Conti…

Progeny No.	VP 1 (M) family					SKI 215 family				
	Control	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**	**Control**	**50 mM EMS**	**60 mM EMS**	**1000 ppm S.S**	**1500 ppm S.S**
9-14	0.01	0.08	NG	0.08	0.02	0.04	0.01	NG	0.22	NG
9-15	0.02	0.06	0.02	0.26	0.45	0.02	0.08	0.53	0.06	10.44
9-16	0.02	0.11	0.72	0.16	0.14	0.02	0.10	0.03	NG	NG
9-17	NMF	NG	0.44	NMF	NG	0.02	NG	0.02	0.09	**80.00**
9-18	0.01	0.10	0.12	0.03	0.01	0.03	0.11	0.15	0.03	24.70
9-19	NMF	0.14	0.42	0.01	0.02	0.02	0.09	NG	0.05	NG
9-20	0.02	NMF	0.45	NMF	0.06	0.03	0.00	0.03	0.15	19.78
9-21	0.01	0.04	0.07	0.68	0.02	0.03	0.02	0.20	0.23	35.68
9-22	0.00	0.02	0.33	0.33	0.30	0.04	0.02	0.05	NG	58.40
9-23	NG	0.05	NG	0.07	NG	0.03	NG	0.22	0.20	49.22
9-24	0.02	NS	NMF	0.19	0.02	0.04	0.09	NG	0.08	NG
9-25	0.02	0.19	NG	0.15	0.32	0.04	0.07	0.04	0.09	NS
9-26	0.00	0.00	0.45	NG	NG	0.00	0.03	NS	0.14	26.34
9-27	NMF	0.14	NG	0.07	0.03	0.05	0.09	0.17	0.38	51.66
9-28	0.02	0.12	0.34	0.44	0.09	0.04	0.08	0.26	0.00	NS
9-29	0.02	0.02	NMF	0.06	NG	0.01	0.09	0.21	0.27	22.56
9-30	0.01	0.06	0.61	0.19	0.30	0.04	0.09	0.19	0.22	45.42
10-1	NMF	0.01	NG	0.50	NMF	0.04	0.06	0.48	0.12	0.35
10-2	0.01	0.19	0.01	0.06	0.02	0.01	0.09	0.40	0.39	NG
10-3	0.01	NG	0.44	0.36	0.05	NS	0.01	NG	0.10	NG
10-4	0.01	0.08	NS	0.06	0.16	0.03	0.11	0.24	0.01	0.32
10-5	NS	NMF	0.04	0.33	NG	0.00	0.12	0.36	0.25	0.34
10-6	0.02	NG	0.19	NG	0.02	0.05	0.10	NS	0.37	NG
10-7	0.00	0.14	NG	0.38	0.16	0.02	0.11	0.04	0.04	0.51
10-8	NMF	0.16	NMF	0.47	NG	0.05	NS	NG	0.27	0.18
10-9	0.02	0.13	0.24	0.43	0.03	0.01	0.03	0.03	0.17	0.08
10-10	0.01	0.01	0.00	NG	0.15	0.01	0.12	0.03	0.42	0.31
10-11	0.01	0.04	0.13	0.03	0.27	0.04	0.03	0.00	0.29	0.14
10-12	0.02	NMF	0.23	0.01	NG	0.04	NG	NG	0.43	0.03
10-13	NG	0.12	NS	0.01	0.40	0.00	0.09	0.40	0.14	0.31
10-14	0.01	NG	0.25	0.49	NG	0.00	0.02	NG	0.08	NG
10-15	NMF	0.13	0.38	0.00	0.42	0.05	NG	0.08	0.11	NG
10-16	0.01	NG	0.26	NMF	0.03	0.05	0.10	0.22	NG	0.33
10-17	0.02	0.06	NS	0.01	0.39	0.02	0.09	NS	0.29	0.39
10-18	0.01	0.12	0.10	NG	NG	0.04	0.04	0.00	0.30	0.00
10-19	NMF	0.05	0.16	0.02	0.23	0.03	0.10	0.03	0.04	0.19
10-20	0.02	0.19	NMF	0.75	0.24	0.01	0.07	0.40	0.12	0.03
10-21	0.02	0.07	0.05	0.27	NMF	0.04	NG	0.27	0.01	0.21
10-22	0.02	0.07	0.05	0.09	0.44	0.02	0.09	NG	0.13	0.15
10-23	0.01	NS	0.06	0.38	0.26	0.02	0.01	0.00	0.16	NG
10-24	0.02	0.09	NG	0.02	NG	0.01	0.00	0.20	0.10	0.10
10-25	0.02	0.03	NG	0.01	0.02	0.01	0.04	NG	NS	NG
10-26	NMF	0.14	0.12	0.01	0.46	0.05	0.07	0.01	0.05	0.07
10-27	0.01	NG	0.01	NG	0.37	0.05	NS	0.01	0.28	0.06
10-28	0.01	0.01	0.22	0.06	NG	0.01	0.02	0.24	0.11	0.11
10-29	NMF	0.03	0.19	0.00	0.06	0.02	0.03	0.27	0.00	0.08
10-30	0.02	0.06	0.45	0.05	0.27	0.01	0.08	0.00	0.08	0.25
Total	3.36	23.97	42.93	898.23	872.82	7.56	15.52	45.45	32.28	742.69
Range (Min-Max)	0.00-0.02	0.00-0.60	0.00-0.72	0.00-84.61	0.00-95.83	0.00-0.05	0.00-0.12	0.00-0.69	0.00-0.48	0.00-80.00
Mean	0.01	0.08	0.14	2.99	2.91	0.03	0.05	0.15	0.11	2.48

NG= not germinated, NS= not survived and NMF= not male flower

Table 4.9: Periodically pollen sterility status of identified three plants of M_2 generation along with meteorological data

Plant No.	Month and Year	Std.week No.	Temperature (^oC)		Relative Humidity (%)		Treatment (S.S) VP 1 (M)		Treatment (S.S) SKI 215
			Max.	Min.			1000 ppm Plant no.(36)	1500 ppm Plant no. (61)	1500 ppm Plant no. (17)
					Morning	Evening	Pollen sterility %		
1	November 2021	45	28.1	13.6	70	35	42.50	80.83	47.81
2		46	26.5	10.6	70	32	39.34	70.00	41.44
3		47	25.2	7.6	70	30	29.13	83.33	32.04
4		48	27.1	11.7	76	41	43.24	76.74	43.48
5	December 2021	49	25.9	12.7	76	53	32.48	87.22	33.4
6		50	**21.9**	**7.0**	**67**	**45**	**12.30**	**66.66**	**28.57**
7		51	24.9	8.5	68	39	21.42	82.14	75
8		52	25.0	6.0	57	35	29.41	86.59	42.61
9	January 2022	01	27.6	8.8	65	33	40.22	91.32	51.42
10		02	27.9	9.5	64	31	46.42	91.90	70.06
11		03	30.3	10.0	65	29	56.44	92.23	75.24
12		04	32.4	12.6	69	26	59.46	92.80	67.39
13	February 2022	05	28.1	13.6	70	35	55.34	91.10	58.86
14		06	26.5	10.6	70	32	43.48	87.34	46.42
15		07	25.2	7.6	70	30	46.43	88.76	54.05
16		08	32.4	12.6	69	26	58.93	94.24	57.9
17	March 2022	09	32.9	15.4	69	23	56.94	88.10	58.9
18		10	35	16.1	69	22	70.69	91.86	74.32
19		11	**39.2**	**17.7**	**71**	**20**	**84.61**	**95.83**	78.95
20		12	**38.8**	**18.1**	**71**	**25**	79.41	92.65	**80.00**

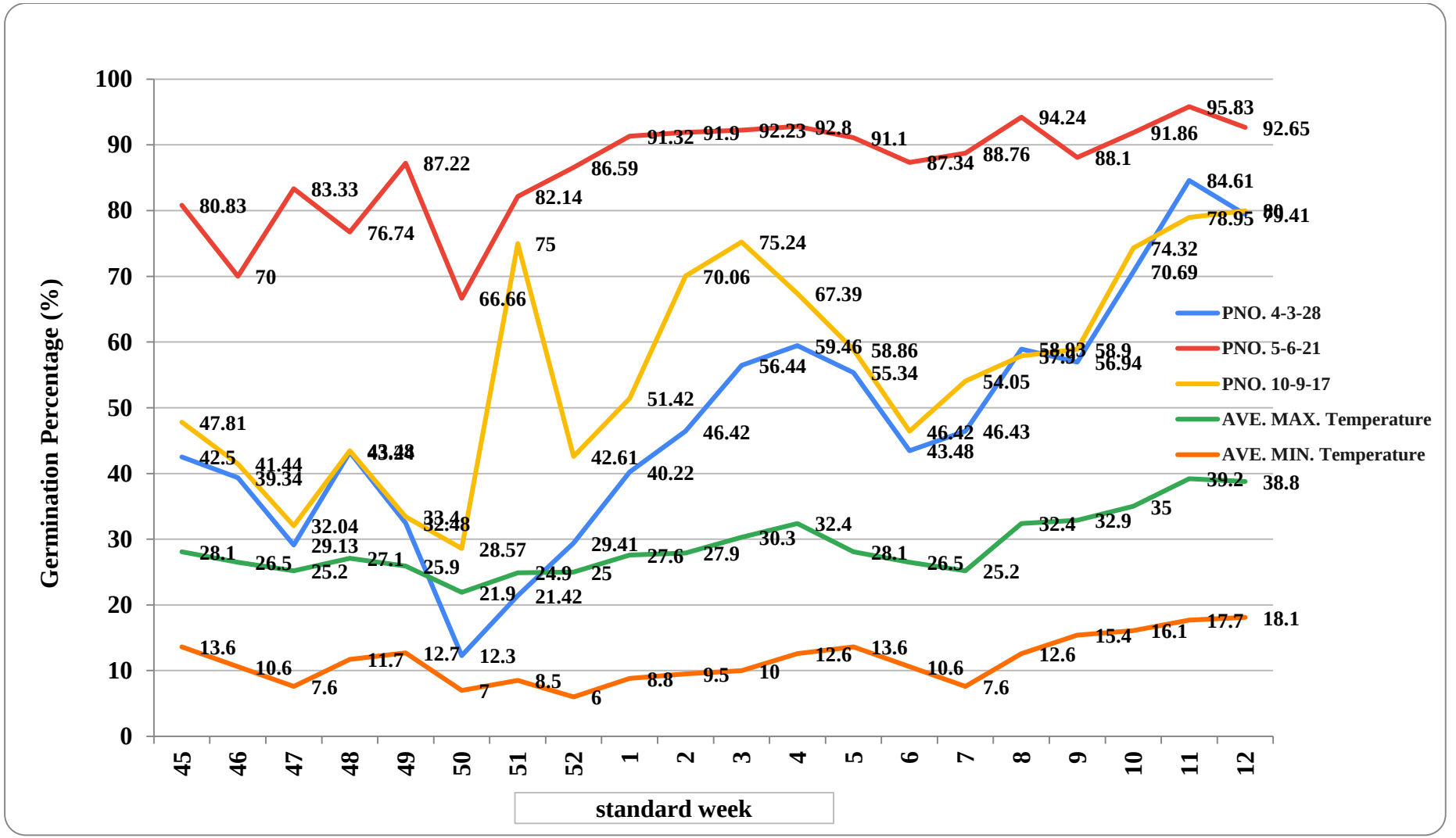


Fig. 5 Response of sterile plants for pollen sterility on meteorological parameter

1000 ppm streptomycin sulphate in 11th standard week of the year 2022 (11th SWY 2022) at that time temperature was observed highest (39.2 ^{o}C). SKI 215 when treated with 1500 ppm streptomycin sulphate showed the highest pollen sterility (80.00%) in plant No. 17 of 9th progeny during 12th SWY 2022. It can be noted that this week observed mean of maximum temperature 38.8 ^{o}C which was followed by the highest average maximum temperature of standard week eleven in Table 4.9. Looking to this results higher level sterile plants were observed in both the genotypes when treated with streptomycin sulphate. There was no sterile single plant observed in both the genotypes treated with EMS. This result supported by Athma and Reddy (1986) in castor using gamma rays treatment in M_1 generation. They found that mean amount of pollen sterility was maximum at meiotic stage (38.5%) followed by gametic (31.6%), post-gametic (20.2%) and seedling (17.7%) stages. Whereas, the seed sterility was maximum at meiotic stage (29.1%) followed by post-gametic (23.0%), seedling (20.8%) and gametic (18.1%) stages. Burghate *et al*. (2013) in groundnut TAG-24 variety using gamma rays doses and ethyl methane sulphonate and their combinations in M_1 generation, found that pollen sterility increased in all the treatment of gamma rays, ethyl methane sulphonate and their combinations as compared to their respective control. Rohini *et al*. (2020) in sesame seeds using various doses/ concentrations of gamma radiation (GR-300 to 500Gy), ethyl methane sulphonate (EMS- 0.3 to 0.5%) and sodium azide (SA-0.15, 0.20, 0.25%) reported that pollen sterility induced by gamma radiation, EMS, and SA treatments. There was liner increase in pollen sterility with increasing dose/ concentrations of mutagens. Highest pollen sterility (31.09%) was recorded in 500 Gy and lowest in 300 Gy. On the other hand the highest pollen sterility (23.59%) was noted in 0.5 per cent EMS, while lowest pollen sterility was found in 0.3 per cent EMS (17.21%).

