GENETIC IMPROVEMENT OF SAFFLOWER (*Carthamus tinctorius* L.) THROUGH INDUCED MUTATION

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M.Sc.(Agriculture)

DOCTOR OF PHILOSOPHY

(AGRICULTURE)

IN

AGRICULTURAL BOTANY

(GENETICS AND PLANT BREEDING)

DEPARTMENT OF AGRICULTURAL BOTANY

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Submitted by

GAWANDE SHAILESH MURLIDHAR

M.Sc.(Agriculture)

A thesis submitted to
Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
in partial fulfillment of the requirement for the degree of

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2022

DECLARATION BY THE CANDIDATE

I hereby declare that the thesis entitled, "**GENETIC IMPROVEMENT OF SAFFLOWER (*Carthamus tinctorius* L.) THROUGH INDUCED MUTATION**", submitted by me is based on the actual work carried out by me under the guidance and supervision of **GHUGE SHYAMRAO BHIMRAO**. The extent of information derived from existing literature have been duly cited and referenced. The existing research work or its any part is not submitted anywhere else for the award of any degree or diploma.

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(Shailesh Murlidhar Gawande)

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ABBREVIATIONS USED

/	-	Per
%	-	Per cent
^{0}C	-	Degree centigrade
Conc.	-	Concentration
C.D.	-	Critical difference
Cm	-	Centimeter (s)
CO^{60}	-	Cobalt – 60
CV	-	Coefficient of variation
EMS	-	Ethylmethane sulphonate
e.g.	-	Exampli Gratia (for Example)
et al.	-	et alia (and others)
etc.	-	Etcetera
Fig.	-	Figure (s)
g	-	Gram
GA	-	Genetic advance
GCV	-	Genotypic coefficient of variation
Gy	-	Gray
h^2	-	Heritability
hrs.	-	Hours
i.e.	-	Id est (That is)
Kg/ha	-	Kilogram (s) per hectare
kR	-	Kilo Roentgen
LD_{50}	-	Lethal dose 50
Mm	-	millimeter
No.	-	Number (s)
PCV	-	Phenotypic coefficient of variation
S.E. (m) ±	-	Standard error of mean
sp.	-	Species
SE	-	Standard error
Sq	-	Square
viz.,	-	Videlicet (namely)

THESIS ABSTRACT

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Title of thesis	:	GENETIC IMPROVEMENT OF SAFFLOWER (*Carthamus tinctorius* L.) THROUGH INDUCED MUTATION.
Full name of candidate	:	Gawande Shailesh Murlidhar
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College / University	:	College of Agriculture, VNMKV, Parbhani
Degree to be awarded	:	Ph.D. Agriculture (Genetics and Plant breeding)

ABSTACT

The present investigation entitled "Genetic improvement of safflower (*Carthamus tinctorious* L.) through induced mutation" was undertaken to estimate variability, heritability, correlation and path analysis in safflower crop and was also aimed at elucidating information mainly on the sensitivity of safflower populations to gamma irradiation, EMS treatments and their combination, besides the effect of mutagens on character association in mutant populations. In order to generate desirable variability, a well adapted and popular variety of safflower, PBNS-12 was used as experimental material. The seeds of PBNS-12 variety were irradiated with gamma rays at different dose *viz.,* 100 Gy, 200 Gy, 300 Gy, 400 Gy and 500 Gy and were also treated with different concentration of EMS *viz.,*0.1%, 0.2%, 0.3% and 0.4% alone and their combinations. The treated seeds were sown in field at AICRP on Safflower, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani during *rabi* 2019-20 (M_1 generation) and individual M_1 progenies were grown during *rabi* 2020-21 (M_2 generation).

The observations on mutagenic effects in M_1 generation revealed dose dependent reduction in seed emergence and plant survival. Mutagen damage measures for emergence and survival was more pronounced in gamma irradiated populations compared to EMS treatments and combinations. The LD_{50} dose was calculated based on reduction of plant survival percentage. The LD_{50} dose of 299.5 Gy was found in case of gamma rays and 0.2536% concentration in case of EMS. In general, frequency of chlorophyll mutants was more expressed in M_2 generation on seedling basis. Single plant of xantha type chlorophyll mutant was observed in 0.3% EMS concentration treatment. Total 125 putative mutants were isolated in M_2 generation. Out of this some

high seed yield along with earliness, high oil content and high oleic acid putative mutants were identified. Estimation of viable mutation frequency was done on M_2 seedling basis. Maximum mutation frequency (2.25%) was recorded at 200 Gy+ 0.1% EMS followed by 0.2% EMS (1.87%) and 200 Gy (1.70 %) dose of gamma rays.

The mutagenic effectiveness and efficiency have indicated that lower/ intermediate dose to be more effective and efficient compared to higher doses in both the mutagens and combination treatment. Maximum mutagenic effectiveness (8.50%) was recorded at 200 Gy dose of gamma rays followed by 200 Gy +0.1% EMS (6.25%) dose of combination treatment and 0.2% EMS (5.19%) concentration treatment.

Mutations affecting plant habit, leaf morphology, plant height, days to maturity, highly branched characteristics were noticed. In the present investigation, it was observed that combination of mutagenic treatments generated more variability than that of individual treatments with physical and chemical mutagens. High estimates of PCV, GCV, heritability and genetic advance were recorded in majority of the characters indicating that most of the characters were controlled by genetic factors and highly sensitive to environment. Induced variability indicated that significant improvement can be achieved by proper selection techniques.

Correlation studies revealed significant and positive association of plant height, numbers of primary branches per plant , number of secondary branches per plant , number of capsule per plant , 100 seed weight with seed yield per plant at 200 Gy, 0.2% EMS, 200 Gy +0.1% EMS and 300 Gy+ 0.1% EMS dose of mutagenic treatment for all the populations.

Path analysis revealed high positive direct effect of plant height, number of primary branches per plant, number of secondary branches per plant, number of capsules per plant, 100 seed weight with seed yield per plant at 200 Gy, 200 Gy +0.1%EMS, 300 Gy+0.2%EMS and 0.2 % EMS dose/ concentration of mutagenic treatments for all the populations.

Key word: LD_{50}, Gamma rays, EMS, mutation frequency, mutagenic effectiveness, mutagenic efficiency

CHAPTER-I

INTRODUCTION

CHAPTER - I

INTRODUCTION

1.1 Background information

Safflower (*Carthamus tinctorius* L.) belongs to compositae or asteraceae family. *Carthamus* is a latinizedform of the Arabic term quartum /or gurtum, which refers to the colour of the safflower dye produced from the petals. Safflower is thought to have developed from various written forms of usfar, affore, asfiore, and saffiore. In the genus *Carthamus*, there are 25 species, however only *Carthamus tinctorius* L. (2n=24) is cultivated. It is thought to have evolved from the wild and closely related *Carthamus oxyacantha* and *Carthamus lanatus* and is used to make oil (Gupta and Das, 1997). Safflower is thought to have originated in three places: India, Irano-Afghanistan, and Ethiopia (Vavilov, 1949). Safflower has been cultivated in India since the dawn of time. Ancient scriptures refer to it as kusumba.In India, it is frequently referred to as kardai in Marathi and kusum in Hindi.

Safflower like other related plants like artichoke and thistles has spine-tipped leaves that are unpleasant to touch. It is a 2 to 6 foot tall annual with a coarse stalk and multiple branches, each of which ends in a 1/2 inch to $1^{½}$ inch wide yellow or orange (occasionally white or red) flower head (Knowles, 1958). Safflower is typically thought to be a self-pollinated plant. Classen (1950), on the other hand, observed cross-pollination rates ranging from 0 to 100 percent, while most of the plants he used had detectable crossing rates of 5 to 40 percent

A versatile crop which is high in vitamin A, iron, phosphate and calcium.For generations, it has been cultivated in India for the orange-red dye (carthamin) generated from its vibrantly coloured blooms, as well as its high-quality oil, rich in polyunsaturated fatty acids (linoleic acid, 78 percent). Safflower blooms are commonly utilized in Chinese herbal medicines and are believed to have various therapeutic benefits for healing a variety of chronic ailments (Li and Mundel, 1996). Safflower leaves, shoots and thinning are used as a salad and a pot herb. Safflower tea prepared from the plant's leaf and blooms have been developed in China and India and are sold as herbal health tea all over the world. Teas produced from leaves have been used by women in India and Afghanistan to prevent abortion and infertility. The tea

has also been used as a prophylactic measure against heart and circulatory problems (Emongor, 2010). In India and other surrounding countries, bundles of young plants are often offered as a green vegetable (Nimbkar, 2002). Grazed or stored as hay or silage, safflower is a versatile crop. The feed value and yields of safflower fodder are comparable to or better than those of oats or alfalfa. As a result, each portion of the safflower has a monetary worth. Low moisture tolerance is a strong suit for safflower. As a result, safflower yields can be increased with minimal irrigation. Safflower is an oilseed crop farmed largely for the high quality edible oil it produces. The oil content of the seed varies between 28 and 36 percent; the oil is high in linoleic acid, an unsaturated fatty acid that helps decrease blood cholesterol. The optimal commercial uses of a vegetable oil are determined by its fatty acid makeup. In China, safflower has been utilized as an attractive plant, a medicinal herb and a cosmetic substance for generations.Safflower seed oil was historically widely utilized in the production of alkyd resins for paints and varnishes due to its high linoleic acid concentration. It could potentially be a possible raw material for the manufacturing of liquid fuels based on vegetable oils in the near future. Because of its high oleic acid concentration, safflower oil has become popular frying oil due to its high stability and blend flavor. Safflower oil contains two main unsaturated fatty acids: oleic (18:1) and linoleic acid (18:2). They account for about 90% of the total fatty acids. The remaining 10 percent correspond to the saturated fatty acids, palmitic (16:0) and stearic (18:0). Standard safflower oil aims about 6-8 percent palmitic acid, 2-3 percent stearic acid, 16-20 percent oleic acid and 71-75 percent linoleic acid.

Because of its taproot system, safflower is considered a moderately drought-resistant crop. It can access a broader region to obtain water than other crops, making it a moderately drought-resistant crop. Safflower, like barley or cotton is thought to have a moderate to high tolerance to salinity (GRDC, 2010). Frost tolerance is moderate during the rosette stage but it is vulnerable to frost damage from the stem elongation stage to maturity. It is also relatively resistant to harm from hail or wind (Mundel *et. al.*, 2004).

Safflower has been grown for centuries throughout the world, mostly as a source of edible oil and dyes. The top producers of safflower for oil extraction are India, the United States, Mexico, Australia and Ethiopia which account for 85 percent of global production. The fact that India is the world's greatest producer of safflower

is a source of real pride. Safflower is grown in more than 60 nations of the world but India produces more than half of it, primarily for the vegetable oil industry.

India farmed 0.24 lakh ha, produced 0.45 lakh tonnes of seed, and had an average productivity of 537 kg/ha making it the world's leading safflower producer (Anonymous 2019). Maharashtra, Karnataka, Madhya Pradesh, and a portion of Andhra Pradesh are the most important safflower-growing states in India. Maharashtra and Karnataka are the major safflower-growing states with 73 percent and 22 percent of the total acreage and 63 percent and 35 percent of the total production, respectively (Goyal, 2006).