Periodical observation of sterility of those three plants is presented Table 4.9. The observation and sterility started in standard week 45 to 12 week and minimum temperature of 7.0 to 17.7 and per cent correlation coefficient were calculated in MS Excel office version-13 and the results are shown in Table 4.10.

The highest correlation coefficient (Pearson, 1902) observed with average maximum temperature of a week to the pollen sterility followed by average minimum temperature of a week. Negative correlations were observed with humidity at morning and evening. These results indicates that higher temperature with dry day are favourable for increasing pollen

Table 4.10: Correlation coefficient in between meteorological parameter and pollen sterility of mutant plants in M_2 generation

Family-Progeny-Plant No.	Treatment (S.S.)	Temperature (^oC)		Relative humidity (%)	
		Max.	Min.	Morning	Evening
4-3-28	1000 ppm VP 1 (M)	0.95	0.83	-0.77	-0.11
5-6-21	1500 ppm VP 1 (M)	0.64	0.46	-0.11	-0.56
10-9-17	1500 ppm (SKI 215)	0.74	0.53	-0.12	-0.65

sterility in those three observed mutant plants. Elkonin and Tsvetova (2007) in sorghum callus cultures with 500–1000 mg/l streptomycin led to a high regeneration frequency of plants with partial or complete male sterility (MS). They found that the mutation was inherited as a recessive nuclear mutation in test crosses of sterile plants segregated in the progenies of fertile and semi sterile revertants and was expressed only in single cases in a test cross for ms-str transfer through pollen of hybrids with restored male fertility.

4.2.5 Variability parameters

Selfed seed of each and every plant grown in field in year 2020-21 in M_1 generation. It was advanced in M_2 generation. All the treatments including untreated controls of both the genotypes was consisted to families and they were grown in field in the year 2021-22. Randomly selected progenies which have sufficient seed that were grown to three replication *i.e.*, ten dibbled of each progeny grown in compact family block design. Only quantitative observations were considered for CFBD analysis to study matric trait variations in plants and averaged out. The recorded observation were analysed accordingly method sugeested by Panse and Sukhatme (1995) for CFBD and presented in Table 4.11 and Table 4.12.

4.2.3.1 Analysis of Variance

The analysis of variance for compact family block design was carried for ten characters and is presented in Table 4.11. The analysis of variance between families revealed that mean squares of the ten families differed significantly for all the characters *viz.*, days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of node up to primary raceme, effective length of primary raceme, number of effective branch per plant, number of capsule on primary raceme, seed yield per plant, 100-seed weight and oil content. The chi-square for Barlett's test of homogeneity of error variances being significant for all the characters except days to flowering of primary raceme, 100-seed weight and oil content, it indicated the necessity

to perform analysis of variance separately for each of the family.

The analysis of variance in M_2 generation (Table 4.12) between progenies within family indicated that progeny mean squares were significant for all the characters *viz*., days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of node up to primary raceme, effective length of primary raceme, number of effective branch per plant, number of capsule on primary raceme, seed yield per plant, 100-seed weight and oil content in all ten mutation families. This indicated that considerable variation was observed between progenies within families due to mutation treatments. For control treatment progenies had non-significant mean squares for all the characters except family 5 (untreated VP 1 (M)) for number of capsule on primary raceme and 100-seed weight. Family 10 (untreated SKI 215) for 100-seed weight exhibited significant mean square due to progeny. These similar result had also been reported by Khatri *et al*. (2005) in mustard using S-9 variety with different doses of gamma rays (750 and 1000 Gy) and EMS (0.75% and 1.0%) to induce genetic variability. They observed significant ($p \leq 0.05$) differences were observed amongst all the families for the quantitative traits under evaluation and three mutants progenies S 97-75/36, S 97-1.0E/20 and S 97-1.0E/21 were significantly ($p \leq 0.05$) superior to all other entries in seed yield and these were also found early in maturity, short stature and having high seed index. Emrani *et al*. (2012) treated seeds of two canola cultivars ('RGS003' and 'Sarigol') with 0, 800, 1000, 1200 Gy doses of gamma rays and the resultant M_2 and M_3 lines were grown under field conditions indicated highly significant effects of mutagenic doses and genotypes indicating the differential response of genotypes to mutagenic treatments in terms of inducing genetic variation.

4.2.6 Genetical variability studies in M_2 generation

Many quantitative characters including yield and yield components of crop plants are governed by polygenic system. The variability for these characters can be enhanced on positive as well as negative side through induced mutagenesis. Study of the extent of the variability for quantitative traits is important in ascertaining whether mutation breeding can be resorted for improvement of the character. If a genotype shows increase in mean, there is scope for making genetic advance by selection and thus improving the character.

Genotypic coefficient of variation (GCV) would be more useful for the assessment of inherent or real variability as it exhibits the heritable portion only (Allard, 1960). The estimated GCV for different characters were almost the same as that of PCV. It is evident therefore, that the influence of environment on the expression of these characters was

Table 4.11: Analysis of variance (mean square) between families for different characters in M_2 generation of castor

Sources	d.f.	Days to 50% flowering of primary raceme	Days to maturity of primary raceme	Plant height upto primary raceme (cm)	Number of node up to primary raceme	Effective lengthof primary raceme (cm)
Replications	2	3.31	4.92	4.19	0.86	25.13
Families	9	769.54**	3662.24**	30663.56**	195.93*	142.24**
Error	18	1.25	3.00	43.35	0.98	36.55
Chi-square		**NS**	**S**	**S**	**S**	**S**

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	11.45	105.35	5638.00	1.87	0.90
Families	9	510.05**	687.02**	17676.22**	50.60**	11.46**
Error	18	3.34	33.64	2079.44	0.61	0.81
Chi-square		**S**	**S**	**S**	**NS**	**NS**

*, ** = Significant at P = 0.05 and 0.01 %, respectively

Where '**S**'- Error variances are heterogeneous; '**NS**'- Error variances are homogeneus

Table 4.12: Analysis of variance (mean square) between progenies within families for different characters in M_2 generation of castor

Family 1 (Genotype: VP 1 (M); Dose: Control)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	3.82	16.56	6.65	0.32	22.56
Progenies	9	6.24	7.06	9.77	2.68	36.57
Error	18	2.77	5.76	4.92	1.25	15.11

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	1.22	8.91	1047.82	0.96	0.51
Progenies	9	2.12	152.33*	2597.79	4.52**	1.42
Error	18	0.96	43.21	1126.74	0.62	0.60

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont...)

Family 2 (Genotype: VP-1 (M); Dose: EMS 50 mM)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	0.36	0.26	28.74	1.04	57.17
Progenies	9	3.82*	6.15*	26.17*	4.66*	84.63**
Error	18	1.55	1.94	10.58	1.31	23.36

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	3.53	130.61	66.83	1.14	0.77
Progenies	9	3.40*	155.58*	3502.67**	2.73**	2.68**
Error	18	1.05	48.17	552.64	0.66	0.55

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont...)

Family 3 (Genotype: VP 1 (M); Dose: EMS 60 mM)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	1.18	0.89	18.66	0.11	57.33
Progenies	9	4.92*	6.01*	22.18*	2.02*	204.99**
Error	18	1.42	2.07	8.37	0.67	16.84

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	4.61	45.12	3237.72	0.53	1.12
Progenies	9	8.27**	114.87*	2308.47*	4.84**	4.09**
Error	18	1.47	36.15	935.57	1.02	0.90

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont…)

Family 4 (Genotype: VP 1 (M); Dose: streptomycin sulphate 1000 ppm)

Sources	d.f.	Days to 50% flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	1.44	2.09	7.82	3.09	93.92
Progenies	9	3.74*	5.65*	18.17*	8.71**	137.77**
Error	18	1.46	2.15	6.12	1.51	30.08

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	1.49	16.02	150.82	0.43	1.22
Progenies	9	2.28*	102.16*	935.47*	3.17**	4.46*
Error	18	0.90	29.95	371.90	0.61	1.26

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont...)

Family 5 (Genotype: VP 1; Dose: streptomycin sulphate 1500 ppm)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	1.16	1.16	12.25	2.44	24.03
Progenies	9	7.22*	6.96*	14.78*	2.76*	67.70**
Error	18	2.11	2.25	5.63	1.10	13.26

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	1.30	65.13	2068.03	1.02	0.50
Progenies	9	1.76*	73.51**	3389.70*	4.13**	2.44*
Error	18	0.55	18.71	1329.89	0.90	0.86

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont...)

Family 6 (Genotype: SKI 215; Dose: Control)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	1.23	2.56	8.61	1.05	3.09
Progenies	9	3.72	1.89	61.80	2.21	29.96
Error	18	1.95	2.28	41.44	0.94	14.31

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	0.22	3.61	3527.84	0.45	0.09
Progenies	9	4.93	69.88	3151.75	5.41**	1.91
Error	18	3.80	29.66	1303.90	1.27	0.79

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont...)

Family 7 (Genotype: SKI 215; Dose: EMS 50 mM)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	1.76	2.23	141.96	0.46	2.80
Progenies	9	4.00*	6.09*	157.23*	5.14**	37.73**
Error	18	1.57	2.45	58.28	0.48	4.30

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	13.08	22.80	1697.94	0.11	1.25
Progenies	9	38.52**	149.12**	8713.43**	7.60**	2.63**
Error	18	3.90	14.78	1331.99	0.77	0.42

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont...)

Family 8 (Genotype: SKI 215; Dose: EMS 60 mM)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	1.94	1.63	152.80	0.20	37.70
Progenies	9	4.03*	5.21*	107.06*	1.20*	40.93*
Error	18	1.62	2.00	43.52	0.43	11.43

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	5.56	21.31	3199.69	1.59	1.73
Progenies	9	5.83*	31.35*	4757.02*	3.39*	1.43*
Error	18	2.22	11.68	1638.87	1.09	0.56

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont...)

Family 9 (Genotype: SKI 215; Dose: streptomycin sulphate 1000 ppm)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	0.86	1.56	5.63	0.62	4.92
Progenies	9	5.01*	6.22*	75.27*	1.43*	26.46*
Error	18	1.93	2.16	29.75	0.54	10.71

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	2.36	11.91	4704.01	0.67	0.52
Progenies	9	5.48*	75.49**	3904.84*	2.69*	1.59*
Error	18	2.01	18.46	1418.63	0.99	0.56

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

Table 4.12: (Cont…)

Family 10 (Genotype: SKI 215; Dose: streptomycin sulphate 1500 ppm)

Sources	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Replications	2	0.77	2.96	11.26	0.29	50.47
Progenies	9	9.98*	9.83*	121.14*	1.76*	37.38*
Error	18	3.98	3.91	48.20	0.61	15.18

Sources	d.f.	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
Replications	2	8.10	82.71	4648.86	0.39	0.48
Progenies	9	14.79**	183.81**	6450.24**	2.05*	2.89**
Error	18	2.45	24.15	1414.82	0.75	0.68

*, ** = Significant at P = 0.05 and 0.01 %, respectively.

invariably low in the study. It may be assumed that the phenotypic variability as such can be utilized in making selection.

Heritability estimates reveals the heritable portion of variability present in different characters. The knowledge of heritability enables the plant breeder to decide the course of selection procedure to be followed under given situation. However, heritability values coupled with genetic advance would be more reliable (Johnson *et al*., 1955) and useful in formulating selection procedure. High heritability accompanied with high genetic advance indicates that it is due to additive gene effects and selection may be effective. High heritability with moderate genetic advance indicates that the characters are less influenced by environment but governed by both additive and non-additive gene action. High heritability accompanied with low genetic advance indicates that it is due to non – additive gene effects and selection may not be effective. In the present study, heritability estimates in broad sense and genetic advance as per cent mean were estimated using data under CFBD.

4.2.6.1 Days to flowering of primary raceme

The relative amount of variability present in the experimental material expressed by different traits was judged through estimates of phenotypic and genotypic co-efficient of variation. To predict the inheritance capacity of characters from one generation to another, total variation in the population should be partitioned into heritable and non-heritable portion since only heritable portion is transmitted into next generation which is determined with help of heritability.

Phenotypic range, mean, GCV, PCV, heritability, genetic advance and genetic advance as per cent of mean are given in Table 4.13.