Table 1.1: Area, production and productivity of safflower during 2018-19, 2019-20 and 2020-21:-

	Years	Marathwada	Maharashtra	India
Area (lakh ha)	2018-19	0.16	0.18	0.24
	2019-20	0.20	0.21	0.52
	2020-21	0.14	0.20	0.76
Production (lakh tones)	2018-19	0.58	0.63	0.45
	2019-20	0.11	0.15	0.34
	2020-21	0.11	0.14	0.48
Productivity (kg/ha)	2018-19	285	347	537
	2019-20	525	691	537
	2020-21	304	704	637

(Source: Anonymous 2019, 2020 and 2021)

In India, a safflower development initiative began in 1931, with N-630 being the first variety commercialized in 1942.In Maharashtra, important varieties released are Tara, Nira, Bhima, Girna, Sharada, PBNS-12, PhuleKusum, AKS-207 (Spiny) and NARI-6 (Non- spiny).Bhima was released from solapur and it was identified by Dr. P.D.K.V. Akola in 1983. Sharada variety was released from AICRP (Safflower) Centre, V.N.M.K.V, Parbhani in1990.Also, PBNS-12 variety released by AICRP (Safflower) Centre, V.N.M.K.V, Parbhani in 2001. AKS- 207 was released in 2006 by Dr. P.D.K.V., Akola. Dr.P.D.K.V., Akola recently released the high oil containing wilt tolerant cultivar PKV- Pink in 2011. Further improvement for seed yield and oil

content with inbuilt tolerance and resistance to biotic and abiotic stresses are in progress through eight AICRP Centres in India under Indian Institute of Oilseeds Research, Hydrabad.

1.2 Importance and need of study

The occurrence of natural variability in a self-pollinated crop is crucial to the conventional breeding process. Safflower is mostly a self-pollinating plant. Cross pollination was primarily accomplished by honey bees, with a 28 percent success rate in safflower (Kadam and Patanker, 1942). Any successful breeding programme requires genetic variability for economic traits, yet the inherent variability in safflower is limited for achieving desired improvement. If the range of genetic variability in safflower could be expanded, breeding efforts would be boosted. Therefore, genetic variability in safflower must be increased by mutation breeding.Only for recombining simple hereditary traits have traditional breeding procedures proved highly useful. As a result, traditional breeding approaches have been ineffective in enhancing quantitatively inherited traits such as seed yield, oil content, stress tolerance, and horizontal resistance to disease and insect (Jensen and Zimmer, 1970). Furthermore, for the amount of development achieved, the crossing and record-keeping procedures are frequently both costly and time-consuming.

Traditional breeding has not been successful in increasing per-hectare yields of "oil" or "seed." The "ultimate product" in safflower is difficult to enhance genetically since it involves both increasing seed yield and oil content. Alternatively, "mutagenesis" in which adequate genetic variability for the traits under discussion is developed, may be used to alleviate such challenges (Khadeer and Anwar, 1991). Apart from polygenic traits, complex traits such as oil quality and/or quantity, sufficient variability can be induced *via.* mutagenesis and induced variability can be utilized by the breeder for the genetic enhancement of desirable qualities in safflower.In addition to traditional breeding methods, mutation breeding can play a unique role in crop development by giving plant breeders a new technique to boost agricultural crop yield.When it comes to correcting minor flaws in any crop, this is the approach of choice for getting faster results.

Mutation breeding is recognized as one of evolution's driving forces. Mutation breeding is a less time-consuming way for improving various crop species. It is an

important approach for increasing genetic diversity in plant breeding programmes by creating variability for quantitatively inherited features in different plants (De Oliveira Camargo *et. al.,* 2000). It is often used to correct defects in a cultivar which has a set of good agronomic characteristics.

Artificial mutagenesis allows for the inductions of desirable traits that are either not found naturally or have been lost, and mutation induction is a real and proven approach to create variation within a crop variety. Induced mutations can allow for focused recombination in well-adapted varieties in the shortest amount of time with the least amount of yield and quality loss (Bhatnagar and Tiwari, 1991). Because of its low seed oil content, spines, fiber-rich seed meal, and vulnerability to a variety of diseases and pests, safflower has remained a neglected crop despite its huge potential and growing adaptability to a wide range of agro-ecological situations. (Sujata, 2007).

Safflower area in India has been declining year after year due to genotypes suffering from a variety of issues, including a long maturation period (140-145 days), low seed yield, and low seed oil content. To address these issues an attempt is made to broaden the genetic base of the safflower production, the current study's goal is to develop an early, high seed yielding, high oil content variety of safflower through induced mutagenesis and identify desirable mutants possessing high oil and seed yield.

1.3 Objectives of study

The present study was carried out with the following objectives, keeping in view the preceding importance:

1. To study the relative effect of physical and chemical mutagens in M_1 generation of safflower.
2. To study the extent of variability for quantitative and qualitative traits in M_2 generation of safflower.
3. To isolate the desirable mutants for yield, earliness and quality traits in M_2 generation of safflower.

1.4 Scope and limitations

The findings of this study can be used by safflower breeders to exploit the promising mutants for use in breeding programmes either directly as new mutant varieties or indirectly as parental lines in crossbreeding. Any crop development effort must have genetic heterogeneity as a prerequisite. Plant breeding uses mutagenesis to create genetic variability for further selection, hybridization and the development of raw materials for genetic improvement of commercially significant crops (Adamu and Aliyu, 2007). The paucity of genetic variation in existing germplasm collections was a fundamental barrier in the traditional approach. Mutation approaches may be able to help in this situation. In addition, induced mutations are one of the most essential tools for spreading genetic variation to overcome bottlenecks encountered in standard breeding methods (Sahaand Paul 2018).Other approaches of crop enhancement for creating genetic variability were shown to be inferior to the mutation approach (Gustafsson, 1940). The most important aspects of mutation breeding have been the rapid correction of defects in varieties and advanced breeding lines, induction of polygenic mutations, and production of ideotypes for various agro-climatic conditions.The present study's drawbacks include the low frequency of obtaining desirable mutants, the need to screen a large population for selecting the desired mutants and the association of certain desirable mutations with undesirable characters.

1.5 Hypothesis

Mutation breeding can be used to obtained desirable mutant for seed yield, earliness and quality traits in safflower. These desirable mutants that could be used in breeding program to evolve new mutant variety.

CHAPTER-II

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

Plant breeding is simply the process of improving crops to meet human demands. The extent of improvement depends upon the variability available (or generated) and the efficiency of selection schemes.

Induced mutations have emerged as a powerful tool for creating variability. Hugo de Vries (1910) proposed the concept of induced mutation and Muller (1927) established its importance in Drosophila using X-rays mutation. The breeder has access to a variety of ionizing radiations including gamma rays, alpha and beta particles, protons and neutrons. The primary sources of gamma rays are cobalt^{60} and caesium^{17}. Another watershed moment in the history of induced mutations was the discovery of chemical mutagens during World War II. Auerbach (1943) was the first to state unequivocally that potent chemical mutagens exist. Many chemical mutagens have since been utilized in mutation investigations, including ethyl-methane sulphonate, methyl methane sulphonate, ethylene-imines, nitroso compounds, base analogues and various antibiotics. A physical and chemical mutagen *viz.,* gamma rays and ethyl methane sulphonate respectively and their combination were used in the present study.

2.1 Gamma rays

Physical mutagens such as gamma rays are effective and efficient. Because they have a shorter wavelength, they have more energy per photon than X-rays. These rays can penetrate up to several centimeters and are produced in a wide range of energy, similar to X-rays. CO^{60} has a half-life of 5.3 years, with energy of 133 Mev (μ1) or 1.17 Mev (μ2) has a specific activity of 1.400 ci/g and can penetrate to a depth of 5 cmpb. When gamma rays strike matter, they cause a series of physical reactions (photoelectric absorption, Compton scattering, and ion pair formation) in which energy is absorbed by the target material's atoms and released as fast charged particles. The photons in gamma rays have a high energy, which allows them to penetrate the surface and cause ionization. Ionizing radiation of water produces extremely reactive hydroxyl radicals, which is the main consequence. Organic biological components, particularly DNA, are attacked by these radicals.

2.2 Ethyl methane sulphonate ($C_2H_5SO_2CH_3$)

This chemical has been known to react particularly with the base guanine (Bautz and Freese, 1960). According to Krieg (1963), this compound's reactivity with three of the four bases diminishes in the following order: guanine, adenine, and cytosine. Ethyl methane sulphonate, like any other alkylating chemical can react with either the phosphate group of nucleic acids or the purine bases, particularly the guanine of the DNA molecule. Ethylation of N7, which acts on the guanine base is thought to be a key mechanism in mutation and chromosome breakage. The alkylation of purine at the seventh position, results in to unstable quaternary nitrogen's. Either the alkyl group hydrolyzes away from the purine, or the alkylated purine separates from deoxyribose and becomes depurinated. Purines that have been ethylated or methylated have been found to be liberated from DNA bases (Bautz and Freese, 1960, Lett *et al.*, 1962). The gap could obstruct DNA duplication or result in the incorrect nucleotide being included. Based on their experimental findings and theoretical considerations, Bautz and Freese (1960) concluded that the elimination of guanine was the primary source of mutations caused by ethyl methane sulphonate.

2.3 Mutagenic effects

The most important aspect in mutation breeding is to decide about the appropriate mutagen to be used and method of treatment to be adopted. This is decided by considering the mutagen effectiveness and its efficiency to induce more number of mutations in M_2 generation has been used as a valid criterion for selection of the proper treatment conditions. In addition to chlorophyll mutations, the frequency and spectrum of viable mutations also have been used as criteria to assess the potentiality of safflower population and the mutagens. The literature related to the present investigation has been reviewed and presented under the following sub-headings.

2.3.1 Mutagenic effects in M_1 generation

2.3.1.1 Germination or seedling emergence

Chatterdi, A.K. and Prasad, N. (1970) carried out investigation to study the effect of radiation on safflower. They reported that germination of the irradiated seeds

was fairly high, it was 85.5% as against 94.4% in control. The seedling survival, however, was reduced from 91.0% in the control to 80.5, 73.2 and 64.7% in 10, 20 and 40 kR dose respectively. At flowering stage, dwarfness and reduced branching was noticed in 40 kR treatment. There was general reduction in the fertility and found large number of shrunken and aborted seeds. The pollen sterility was highest at 40 kR and was to the extent of 58.5 % as against 7.6% in control.

Ramachandram, M. and Goud, J.V. (1983) studied the effect of gamma irradiation on three thick hull varieties (A1, S 144 and US 104) and two thin hull varieties (Th 5 and AC 1) of safflower in M_1 generation. Varietal response to increased dose of irradiation in respect of germination, root and shoot growth in the laboratory, seedling emergence and survival in the field, plant height, days to flowering, pollen fertility, seed setting and the frequency of chimeric plants followed two distinct patterns based on hull content of the achene. Thin hull varieties were more sensitive to irradiation than thick hull varieties. The biological damage in terms of growth and pollen and seed sterility of thin hull group with 30 kR was nearly equal to that of thick hull group with 45 kR. Differential radio- sensitivity of varietal groups was attributed to the differences in the proportion of hull in the achene rather than the quality and quantity of oil.

Patil *et. al.* (1985) carried out investigation to study the effect of gamma irradiation on some qualitative characters of soybeans. The seeds of the two cultivars of soybean- Bragg and Ankur were subjected to 5, 10, 15, 20 and 30 kR gamma irradiation. In M_1 generation, the leaf variations, germination percentage, branching pattern, plant height, days to flower were noted. A comparison of the response shown by the two cultivars indicates that Ankur variety is more sensitive than bragg. The doses 10-20 kR seem to be most suitable for mutation studies in soybean, since in this range of dosage, maximum variations could be induced.

Boureima *et. al.* (2009) carried out investigation to study the effects of gamma irradiation on germination, seedling height and survival rate of two sesame (*Sesamum indicum* L.) cultivars from Senegal. Seeds of the extensively grown cultivars in Senegal, “32-15” and “38-1-7” were irradiated with 0, 100, 200, 300, 400, 500, 600, 700 and 800 Gy. Irradiated seeds were sown with their respective controls both in field and greenhouse conditions to assess germination rate, seedling height and

survival rate as affected by the different doses of gamma rays. Germination, seedling height and survival rate significantly decreased with increasing irradiation dose. The depressive effect of radiation on germination was more pronounced in the field than in the greenhouse conditions. Cultivar "32-15" was more sensitive to gamma irradiation than cultivar "38-1-7". The effective dose which caused 50% growth reduction was 645 Gy for variety "32-15" and 740 Gy for variety "38-1-7". The lethal dose (LD_{50}) determined at 50 days after sowing was 550 Gy and 740 Gy for "32-15" and "38-1-7", respectively.

Niu *et. al.* (2009) studied the effects of seeds irradiation with Co^{60} gamma ray on shoot growth and physiological status of safflower (*Carthamus tinctorius* L.) and germination rate of seeds, germination, seedling rate, seedling height, root length, fresh weight, root activity and peroxide catalase (CAT), peroxidase (POD), superoxide dismutase (SOD) activity were determined. They found that LD_{50} of radiation dose is about 300 Gy.

Emrani *et. al.* (2011) carried out investigation to evaluate the effect of different dosages of chemical mutagens on seed germination, seed viability and seedling growth characteristics and to identify optimum treatment conditions for chemical mutagens based on the LD_{50} criterion in canola (*Brassica napus* L.). Seeds of spring canola cultivar "RGS 003" were exposed to four chemical mutagens which comprised of EMS, N-nitroso-N- methylurea (NMU), N-nitroso- N- ethylurea (ENU) and sodium azide. Seeds were treated with EMS concentrations of 0, 0.4, 0.8, 1.2 and 1.6% for 3, 6, 9 and 12 h periods. For NMU and ENU treatments, the treatments included solutions of 0, 3, 6, 9 and 12mM for 2, 4, 6 and 8 h. and for sodium azide seeds were treated with 0, 2, 4, 6 and 8 mM solutions for 2, 4, 6 and 8h. The effect of mutagen dosage on seed viability was also assessed using the tetrazolium staining test. Results revealed the significant effects of mutagen dosages and treatment periods on seed viability and seed germination as well as on seedling characteristics for all the mutagens tested. Additionally, it was found that increased dosage and period in each treatment led to significant reductions in seed viability for the tested mutagens. Pretreatment did not significantly influence most of the studied characteristics. The 0.8% EMS for 6h, 12 mM (ENU) and 6mM sodium azide for 8h and 9 mM (NMU) for 4h were considered as optimum treatment conditions.

Aparna *et. al.* (2014) carried out investigation to study the radio sensitivity of gamma rays on groundnut (*Arachis hypogaea* L.). Dry seeds of four popular groundnut varieties *viz.,* Greeshma, Anantha, Kadiri-6 and Kadiri-9 were exposed to gamma radiation ranging from 0.50 to 3.00 kGy. The results indicated that increasing doses of gamma irradiation had significant effect on germination for the first seven days under laboratory conditions in all the varieties. The effectiveness of gamma irradiation on germination % after 7 days was evident at 1.00 and 1.50 (LD_{50}) and reduced significantly at 2.00 kGy and 3.00 kGy in all the varieties. The germination ranged from 22% to 98% in different varieties in the standard germination test. Among all the selected groundnut varieties highest germination percentage (84) was recorded at 0.50 kGy in Greeshma and lowest germination percent was recorded in Anantha (22). The percentage of germination had decreased with increasing doses in all the varieties. Maximum reduction in percentage of germination with a dose 3.00 kGy in Anantha (72.34) followed by Kadiri-9, Kadiri-6 and Greeshma (66.77, 63.83 and 58.33% respectively). The LD_{50} values determined from linear regression analysis based on germination % were ranged from 2.13 kGy (Kadiri-6) to 2.47 kGy (Kadiri - 9).

Franco *et. al.* (2015) carried out investigation to study the effect of gamma radiation in soybean. Soya dry seeds were exposed to different doses of gamma irradiation (25, 50, 75 and 100 Gy). Seed germination and harvest of number of seeds and total production were assessed to identify occurrence of stimulation. Soya seeds and plants were handled as for usual seed production in Brazil. The low doses of gamma radiation in the seeds that stimulate the production were doses of 25, 50 and 75 Gy. There are evidences that the use of low doses of gamma radiation can stimulate germination and plant production.

Gunasekaran, A. and Pavadai, P. (2015) carried out investigation to study the effect of gamma rays on germination, morphology, yield and biochemical studies in groundnut (*Arachis hypogaea* L.). The seeds of peanut cultivar VRI-2 were got treated with gamma radiation doses of 10, 20, 30, 40, 50 and 60 kR. The result showed that the germination was reduced due to increased mutagenic dose in the treatments 60 kR (40.25%) followed by 50 kR (52.36%) and increased germination with decrease dose of gamma rays treatment 10 kR (86.59%). Similarly seedling survival was reduced due to increased dose of gamma rays in the treatments 60 kR

(49.45%) followed by 50 kR (58.20%). Effect of gamma ray treatments were observed in M_1 generation gradually reduced in all parameters except days to first flower to increased concentration of treatment. In M_2, M_3 and M_4 populations, the significant increase of grain yields and yield components of groundnut were observed. Potential high yielding mutants were identified in progenies of treated seeds.

Kharade *et. al.* (2016) carried out investigation to study polygenic variability on seed quality traits in groundnut (*Arachis hypogaea* L.) through mutagens. Seeds of groundnut genotype CTMG-6-1 was treated with gamma radiation (20,30 and 40 kR) and EMS (40mM and 60mM) for studying seed germination, seedling length, seedling dry weight, seedling vigour index (SVI) and electrical conductivity. It was observed that the germination %, speed of germination index, seedling length and seedling vigour index decreases with increase in the doses and concentrations of gamma rays and EMS in M_1 and M_2 generations when compared to control. Maximum germination percentage (86%) was recorded in 40mM followed by 60mM (82%), which were statistically superior to that of control (74%). The LD_{50} (Lethal dose) value was determined based upon the seed germination percentage. Seedling length and seedling vigour index observed were higher in M_2 generation as compared to M_1 generations. It was also revealed that the increase in the doses of mutagenic treatment of gamma rays and EMS, electrical conductivity of seeds were increased.

Vedna Kumari *et. al.* (2016) carried out investigation to study the effect of mutagenesis on germination, growth and fertility in sesame. The seeds of a local variety 'LTK-4' were got irradiated with 6 gamma radiation doses *viz.,* 150 Gy, 300 Gy, 450 Gy, 600 Gy, 750 Gy and 900 Gy. The seeds were also treated with 0.5%, 1.0% and 1.5% EMS. The observation on percent germination, plant survival, reduction in plant survival over control and survival till maturity were recorded in M_1 generation at appropriate stages of crop growth. The analysis of variance indicated that all the 9 treatments differed significantly for seed germination and plant survival parameters indicating the presence of sufficient variability for these parameters. Under field conditions, the maximum reduction in seed germination over control was observed in 900 Gy (35.9%) while lowest was observed in 300 Gy (71.5%) and seed germination was reduced at 1.5 % EMS (28.2%) and highest in 0.5% EMS (65.2%), the maximum reduction in survival over control was observed in 900 Gy (87.7%) while lowest was observed in 150 Gy (61.9%). Likewise, percent survival was highest

in 0.5% EMS (39.3%) and reduced thereafter with increasing concentration of EMS. Percent pollen fertility reduction ranged from 3.1% in 150 Gy to 28.5% in 900 Gy dose while in chemical mutagen, it ranged from 7.1% in 0.5% EMS to 31.5% in 1.5% EMS at both locations. Maximum injury as percent of control was observed in 900 Gy dose (59.6%) and 1.5% EMS (42.2%) in chemical mutagen. Higher doses of gamma radiations and EMS both caused considerable reduction in all biological parameters.

Yadav *et. al.* (2016) carried out investigation to determine the LD_{50} of EMS and effect of different dosages of EMS on seed germination of two Indian mustard varieties (*viz.,* RH-749 and NRCHB-101) and one of its important wild relative *sinapis alba*. Seeds of these varieties were treated with eight different concentrations of EMS (0.1%, 0.25%, 0.5%, 0.75%, 1.0%, 1.25% 1.5% and 2%). Results revealed the significant effects of EMS dosages and treatment periods on seed germination. The percent germination was reduced from 91, 98 and 99 to 2, 7 and 5 % with 1% of EMS for genotypes RH-749, NRCHB-101 and *S. alba*, respectively. At the same time, almost all the genotypes showed zero (0.00%) germination at the concentration of 1.25% and higher dose of EMS. The EMS doses (LD_{50}) at 0.42%, 0.73% and 0.3% for duration of 12 h were found to be optimum for Indian mustard varieties (RH-749, NRCDR-101) and *S. alba* respectively. The LD_{50} of EMS for *Brassica juncea* was higher than the *S. alba* and it also varied for two varieties of *B. juncea.* This information would be highly useful for initiating mutation breeding programme in rapeseed- mustard crops.

Aditya *et.al.*(2017) carried out investigation to study the effect of gamma rays on seed germination, plant survival and quantitative characters on two varieties of soybean (*Glycine max.(*L.) Merrill.) *viz.,* BSS-2 and RKS-18 in M_1 generation. The seeds of two varieties were exposed to gamma irradiation at doses of 50, 100, 150, 200 and 400 Gy. A difference was observed between the varieties BSS-2 and RKS-18 in the degree of tolerance to the mutagens. Germination and survival percentage in both the varieties was lower as compared to control. Reduction in germination percentage was associated with increase in dose of mutagen in both varieties BSS-2 and RKS-18. Germination percentage was higher in the variety BSS-2 as compared to RKS-18, while a higher survival percentage of the seedlings were recorded in RKS-18 which showed a higher genetic damage in the variety BSS-2. In variety BSS-2 at 100 Gy dose a higher survival percentage 94.6% was recorded as compared to lower dose

50 Gy while in RKS-18 the lower dose of 50 Gy (79.4) showed much higher survival percentage in comparison to higher dose of 100 and 150 Gy.

Kusmiyati *et. al.* (2017) carried out investigation to study the effect of different dose of gamma rays as induced mutagen on physiological, morphological and anatomical markers during seed germination and seedling growth of soybean. Seeds of soybean cultivars 'Dering-1' were irradiated with 11 doses of gamma rays (0, 5, 10, 20, 40, 80, 160, 320, 640, 1280 and 2560 Gy. Results showed that soybean seed exposed at high doses (640, 1280 and 2560 Gy) did not survive more than 20 days, the doses were then removed from anatomical evaluation. Higher doses of gamma rays significantly reduced germination percentage at the first count and final count, coefficient of germination velocity, germination rate index, germination index, seedling height and seedling root length and significantly increased mean germination time, first day of germination, last day of germination and time spread of germination. However, the effect of gamma rays were varies for density, width and length of stomata. The LD_{50} obtained based on survival percentage was 314.78 Gy. It can be concluded that very low and low doses of gamma rays (5-320 Gy) might be used to study the improvement of soybean diversity.

Singh *et. al.* (2018) carried out investigation to study the effect of mutagens on germination, plant survival, and pollen viability in sesame under the laboratory condition. The seeds of sesame variety ' Gujrat Til-1 were got treated with gamma rays doses of 15, 20, 25, 35, 45 and 60 kR and for combinations treatments of radiation and chemical, the seeds treated with 15 and 20 kR gamma rays were soaked in 0.1 and 0.2% aq. Solutions each of hydroxylamine and maleic hydrazide and in combinations of both. The result showed that the germination was reduced due to increase mutagenic dose in the treatments 20 kR + 0.2% HA, 20 kR + 0.2% MH, 0.2% HA, 0.2% MH, and 0.2% HA + 0.2% MH except 0.1% MH. Under laboratory condition seedling vigour index was found highest in the treatment 15 kR followed by 0.1% MH wet and dry control. Under field condition highest germination percentage was recorded under wet control followed by dry control and mutagenic treatments. The plant survival decreases with increase the dose of gamma rays, concentration of chemical mutagen and their combination. Highest pollen viability was observed in dry control followed by wet control and decrease with dose of gamma rays, chemical mutagen and their combination treatment.