VP 1 (M)

Enhancement in phenotypic range was observed in present study due to chemical and antibiotic treatment. The highest observed phenotypic range was for 1500 ppm streptomycin sulphate (50.06-55.27 days). Maximum mean for days to flowering (52.59 days) was found in 1500 ppm followed by 1000 ppm streptomycin sulphate treatment (50.55 days) and 60 mM EMS (51.05 days). Decrease in mean value for days to flowering was observed in treated family when compared with control. With these, early variants were detected in family treated with EMS 50 mM concentration (48.80 days). Similar results were observed by Dhakshanamoorthy *et al*. (2010) in jatropha using gamma rays and EMS treatment in healthy and dry seeds. They recorded minimum decrease in days to first flowering (255 days) and days taken for flowering to fruiting (6 days) in 5 Kr dose when compared to control. Emrani

et al. (2012) in canola using 1200 Gy gamma ray treatment in M_3, induced 7 per cent earliness in flowering compared to control in 'Sarigol' cultivar.

The GCV values were higher in the treated families than control family (3.82%) except 1000 ppm streptomycin sulphate (3.57%) and 50 mM EMS treatment (3.72%) and PCV value were higher in the treated family as compared control (4.71%) except 1000 ppm streptomycin sulphate (4.30%) and 50 mM EMS (4.51%), which indicating that variability was increased due to chemical and antibiotic treatments and the highest values for GCV (4.85%) and PCV (5.58%) were recorded in 1500 ppm streptomycin sulphate treatment. High heritability found in mutagen treatment 60 mM EMS (75.74%) followed by 50 mM EMS (68.07%), indicating the treatment effect could inherit in their progenies as well. All mutagen treatments had low genetic advance and GA as per cent of mean for days to flowering. Indicating presence of non-additive gene action in the control of character and thus selection won't be effective for further development. Maximum genetic advance and GA as per cent of mean observed in family no. 5 having mutagen treatment of 1500 ppm streptomycin sulphate *i.e*., 4.57 per cent and 8.69 per cent, respectively. Heritability, genetic advance and genetic advance as per cent of mean found to be improved overall in all the treated families compared with control. This result are supported by Emrani *et al*. (2012) in canola using different doses of gamma irradiation on seeds of two canola cultivars 'RGS003' and 'Sarigol. They found that treatment with 1200 Gy mutagen induced the highest heritability of flowering date (96.43%, 93.32%) in both cultivars, respectively, while treatment with 1000 Gy showed the highest values for GCV, PCV and GAM in RGS003 and Sarigol both the cultivars.

SKI 215

In this genotype (SKI 215) phenotypic range for days to flowering observed higher in mutation treatments as compared to control. The highest range was observed in case of 1500 ppm streptomycin sulphate (54.46-61.26 days). Mean values for days to flowering was shifted in both the direction indicated presence of good variability. Maximum mean value of days to flowering observed in 60 mM EMS (60.85 days) followed by 1000 ppm streptomycin sulphate (60.25 days), and 50 mM EMS (59.54 days). Decrease in mean value for days to flowering was observed in the treated families as compared with control and early variants were observed by 1500 ppm streptomycin sulphate treatment (58.29 days). Similar results obtained by Giriraj *et al*. (2004) in sunflower. They found that 0.5 per cent EMS treatment to 6D-1 genotype was helpful in isolating early flowering mutant lines as flowering ranged from 54 to 75 days in the mutant population against 65 to 81 days in the

untreated population. Ravichandran and Jayakumar (2015) in sesame using gamma rays and EMS treatment for VRI-1 variety observed slight decrease in number of days to first flower in gamma rays and EMS treatment than in the control. The treatment at EMS 2.0 mM took more number of days to first flower (42.00 days), while the minimum number of days (38.00 days) to first flower was observed at 40 KR of gamma rays.

All mutagen treatments had low phenotypic and genotypic coefficient of variation. Maximum PCV(6.10%) and GCV (5.05%) observed in 1500 ppm streptomycin sulphate. Low PCV (3.72%) and GCV (3.07%) found in 60 mM EMS. The GCV, PCV, genetic advance and genetic advance as per cent of mean of days to flowering were higher than the control for both the treatments. All mutagen treatments varies 61.12 per cent to 69.33 per cent heritability. High heritability found in mutagen treatment 1000 ppm Streptomycin sulphate (69.33%) followed by 1500 ppm streptomycin sulphate (68.50%). The high heritability estimates obtained may be due to additive gene effects which can be exploited for direct selection for these traits.Maximum genetic advance and GA as per cent of mean observed in mutagen treatment 1500 ppm streptomycin sulphate 5.02 and 8.60 per cent, respectively. Similar results supported by Giriraj *et al*. (2004) in sunflower using different concentration 0.5 per cent and 0.1 per cent EMS for RHA 265, RHA 265 (non-branching) and 6D-1 two restorer line, found that 0.5 per cent EMS treatment to RHA 265 restorer line noted high heritability (86%) with good genetic advance.

4.2.4.2 Days to maturity of primary raceme

Phenotypic range, GCV, PCV, heritability, genetic advance and genetic advance as per cent of mean are given in Table 4.13.

VP 1 (M)

In VP 1 (M) genotype, all the mutation treatments showed lower phenotypic range as compare to control (121.00-132.67). Minimum range was observed in 50 mM EMS (112.13-116.87) followed by 60 mM EMS (114.80-118.60) and 1000 ppm streptomycin sulphate (120.07-124.93). Decrease in mean value for days to maturity was observed in treated family as compared to control (130.13 days) and early variants were observed in 50 mM EMS (114 days) treatment. Similar results were obtained by Gothaliya and Madariya (2019) in castor using gamma radiation in JP-94, JI-444 and GP-15-1 genotypes, found that JP-15 noted number of the days to maturity of primary raceme for both the treatments is lower than control (140.66 days). Early variants were observed in 500 Gy (128.70 days) treatment. They have also noted that values for mean days to maturity of primary raceme

Table 4.13: The estimates of genotypic and phenotypic variances and other genetic parameters for days to flowering of primary raceme in M_2 generation of castor

Treatments	Phenotypic Range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	57.86-62.86	8.28	60.34 ± 0.30	5.31	8.08	3.82	4.71	65.74	3.85	6.38
50 mM EMS	47.33-50.53	6.55	48.80 ± 0.23	3.30	4.86	3.72	4.51	68.07	3.08	6.33
60 mM EMS	49.73-53.60	7.58	51.05 ± 0.22	4.44	5.86	4.12	4.74	75.74	3.78	7.40
1000 ppm S.S	49.33-52.26	5.79	50.55 ± 0.22	3.25	4.71	3.57	4.30	69.04	3.09	6.11
1500 ppm S.S	50.06-55.27	9.90	52.59 ± 0.26	6.52	8.63	4.85	5.58	75.52	4.57	8.69
SKI 215										
Control	60.26-63.60	5.38	62.07 ± 0.25	3.07	5.02	2.82	3.61	61.12	2.82	4.54
50 mM EMS	57.47-61.40	6.60	59.54 ± 0.23	3.48	5.05	3.13	3.77	68.95	3.19	5.36
60 mM EMS	59.8-62.53	4.48	60.85 ± 0.23	3.49	5.12	3.07	3.72	68.23	3.18	5.22
1000 ppm S.S	58.13-62.53	7.30	60.25 ± 0.25	4.37	6.30	3.47	4.16	69.33	3.58	5.95
1500 ppm S.S	54.46-61.26	11.66	58.29 ± 0.36	8.66	12.64	5.05	6.10	68.50	5.02	8.60

were lower than control in all the genotypes indicated early maturity of genotypes than control.

Low phenotypic and genotypic coefficient of variation was observed in all treatments for days to maturity of primary raceme. Maximum GCV (2.06%) and PCV (2.40%) observed in 50 mM EMS treatment. Minimum GCV and PCV found in 1000 ppm streptomycin sulphate (1.84%, 2.21%, respectively). Days to maturity showed little difference between PCV and GCV indicating that it is less affected by environmental fluctuations.

Moderate to high heritability observed in all treatments. Maximum heritability was observed in 50 mM EMS (73.94%) followed by 1500 ppm streptomycin sulphate treatment (73.42%), 60 mM EMS treatment (72.02%) and 1000 ppm streptomycin sulphate treatment (69.63%). All mutagen treatments had low genetic advance and GA as per cent of mean for days to maturity. Genetic advance (4.40) and genetic advance as per cent (3.70 %) found higher in 1500 ppm streptomycin sulphate followed by 50 mM EMS (4.16, 3.65%) as compared to control (3.21, 2.46%), respectively. Similar results were obtained by Emrani *et al*. (2012) with 1200 Gy gamma rays and also by Dwimahyani and Ishak (2004) in Jatropha showed that gamma irradiation on cutting of *Jatropha curcas* with the dose of l0 Gy created genetic variability which was showed by earlier maturity on J10-04 genotype. Abdullah *et al*. (2005) studied mustard mutant through gamma rays and EMS treatment and observed that mutant strain S 97-1.0E/21 took (112.7) early days to maturity respect to other mutant.

SKI 215

In SKI 215 genotype, all the mutation treatments showed lower phenotypic range as compare to control (140.00-142.33). Minimum range was observed in 1500 ppm streptomycin sulphate (134.33-141.00) followed by 50 mM EMS (136.60-141.60) and 1000 ppm streptomycin sulphate (138.00-142.60). Decrease in mean value for days to maturity was observed in treated family as compared to control (141.49 days) and early variants were observed in 1500 ppm streptomycin sulphate (138.30 days) treatment. Similar results were obtained by Emrani *et al*. (2012) in canola found that, gamma irradiation treatment induced early maturity in 'Sarigol' cultivar having days to maturity reduction of 5.64 and 10.49 per cent in M_2 and M_3 generations, respectively.

GCV and PCV were increased as compared to control with rest of treatments indicating that variability was increased due to chemical and antibiotic treatment. Maximum PCV (2.55%) and GCV (2.11 %) was observed in 1500 ppm streptomycin sulphate treatment.

Table 4.14: The estimates of genotypic and phenotypic variances and other genetic parameters for days to maturity of primary raceme in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	121.00-132.67	8.97	130.13 ± 0.44	5.14	10.90	1.74	2.54	47.14	3.21	2.46
50 mM EMS	112.13-116.87	4.16	114.00 ± 0.24	5.50	7.45	2.06	2.40	73.94	4.16	3.65
60 mM EMS	114.80-118.60	3.26	116.42 ± 0.26	5.32	7.39	1.98	2.33	72.02	4.03	3.46
1000 ppm S.S	118.60-122.60	3.32	120.46 ± 0.27	4.93	7.08	1.84	2.21	69.63	3.82	3.17
1500 ppm S.S	120.07-124.93	3.96	122.59 ± 0.27	6.21	8.46	2.03	2.37	73.42	4.40	3.70
SKI 215										
Control	140.00-142.33	1.64	141.49 ± 0.28	1.13	3.41	0.75	1.30	33.07	1.26	0.89
50 mM EMS	136.60-141.60	3.58	139.57 ± 0.29	5.28	7.72	1.64	1.99	68.31	3.91	2.80
60 mM EMS	138.33-142.60	3.03	140.73 ± 0.26	4.55	6.55	1.51	1.82	69.41	3.66	2.60
1000 ppm S.S	138.00-142.60	3.28	140.17 ± 0.27	5.50	7.66	1.67	1.97	71.81	4.09	2.92
1500 ppm S.S	134.33-141.00	4.82	138.30 ± 0.36	8.53	12.43	2.11	2.55	68.58	4.98	3.60

Minimum PCV (1.82%) and GCV (1.51%) was found in 60 mM EMS. Days to maturity showed little difference between PCV and GCV indicating that it is less affected by environmental fluctuations. Moderate to high heritability observed in all treatments. Heritability, genetic advance and GA as per cent of mean were also improved in treated families as compared to control family. Maximum heritability was observed in 1000 ppm streptomycin sulphate (71.81%) followed by 60mM EMS treatment (69.41%) 1500 ppm streptomycin sulphate treatment (68.58%). All mutagens treatment had low genetic advance and GA as per cent of mean for days to maturity. Genetic advance (4.98) and genetic advance as per cent (3.60%) was found higher in 1500 ppm streptomycin sulphate followed by 60 mM EMS (4.09 days, 3.60%) as compared to control (1.26, 0.89%), respectively. This result has been supported by finding of Ahmed *et al*. (2012) in castor studying nineteen mutant lines in M_4 and M_5 generations evolved through 300-500 Gy. They found that GCV and PCV value (6.54%, 6.61%) for days to maturity, while highest heritability with high GAM was observed for days to mature (89.80%, 11.37%) in CBM line of castor.

4.2.4.3 Plant height up to primary raceme (cm)

Phenotypic range, mean, GCV, PCV, heritability, genetic advance and genetic advance as per cent of mean are given in Table 4.15.

VP 1 (M)

In this genotype, narrow phenotypic range was observed in control (23.67-29.53 cm). Maximum phenotypic range was observed in family no. 2 50 mM EMS (26.07-34.87cm) followed by 1000 ppm streptomycin sulphate (23.93-31.93), 60 mM EMS (26.37-33.27) and 1500 ppm streptomycin sulphate (23.88-30.49). The mean of plant height was higher in 50 mM EMS (30.09 cm) followed by 60 mM EMS (29.23 cm), 1500 ppm streptomycin sulphate (28.05 cm) and 1000 ppm streptomycin sulphate (27.91 cm). Similar results has been supported by Ravichandran and Jayakumar (2015) in sesame using gamma rays and EMS treatments for VRI-1 variety. They reported that plant height was increased in all the mutagenic treatments than the control. The maximum plant height was recorded at 40 KR of gamma rays (90.10 cm), while the minimum plant height was recorded at 50 KR of gamma rays (81.75 cm).