Bhoite *et. al.* (2019) carried out investigation to study the mutagenic sensitivity of gamma rasys in M_1 generation of three varieties of soybean (*Glycine max* L.) *viz.,* Phule Agrani (KDS-344), Phule Sangam (KDS-726) and KS-103. The seeds of three varieties were exposed to three doses of gamma radiation 200, 300 and 400 Gy dose. The observation on mutagenic effects in M_1 generation revealed dose dependent reduction in seed germination and survival. Among the genotypes, KS-103 soybean was more sensitive for mutagenic treatments than Phule Agrani and Phule Sangam. Maximum mortality was observed in 400 Gy being lowest among the all doses of three genotypes. The LD_{50} dose between 300-400 Gy gammas were found to be ideal for mutagenic treatments irrespective of the genotype

Deshpande, A.S. and Malode, S.N. (2019) carried out investigation to study the effect of sodium azide and ethyl methane sulphonate on seed germination, Seedling height and pollen fertility in *Linum usitatissimum* var. Pkv NI 260. Seeds were treated with EMS concentrations of 0, 0.01, 0.02 and 0.03% (v/v) periods for 18 Hrs. and 12 Hrs. PSW +6Hrs. treatment. While for sodium azide treatments, seeds were treated with 0, 0.01, 0.02 and 0.03% solutions for 18 Hrs. dry seed treatment and 12 Hrs. PSW+ 6Hrs. treatments. It was found that 18 Hrs. Dry SA treatments found to have significant inhibitory effect on seed germination, seedling height, seedling survival and pollen fertility. Drastic reduction in all parameters was recorded in 18 Hrs. Dry seed and 18 Hrs. Presoaked + 6Hrs.sodium azide treatments over control. Whereas in case of EMS treatments except seedling survival all parameter found to have unusual effect. Seedling survival was found to be decreased with increase in dose of mutagen. 0.01% EMS and 0.02% EMS showed increase germination percentage over the control in both treatments; whereas seedling height of all EMS concentration were found to be increased over the control in both treatments except 0.2% EMS and 0.03% EMS dose in 18 Hrs. Presoaked + 6 Hrs. mutagen treatment. All treatment showed decreased pollen fertility over the control except 18 Hrs. Dry 0.01% EMS treatment and 0.01% SA, 0.02% EMS and 0.03%EMS concentrations of 18 Hrs. Presoaked + 6 Hrs. treatment. All treatments found to effective to induce mutation and generate phenotypic as well as genotypic variants.

Parthasarthi *et. al.* (2020[a]) carried out investigation to determine optimal lethal dose for gamma rays and EMS induced mutagenesis in TMV-7 and SVPR-1 Sesame (*Sesamum indicum* L.) varieties. The seeds of two sesame varieties were treated with

varying doses of gamma rays (250, 300, 350, 400 and 450 Gy) and Ethyl Methane Sulphonate (EMS) of different concentrations *viz.* 0.2, 0.4 and 0.6%. The seed germination percentage was greatly affected by mutagenic treatment of gamma rays and EMS which showed a negative dose dependent relationship in both the varieties. The expected LD_{50} values were calculated through probit analysis. The LD_{50} values for TMV7 and SVPR1 were fixed at 416.86 Gy and 389.04Gy for gamma rays and 0.490% and 0.349% for EMS. The germination percentage of SVPR1 was greatly reduced (17.80 and 20.55%) and the lethal dose to kill fifty percent of mutated population was lower (6.68% and 28.78%) than that of TMV7 in both gamma ray and EMS treatment. EMS treatment exhibited significant reduction in seed germination (62.16% and 66.67%) than gamma irradiation (56.76% and 54.55%) in TMV7 and SVPR1 respectively. The study concluded that both the mutagens are effective to produce significant variations in sesame which can be further explored for mutation mapping

Parthasarthi *et. al.* (2020[b]) carried out investigation to study the gamma ray sensitivity of two sesame (*Sesamum indicum* L.) varieties *viz.,* SVPR1 and TMV7 irradiated with five different doses from 250 Gy to 450 Gy at 50 Gy intervals. Germination percentage, root and shoot length, pollen fertility (%) decreased gradually and observed a dose dependent relationship with an increase in dosage of gamma rays. Survival percentage recorded irregular decreasing trend with upsurge in survival rate at certain doses. SVPR1 showed a pronounced maximum reduction in germination percentage (37.5%) than TMV7 (40.05) at 450 Gy, whereas survival percentage of TMV7 (20.02%) and SVPR1 (19.5%) was drastically reduced at 250 Gy itself. At a higher dose of 450 Gy, root (3.08) and shoot (3.03) length of seedlings of SVPR1 were greatly inhibited. Pollen fertility percentage showed a linear reduction irrespective of the genotypes, and maximum reduction was rear at 450 Gy in SVPR1 (62.76%) was recorded. LD_{50} values that showed 50% reduction in biological parameters differed between TMV7 and SVPR1. Based on all the biological parameters studied, the mutagen sensitivity of SVPR1 is higher than TMV7. The overall considerations on M_1 generation effects showed that SVPR1 were highly sensitive to gamma rays.

Sandhiya *et. al.* (2020) carried out investigation to determine optimal lethal dose of chemical mutagen for large scale seed treatment of white seeded sesame

(*Sesamum indicum* L.) varieties. The seeds of two white seeded sesame varieties VRI 3 and SVPR 1 were treated with seven different concentration *viz.,* 0.2%, 0.4%, 0.6%, 0.8%, 1%, 1.2% and 1.4% of chemical mutagen Ethyl methane sulphonate (EMS). Germination percentage and germination index were tested using two different germination methods. Seed germination percentage and germination index was decreased with increased doses of EMS in both the varieties. The higher concentration of EMS completely arrested the seed germination. The optimum dose of the mutagen should be tested to maintain the require plant population in the M_1 generation and increasing the effectiveness and efficiency of the mutagen. LD_{50} value was determined using probit analysis. For SVPR1 and VRI 3, LD 50 value was found to be 0.36% and 0.44% respectively. For fixing the lethal the lethal dose for the chemical mutagen, pro tray method of germination test was found to be reliable than germination paper method.

2.3.2 Mutagenic effects in M_2 generation

2.3.2.1 Frequency and spectrum of chlorophyll and viable mutations

The scoring of chlorophyll mutations in M_2 generation has been proved to be most dependable index for evaluating the genetic effects of mutagenic treatments (Gustafsson 1951; Gustafsson and Wettstein, 1958). Chlorophyll mutations have great significance in methodological investigation of mutation breeding. Frequency of chlorophyll mutations in M_2 generation following the treatment with mutagens serves as a guideline to determine the effectiveness of the treatments.

Rai, M. and Das, K. (1975) carried out investigation to study the gamma rays induced chlorophyll mutations in linseed. Dry seeds of *Linum usitatissimum* L. var. Hira, Mukta and Neelum were exposed to 10, 20, 30 and 40 kR of gamma rays. Albino and white tipped mutants were most frequent in Mukta. Fired and yellowish-white appeared with a low frequency in Hira and Neelum, respectively. Among different varieties, maximum percentage of mutated plants was recorded in Mukta (47.88%) followed by Neelum (38.03%) and Hira (14.08%). It is clear that different types of mutants were obtained in different varieties despite the fact that the varieties chosen had a very narrow genetic base. In all the mutants, days to flowering, days to maturity, number of non-bearing tillers and number of leaves per cm. on the main

tiller increased considerably while plant height, number of capsules per plant and number of seeds per capsule were reduced drastically.

Wakode *et. al.* (2000) carried out investigation to study the effects of gamma rays on frequency and spectrum of chlorophyll and morphological mutations in five cultivars of soybean *viz.,* JS-8021, JS-335, JS- 7105, Monetta and PKV-1. Seeds of these varieties were treated with 10, 20 and 30 kR doses of gamma rays. The highest frequency and spectrum of chlorophyll and morphological mutations was noticed in variety JS-8021 in which 20 different gene loci for various characters was mutated. However variety JS-7105 showed less radio sensitive response for different traits in which only 12 different loci were mutated. While JS-335, Monetta and PKV-1 showed moderate response to frequency and spectrum of various mutations. These varieties showed differential response to radio sensitivity, some useful mutations included, high yielding mutant in 20 kR, non-shattering mutant in 30 kR and vine type mutant in 10 kR in variety Monetta. Extra early type, erect and high branched type mutant were recorded with high frequency in 10 and 20 kR respectively in variety JS-8021. In general, 20 kR dose was found more effective in all the varieties.

Ahire *et. al.* (2005) carried out investigation to induce variability for quantitative traits in MACS 450 variety of soybean. Dry seeds of soybean variety MACS 450 were subjected to combination treatments of gamma rays and EMS (50 Gy + 0.2 % EMS, 50 Gy + 0.4% EMS, 100 Gy + 0.2% EMS and 100 Gy + 0.4% EMS). The combination treatments of 50 and 100 Gy gamma rays doses with 0.4 % EMS showed higher percentage of lethality as compared to their combinations with 0.2% EMS. Highest frequency of chlorophyll mutations was observed in combination treatment of 100 Gy gamma rays and 0.4% EMS. In M_2 generation, a large number of morphological mutants with altered plant height, flower colour, sterility, leaf shape, pod number, seed size and colour and also the mutants with early or late maturity were isolated. The results indicated that 100 Gy gamma rays treatment in combination with 0.4 % EMS was the most effective dose to induce a wide range of genetic variability in soybean.

Begum, T. and Dasgupta, T. (2005) studied the spectrum and frequency of chlorophyll mutations in M_1 and M_2 generations in three sesame cultivars; Rama, SI 1666 and IC 21706, respectively with a range of gamma rays (20 kR, 40 kR and 60

kR) and ethyl methane sulphonate (EMS) (0.5%, 1%, 1.5% and 2.0%) doses. Both gamma ray and EMS induced a wide range of chlorophyll mutations. The percentage of chlorophyll mutants was found to be greater in M_1 generation than in M_2 generation, irrespective of the genotype. Certain chlorophyll mutations such as 'variegated' and 'viridis' ones were found more frequently than others. A reasonably higher frequency of chlorophyll mutants was obtained with EMS than with gamma ray in both generations. In both M_1 and M_2 generations, frequency of chlorophyll mutants increased with an increase in gamma ray dosage and Ems concentration in a mutagen – treated population of SI 1666. Maximum chlorophyll mutants were observed in EMS treated population of SI 1666 in M_1 and M_2 generations.

Kotcha *et. al.* (2007) carried out investigation to induced genetic variability in M_2 population of safflower through gamma radiation. The seeds of spiny safflower lines KUsaf 5058 and 5059 were irradiated with gamma rays. The M_2 populations of KUsaf 5058 and 5059 lines gave spineless plants of 44.54 and 47.48 percent respectively. The mutant characteristics of smooth seed hull were found in six populations. They were brown striped hull, brown hull and white hull with pappus. The flower colour was mutated from orange- red to yellow –orange and yellow. In additional the promising plant type is branching with narrow angle, uniform branch and capitulum height. This plant type would be convenient for harvesting flower and seed.

Diouf *et. al.* (2010) carried out investigation to determine the spectrum and frequency of different mutants induced by gamma rays in three genetic backgrounds of sesame and to test the hypothesis that "closed capsule mutants are inducible with efficient mutagenesis and screening large populations." Seeds of the two cultivars "32-15" and "38-1-7"extensively grown in Senegal and a recently released Turkish cultivar, "Birkan", irradiated by two doses (300 and 400 Gy) of gamma rays. Both irradiated and untreated seeds were sown greenhouse to raise the M_1 populations. The M_2 population produced from the bulked M_1 plants. The selected potential mutants in the 2-set of M_2 populations were grown in the M_3 stage in bambey to confirm their true breeding behavior. Results indicate that the mutants confirmed shared a wide and unique spectrum of the mutants such as closed capsules, branching habit, flowering types, capsule number and shape. Also at least one closed capsule mutant could be induced from each of the three genetic backgrounds of sesame tested. Among the

cultivars tested "38-1-7" had the highest total mutant frequency (5.6 x 10^{-3}) followed by "Birkan" (4.2 x 10^{-3}). The lowest mutant frequency (2.7 x 10^{-3}) was recorded in "32-15". From these results, it appears that medium dose range of gamma rays was enough to induce viable and useful mutations in sesame.