PCV, GCV were found moderate in all the mutation treatment including control. Maximum PCV (19.15%) and GCV (15.81%) was observed in 50 mM EMS followed by 60 mM EMS (18.02%, 15.06%). Minimum PCV (15.35%) and GCV (12.81%) was found in 1500 ppm streptomycin sulphate mutagen treatment followed

by 1000 ppm streptomycin sulphate (16.90%, 14.39%). Heritability was high in all mutagen treatment ranged from 68.16 per cent in 50 mM EMS to 72.50 per cent in 1000 ppm streptomycin sulphate than control (62.32%).

Maximum heritability found in 1000 ppm Streptomycin sulphate mutagen treatment (72.50%) followed 60 mM EMS (69.85%), 1500 ppm Streptomycin sulphate (69.62%) and 50 mM EMS (68.16%) as compared to control. Genetic advance and GA as per cent mean was observed high in all treatments than control. Mutagen treatment 50 mM EMS had high genetic advance (8.09) and GA as per cent of mean (26.89%) followed by 60 mM EMS (7.58, 25.93%) and 1000 ppm streptomycin sulphate (7.04, 25.24%). Mutagenic treatment 1500 ppm streptomycin sulphate had a low genetic advance (6.18) and GA as per cent of mean (22.02%). This result are supported by Emrani *et al*. (2012) in canola found that mutant lines RGS003 in 800 Gy-treatment had the highest mean values for plant height (87.83 cm). The highest phenotypic and genetic coefficients of variation, heritability and genetic advance for plant height were obtained at mutagenic treatment 1000 Gy in 'RGS003' (21.84%, 23.27%, 88.09%, 54.13%), while these were obtained for 'Sarigol' at 800 Gy-treatment (19.85%, 21.17%, 87.86%, 49.11%), respectively.

SKI 215

In SKI 215, when treated with 50 mM EMS showed shift in lower side of phenotypic range and other showed higher side shift in phenotypic range as compared to control (82.87-98.50 cm). Maximum phenotypic range was observed in 50 mM EMS (81.27-101.00 cm) followed by 60 mM EMS (75.13-93.87 cm) and minimum phenotypic range was observed in 1000 ppm streptomycin sulphate (82.06-97.67 cm) followed by 1500 ppm streptomycin sulphate (85.07-101.00 cm). The mean values for plant height was shifted in both the direction indicated good variability developed for this character (Table 4.15). Lower difference in GCV and PCV indicated the presence of less environmental effect. The mean of plant height was observed higher in 1500 ppm streptomycin sulphate (91.77 cm) and 1000 ppm streptomycin sulphate (90.50 cm), 50 mM EMS (88.87%) and 60 mM EMS (84.83%). These result are supported by Gothaliya and Madariya (2019) in castor using gamma radiation in JP-94, JI-444 and GP-15-1 genotypes. In GP15-1 short variants were observed in 750 Gy (76.44) and tall variants were observed in 500 Gy (83.06) treatment. Mean values for plant height were shifted in both the directions in JP-96 and GP-15-1 indicated good variability present for this character.

Table 4.15: The estimates of genotypic and phenotypic variances and other genetic parameters for plant height up to primary raceme (cm) in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	23.67-29.53	21.34	27.46 ± 0.40	8.13	13.05	10.38	13.15	62.32	4.64	16.89
50 mM EMS	26.07-34.87	29.24	30.09 ± 0.59	22.65	33.23	15.81	19.15	68.16	8.09	26.89
60 mM EMS	26.37-33.27	23.60	29.23 ± 0.53	19.39	27.75	15.06	18.02	69.85	7.58	25.93
1000 ppm S.S	23.93-31.93	28.66	27.91 ± 0.45	16.13	22.25	14.39	16.90	72.50	7.04	25.24
1500 ppm S.S	23.88-30.49	23.56	28.05 ± 0.43	12.92	18.55	12.81	15.35	69.62	6.18	22.02
SKI 215										
Control	82.87-98.5	17.45	89.56 ± 1.17	47.99	89.43	7.73	10.56	53.66	10.45	11.67
50 mM EMS	81.27-101.00	22.20	88.87 ± 1.39	137.80	196.08	13.21	15.76	70.28	20.27	22.81
60 mM EMS	75.13-93.87	22.09	84.83 ± 1.20	92.55	136.07	11.34	13.75	68.02	16.34	19.27
1000 ppm S.S	82.06-97.67	17.24	90.50 ± 1.00	65.66	95.10	8.93	10.77	68.72	13.80	15.25
1500 ppm S.S	85.07-101.00	17.35	91.77 ± 1.26	105.07	153.28	11.17	13.49	68.55	17.48	19.05

PCV, GCV were found moderate in all treatments. Maximum PCV (15.76%) and GCV (13.21%) was observed in 50 mM EMS followed by 60 mM EMS (13.75%, 11.34%). Minimum PCV (10.77%) and GCV (8.93%) was found in 1000 ppm streptomycin sulphate mutagen treatment followed by 1500 ppm streptomycin sulphate (13.49%, 11.17%). Heritability was high in all mutagen treatment than control(53.66%). Maximum heritability found in 50 mM EMS mutagen treatment (70.28%) followed by 1000 ppm streptomycin sulphate (68.72%), 1500 ppm streptomycin sulphate (68.55%) and 60 mM EMS (68.02%). Similar results obtained by Ahmed *et al*. (2012) in castor studied M_4 and M_5 generations of gamma irradiation with maximum heritability in plant height (96.3%). Genetic advance and GA as per cent of mean was observed high in all treatments than control. Mutagen treatment 50 mM EMS had high genetic advance (20.27) and GA as per cent of mean (22.81%) followed by 60 mM EMS (16.34, 19.27%) and 1500 ppm streptomycin sulphate (17.48, 19.05%). Mutagenic treatment 1000 ppm Streptomycin sulphate had a low genetic advance (13.80) and GA as per cent of mean (15.25%). This result is supported by Pavadai *et al*. (2010) using different doses of gamma radiation in seeds of soybean variety CO 1. They found that the treatment at 50 kR gamma rays produced highest PCV (13.71%), GCV (11.68%), h^2 (72.53%) and GA as per cent of mean (20.45%).

4.2.4.4 N**umber of node up to primary raceme**

Phenotypic range, mean, GCV, PCV, heritability, genetic advance and genetic advance as per cent of mean are given in Table 4.16.

VP 1 (M)

Higher value of phenotypic range was recorded for 1000 ppm streptomycin sulphate (12.73-17.60) and 50 mM EMS (12.60-17.53) treatment as compared to control (12.53-15.33) and lower phenotypic range in respect to control was observed in 60 mM EMS (13.93-16.17) and 1500 ppm streptomycin sulphate (12.93-15.67). There were minor differences between mean of all treatments as compare to control (Table 4.15). Maximum mean value for number of nodes up to primary raceme found in 60 mM EMS (15.01) followed by 50 mM EMS (14.94), 1000 ppm streptomycin sulphate (14.15) and 1500 ppm streptomycin sulphate (14.07).

PCV and GCV observed as low to moderate. Difference between PCV and GCV indicated the less effect of environment on number of node up to primary raceme. Maximum PCV (22.03%) and GCV (20.25%) was found in 1000 ppm streptomycin sulphate mutagen treatment followed by 50 mM EMS (15.74%, 13.75%), respectively.

Low PCV (10.40) and GCV (8.87) was observed in 60 mM EMS followed by 1500 ppm streptomycin sulphate (13.28, 10.99%), respectively. Higher heritability observed in all mutagen treatments. Mutagen treatment 1000 ppm streptomycin sulphate had maximum heritability (84.49%) with high genetic advance as per cent of mean (38.34%) followed by 50 mM EMS mutagen treatment with high heritability (76.33%) and genetic advance as per cent of mean (24.75%).

SKI 215

In both treatments, phenotypic range was observed high in 50 mM EMS (16.40-19.87) and 1500 ppm streptomycin sulphate (18.47-21.30) treatment as compared to control (17.73-20.40) and lower phenotypic range in respect to control was observed in 60 mM EMS (20.53-18.60) and 1000 ppm streptomycin sulphate (20.73-18.87). There were minor differences between mean of all treatments and control (Table 4.16). Maximum mean value for number of nodes up to primary raceme was found in 1000 ppm streptomycin sulphate (19.81) followed by 1500 ppm streptomycin sulphate (19.64) and 60 mM EMS (19.46). Minimum mean value for number of node up to primary raceme was found in 50 mM.EMS (17.55) which was lowest in respect to control (19.06). This result is in accordance with Gothaliya and Madariya (2019) in castor found that GP-15-1 had lower number of nodes in both the treatments than control and lowest value was observed in 750 Gy (16.74) treatment.

PCV and GCV observed as low to moderate. Difference between PCV and GCV indicated the less effect of environment on number of nodes up to primary raceme. Maximum PCV (13.31%) and GCV (12.71%) was found in 50 mM EMS mutagen treatment followed by 1500 ppm Streptomycin sulphate (7.49%, 6.35%), respectively. Low PCV (6.29%) and GCV (5.30%) was observed in 60 mM EMS followed by 1000 ppm streptomycin sulphate. Similar result obtained by Reddy and Dhaduk (2014) in okra found that in GO-2 genotype recorded the highest genotypic coefficient of variability (GCV) (8.83%) and highest GAM (13.55%) in 40 kR treatment for number of nodes on main stem and high heritability (58.55%) in 0.25 per cent EMS dose.

4.2.6.5 Effective length of primary raceme (cm)

Data for phenotypic range, mean, GCV, PCV, heritability and genetic advance for two genotypes are summarized in Table 4.17.

VP 1 (M)

Higher phenotypic range was observed with respect to control for all treatments. Maximum value of phenotypic range was observed in 60 mM EMS (51.20-74.20 cm)

Table 4.16: The estimates of genotypic and phenotypic variances and other genetic parameters for number of node up to primary raceme in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	12.53-15.33	20.04	13.97 ± 0.20	2.26	3.52	10.77	13.42	64.39	2.49	17.80
50 mM EMS	12.60-17.53	32.99	14.94 ± 0.21	4.22	5.53	13.75	15.74	76.33	3.70	24.75
60 mM EMS	13.93-16.17	18.41	15.10 ± 0.15	1.79	2.47	8.87	10.40	72.67	2.35	15.58
1000 ppm S.S	12.73-17.60	34.41	14.15 ± 0.22	8.21	9.72	20.25	22.03	84.49	5.43	38.34
1500 ppm S.S	12.93-15.67	19.47	14.07 ± 0.19	2.39	3.49	10.99	13.28	68.56	2.64	18.75
SKI 215										
Control	17.73-20.40	13.98	19.09 ± 0.18	1.90	2.84	7.21	8.82	66.84	2.32	12.15
50 mM EMS	16.40-19.87	19.77	17.55 ± 0.13	4.98	5.46	12.71	13.31	91.16	4.39	25.00
60 mM EMS	18.60-20.53	9.91	19.46 ± 0.12	1.06	1.50	5.30	6.29	71.05	1.79	9.20
1000 ppm S.S	18.87-20.73	9.69	19.81 ± 0.13	1.25	1.80	5.65	6.77	69.64	1.92	9.71
1500 ppm S.S	18.47-21.30	14.40	19.64 ± 0.14	1.55	2.17	6.35	7.49	71.79	2.18	11.08

followed by 1000 ppm streptomycin sulphate (57.73-80.80 cm), 50 mM EMS (54.20-69.80 cm) and 1500 ppm streptomycin sulphate (57.73-73.13 cm). There were minor differences between mean of all treatments as compared to control (Table 4.16). Maximum mean value for number of effective length of primary raceme was found in 1500 ppm streptomycin sulphate (63.89 cm) followed by 1500 ppm streptomycin sulphate (62.80 cm). This result has been supported by Deshmukh *et al*. (2018) using gamma rays and EMS treatment in sorghum Parbhani Moti cultivar. They found that mean values for ear head length was decreases with increase in dose level of gamma rays and EMS. The highest mean value for ear head length was found in treatment T_1 (16.3 cm) and T_4 (15.76 cm) while lowest mean value for ear head length was found in T_3 (15.03 cm) and T_6 (15.23 cm) among gamma rays and EMS, respectively.

GCV and PCV values were found to be low to moderate. Difference between PCV and GCV indicates less effect of environment on effective length of primary raceme. Maximum PCV (24.74%) and GCV (23.78%) found in 60 mM EMS mutagen treatment followed by 1000 ppm streptomycin sulphate (20.00%, 18.00%), respectively. Low PCV (13.69%) and GCV (12.45%) observed in 1500 ppm streptomycin sulphate followed by 50 mM EMS (16.36%, 14.32%), respectively. Higher heritability was observed in all mutagen treatments. Mutagen treatment of 60 mM EMS had maximum heritability (92.21%) with high genetic advance as per cent of mean (47.00%) followed by 1500 ppm streptomycin sulphate mutagen treatment with high heritability (82.67%) and genetic advance as per cent of mean (23.32%). Similar result obtained by Ahmed *et al*. (2012) in castor using gamma radiation in nineteen mutant lines in M_4 and M_5 generations ranging from 300-500 Gy rays in comparison with a check variety DS-30. High GCV, PCV, h^2 and GAM were reported (27.04%, 33.83%, 68.90%, 38.04%), respectively in M_5 generation.

SKI 215

Phenotypic range deviated in both the directions as compared to control (56.33-66.00 cm). In this genotype phenotypic range was observed high in 60 mM EMS (55.00-66.07 cm), 1500 ppm streptomycin sulphate (56.80-67.30 cm) and 50 mM EMS (57.60-67.67 cm) treatment as compared to control (56.33-66.00 cm) and lower phenotypic range in respect to control was observed in 1000 ppm streptomycin sulphate (53.33-62.07 cm). There were minor differences between mean of all treatments and control (Table 4.17). Maximum mean value for effective length of primary raceme was found in 50 mM EMS (62.28 cm) followed by 1500 ppm

Table 4.17: The estimates of genotypic and phenotypic variances and other genetic parameters for effective length of primary raceme in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	51.80-64.80	23.02	56.47 ± 0.71	31.53	46.64	9.94	12.09	67.60	9.51	16.84
50 mM EMS	54.20-69.80	25.49	61.20 ± 0.88	76.84	100.20	14.32	16.36	76.69	15.81	25.84
60 mM EMS	51.20-74.20	38.70	59.43 ± 0.75	199.38	216.22	23.78	24.74	92.21	27.93	47.00
1000 ppm S.S	57.73-80.80	36.73	62.80 ± 1.00	127.75	157.83	18.00	20.00	80.94	20.94	33.35
1500 ppm S.S	57.73-73.13	24.10	63.89 ± 0.66	63.27	76.54	12.45	13.69	82.67	14.90	23.32
SKI 215										
Control	56.33-66.00	15.95	60.59 ±0.69	25.19	39.49	8.28	10.37	63.77	8.26	13.62
50 mM EMS	57.60-67.67	16.16	62.28 ± 0.38	36.29	40.59	9.67	10.23	89.40	11.73	18.84
60 mM EMS	55.00-66.07	18.26	60.62 ± 0.62	37.12	48.55	10.05	11.49	76.46	10.97	18.10
1000 ppm S.S	53.33-62.07	14.98	58.31 ± 0.60	22.89	33.60	8.20	9.94	68.12	8.13	13.95
1500 ppm S.S	56.80-67.30	17.18	61.10 ± 0.71	32.32	47.50	9.30	11.28	68.04	9.66	15.81

streptomycin sulphate (61.10 cm). Minimum mean value was observed in 60 mM EMS (60.62 cm) and 1000 ppm streptomycin sulphate (58.31 cm) which was lowest as compared to control (60.59 cm). This result supported by Gothaliya and Madariya (2019) in castor using gamma radiation. In JI-444 effective length of primary raceme was decreased with increased dosage and it was lower as compared to control (77.36 cm).

PCV and GCV was observed low to moderate. Difference between PCV and GCV indicates less effect of environment on effective length of primary raceme. Maximum PCV (11.49%) and GCV (10.05%) was found in 60 mM EMS mutagen treatment followed by 1500 ppm streptomycin sulphate (11.28%, 9.30%), respectively. Low PCV (9.94%) and GCV (8.20%) was observed in 1000 ppm streptomycin sulphate followed by (10.23%, 9.67%), respectively. Higher heritability observed in all mutagen treatments. Mutagen treatment of 50 mM EMS had maximum heritability (89.40%) with high genetic advance as per cent of mean (18.84%) followed by 60 mM EMS mutagen treatment with high heritability (76.46%) and moderate genetic advance as per cent of mean (18.10%). These traits are therefore governed by additive genes and for the improvement of seed yield, selection may be based directly on these attributes. The results are in confirmation with Sarwar and Chaudhry (2008) in castor using gamma radiation on DS30 castor seeds. They observed high heritability combined with good genetic advance (88.60%, 33.34%). Srivastava *et al*. (2011) using different concentration of sodium azide for inducing polygenic variability in wheat HD-2733 variety, found that high PCV, GCV and heritability for spike length in family II (8.43%, 7.05%, 69.97%, respectively).

4.2.4.6 Number of effective branch per plant

The nature of induced variability as measured by different statistical parameters for two genotypes have been given in Table 4.18.

VP 1 (M)

Phenotypic range was observed high with respect to control for EMS treatments. Maximum value of phenotypic range was observed in 60 mM EMS (11.40-16.79) followed by 50 mM EMS (10.27-13.32) and lower phenotypic range was observed in 1500 ppm streptomycin sulphate (11.30-13.80) followed by 1000 ppm streptomycin sulphate as compared to control (11.18-14.03). There were minor differences between mean of all treatments as compared to control (Table 4.18). Maximum mean value for number of effective branch per plant was found in 60 mM EMS (14.08) followed by

1000 ppm streptomycin sulphate (12.82). The present results are in accordance with the finding of Ravichandran and Jayakumar (2015) using different dose/concentrations of gamma rays (30, 40 and 50 KR) and ethyl methane sulphonate (1.0, 1.5 and 2.0 mM) on sesame. They found that increase in number of branches in all the treatments compared to control and maximum number of branch (9.00) was observed at 40 KR of gamma rays. The minimum number of branch (4.00) was observed at 2.0 mM of EMS.

Moderate to high PCV and GCV found in all of mutagen treatments. Difference between PCV and GCV indicates less effect of environment on number of effective branches per plant. Maximum PCV (21.60%) and GCV (19.81%) was found in 60 mM EMS mutagen treatment followed by 50 mM EMS (16.97%, 14.64%, respectively). Low PCV (11.66%) and GCV (10.03%) was observed in 1500 ppm streptomycin sulphate followed by 1000 ppm streptomycin sulphate (13.24%, 10.98%, respectively). Higher heritability was observed in all mutagen treatments. Mutagen treatment of 60 mM EMS had maximum heritability (84.12%) with high genetic advance as per cent of mean (37.44%) followed by 50 mM EMS mutagen treatment with high heritability (74.49%), and genetic advance as per cent of mean (26.03%). Mensah and Obadoni (2007) using different concentrations of sodium azide (0.01 to 0.05%) on groundnut SS1145B and RMP 91 cultivar, found that phenotypic variance (2.26%, 2.16%), geotypic variance (1.41%, 1.40%) and heritability (62.49%, 74.80%) in both the cultivars, respectively for the number of branch per plant.

SKI 215

Phenotypic range was observed high with respect to control for all the treatments. Maximum value of phenotypic range was observed in 50 mM EMS (20.27-30.32) followed by 1500 ppm streptomycin sulphate (16.80-23.53), 60 mM EMS (15.80-22.53) and 1000 ppm streptomycin sulphate (18.20-22.54) as compared to control (17.47-20.87). Maximum mean value for number of effective branch per plant was found in 50 mM EMS (23.18) followed by 1500 ppm streptomycin sulphate (20.23). Minimum mean value for number of effective branch per plant was found in (17.57) as compared to control (19.69). Similar results obtained by Pavadai *et al*. (2010) using different doses of gamma radiation in soybean CO 1 variety. They reported that most of the treatments were in positive shift. Maximum mean value for number of branch per plant recorded (4.87) in 50 kR treatment as compared to control (4.27) in M_1 generation.

Table 4.18: The estimates of genotypic and phenotypic variances and other genetic parameters number of effective branch per plant in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	11.18-14.03	22.90	12.44 ± 0.18	1.80	2.76	10.79	13.35	65.32	2.23	17.96
50 mM EMS	10.27-13.32	25.56	11.93 ± 0.19	3.05	4.10	14.64	16.97	74.49	3.11	26.03
60 mM EMS	11.40-16.79	38.23	14.08 ± 0.22	7.79	9.25	19.81	21.60	84.12	5.27	37.44
1000 ppm S.S	11.46-14.00	20.28	12.82 ± 0.17	1.98	2.88	10.98	13.24	68.74	2.40	18.75
1500 ppm S.S	11.30-13.80	20.00	12.50 ± 0.14	1.57	2.13	10.03	11.66	73.91	2.22	17.76
SKI 215										
Control	17.47-20.87	17.27	19.69 ± 0.36	3.66	7.46	9.72	13.87	49.11	2.76	14.03
50 mM EMS	20.27-30.32	43.36	23.18 ± 0.36	37.22	41.12	26.32	27.66	90.52	11.96	51.58
60 mM EMS	15.80-20.53	26.92	17.57 ± 0.27	5.09	7.31	12.84	15.39	69.61	3.88	22.07
1000 ppm S.S	18.20-22.54	22.00	19.73 ± 0.26	4.82	6.83	11.13	13.25	70.56	3.80	19.26
1500 ppm S.S	16.80-23.53	33.26	20.23 ± 0.29	13.98	16.42	18.48	20.03	85.10	7.10	35.11

Low to high PCV and GCV were found in all of mutagen treatments. Difference between PCV and GCV indicates less effect of environment on number of effective branches per plant. Maximum PCV (27.66%) and GCV (26.32%) found in 50 mM EMS mutagen treatment followed by 1500 ppm streptomycin sulphate (20.03%, 18.48%, respectively). Low PCV (13.25%) and GCV (11.13%) was observed in 1000 ppm streptomycin sulphate followed by 60 mM EMS (15.39%, 12.84%, respectively). Higher heritability observed in all mutagen treatments. Mutagen treatment of 50 mM EMS had maximum heritability (90.52%) with high genetic advance as per cent of mean (51.58%) followed by 1500 ppm streptomycin sulphate mutagen treatment with high heritability (85.10%) and genetic advance as per cent of mean (35.11%). Minimum heritability was observed in 60 mM EMS (69.61%) with genetic advance as per cent of mean (22.07%). This result indicating additive gene action which are useful to improvement in seed yield direct by selecting higher branches per plant. Similar results obtained by Pavadai *et al*. (2010) using different doses of gamma radiation in soybean CO 1 variety. Highest PCV, GCV, h^2 and GA as per cent of mean were recorded in 50 kR gamma rays (9.24%, 5.19%, 31.54%, 6.00%, respectively) for number of branch. Reddy and Dhaduk (2014) in okra using 40 kR radiation on GO-2 genotype observed high heritability and moderate genetic advance for number of branch (57.22%, 34.06%, respectively).

4.2.4.7 Number of capsule on primary raceme

Data for phenotypic range, mean, GCV, PCV, heritability and genetic advance for two genotypes are summarized in Table 4.19.

VP 1 (M)

In both the treatments, phenotypic range was higher than control (43.27-62.58) in 50 mM EMS (45.00-69.60) and it was minimum in 1500 ppm streptomycin sulphate (39.47-68.20) followed by 60 mM EMS (49.07-60.20) and 1000 ppm streptomycin sulphate (42.27-58.67) as compared to control (43.27-62.58). Maximum mean value for number of capsule on primary raceme was found in 60 mM EMS (56.09) followed by 50 mM EMS (54.12), 1000 ppm streptomycin sulphate (49.21) and 1500 ppm streptomycin sulphate (48.98). Similar results obtained by Gothaliya and Madariya (2019) in castor and found that in JP-96, mean values for this trait was shifted in both the directions indicated presence of good variability and it was highest in 500 Gy (89.86) treatment.

Table 4.19 The estimates of genotypic and phenotypic variances and other genetic parameters for number of capsule on primary raceme in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	43.27-62.58	38.02	50.79± 1.20	137.93	181.14	23.12	26.50	76.14	21.11	41.56
50 mM EMS	45.00-69.60	45.45	54.12 ± 1.27	139.53	187.70	21.82	25.31	74.34	20.98	38.76
60 mM EMS	49.07-66.20	30.54	56.09 ± 1.10	102.83	138.97	18.08	21.01	73.99	17.97	32.03
1000 ppm S.S	42.27-58.67	33.33	49.21 ± 1.00	92.18	122.13	19.51	22.46	75.47	17.18	34.92
1500 ppm S.S	39.60-53.60	28.58	48.98 ± 0.79	67.28	85.98	16.74	18.93	78.24	14.95	30.51
SKI 215										
Control	48.07-63.55	28.03	55.23 ± 0.99	59.99	89.65	14.02	17.14	66.91	13.05	23.63
50 mM EMS	28.47-50.33	53.11	41.16 ± 0.70	144.19	158.97	29.17	30.63	90.70	23.56	57.23
60 mM EMS	43.73-53.07	18.89	49.42 ± 0.62	27.45	39.14	10.60	12.66	70.15	9.04	18.29
1000 ppm S.S	42.13-55.47	27.01	49.38 ± 0.78	69.34	87.80	16.86	18.97	78.97	15.24	30.87
1500 ppm S.S	39.47-68.20	49.86	57.61 ±0.90	175.75	199.91	23.01	24.54	87.92	25.61	44.45

PCV and GCV was observed moderate to high. Difference between PCV and GCV indicates less effect of environment on number of capsule on primary raceme. Maximum PCV (25.31%) and GCV (21.82%) was found in 50 mM EMS mutagen treatment followed by 1000 ppm streptomycin sulphate (22.46%, 19.51%), 60 mM EMS (21.01%, 18.08%) and 1500 ppm streptomycin sulphate (18.93%, 16.74%) respectively, which was lower than control (26.50%, 23.12%) respectively. Higher heritability observed in all mutagen treatments. Mutagen treatment of 1500 ppm streptomycin sulphate had maximum heritability (78.24%) with genetic advance as per cent of mean (30.51%) followed by 1000 ppm streptomycin sulphate mutagen treatment with high heritability (75.47%), and genetic advance as per cent of mean (34.92%). High genetic advance as per cent of mean (41.56%) was observed in control followed by 50 mM EMS (38.76%), 1000 ppm Streptomycin sulphate (34.92%) and 60 mM EMS (32.03%). This results supported by Sarwar and Chaudhary (2008) in castor using gamma radiation treated DS30 seeds. They observed high GCV and PCV (41.71%, 46.45%, respectively) with high heritability and genetic advance as per cent of mean (80.60, 66.04%) for number of capsule on primary raceme.