Hanafiah *et. al.* (2010) carried out investigation to know the response of doses level by micro mutation on gamma ray irradiation to the growing and development of Argomulyo variety of soybean (*Glycine max* (L) Merr). The seeds were irradiated by gamma ray at 0 Gy, 50 Gy, 100 Gy, 150 Gy and 200Gy. Variations that were obtained of each character at generation M_1 and M_2 influences plants growth and development either through qualitative and quantitative that finally will influence plants production. The average highest genetic variation at M_2 generation of soybean was 200 Gy dose. Result of the research indicated that gamma- ray irradiation on 200 Gy dose effectively caused by plant genetic variation.

Tambe *et. al.* (2010) carried out investigation to induce chlorophyll mutations in soybean (*Glycine max* (L.) Merill) by employing EMS and gamma rays. The seeds of soybean cultivar MACS 450 were treated with different concentration of EMS (10, 20,30 and 40 mM) for 8 hrs and dry seeds were irradiated with different doses (100, 200, 300 and 400 Gy) of gamma rays. The M_2 population was screened seems from the first day of emergence of the seedlings up to the harvesting for chlorophyll mutations and viable mutations. Four different types of chlorophyll mutations *viz.,* albino, viridis, chlorina and xantha were observed in the M_2 progeny of soybean. The frequency of chlorophyll mutations increased with an increase in the concentration of the mutagens except at 20 mM EMS concentrations. The frequency of chlorophyll mutations 2.12 to 8.12 % in EMS and 4.04 to 7.78% in gamma rays. The maximum frequency of chlorophyll mutations (8.12%) was observed at 40 mM EMS concentration and it was maximum (7.78%) at 400 Gy dose of gamma rays. The overall spectrum of induced chlorophyll mutations as observed in soybean was in the following order. Chlorina (17.61%)> Viridis (15.67%)> Xantha (11.07%)> albino (0.56%).

Srivastava, P. and Kumar, G. (2011) carried out investigation to study the radiation induced effects on some morphological and biochemical indices of safflower. Pure and dry seeds of safflower (*Carthamus tinctorius* L. var A1) were

irradiated with 150 Gy, 300 Gy and 450 Gy of gamma rays from Co^{60} gamma source. Seeds treated with gamma irradiation showed significant reduction in plant height, head diameter, number of capitulum per plant, number of seeds per capitulum, seed yield per plant and 1000 seed weight as compared to plants produced from non-irradiated seeds in M_2 generation. Such plants on further biochemical analysis were found to have reduced oil, protein, chorophyll (a+b) and carotenoid content. However, irradiation at the lowest dose (150 Gy) effectively influences at improving the various morphological and biochemical aspects in safflower.

Ahmed *et. al.* (2012) carried out investigation for induction of mutations in safflower (*Carthamus tinctorius* L.). The seeds of three safflower lines; line3, line 6 and line 79 were irradiated with gamma ray doses, 100, 150 and 200 Gy and treated with sodium azide solution at concentration 0.001, 0.002 and 0.003 m at pH 3. The selected variants included apparent morphological characters, especially earliness and spineless change, as well as the change in seed yield, yield attribute characters and seed shape. These variants screen to isolate 5 at M_1 and 428 at M_2 generations. These mutants characterized with, spineless leaf, plant height (dwarf and semi dwarf), flowering date (earliness, late ness), seed shape and seed weight. The results confirmed that promising mutants derived line 3 posses high oil content, spineless and earliness, *i.e.*, number 4 and number 2 (tip spine) as well as high seed yield.

Cvejic *et. al.* (2015) carried out investigation to provide new genetic variability that can be exploited for improvement of important agronomic traits in sunflower production. The seeds of eight sunflower inbred lines were irradiated with gamma rays and fast neutrons and treated in an EMS solution. The manifestation of mutation was mostly expressed in the M_2 and M_3 generations. Seven mutants were selected: 1 early flowering (L3ME), 2 short (L2MS and R1MS) and 1 high stature (R3MT), 2 with higher oil content (L1MO, R2MO) and 1 with branching (L4MBr). The stable progenies were evaluated in micro- plot tests in M_6 and M_7 generations for seed yield and other agronomic traits in comparison with their respective original lines.

Kumar, R. and Shunmugavalli, N. (2015) carried out investigation to induce genetic variability in sesame through mutation. Seeds were subjected to different treatment levels of gamma rays and ethyl methane sulphonate (EMS). The treated

plants were self- fertilized for generations to observe different morphological characters in M_2 generation. Several unique and interesting mutants were isolated. These independent mutants had different phenotypes from the control. Highest mutation frequencies for flower colour and seed characteristics were found to be induced by 400 Gy gamma rays and by 1.0 percent EMS in VRI 2. The most distinct mutants isolated were flower colour variants along with altered size, shape and coat colour of seeds.

Ravichadran, V. and Jayakumar, S. (2015) carried out investigation to study the mutagenic effect of different dose/ concentrations of gamma rays and EMS on sesame (*Sesamum indicum* L.) varieties VRI-1. Seeds of sesame variety VRI-1 were treated with 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 kR doses of gamma rays and 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0 mM solution of EMS. In the present study a significant positive shift in quantitative mean performance was observed in days to first flower, plant height, number of branches per plant, number of capsule per plant, number of seeds per capsule and seed yield per plant were also due to effect of gamma rays and EMS. Among the mutagens, 40 kR of gamma rays and 1.5mM of EMS provided remarkable increase in above traits than control in M_2 generation. The significant reduction of days to first flowering at 40 kR (38 days) of gamma rays and 1.5 mM of EMS (39 days) observed early maturity plants. The treated population was higher than the control in all the yield traits, namely, plant height, number of branches per plant, number of capsule per plant, number of seeds per capsule and seed yield per plant at 40 kR of gamma rays and 1.5 mM of EMS respectively. The highest number of mean values was noted in M_3 generation than in M_2 generation of gamma rays and EMS treated plants when compared to control.

Hussain *et. al*. (2017) carried out investigation to study the effect of different doses (0.2%, 0.4%, 0.6% and 0.8%) of sodium azide (SA) on M_2 generation of *Brassica napus* (variety Dunkled) on some qualitative, quantitative and biochemical parameters. The result showed that days to germination, days to flowering and days to siliqua maturation were delayed (9.4, 98 and 153 days respectively) in higher treatment as compared to control (5.4, 96 and 147 days respectively). Higher concentration of SA (0.8%) decreased germination percentage (88.56%), plant height (97.95 cm), stem diameter (3.49 cm), number of branches/ plant (3.49), number of leaves/ plant (10), number of siliqua / plant (64.68), number of seed/ siliqua (20.09)

and 1000 seeds weight (3.91 g) as compared to control. An increase was noticed for siliqua length (5.42 cm) in higher concentration of SA (0.8%) as compared to control (5.24 cm). Proximate analysis showed a significant decrease in oil, oleic acid and glucosinolates contents percentage (42.6%, 54.9%, and 58.5 umol/g respectively) in higher concentration of SA (0.8%) as compared to control (44.7%, 58.1% and 71.3 umol/g respectively) while a significant increase was noticed in proteins, moisture, linoleic acid and erucic acid percentage (28.4%, 5.9%, 9% and 37.3% respectively) in higher concentration of SA (0.8%) as compared to control (26.8%, 5.5%, 8.4% and 35.2% respectively).

Lande *et. al.* (2018) carried out investigation to study the variability in M_2 generation of soybean for the qualitative and quantitative characters. Seeds of Indian soybean variety TAMS-38 were treated with 200, 250 and 300 Gy doses of gamma rays. In M_2 generation, days to flowering and days to maturity increased significantly in all the treatments. Plant height, number of branches per plant and length of primary root reduced significantly in all the treatments. Number of pods per plant and grain yield /plant significantly increased in all the treatments and 100 seed weight significantly decreased in all the treatments as compared to control. Visible macro mutants like chlorophyll mutants, early flowering, late flowering, early maturing, late maturing, dwarf, tall, increased root length, increased 100 seed weight, small leaf, wrinkled leaf, viney type mutant, sterile, high yielding, more pods, more branched mutants were identified and isolated in M_2 generation. The economical and morphological mutants were isolated from the variety of TAMS-38. High yielding mutant with 12 g to 17 g yield as against 4.40 g in control were identified from this variety. Early maturing mutant matured 11.2 to 20.2 days earlier than control were isolated from this variety. These mutants need to be evaluated for their breeding behavior in further generation and their utilization in improvement of soybean.

Singh, L. and Singh, P.P. (2018) carried out investigation to study the response of mutagens on spectrum and frequency of chlorophyll and other viable mutations in sesame. The seeds of sesame variety Gujarat Til-1 were treated with gamma rays doses of 15, 20, 25, 30, 45 and 60 kR and for combinations treatments of radiation and chemical, the seeds treated with 15 and 20 kR gamma rays were soaked in 0.1 and 0.2% aq. solutions each of hydroxylamine and maleic hydrazide and in combination of both for 6 hrs. In M_2 generation, the highest chlorophyll mutations

were recorded in 25 kR followed by 0.2% HA, 0.2% HA + 0.2% MH and 0.2% MH. The leathery leaves had high frequency followed by xantha, albino and chimera. The stem types mutations were recorded highest in 0.1% HA + 0.1% MH followed by 0.2% HA + 0.2% MH, 0.2% MH, 20kR and 0.1% HA. The lowest frequency was recorded in 25 kR. Bushy stem were observed highest and lax branched as lowest. The leaf type's mutants have highest frequency in 20 kR followed by 15 kR + 0.1% HA, 30 kR and 60 kR. Narrow leaf mutants were found highest followed by thick leaves, elongated leaves bunchy and long petiole. The highest frequency of flower and capsule type mutants were recorded in 30 kR followed by 60 kR, 20 kR+ 0.1% HA, 0.1% HA and 45 kR. The mutations rate was maximum in 60 kR followed by 20 kR + 0.1% HA, 30kR and 20kR (reduced with dose of mutagens) 0.1% HA + 0.1% MH was observed as most effective mutagens followed by 0.1% HA, 0.2% MH and 0.1% MH. Moreover, 0.1% HA + 0.1% MH also found most efficient and the efficiency of 0.2% HA + 0.2% MH, 60 kR, 15kR + 0.1% MH and 20kR + 0.1% HA was observed in decreasing order.

Tabti *et. al.* (2018) carried out investigation to identify desirable mutants in quantitative traits of lentil at early (M_2) generation. Seeds of lentil variety Idlib-3 were treated with eight doses (45, 60, 75, 90, 100, 200, 300 and 400 Gy) of gamma rays. Germination percentage was recorded to determine LD_{50} by probit analysis. The LD_{50} of gamma rays was calculated as 104.34 Gy. In M_2 generation, different types of chlorophyll mutants such as xantha, viridis and chlorine were observed in the present study. The frequency of chlorophyll mutation was found to be 2.76% (116 mutants). The viable mutants observed in the present study consisted of forty eight stunted growth mutants (1.14%), fifteen dwarf mutants (0.35%), three mutants with four pods per peduncle (0.07%) and three mutants with abnormal leaves (0.07%). Dennett's test revealed a total of 13 superior families over parent for various quantitative traits. The results of Best Linear Unbiased Predictors (BLUPs) confirmed the recurrence and superiority of same seven families, identified in Dennett's test for high seed yield.