SKI 215

Phenotypic range was higher than control (48.07-63.55) in 50 mM EMS (28.47-50.33) followed by 1500 ppm streptomycin sulphate (39.47-68.20) and it was minimum in 60 mM EMS (43.73-53.07) and 1000 ppm streptomycin sulphate (42.13-55.47) as compared to control (48.07-63.55). Maximum mean value for number of capsule on primary raceme was found in 1500 ppm streptomycin sulphate (57.61) as compared to control (55.23). Similar results obtained by Ravichandran and Jayakumar (2015) using different dose/concentrations of gamma rays (30, 40 and 50 KR) and ethyl methane sulphonate (1.0, 1.5 and 2.0 mM) on sesame. They found that number of capsules was increased at all dose/concentration of treatment when compared to control. The maximum mean was observed at 40 KR of gamma rays (38.00), while the minimum mean was observed at 2.0 mM of EMS (25.00).

PCV and GCV was observed moderate to high. Difference between PCV and GCV indicates less effect of environment on number of capsule on primary raceme. Maximum PCV (30.63%) and GCV (29.17%) was found in 50 mM EMS mutagen treatment followed by 1500 ppm streptomycin sulphate (24.54%, 23.01%) and 1000 ppm streptomycin sulphate (18.97%, 16.86%), respectively. Higher heritability was observed in all mutagen treatments. Mutagen treatment of 50 mM EMS had maximum

heritability (90.70%) with genetic advance as per cent of mean (57.23%) followed by 1500 ppm streptomycin sulphate mutagen treatment with high heritability (87.92%), and genetic advance as per cent of mean (44.45%). Heritability (90.70%), genetic advance (23.56) and genetic advance as per cent of mean (57.23%) were highest in 50 mM EMS treatment. Thus, 50 mM EMS treatment seems to be good for improving this character.

Mean values for number of capsules on primary raceme showed bidirectional shifts in VP 1 (M) and SKI 215 indicated good variability was present for this character and high heritability indicating the predominance of additive gene action in the inheritance of this trait, thus, simple selection would be effective for genetic improvement of the characters in desired direction. Results are in accordance with the finding of Maibam *et al*. (2018) using different doses of ethyl methane sulphonate for three sesame entries *viz*., Gujarat Til-4 (GT-4), Gujarat Til-10 (GT-10) and Patan-64. Number of capsule per plant treatment V_2D_3 (1.5% EMS) recorded high values (32.37) suggesting their superiority than control which was a positive result from mutagenesis. High PCV and GCV (41.02%, 38.26%), heritability and genetic advance as per cent of mean was observed for number of capsule per plant (87% and 73.49%, respectively).

4.2.6.8 Seed yield per plant (g)

Phenotypic range, mean, PCV, GCV, heritability and genetic advance for two genotypes are summarized in Table 4.20

VP 1 (M)

For seed yield per plant, phenotypic range was higher than control (255.27-340.60 g) in 50 mM EMS (232.73-326.13 g) followed by 60 mM EMS (292.67-390.47 g) and it was lower in 1500 ppm streptomycin sulphate (273.73-359.27) and 1000 ppm streptomycin sulphate (268.00-321.27 g) as compared to control. Maximum mean value for seed yield per plant was found in 60 mM EMS (324.43) and minimum mean value was found 50 mM EMS (265.68 g) as compared to control (299.67 g). This result is in accordance with Gunasekaran and Pavadai (2015) in groundut. They observed positive shift for kernal yield per plant for most of the treatments. Maximum kernal yield/plant was recorded at 50 KR gamma rays treatment (30.15 g), while the minimum kernal yield/plant was recorded at 0.1 per cent EMS treatment (23.54 g) when compared to untreated plant (25.64 g).

Table 4.20 The estimates of genotypic and phenotypic variances and other genetic parameters for seed yield per plant (g) in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	255.27-340.60	28.47	299.67 ± 6.13	2222.21	3348.95	15.73	19.31	66.35	79.10	26.40
50 mM EMS	232.73-326.13	35.15	265.68 ± 4.29	3318.45	3871.10	21.68	23.42	85.72	109.87	41.35
60 mM EMS	292.67-390.47	30.14	324.43 ± 6.66	2946.41	4276.29	16.73	20.16	68.90	92.82	28.61
1000 ppm S.S	268.00-321.27	18.24	291.98 ± 3.52	811.50	1183.41	9.76	11.78	68.57	48.59	16.64
1500 ppm S.S	273.73-359.27	26.77	319.58 ± 5.58	1996.61	2932.19	13.98	16.94	68.10	75.96	23.77
SKI 215										
Control	231.20-323.47	32.49	283.98 ± 6.59	2717.12	4021.02	18.35	22.33	67.57	88.27	31.08
50 mM EMS	242.73-400.33	52.45	300.48 ± 6.66	8269.44	9601.43	30.26	32.61	86.13	173.85	57.86
60 mM EMS	279.90-421.93	43.60	325.78 ± 7.39	4210.73	5849.61	19.92	23.48	71.98	113.41	34.81
1000 ppm S.S	245.07-404.08	53.40	297.74 ± 6.87	5978.63	7393.45	25.97	28.88	80.86	143.23	48.11
1500 ppm S.S	291.27-394.40	29.46	350.08 ± 6.88	3431.96	4850.59	16.73	19.89	70.75	101.51	29.00

PCV and GCV indicates less effect of environment on seed yield per plant. Maximum PCV (23.42%) and GCV (21.68%) was found in 50 mM EMS mutagen treatment followed by 60 mM EMS (20.16%, 16.73%, respectively). Minimum PCV (11.78%) and GCV (9.76%) was found in 1000 ppm streptomycin sulphate followed by 1000 ppm streptomycin sulphate (16.94%, 13.98%) as compared to control (19.31%, 15.73%), respectively. Higher heritability observed in all mutagen treatments. Mutagen treatment of 50 mM EMS had maximum heritability (85.72%) with genetic advance as per cent of mean (41.35%) followed by 60 mM EMS mutagen treatment with high heritability (68.90%) and genetic advance as per cent of mean (28.61%). Genetic advance as per cent of mean was found high in mutagen treatments except 1500 ppm streptomycin sulphate (23.77%) and 1000 ppm streptomycin sulphate (16.64%) as compared to control (26.40%). Heritability (85.72%) and genetic advance as per cent of mean (41.35%) were highest in 50 mM EMS treatment. Thus, 50 mM EMS treatment seems to be good for improving this character. The results are in accordance with the finding Ahmed *et al*. (2012) in castor using nineteen mutant lines in M_4 and M_5 generations evolved through 300-500 Gy. They found that high GCV and PCV value (20.35, 37.42%) and low heritability with high GAM was observed for seed yield per plant (29.60%, 19.49%) in M_5 generation of CBM line castor. Reddy and Dhaduk (2014) using different doses of gamma radiation in okra GO – 2 and GJO-3 variety, found that 40 kR treatment was recorded the highest GCV, heritability and genetic advance as per cent of mean (19.57%, 81.44%, 36.38%), respectively in fruit yield per plant.

SKI 215

For seed yield per plant, phenotypic range was higher than control (231.20-323.47 g) in 1000 ppm streptomycin sulphate (245.07-404.08 g) followed by 50 mM EMS (242.73-400.33 g), 60 mM EMS (279.90-421.93 g) and phenotypic range was lower in 1500 ppm streptomycin sulphate (291.27-394.40 g) as compared to control. Mean values were high for all mutagenic treatment as compared to control. Maximum mean value for seed yield per plant was found in 1500 ppm streptomycin sulphate (350.08 g) as compared to control (283.98 g).

Seed yield per plant had moderate to high range of PCV and GCV. Difference between PCV and GCV indicates less effect of environment on seed yield per plant. Maximum PCV (32.61%) and GCV (30.26%) was found in 50 mM EMS mutagen treatment followed by 1000 ppm streptomycin sulphate (28.88%, 25.97%) and 60 mM

EMS (23.48%, 19.92%), respectively. Minimum PCV (19.89%) and GCV (16.73%) was found in 1500 ppm streptomycin sulphate as compared to control (19.31%, 15.73%), respectively. Higher heritability observed in all mutagen treatments. Mutagen treatment of 50 mM EMS had maximum heritability (86.12%) with genetic advance as per cent of mean (57.86%) followed by 1000 ppm streptomycin sulphate mutagen treatment with high heritability (80.86%) with genetic advance as per cent of mean (48.11%) and 60 mM EMS with high heritability (71.98%) with genetic advance as per cent of mean (34.81%). Genetic advance as per cent of mean was found high in all mutagen treatments except 1500 ppm streptomycin sulphate (29.00%) as compared to control (31.08%). Heritability (86.13%) and genetic advance as per cent of mean (57.86%) were noted the highest in 50 mM EMS treatment. Thus, 50 mM EMS treatment seems to be good for improving this character. Similar result were also observed by Emrani *et al*. (2012) in canola. They found that seed yield per plant was differently affected by gamma rays than its components increasing up to 1000 Gy and then decreases at 1200 Gy in both the generations and cultivars. In M_2 generation, 1000 Gy gamma rays caused the highest heritability, genotypic coefficient of variation and genetic advance in M_2 lines of 'RGS003' (88.21%, 34.61%, 85.81%), while 800 Gy treatment lead to the highest amount of these parameters in 'Sarigol' mutant lines (86.53%, 36.41%, 89.43%), respectively. Maibam *et al*. (2018) using different doses of ethyl methane sulphonate for three sesame entries *viz*., Gujarat Til-4 (GT-4), Gujarat Til-10 (GT-10) and Patan-64, they found that, Genotype GT-10 with control dose (D_5) recorded maximum yield per plant, while Patan 64 with dose D_4 *i.e*. 2.00 per cent EMS recorded the least yield per plant. High PCV, GCV (105.00%, 104.26%) and heritability with genetic advance as per cent of mean (98.00%, 213.84%) respectively observed in yield per plant.

4.2.4.9 100- seed weight

Phenotypic range, mean, GCV, PCV, heritability and genetic advance for two genotypes are summarized in Table 4.21.

VP 1

Phenotypic range for 100-seed weight was found higher than control (23.24-26.57 g) in 60 mM EMS (21.77-25.41 g) followed by 1500 ppm streptomycin sulphate (23.89-27.39 g) and phenotypic range was lower in 1000 ppm streptomycin sulphate (22.73-25.41 g) and 50 mM EMS (22.06-25.16 g) as compared to control. Mean values were low for all mutagenic treatments as compared to control (24.91 g)

except 1500 ppm streptomycin sulphate (25.52 g). The similar result was reported by Gothaliya and Madariya (2019) in castor using gamma radiation. They found that observed mean values for 100-seed weight were decreased in JP-96 and GP-15-1 in both the treatments as compared to control.

100-seed weight had low to moderate range of PCV and GCV. Maximum PCV (10.16%) and GCV (9.17%) was found in 60 mM EMS mutagen treatment and minimum PCV (7.42%) and GCV (6.60%) was found in 50 mM EMS, 1000 ppm streptomycin sulphate (7.84%, 7.14%) and 1500 ppm streptomycin sulphate (8.52%, 7.67%) as compared to control (8.92%, 8.33%), respectively. Low heritability was observed in all treatments as compared to control (87.37%). In all mutagen treatments low genetic advance and genetic advance as per cent of mean was found as compared to control (16.05%) except 60 mM EMS (17.06%) mutagenic treatment. This result supported by Ahmed *et al*. (2012) in castor using gamma radiation in M_5 generation. They found that moderate PCV, GCV and high heritability (11.17%, 13.08%, 72.90%, respectively) for 100 seed weight.

SKI 215

Phenotypic range for 100-seed weight was found lower than control (24.23-28.36 g) in all the mutagenic treatments except 50 mM EMS (24.11-28.61 g). Mean values were low for 100-seed weight for all mutagenic treatments as compared to control (26.34 g) except 1500 ppm streptomycin sulphate (27.64 g). Similar result obtained by Mensah *et al*. (2003) in rice. They found that M_3 progenies of ITA 150 variety treated with streptomycin solution had lowest mean (1.60 g) compared to control (1.65 g). Gunasekaran and Pavadai (2015) in groundnut VRI-2 variety, found positive shift 100-seed weight for most of the treatments. Maximum 100-seed weight was recorded at 50 kR gamma rays treatment (33.69 g), while the minimum 100-seed weight was recorded at 0.2 per cent EMS treatment (26.55 g) when compared to untreated plant (30.27 g).

100-seed weight had low to moderate range of PCV and GCV. Maximum PCV (10.94%) and GCV (10.41%) was found in 50 mM EMS mutagen treatment and minimum PCV (8.17%) and GCV (7.00%) was found in 60 mM EMS, 1000 ppm streptomycin sulphate (7.17%, 6.01%) and 1500 ppm streptomycin sulphate (5.77%, 4.85%) as compared to control (9.50%, 8.48%), respectively. Low heritability was observed in all treatments as compared to control (79.68%) except 50 mM EMS

Table 4.21 The estimates of genotypic and phenotypic variances and other genetic parameters for 100-seed weight (g) in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	23.24-26.57	13.36	24.91 ± 0.14	4.31	4.93	8.33	8.92	87.37	4.00	16.05
50 mM EMS	22.06-25.16	12.91	24.01 ± 0.15	2.51	3.17	6.60	7.42	79.16	2.90	12.10
60 mM EMS	21.77-25.41	15.74	23.13 ± 0.18	4.50	5.52	9.17	10.16	81.52	3.95	17.06
1000 ppm S.S	22.73-25.71	12.34	24.14 ± 0.14	2.97	3.58	7.14	7.84	83.03	3.24	13.41
1500 ppm S.S	23.89-27.39	13.71	25.52 ± 0.17	3.83	4.73	7.67	8.52	80.95	3.63	14.21
SKI 215										
Control	24.23-28.36	15.68	26.34 ± 0.21	5.00	6.26	8.48	9.50	79.68	4.11	15.59
50 mM EMS	24.11-28.61	17.28	26.03 ± 0.16	7.34	8.12	10.41	10.94	90.50	5.31	20.40
60 mM EMS	23.58-26.24	10.70	24.85 ± 0.19	3.03	4.12	7.00	8.17	73.62	3.08	12.39
1000 ppm S.S	23.97-27.12	12.34	25.52 ± 0.18	2.35	3.35	6.01	7.17	70.27	2.65	10.38
1500 ppm S.S	26.45-28.98	9.15	27.64 ± 0.16	1.80	2.55	4.85	5.77	70.53	2.32	8.39

(90.50%). In all mutagen treatments, low genetic advance and genetic advance as per cent of mean was found as compared to control (4.11, 15.59%), except 50 mM EMS (5.31, 20.40%) mutagenic treatment. Similar result obtained by Mensah *et al*. (2003) in rice. They found that M_3 progenies of ITA 150 variety had high heritability (69.05%) with streptomycin solution. Dwimahyani and Ishak (2004) in jatropha found high heritability in 10 Gy treatment (62.70%) for 100-seed weight. Emrani *et al*. (2012) in canola found that highest heritability was obtained for 1000 Gy irradiation in RGS003, while 800 Gy-treated 'Sarigol' lines showed high heritability (82.59%, 89.63%) in both M_2 and M_3 generations.

4.2.6.10 oil content (%)

VP 1 (M)

Phenotypic range of oil content was higher than control (44.41-46.71%) in all the mutagenic treatments. Maximum phenotypic range was observed in 1000 ppm streptomycin sulphate (45.15-48.32%). Mean values were high for oil content in all mutagenic treatments as compared to control (46.00%). Maximum mean value for oil content was found in 60 mM EMS (47.56%) as compared to control (46.00%). Gothaliya and Madariya (2019) in castor using gamma radiation observed high mean value for oil content in GP-15-1 control (48.43%) and 750 Gy (48.43%) treatment.

Oil content had low range of PCV and GCV. Maximum PCV (4.91%) and GCV (4.28%) was found in 1000 ppm streptomycin sulphate followed by 50 mM EMS (4.59%, 4.13%), 1500 ppm streptomycin sulphate (3.69%, 3.12%) and 60 mM EMS (3.67%, 3.32%) as compared to control (2.93%, 2.40%), respectively. Higher heritability was observed in all mutagen treatments as compared to control (67.18%). Mutagen treatment of 60 mM EMS had maximum heritability (81.84%) with genetic advance as per cent of mean (6.19%) followed by 50 mM EMS mutagen treatment with high heritability (80.87%) with genetic advance as per cent of mean (7.64%) and 1000 ppm streptomycin sulphate with high heritability (76.75%) with genetic advance as per cent of mean (7.71%). Genetic advance as per cent of mean was found high in mutagen treatments as compared to control (4.06%).

SKI 215

In SKI 215, phenotypic range was lower than control (45.12-48.12%) in all

Table 4.22 The estimates of genotypic and phenotypic variances and other genetic parameters for oil content (%) in M_2 generation of castor

Treatments	Phenotypic range	Phenotypic range as % of mean	Mean ± SEm	Genotypic variance	Phenotypic variance	GCV %	PCV %	H^2 (BS)	GA	GA (% mean)
VP 1 (M)										
Control	44.41-46.71	5.00	46.00 ± 0.14	1.22	1.82	2.40	2.93	67.18	1.87	4.06
50 mM EMS	45.67-48.85	6.74	47.17 ± 0.17	3.79	4.68	4.13	4.59	80.87	3.60	7.64
60 mM EMS	46.21-49.15	6.18	47.56 ± 0.14	2.50	3.05	3.32	3.67	81.84	2.94	6.19
1000 ppm S.S	45.15-48.32	6.76	46.90 ± 0.20	4.04	5.30	4.28	4.91	76.25	3.61	7.71
1500 ppm S.S	45.84-48.32	6.33	47.05 ± 0.17	2.15	3.01	3.12	3.69	71.46	2.55	5.43
SKI 215										
Control	45.12-48.12	6.41	46.76 ± 0.16	1.64	2.43	2.74	3.34	67.48	2.17	4.64
50 mM EMS	44.91-47.8	6.26	46.43 ± 0.12	2.49	2.92	3.40	3.68	85.42	3.00	6.47
60 mM EMS	46.29-48.25	4.14	47.30 ± 0.14	1.24	1.80	2.35	2.84	68.78	1.90	4.02
1000 ppm S.S	46.32-48.39	4.37	47.39 ± 0.14	1.40	1.96	2.50	2.95	71.51	2.06	4.35
1500 ppm S.S	47.29-50.42	6.49	48.22 ± 0.15	2.67	3.35	3.39	3.79	79.69	3.00	6.23

the mutagenic treatments except 1500 ppm streptomycin sulphate (47.29-50.42%). Mean values of oil content were high for all mutagenic treatments as compared to control (46.76%) except 50 mM EMS (46.43%) mutagenic treatment. Maximum mean value for oil content was found in1500 ppm streptomycin sulphate (48.22%) as compared to control (46.76%). The similar result was found by Gunasekaran and Pavadai (2015) in groundnut. They found that oil content recorded as positive shift for all the mutagenic treatments. The maximum oil content (50.88%) was observed at 50 KR gamma rays treatment. The minimum oil content (45.25%) was observed at 0.2 per cent EMS treatment, when compared to control (49.12 %).

Oil content had low range of PCV and GCV. Maximum PCV (3.79%) was found in 1500 ppm streptomycin sulphate and GCV (3.40%) in 50 mM EMS. Minimum PCV (2.84%) and GCV (2.35%) was found in 60 mM EMS and 1000 ppm streptomycin sulphate (2.95%, 2.50%) as compared to control (3.34%, 2.74%), respectively. Higher heritability was observed in all mutagen treatments as compared to control (67.48%). Mutagen treatment of 50 mM EMS had maximum heritability (85.42%) with genetic advance as per cent of mean (6.47%) followed by 1500 ppm streptomycin sulphate mutagen treatment with high heritability (79.69%) with genetic advance as per cent of mean (6.23%) and 1000 ppm streptomycin sulphate (71.51%) with genetic advance as per cent of mean (4.35%). Genetic advance as per cent of mean was found high in mutagen treatments as compared to control (4.64%) except 60 mM EMS (4.02%) and 1500 ppm streptomycin sulphate (4.35%). Similar result was obtained by Dixita (2018) in castor using different gamma rays doses. They found that JI-444 had the maximum values of GCV (0.69%) and PCV (6.24%) in treatment of 500 Gy. Maximum heritability (9.99%), genetic advance (0.14%) and genetic advance as per cent of mean (0.28%) were found in 750 Gy treatment.

High value of genotypic coefficient of variation and phenotypic coefficient of variation was observed for effective length of primary raceme, number of effective branch per plant, number of capsule on primary raceme and seed yield per plant and low value of genotypic coefficient of variation and phenotypic coefficient of variation was observed for days to flowering, days to maturity, number of node up to primary raceme, 100-seed weight and oil content. Less differences between phenotypic and genotypic coefficient of variation indicated that most of the characters were less influenced by the environment and selection would prove efficient.

With the help of genotypic coefficient of variation alone, it is not possible to

determine the extent of variation which is heritable. Thus, the knowledge of heritability of a character helps the plant breeders in predicting the genetic advance for any quantitative characters and aids in exercising necessary selection procedure. Burton (1952) suggested that genotypic coefficient of variation together with heritability estimates would give the best picture for selection.

The maximum heritability (broad sense) was observed for days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of node up to primary raceme, effective length of primary raceme, number of effective branch per plant, number of capsule on primary raceme, seed yield per plant, 100-seed weight and oil content. High heritability for the above traits which were controlled by polygenes might be useful to the plant breeders for making effective selection.

V. SUMMARY AND CONCLUSIONS

The present investigation entitled “Mutagenesis study in castor (*Ricinus communis* L.)” was undertaken to find out the mutagenic frequency, effectiveness, spectrum of induced mutations in qualitative and quantitative characters, and induced variability.

The seeds were obtained from Center for Oilseeds Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The seeds of both genotype VP 1 (M) and SKI 215 were treated with 50 mM and 60 mM EMS and 1000 ppm and 1500 ppm streptomycin sulphate. Treated seeds were considered as M_1 generation. Laboratory study (M_1 generation) was carried out during *kharif*-2020 at Department of Genetics and Plant Breeding, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar. Field study was carried out for M_1 generation during *kharif* 2020-21, whereas for M_2 generation such study was carried out in a compact family block design during *kharif* 2021-22 as field experiments at Center for Oilseeds Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat .

In M_1 generation, observation were recorded for germination per cent, survival per cent, morphological variant and pollen study.

In M_2 generation, observations for traits like mutagenic effectiveness and efficiency, morphological variant as well as metric observations for quantitative traits *viz.*, days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme (cm), number of node up to primary raceme, effective length of primary raceme (cm), number of effective branch per plant, number of capsule on primary raceme, seed yield per plant (g), 100-seed weight (g) and oil content (%) were recorded.

The salient results obtained from this study and their implications in the genetic improvement of castor are summarized as below.

1. The study of M_1 generation revealed that germination and survival was reduced in both the genotypes when treated by both the mutagens as compared to untreated control.
2. While, comparing mutagens more effect on germinations and survival was found in EMS treatments as compared to streptomycin sulphate.
3. Results of M_1 generation on castor genotypes VP 1 (M) and SKI 215 treated with EMS and streptomycin sulphate reveals that VP 1 (M) pistillate line is more sensitive to both the mutagens.
4. Preliminary experiment are indicating reduction up to 50 per cent germination

assumed to be in between 50 and 60 mM EMS, whereas for streptomycin sulphate between 1000 and 1500 ppm assumed for both VP 1 (M) and SKI 215 genotypes.

5. By converting the observed data of the treatment into trend the linear graph was prepared using formula generated from Excel of MS office-13 version. The equation derived by this spread sheet using prescribed commands were used to estimate treatment values that can produce 50 per cent germination. By this way LD_{50} for VP 1 (M) estimated for EMS as mutagen was 65 mM and streptomycin sulphate was 1492 ppm and for SKI 215, LD_{50} was found 63 mM of EMS and 1460 ppm of streptomycin sulphate.
6. In M_1 generation, morphological mutation were also observed for leaf variant and plant height.
7. Pollen sterility percentage ranged between 0.03-73.68 per cent among all the mutation treatments.
8. In M_2 generation, morphological variants were also observed in treated progenies derived from M_1 generation.
9. Low range of variation were also noticed as already observed in M_1 generation for untreated control.
10. In M_2 generation morphological variant like leaf colour, plant height and stem thickness difference were observed.
11. Pollen sterility in M_1 and M_2 generation indicated that: M_1 generation had produce partial sterile plant in population of SKI 215 when treated with 60 EMS and 1500 ppm streptomycin sulphate. Similarly total three sterile plants were also observed in M_2 population. Comprising of two in VP 1 (M) genotype treated with 1000 ppm and 1500 ppm streptomycin sulphate. The third plant was observed in SKI 215 when treated with 1500 ppm streptomycin sulphate.
12. Periodically observations were taken on those three pollen sterile plants. Every week and compared with meteorological parameters and it reveals that increasing in temperature and decrease in humidity increases pollen sterility.
13. Sterility was found 12.30-95.83 per cent during growing period for all three pollen sterile plants.
14. Higher frequency of mutants in M_2 generation were found in both the genotypes VP 1 (M) and SKI 215 treated with 1500 ppm streptomycin sulphate.
15. In both genotypes, mutagenic effectiveness and efficiency was found higher in

1500 ppm streptomycin sulphate followed by 1000 ppm streptomycin sulphate and 60 mM EMS treatment.