Channaoui *et. al*. (2019) carried out investigation to evaluate the novel induced variability observed for some important quantitative traits and to select mutants with modified and interesting characteristics. Seeds of *Brassica napus* L. (variety 'INRA-CZH2') were treated with EMS in 1, 1.2, 1.4 and 1.6% doses for 6, 7 and 14 hours. A considerable variability was observed, and EMS treatment had

significant effect on all the traits studied. Compared to control plants, mutant coming from seeds treated with low EMS doses for moderate time, namely 1% EMS (7 hours), flowered and matured earlier and had higher number of pods per plant in both environments. The Promising mutant exhibiting its stability throughout M_1 and M_2 generations in both the environments will be valuable and useful for fast development of adopted and agronomically superior rapeseed cultivar.

Olorunmaiye *et. al.* (2019) carried out investigation to assess the mutagenic effect of EMS concentrations on growth, yield and nutrient composition of *Arachis hypogea* (Samnut 24 vr.). Seeds treated with varying concentrations (0.00, 0.25, 0.50, 0.75, 1.00 and 1.25% v/v) of EMS for 12 hours. Alkylating effect of the EMS was studied on growth and yield parameters while nutritional quality was determined by proximate analysis at M_1 and M_2 generations. Concentrations of 0.75% and 1.00% increased growth, biological yield and seed related parameters significantly (at $P< 0.05$). Maturity time was significantly shortened by EMS application across the generations. Higher percentage seed crude fat and protein were induced by the treatments with optimal performance at 0.75- 1.00% concentrations. Mineral content indicated by the percentage ash was marginally increased. The trend in response to the EMS was similar across the generations, however, decreased vigour, reduced growth, less nut and biological yields were observed at M_2. In most traits evaluated, performance of 0.00, 0.25 and 0.50% treatments were similar, 0.75- 1.00% treatments were optimal while 1.25% v/v of EMS was detrimental.

2.4 Mutagenic effectiveness and efficiency

Sheeba *et. al.* (2003) studied the effectiveness and efficiency of gamma rays and EMS in relation to chlorophyll mutations in two varieties of sesame (*Sesamum indicum* L.) *viz.,* SVPR 1 and Co 1, in M_2 generation. Four types of chlorophyll mutants namely, Xantha, Chlorina, Striata and Xantha viridis were observed. Xantha viridis was observed in maximum proportion followed by Chlorina and Striata in both the varieties. Gamma rays were found to be more efficient and effective than EMS in both the varieties. The effectiveness and efficiency of both the mutagens was higher in SVPR 1 than in Co 1.

Kavithamani *et. al.* (2008) carried out investigation to study the mutagenic effectiveness and efficiency of gamma rays and EMS in soybean (*Glycine max* L.)

Merrill). Seeds of soybean cultivars Himso 1563 and TS 82 were exposed to gamma radiation (10, 20, 30, 40 or 50 kR) and EMS (5, 10, 15, 20 or 25 nM). Germination, survival and fertility were recorded for the M_1 and M_2 generations. The M_1 generation seeds and the control progenies were screened for lethal chlorophyll mutations during the first 5 weeks after germination. Pollen fertility decreased with the increased concentration of the mutagens. The lowest level of pollen fertility was obtained with 50 kR gamma radiation in TS82 (33.86%). Seed fertility also decreased with the increase in mutagen concentration. The lowest level of seed fertility was obtained with 25 mM EMS in Himso 1563 (43.60%). The highest level of mutagenic effectiveness was recorded for 50 kR treatment in Himso 1563 (15.45%) and TS 82 (14.27%). Compared to gamma radiation, EMS was less effective. The efficiency of induction of chlorophyll mutation ranged from 5.05 to 6.66% in Himso 1563, and from 6.00 to 10.78% in TS 82 for the gamma radiation treated population. For EMS, the corresponding values ranged from 2.76 to 3.32% in Himso 1563, and from 3.11 to 4.36% in TS 82. In both mutagens, sterility, lethality and injury levels increased with the increase in mutagen concentration.

Pavadai *et. al.* (2009) carried out investigation to study the mutagenic effectiveness and efficiency of physical and chemical mutagens *viz.,* gamma rays, EMS, diethyl sulphate and colchicine in the CO-1 variety of soybean (*Glycine max* (L.) Merr). The seeds were exposed to 10, 20, 30, 40, 50 and 60 kR doses of gamma rays and also treated with EMS (0.1, 0.2, 0.3, 0.4, 0.5 and 0.6%), diethyl sulphate and Colchicine (0.01, 0.02, 0.03, 0.04, 0.05 and 0.06%). The chlorophyll mutant's *viz.,* Albino, Viriscence and Xantha and viable mutant's *viz.,* plant type, days to maturity, early flowering, seed colour, seed shape, pod shape and male sterility etc. were recorded with various frequencies. On M_2 seedling basis, maximum mutation frequency was observed at 10 kR (3.51) of gamma rays. Whereas in chemical mutagens maximum mutation frequency was recorded at 0.05% (3.41) followed by 0.14% of EMS (3.23) and 0.04% of DES (2.67) respectively. Gamma rays were found to be more effective than other mutagens in producing chlorophyll and viable mutant. Maximum effectiveness was observed at 10kR gamma rays (35.1) followed by 0.1% of EMS (27.0), 0.001% of DES (27.3) and 0.01% of COH (19.5). The maximum efficiency of chlorophyll and viable mutant on M_2 generation was recorded at 10 kR of gamma rays (21.19 and 23.24) followed by 0.1 % EMS (12.48 and 15.89), 0.01%

DES (11.16 and 11.95) and 0.03 and 0.04% COH (6.10 and 9.79) respectively. The highest protein content was measured at 0.5% EMS and 50kR of gamma rays than the other mutagenic treatments.

Khan, M.H. and Tyagi, S.D. (2010) studied mutagenic effectiveness and efficiency of gamma rays, EMS and combined treatments in terms of M_2 (progenies) lethality and chlorophyll mutations in two cultivars of soybean (Pusa-16 and PK-1042). Dry seeds (9-12% moisture) of two cultivars Pusa-16 and PK-1042 of soybean were treated with EMS (0.1, 0.2 and 0.3% concentration) and Gamma rays (15, 30 and 45 kR) and irradiated seeds (Gamma ray) were subjected to 0.2% EMS for eight hours. In general the frequencies of chlorophyll mutations were high in gamma rays and combined treatments. Four types of mutant's *viz.,* albino, xantha, chlorina and viridis were observed in the study. Gamma rays were found to be more effective to induce chlorophyll mutations in both cultivars. Pk-1042 cultivar exhibited higher mutagenic efficiency as compared to pusa-16 in EMS and gamma rays treatment.

Kumar *et. al.* (2010) carried out investigation to study the effect of single treatment with gamma rays, sodium azide and their combination on seed germination, seedling survival, pollen fertility and seed set in sunflower *(Helianthus annus* L.) in the varieties of USH-430 and SHSF-333 in M_2 generation. The seeds of two varieties were exposed to 2, 4, 6, 8 and 10kR of gamma rays , presoaked seeds were subjected to treatment with sodium azide at different concentration of 2, 4, 6, 8 and 10 mM and their combination at (2 kR + 2mM, 4kR+ 4mM, 6 kR + 6mM, 8kR+8mM and 10kR+ 10mM). 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 6 kR, 4 mM and 6 kR + 6mM, 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 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. The linear correlation co-efficient was positive in case of gamma rays and sodium azide separated, whereas in combined treatment, negative correlation was observed.

Banakar *et. al.* (2013) carried out investigation to study mutagenic effectiveness and efficiency of gamma rays in the four inbreds of sunflower. Gamma rays produced high frequency as well as a wide spectrum in mutation. The frequency of mutation was high at higher dose of mutagen. The mutagenic effectiveness and efficiency was calculated based on biological damage. In M_1 generation based on seed lethality and pollen sterility and M_2 generation was carefully screened for various chlorophyll and viable mutation. Mutagenic effectiveness and efficiency reduced with the increase in dose or concentration. In present investigation higher dose of 20 kR was very effective and efficient in induction of mutation in all the genotypes studied except CMS-104B where 15 kR dose was effective and efficient.

Ramadoss *et. al.* (2014) carried out investigation to study the mutagenic effectiveness and efficiency of gamma rays in the genotypes of Sesame (*Sesamum indicum* L.) *viz.,* TTVS 51 and TTVS 19. Well filled seeds of both the genotypes were irradiated with gamma rays at 250Gy, 359Gy, 450Gy, 550Gy and 650Gy. The dosage of gamma rays for mutagenic treatments was fixed based on the LD_{50} values available in the literature in relation to sesame and allied oilseed crops. The mutagenic effectiveness and efficiency is high at 250Gy in both genotypes. The frequency of viable mutants was high in 450GY on M_2 seedling basis. Mutants with wider spectrum of variation were found at 250Gy and 350Gy of gamma rays. Mutagenic effectiveness and efficiency increased with the decreased in dose or concentration in sesame. Compared to TTVS19, TTVS 51 produced more economically viable mutations.

Anbarasan *et. al.* (2015) carried out investigation to study the mutagenic effectiveness and efficiency of gamma rays, EMS and combined treatment in Sesame (*Sesamum indicum* L.). The seeds of sesame var. TMV 3 were treated with different doses of gamma rays such as 30, 40, 50, 60 and 70 kR; EMS (0.6, 0.8, 1.0, 1.2 and 1.4 mM) and the combined treatments of both EMS and gamma rays like 30 kR + 0.6mM, 40 kR + 0.8 mM, 50kR + 1.0 mM, 60 kR + 1.2 mM and 70 kR + 1.4 mM. The effects of mutagens were analyzed in M_1 and M_2 generations. In M_1 generations, the seed germination percentage on 15^{th} day, seedling survival (lethality) on 30^{th} day and seedling height (injury) on 30^{th} day was recorded. In M_2 generation, the chlorophyll mutants like chlorina, xantha, viridis and albino were observed from 10 to 15 days and the mutation frequency was calculated based on their occurrence. The

result showed a gradual reduction in germination, survivability and seedling height in M_1 generation. The maximum mutation frequency was observed at 50 kR + 1.0 mM of combined treatment (1.99), 1.0 mM of EMS (1.81) and 50 kR of gamma rays (1.65). The highest mutation effectiveness and efficiency was observed at lower doses/ concentrations of mutagens, *i.e.,* 30kR + 0.6 mM of combined treatment (0.39), 0.6 mM of EMS (0.37) and 30 kR of gamma rays (0.34).The mutation effectiveness and efficiency were gradually decreased with increasing doses/ concentration of mutagens used.

Kumar *et. al*. (2015) carried out investigation to study mutagenic effectiveness and efficiency of gamma rays and EMS in the genotypes of sesame *viz.,* TMV 4, TMV 7, VRI 2, Thilak and TNY Local. The dosage of gamma rays and EMS for mutagenic treatments was fixed based on the LD_{50} values available in the literature in relation to sesame and allied oilseed crops. The mutagenic effectiveness and efficiency was high at 300 Gy and 0.7% EMS in all genotypes. The frequency of viable mutants was high in 400 Gy on M_2 seedling basis. Mutants with wider spectrum of variation were found at 300 Gy, 350 Gy of gamma rays and 0.7%, 1% of EMS. Mutagenic effectiveness and efficiency increased with the decrease in dose or concentration of the mutagens in sesame. Compared to others genotypes TMV 4 and VRI 2 produced more economically viable mutations.

Narmadha *et. al.* (2015) carried out investigation to study the mutagenic effectiveness and efficiency of EMS and gamma rays in two varieties of soybean (Co $(soy)^3$ and JS-335 in terms of M_2 progenies; lethality and injury on the basis of chlorophyll and viable mutation frequency. Both mutagens produced high frequency as well as wide spectrum of mutations. The frequency of mutation was high at higher concentration/ dose of mutagen. EMS was the most effective and efficient mutagen compared to gamma rays. Higher the dose, higher the mutagenic effectiveness and lower the efficiency. JS 335 was the most sensitive variety to both mutagens.

Rampure *et. al.* (2017) carried out investigation to isolate mutants having promising traits for safflower *(Carthamus tinctorius* L.) improvement. In their study, dry, healthy and uniform seeds of var. AKS-207 and Bhima were exposed to 400, 500 and 600 Gy dose of gamma rays and also treated with chemical mutagen such as EMS at 0.2%, 0.3% and 0.4% concentration for var. AKS-207 and 0.1%, 0.2% and 0.3%

concentration for var. bhima and 0.005%, 0.010% and 0.015% concentration of sodium azide for both varieties. In M_2 generation several putative mutants of var. AKS-207 and Bhima were isolated. The effectiveness of EMS was more in var. Bhima as compared to var. AKS-207. Similarly, the effectiveness of EMS decreased due to pre-soaking in var. AKS-207; it was increased in var. Bhīma due to presoaking. In constract to EMS the effectiveness of SA was more in var. AKS-207 than Var. Bhima. Although, presoaking decreased the effectiveness of SA in both the varieties, but decrease was more in var. Bhima as compared to var. AKS-207. The effectiveness of gamma rays was comparatively more in var. Aks-207 than var. Bhima. The efficiency of EMS was comparatively lower in var. AKS-207 than var. Bhima. Moreover, the efficiency of EMS decreased due to presoaking in var. AKS-207, whereas in var. Bhima the presoaking enhanced the efficiency of EMS. In contrast to this, the efficiency of SA was best demonstrated in var. AKS-207 than var. Bhima. Similarly, the gamma ray was found to be more efficient in var. AKS-207 than var. Bhima.

Julia *et. al.* (2018) carried out investigation to study mutagenic effectiveness and efficiency of gamma rays in three genotypes of Indian mustard *viz.,* CAULC-1 (Potsangbamyella), CAULC-2 (Kakchingyella) and PM-25 (Pusa mustard-25). Seeds of all three genotypes were irradiated with 800 Gy, 900 Gy, 1000 Gy, 1100 Gy and 1200 Gy doses of gamma rays. From the present study, it was suggested that the LD_{50} ranging from 1000 Gy (pollen sterility) to 1200 Gy or above (Survival reduction) may be used for gamma ray treatment in Indian mustard. They observed five types of chlorophyll mutants in the order of Albino>Chlorina= Viridis>Xantha = Alboviridis. They recorded highest identifiable mutation frequency from 1000 Gy gamma ray treatment which was followed by 1200 Gy gamma ray treatment. Mutagenic effectiveness was found to be highest at 1000 Gy gamma ray treatment. The mutagenic efficiency, in terms of lethality, was found to be the highest at 800 Gy. However, mutagenic efficiency for both injury and sterility was found to be highest at 1000 Gy gamma ray treatment.

Saha, S. and Paul, A. (2018) carried out investigation to evaluate the mutagenic effectiveness and efficiency of gamma rays on different biological parameters in two genotypes of Sesame *i.e.* Rama and Tillotoma. Seeds of these genotypes were treated with five doses of gamma rays (250 Gy, 300 Gy, 400 Gy and

450 Gy). The effectiveness and efficiency of the mutagen used was assessed with regard to biological damage *viz.,* pollen sterility (%) and plant lethality (%) in the M_1 generation. As compared to control, maximum pollen sterility was recorded in Rama (23.35%) and in Tilotoma (28.18%) at 450 Gy, while minimum pollen sterility was recorded in Rama (8.52%) and in Tillotoma (10.0%) at lowest dose 250 Gy and maximum plant reduction was observed at 450 Gy in Rama (61.60%) and in Tillotoma (80.15%), while minimum reduction was recorded at dose 250 Gy in Rama (29.85%) and in Tillotoma (47.74%). Chlorophyll mutation was recorded in M_2 seedling basis. Among the treatments, the 400 Gy (in Rama 52%, in Tillotoma 55.24%) and 450 Gy (in Rama 66.10%, in Tillotoma 45.95%) gamma rays produced high frequency of chlorina followed by xanthan and albino chlorophyll mutants. All the studied parameters, were decreased with increased dose of gamma rays, whereas, mutagenic effectiveness and efficiency increased in lower doses. Maximum mutagenic efficiency was recorded in 300 Gy dose in Rama (12.57) and in Tillotoma (9.28) followed by 250Gy dose in Rama (11.33) and in Tillotoma (8.67). Maximum effectiveness was also observed in 300 Gy in Rama (0.42) and in Tillotoma (0.41). The findings concluded that lower doses were more effective and efficient among the used doses and can be recommended for exploiting variability with isolating promising mutants.

Manjunath *et. al.* (2020) conducted experiment to retrieve some useful chlorophyll mutants in two groundnut varieties of TMV (Gn) 13 and TMV 7. The seeds of both the varieties were irradiated with gamma rays (150 Gy, 200 Gy, 250 Gy, 300 Gy and 350 Gy) and EMS solution (10 mM, 20 mM, 30 mM, 40 mM and 50 mM). The mutagenic efficiency and effectiveness were calculated by using the chlorophyll mutants. In M_1 generation, the seedling height was decreased with an increased rate of doses/ concentration while lethality and pollen sterility were increased with an increased rate of doses/concentration in both the varieties on both the treatments. The chlorophyll mutants were observed in M_2 generation. The four different chlorophyll mutants were observed such as albino, chlorina, xantha and striata at different crop stages of crop growth. On perusal of data, it was inferred that chlorina occurred at large followed by xantha and albino. Mutagenic effectiveness were significantly higher in gamma rays for TMV (Gn) 13 and TMV 7 (4.25 and 2.64) than the EMS which registered as 3.69 and 2.19 respectively. The mutagenic

efficiency was increased for injury and decreased for lethality and pollen sterility with an increased rate of doses/ concentration.

2.5 Mutagenic effects on oil and Fatty acid composition

Green, A.G. and Marshall, D.R. (1984) treated seeds of linseed cv. Glenelg with either gamma rays (30, 45, 60, 75 and 90 kR) or EMS (either 0.3% or 0.4%) in an attempt to induce mutations with a lower level of linolenic acid in linseed oil. They identified two mutant lines *viz.* M1589 and M1722 in which linolenic acid constituted approximately 29% of the total fatty acid content compared with 43% in seed oil from untreated Glenelg plants. The reduced level of linolenic acid in the mutants is accompanied by an increase in the level of linoleic acid to 30% compared with 18% in Glenelg, but there was no change in the proportions of other fatty acids. These proportions of linolenic acid and linolenic acid are respectively the highest and lowest yet reported in stable genotypes of linseed. The strong inverse relationship between these two fatty acids in these genotypes suggests that linolenic acid is synthesized by desaturation of linolenic acid and indicates that it may be possible to breed an edible linseed oil having both low levels of linolenic acid and high levels of linolenic acid.

Rowland, G.G. and Bhatty, R.S. (1990) treated seeds of the flax cultivar McGregor with the chemical mutagen ethyl methane sulphonate (0.4% EMS) with the objective of producing mutations that reduced the α- linolenic acid content of the seed. They examined the seeds of 2430 M_1 plants by the thiobarbituric test (TBA test), 53 were classified as having reduced linolenic acid levels. Utilizing half- seed analysis by gas chromatography, three lines taken through to the M_4 generation had reduced linolenic acid levels, but all three appeared to have different mutations. Mutant E67 has a palmitic acid level of 28.4%, three times the level found in McGregor. Mutant E1747 had a high linoleic content of 52.2% and mutant E1929 had increased oleic and linoleic levels to twice that of McGregor.

Khadeer and Anwar (1991) carried out investigation to isolate seed mutants for oil and fatty acid composition in safflower (*Carthamus tinctorius* L.). The seeds of two safflower varieties *viz.,* HUS-304 and Bhima were treated with varying dose per concentration of gamma rays (15kR, 30 kR, 45 kR and 60 kR), EMS (0.2%, 0.4% and 0.6%), Sodium Azide (0.002 M, 0.003M and 0.004 M) and N-methyl N-Nitrosourea (0.01%, 0.02% and 0.03%) both single and in combinations. Data were

collected on seven agronomic characters and yield related traits in M_2-M_4 generation. They reported that the striped seed (31.2%) and bold seed (31.3%) mutants induced by 15 kR and EMS+SA had marginal increase in their oil contents over its parent HUS-304 (30%). In Bhima , the striped seed (27%), medium size seeds (30%), conical seeds (27.2%) , bold seeds (28.5%) and bold seeds (27.6%) mutants induced by EMS + SA , 0.003 aq. SA, 0.6% EMS, 0.02% NMU and 0.003 aq. SA respectively had marginal increase in their oil content over its parent Bhima (25%). The linoleic acid in HUS-304 and Bhima was 60.8% and 61.2% respectively. They observed that the increase in linoleic acid in HUS-304 mutants ranged from 1.2% in conical seeds induced by SA+ EMS to 6.0% in the striped seeds induced by 15 kR treatment. While in Bhima and its mutants, the linoleic acid enhancement varied from 2.8 in conical seeds induced by 0.6% EMS to 4.8% in conical seeds induced by 0.003M SA. They observed that the bold seeds mutants recovered from 15 kR, 0.4% EMS and SA+ EMS treatments in HUS-304 showed an improvement in oleic acid over its parents. The increase in oleic acid content ranged from 6% in bold seeds (15kR) to 13% in bold seeds recovered from the sequential treatment (SA+EMS). In Bhima, majority of the treatments induced an increase in oleic acid which ranged from 2.2% in bold seeds (gamma rays + NMU) to 13% in striped seeds (EMS+ SA).They also observed that the bold seeds mutant obtained from SA+ EMS in HUS-304 had 13% steric acid *i.e.* an improvement of 9% over its parent (4.6%). Similarly, the palmatic acid was maximum in bold seed obtained from 0.4% EMS in HUS-304 and 0.02% NMU in Bhima.

Rowland, G.G. (1991) treated seeds of the flax cultivar McGregor with the chemical mutagen ethyl methane sulphonate (0.4% EMS) and the resulting M_1, M_2, M_3 and M_4 progeny were screened for linoleic acid mutants, using the half seed technique. He found two low- linolenic acid (2%) mutant lines *viz.,* E1747-9-1-5 and E1747-9-7-5 in the M_4 progeny. The stability of these two lines was confirmed in the M_5.The low linolenic character is controlled by recessive alleles at two independent loci, apparently the result of a rare double mutation.

Auld *et. al.* (1992) carried out investigation to identify rapeseed mutants with low levels of polyunsaturated fatty acids and increased levels of oleic acid could increase both the utility and value of the oil. Imbibed seed of the spring rapeseed (*B. rapa*) cultivar ‘R-500’ and ‘Cascade’ cultivar of rapeseed (*B. napus*) were treated

with 5% v/v of EMS. The M_2 generations of these populations were screened to identify mutants with low levels of polyunsaturated fatty acids (PUFA) using a modified thiobarbituric acid procedure. Putative mutants and their derived progeny were increased in the greenhouse and the seed analyzed for fatty acid composition using gas chromatography. They identified most promising mutant from 4734 M_2 seeds of B. *rapa*, was M-30, which had 2.1% linoleic acid and 3.0% linolenic acid, vs. 11.9% linoleic and 8.6% linolenic acid in the original cultivar. In F_3 generation, M-30 mutant was crossed with 'Tobin' to derive F_4 lines having <6% total PUFA and oleic acid concentrations > 87%. In *B. napus,* they identified most promising mutant from 39504 M_2 seeds was X-82, which had 6.6% PUFA, vs. 27.4% PUFA in Cascade. Also, several M_3 and M_4 lines derived from X-82 had < 6% total PUFA and > 88% oleic acid.