16. Metric character were observed in M_2 generation grown under factorial CFBD design with three replication. The data for all matric traits were recorded and analysis revealed as below:

    The analysis of variance in M_2 generation for progeny within family that progeny mean squares were significant for all the characters *viz*., days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of node up to primary raceme, effective length of primary raceme, number of effective branch per plant, number of capsule on primary raceme, seed yield per plant, 100-seed weight and oil content in all the mutation families over the control. Mutagenic treatment shifted mean value in both the direction for most of the characters which indicating scope for further selection of these traits. Chi squre Barlett's test of homogeneity of error variances being significant for all the characters except days to flowering of primary raceme, 100-seed weight and oil content, indicated the necessity to perform analysis of variance separately for each of the family for these characters.

17. Doses near to LD_{50} value of the mutagens were more effective for inducing beneficial mutants as compared to higher concentration. 50 Mm EMS and 1500 ppm streptomycin sulphate were responsible for induction of the most desirable mutants with early flowering, early maturity, high plant height, effective length of primary raceme, effective branch per plant, number of capsule on primary raceme, seed yield per plant, 100-seed weight and oil content.
18. Family mean of different mutagenic treatments were also in desirable direction for characters days to flowering, days to maturity, number of node up to primary raceme, effective length of primary raceme, effective branch per plant, seed yield per plant, 100-seed weight and oil content, while negative direction for family mean was observed for plant height.
19. Positive direction family mean of genotype VP 1 (M) for respective characters along with their effective mutagenic treatment has been mentioned: days to flowering and days to maturity proved to be most efficient when the treatment of 50 mM EMS was undertaken, plant height when the mutagenic treatment of 1000 ppm streptomycin sulphate was applied, number of nodes up to primary

raceme when the treatment of 60 mM EMS was applied, effective length of primary raceme when 1500 ppm streptomycin sulphate mutagenic treatment was given, number of effective branches per plant showed highest mean when the mutagenic treatment of 60 mM EMS was applied, number of capsule on primary raceme was highest at 60 mM EMS treatment, seed yield per plant proved to be highest at 60 mM EMS mutagenic treatment, 100-seed weight gave highest mean at 1500 ppm streptomycin sulphate mutagenic treatment, and oil content found to be highest at 60 mM EMS mutagenic treatment. From present conclusions, it can be said that the mutagenic treatment of 60 mM EMS can prove to be efficient considering most of the characters showing positive direction mean after treatment.

20. Positive direction family mean of genotype SKI 215 for respective characters along with their effective mutagenic treatment has been mentioned : days to flowering and days to maturity proved to be most efficient when the treatment of 1500 ppm streptomycin sulphate was undertaken, plant height when the mutagenic treatment of 60 mM EMS was applied, number of node up to primary raceme when the treatment of 1000 ppm streptomycin sulphate was applied, effective length of primary raceme when 50 mm EMS mutagenic treatment was given, number of effective branch per plant showed highest mean when the mutagenic treatment of 50 mM EMS was applied, number of capsule on primary raceme was highest at 1500 ppm streptomycin sulphate treatment, seed yield per plant proved to be highest at 1500 ppm streptomycin sulphate mutagenic treatment, 100-seed weight gave highest mean at 1500 ppm streptomycin sulphate mutagenic treatment and oil content found to be highest at 1500 ppm mutagenic treatment of streptomycin sulphate. From present conclusions, it can be said that the mutagenic treatment of 60 mM EMS can prove to be efficient considering most of the characters showing positive direction mean after treatment.
21. Early mutants were observed in genotypes VP 1 (M) and SKI 215 when the mutagenic treatment of 50 mM EMS and 1500 ppm streptomycin sulphate, respectively. The said conclusion has been derived from the mean values for days to flowering and days to maturity comparing with control.
22. Estimation of genotypic and phenotypic coefficient of variation, heritability and genetic advance for the ten characters studied indicated that the GCV and PCV

was high as well as low among the characters studied depending on the treatments and less differences between phenotypic and genotypic coefficient of variation indicated that most of the characters were less influenced by the environment and selection would prove efficient.

23. Genetic parameters such as heritability and genetic advance as per cent of mean increased many fold in both the mutagenic treatments for all the characters as compared to control. The genotypic and phenotypic coefficient of variation increased in both the mutagenic treatments for all the characters except number of node up to primary raceme for SKI 215 and number of capsule on primary raceme in VP 1 (M). 100-seed weight observed decreased GCV and PCV in both the genotypes (VP 1 (M) and SKI 215) after mutagenic treatment. High heritability with high genetic advance as per cent of mean was observed for plant height up to primary raceme, number of node up to primary raceme, effective length of primary raceme, number of effective branch per plant, number of capsule on primary raceme and seed yield per plant, which indicated that expression of these traits was governed by additive gene action and as a result there was a scope for improving these traits through adopting selection procedure during advancement of mutant generations.

Present investigation has been found an efficient to induce variability for macro and micro mutation in the castor and it is a supplement to conventional breeding methods. In M_2 generation a significant positive shift of mean performance was observed in number of nodes up to primary raceme, effective length of primary raceme, number of effective branches per plant, number of capsules on primary raceme, seed yield per plant, 100-seed weight and oil content. The negative shift of mean performance was observed for plant height indicating dwarf plant can be obtained using mutagenic treatments providing promising dwarf mutants.

Treatments of chemical and antibiotic showed higher mutagenic effect in most of the characters when compared to control. The results indicated the possibilities of evolving higher yield variants through effective selection based upon variability parameters and their respective. Mutagenic treatments increase the genetic variability, which can be utilized for selection and improvement of castor plants.

Treatment of chemical mutagen EMS with concentration of 60 mM proved to be highly efficient on genotype VP 1 (M), while antibiotic streptomycin sulphate with concentration of 1500 ppm proved to be efficient on genotype SKI 215 for overall

morphological mutations. Observations on pollen sterility in M_1 and M_2 generation and periodical observations on three pollen sterile plants of M_2 generation indicates that there is ample scope of development of male sterility system in castor crop that can be helpful for development of high purity commercial hybrids.

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APPENDICES

Appendix A: Meteorological data recorded at Sardarkrushinagar, Dist:Banaskantha during the period of experiment (August-2020 to March-2021)

Month and Year	Standard weeks	Temperature (°C)		Rain fall (mm)	RH (%)	Wind velocity (km/hr)
		Max.	Min.			
August 2021	34	32.60	25.2	127.0	89.5	5.50
	35	33.00	25.1	114.0	90	6.70
September 2021	36	34.50	25.0	9.00	82	3.20
	37	34.50	25.0	96.00	86	3.90
	38	35.10	25.4	3.50	79	3.80
	39	35.20	23.6	17.0	72.5	5.20
October 2021	40	34.40	22.2	8.00	65.5	2.80
	41	35.80	19.0	0.0	55.5	2.30
	42	36.60	25.0	27.00	68	4.20
	43	36.20	15.8	0.0	49	2.50
	44	35.40	13.0	0.0	50	2.10
November 2021	45	34.30	13.8	0.0	47	2.50
	46	34.40	14.3	0.0	47	3.40
	47	33.00	11.6	0.0	41	2.80
	48	31.90	11.6	3.0	37.5	4.60
December 2021	49	32.00	10.7	0.0	35.5	2.10
	50	30.70	9.10	0.0	39.5	4.20
	51	25.50	7.30	0.0	42.5	3.40
	52	22.90	6.70	0.0	38.5	2.60
January 2022	1	23.20	8.10	0.0	52	4.90
	2	23.50	9.20	0.0	48.5	6.00
	3	25.90	10.5	0.0	46	3.40
	4	26.30	7.00	0.0	39	3.80
	5	29.20	8.10	0.0	39	2.30
February 2022	6	35.2	9.8	0.0	44.5	3.30
	7	36.8	12.0	0.0	45	5.50
	8	38.2	14.0	0.0	47	2.00
	9	36.5	14.4	0.0	45.5	2.40
March 2022	10	36.8	15.5	0.0	46.5	3.90
	11	36.9	16.1	0.0	46.5	4.30

Appendix B: Meteorological data recorded at Sardarkrushinagar, Dist: Banaskantha during the period of experiment (August-2021 to March-2022)

Month and Year	Standard weeks	Temperature (ºC)		Rain fall (mm)	RH (%)	Wind velocity (km/hr)
		Max.	Min.			
August 2021	34	36.9	26.0	2.0	76	4.9
	35	35.6	24.7	36.5	82	5.3
September 2021	36	34.4	24.9	41.0	88	5.7
	37	32.9	24.2	109.5	85	3.3
	38	33.5	23.6	6.0	80	4.7
	39	33.1	24.9	87.5	81	5.1
October 2021	40	34.7	25.0	0.0	78	3.9
	41	37.4	25.8	0.0	77	2.1
	42	36.9	21.1	0.0	69	2.2
	43	36.2	18.0	0.0	66	4.7
	44	33.3	15.9	0.0	69	2.3
November 2021	45	28.1	13.6	0.0	70	2.8
	46	26.5	10.6	0.0	70	2.7
	47	25.2	7.6	0.0	70	2.6
	48	27.1	11.7	3.0	76	2.6
December 2021	49	25.9	12.7	0.0	76	2.9
	50	21.9	7.0	0.0	67	2.7
	51	24.9	8.5	0.0	68	3.3
	52	25.0	6.0	0.0	57	2.8
January 2022	1	27.6	8.8	0.0	65	2.4
	2	27.9	9.5	0.0	64	4.4
	3	30.3	10.0	0.0	65	2.8
	4	32.4	12.6	0.0	69	4.1
	5	28.1	13.6	0.0	70	3.2
February 2022	6	26.5	10.6	0.0	70	3.2
	7	25.2	7.6	0.0	70	2.7
	8	32.4	12.6	0.0	69	3.8
	9	32.9	15.4	0.0	69	5.2
March 2022	10	35.0	16.1	0.0	69	4.2
	11	39.2	17.7	0.0	71	3.4

Appendix C: Mean values of different characters in M_2 generation (field) with different mutagen treatments in castor

Genotypes	Family	Treatment	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)	Number of effective branch per plant	Number of capsule on primary raceme	Seed yield per plant (g)	100-seed weight (g)	Oil content (%)
VP 1 (M)	Family 1	Control	60.35	130.13	27.46	13.97	56.47	12.44	50.79	299.67	24.91	46.00
	Family 2	50 Mm EMS	48.80	114.00	30.09	14.94	61.20	11.93	54.12	265.68	24.01	47.17
	Family 3	60 Mm EMS	51.05	116.42	29.23	15.10	59.43	14.08	56.09	324.43	23.13	47.56
	Family 4	1000 ppm S.S.	50.55	120.46	27.91	14.15	62.80	12.82	49.21	291.98	24.14	46.90
	Family 5	1500 ppm S.S	52.59	122.59	28.05	14.07	63.89	12.50	48.98	319.58	25.52	47.05
SKI 215	Family 6	Control	62.07	141.49	89.56	19.09	60.59	19.69	55.23	283.98	26.34	46.76
	Family 7	50 Mm EMS	59.54	139.57	88.87	17.55	62.28	23.18	41.16	300.48	26.03	46.43
	Family 8	60 Mm EMS	60.85	140.73	84.83	19.46	60.62	17.57	49.42	325.78	24.85	47.30
	Family 9	1000 ppm S.S.	60.24	140.17	90.50	19.80	58.31	19.73	49.38	297.74	25.52	47.39
	Family 10	1500 ppm S.S	58.29	138.30	91.77	19.64	61.10	20.23	57.61	350.08	27.64	48.22
		Mean	56.43	130.38	58.82	16.78	60.66	16.41	51.20	305.94	25.21	47.07
		SEm±	0.20	0.32	1.20	0.18	1.10	0.33	1.06	8.32	0.14	0.16
		C.D at 5 %	0.61	0.94	3.57	0.54	3.27	0.99	3.14	24.73	0.42	0.48
			1.98	1.33	11.19	5.89	9.96	11.12	11.32	14.90	3.09	1.91

CERTIFICATE

This is to certify that, I have no objection for supplying to any scientist only one copy or any part of this thesis at a time through reprographic process, if necessary for rendering reference service in a library or documentation center.

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