Osorio *et. al.* (1995) carried out investigation to induce variability for increased levels of saturated fatty acids by using mutagenesis. For this study, mature seeds of two sunflower lines BSD-2-691 and RDF-1-532 were exposed to chemical mutagens such as sodium azide (1, 2 and 4 mM) or EMS (30, 50 and 70 mM) and physical mutagen such as x rays (120, 140 and 160Gy). They isolated four sunflower mutants with altered seed fatty acid compositions by screening single M_2 and M_3 seeds obtained from M_1 plants. The mutant lines included CAS-5, which has an oil with fivefold increase (252 g/kg) in palmitic acid (16:0) and the appearance of palmitoleic acid (16:1; 37g/kg); and CAS-3, CAS-4 and CAS-8, which have from two to six times (99-260g/kg) the stearic acid content normally observed in the oil of cultivated sunflower. The dramatic increase in levels of either palmitic or stearic acids were at the expence of oleic and linoleic acids. The relative proportion of oleic to linoleic varied with the mutants. All showed variation in fatty acid composition among the seeds of the original plant, which indicated that, the fatty acid changes were controlled by the genotype of the embryo. The bimodal distribution in fatty acid composition of CAS-3 and CAS-5 seeds suggested that major recessive genes are involved in the control of these characters.

Fernandez- Martinez *et. al.* (1997) treated dry seeds of high oleic sunflower line BSD-2-423, which had normal palmitic (~3%) and high oleic (~88%) acid levels with X- rays at dose of 120, 140 and 160 Gy. They obtained a new sunflower mutant, CAS-12, which has both high palmitic (~30%) and high oleic acid contents, also a

substantial amount of palmitoleic acid (~7%). The increase of palmitic and palmitoleic acids occurred at the expense of the oleic acid content, which decreased to around 55% in respect to the original line. Linoleic acid content is always under 5%. Palmitic and palmitoleic acid levels were similar to those of the high palmitic mutant CAS-5 obtained in previous programme from a low oleic line isogenic to BSD-2-423 using similar mutagenic treatment. The oil of this mutant will increase the range of potential uses of sunflower oil.

Dwivedi *et. al.* (1998) carried out investigation to enlarge genetic variation in O/L ratio by induced mutagenesis in groundnut. Dry seeds of JL 24 (a widely grown early maturing Spanish cultivar in India) and ICGA 88448 (a large seeded late maturing Virginia breeding line) were treated with 0.3% solution of EMS. The M_1 generation was bulk harvested. They selected 25 M_3 progeny bulks with altered fatty acid composition. Out of these, fourteen phenotypically uniform mutants along with ICGV 88448 and JL 24 were evaluated in a replicated trial for seed quality traits. EMS treatment caused significant differences among mutants in oil content, palmitic, oleic, linoleic, eicosenoic and lignoceric acids contents, TSF and O/L ratio. Stearic and arachidic acids were not affected by EMS. They observed that oil content significantly increased in mutants ICGV 96230, ICGV 96234, ICGV 96238, ICGV96239 and ICGV 962340 and decreased in mutants ICGV 96235, ICGV 96236 and ICGV 96237 over control. Increased oil content led to high oleic and O/L ratio and low palmitic and linoleic acids in mutants ICGV 96230, ICGV 96234, ICGV 96238, ICGV 96239 and ICGV 96240. Behenic and lignoceric acids significantly increased in mutants ICGV 96238, and ICGV 96240 and TSF significantly increased in mutant ICGV 96239. Genotypes with a high oil content had a lower oleic desaturation ratio (ODR= 0.234 to 0.344) compared with those with a low oil content (ODR= 0.501 to 0.517). Low oil content in mutants ICGV 96235, ICGV 96236 and ICGV 96237 is probably associated with a high ODR ratio which results in a lower O/L ratio and therefore, shorter shelf life of the groundnut product/ oil.

Miller, J.F. and Vick, B.A. (1999) carried out investigation to determine the inheritance of low stearic and palmitic acid content in sunflower (*Helianthus annus* L.) oil. Two USDA maintainer inbred lines, HA 821 and HA 382, and two USDA pollen fertility restorer inbred lines, RHA 274 and RHA 801 were treated with two chemical mutagens NMU (at rates of 1 and 2 g/kg) and EMS (at rates of 1 and 2 g /

kg). The fatty acid content of approximately 6800 M_5 lines was analyzed by gas chromatography. Two M_5 lines, HA 821 LS-1 and RHA 274 LS-2, had lower stearic acid content (41 and 20g/kg), and one M_5 line, RHA 274 LP-1, had lower palmitic acid content (47 g/ kg) than their respective parental lines. Segregation ratios of F_2 and test cross progeny indicated that the low stearic acid content in HA 821 LS-1 was controlled by one gene, designated *fas1*, with additive gene action. The low stearic acid content in RHA 274 LS-2 was controlled by two genes with additive gene action. The first gene was designated *fas2*, and the second gene was temporarily designated *fasx*. The allele *fap1* was identified in RHA 274 LP-1 to control low palmitic acid content with additive gene action. The combination of the alleles for low stearic and low palmitic acid content identified in this study could reduce the total saturated fatty acid content of oil in sunflower from 130g/kg to less than 80g /kg.

Schnurbusch *et. al.* (2000) carried out investigation to analyzed genetically and phenotypically characterized with increased palmitic acid content in an induced mutant from European winter oilseed rape (*Brassica napus* L). The mutant M 4936 was isolated after EMS treatment of winter rapeseed, *Brassica napus* L., cv. 'Wotan'. The mutant showed a palmitic acid content of 9.2% compared with 4.5% in the parental cultivar. The oleic acid content decreased from 61.6% to 44.2%, whereas the linoleic and linolenic acid contents increased. The mutant plants grew poorly and their seed oil content was only 31.2% compared with 42.8% in the parental cultivar. The inheritance of the mutant was oligogenic and determined by at least four genes. In the F_2 generation, palmitic acid content was negatively correlated with oil content. This mutant may be useful to improve understanding of the genetic regulation of storage lipid synthesis, but has no immediate value for oilseed rape improvement.

Spasibionek, S. (2006) treated seeds of the winter oilseed rape (*Brassica napus* L.) line PN 3756/93 with 0.5% and .01% solutions of EMS to induce mutations in the fatty acid biosynthetic pathway. The seed mutagenic treatment was repeated in the M_2 generation. After treatments, individual seed and plant selections were made for changes in fatty acid composition during several generations of inbreeding. Self-pollinated plants with changed fatty acid compositions were inbred to obtain genetically homozygous and stable mutant lines. After selection in several subsequent generations M_2- M_7, two mutants M-10453 and M-10464 with significantly increased oleic acid content (over 75%) and reduced linoleic and linolenic acid contents (8.5%

and 7.5% respectively) were selected and one mutant M-681 with high linoleic and low linolenic acid content (27.5% and 2.7% respectively) were also selected by him. The results of selection work during several generations showed that the environment had substantial influence on the composition of seed oil. This made the search for mutants with modify fatty acid compositions difficult. The induced mutants are not directly usable as new varieties, but can be used as parents in crosses for the development of high quality rapeseed varieties.

Patil *et. al.* (2007) carried out investigation with the objective of identifying stable soybean mutant with altered fatty acid composition for improved oxidative stability and nutritional quality. Seeds of soybean cultivar 'MACS 450' were treated with gamma radiation (100, 150, 200 and 250 Gy doses of gamma rays) and ethyl methane sulphonate (EMS) (0.05, 0.10 and 0.15% solution of EMS) and their combinations. The harvest of M_1 plants was evaluated for fatty acid composition by gas chromatography. They observed highly significant variation in all the fatty acids except palmitic acid. Treatment of EMS in higher concentrations as well as combined treatment of both the mutagens, *i.e.* gamma irradiation and EMS was effective in increasing the variability for the fatty acid content in soybean oil. They observed that EMS treatment of 0.1% showed a maximum CV of 34% for stearic acid with a wide range of variation (1.8 -6.77%), EMS treatment of 0.05% and 0.1% showed greater CV for oleic acid than the other treatments and combination of gamma irradiation and EMS (250 Gy + 0.05%) showed greater CV for linolenic acid with a wide range of variation (3.93-7.86%). They also observed that treatment 100 Gy + 0.05% EMS showed maximum reduction in linolenic acid content. The observed linolenic acid content (3.93%) in this treatment is 50% less than the control (8%). The variability was skewed towards high levels of oleic (35-42%) and low levels of linolenic acid (3.77-5%). M_3 and M_4 generations of desirable variants were analyzed for the stability of the mutated trait. Only high oleic variants were stable in M_3 and M_4 generations. Based on fatty acid values, oxidative stability index (OSI), nutritional quality index (NQI) and ratio of essential fatty acids were calculated for the control and M_2, M_3 and M_4 generations. The essential fatty acids ratio in all the high oleic mutants was within the WHO recommended value (5-10%). A significant positive correlation between OSI and oleic acid content ($P<0.001$) indicated improved oxidative stability of the oil while retaining nutritional quality.

Spasibionek, S. (2008) carried out investigation to find out optimal conditions for mutagenesis favorable to the increase of variability of polyunsaturated fatty acids in winter oilseed rape and to obtain mutated lines with high oleic and reduced linoleic acid content. Seeds of the winter rapeseed (*Brassica napus* L.) line PN 3756/93 and PN 5282/98 were treated with 0.5 and 1.0% solutions of EMS. After selection in several subsequent generations M_2- M_7, two mutants M-10453 and M-10464 with significantly increased oleic acid content (over 75%) and one mutant M-681 with high linoleic and low linolenic acid content (27.5% and 2.7% respectively) were selected by him. He also obtained five mutants *viz.,* M-1286/42, M-1288/27, M-1290/361, M-1292/59 and M-1292/271 in different EMS treatment conditions performed on another double low line PN 5282/98 and selected in M_3 –M_6 generations are characterized by increased level of oleic acid average from 74.6 to 77.1% and reduced linolenic acid content average from 4.0 to 4.8%. Significant changes obtained in the content of fatty acids in oil seeds suggest that activity levels of enzymes Δ12 and Δ15 desaturases which influence the content of oleic, linoleic and linolenic acids synthesis undergo considerable damages. It is the effect of mutations in genes fad2 or fad3 (fatty acid desaturase).

Badigannavar, A. and Mondal, S. (2009) carried out investigation to genetic enhancement of groundnut *(Arachis hypogaea* L.) for high oil content through gamma ray mutagenesis. To induce mutations for higher oil content, seeds of TAG 24 were irradiated with 150, 250 and 350 Gy gamma rays. They observed spectrum of genetic variability for oil content in the M_2 population (M_3 seeds). The widest range of oil content of 36.39- 52.85% was observed in the 150 Gy treatments, compared to 43.38-50.83% in TAG 24, followed by 350 and 250 Gy. The highest was 52.85% oil, noted from plants obtained by 150 Gy treatments. In M_2 population, 60 plants had superior oil content (50.40- 57.72%), as well as seed yield (19.3-44.7 g/plant), 46 plants had superior oil content (48.52- 50.36%) and 62 plants had superior oil yield (9.55-22.1 g/ plant) compared to TAG 24. Based on OC and seed yield, 107 plants were advanced. Of the 107 progenies grown, 14 progenies bred true for high oil content by recording 1.5-4.9% increase in mean oil content of M_4 seeds over parent. Among these, 11 progenies also recorded superior seed yields of 3.0- 86% and oil yields of 6.2- 92.4% compared to TAG 24. In the M_5 generation, four mutants (TGOM 2, TGOM 60, TGOM 61 and TGOM168) scored significantly higher progeny mean OC, seed yield

and oil yield with 2.4-5.8%, 46.6-67.8% and 54.4- 71.2% superiority, respectively. True breeding behavior of high oil mutants was confirmed by progeny evaluation in M_6 generation. All the mutants had significantly superior OC with three mutants having greater seed and oil yields.

Mondal, S. and Badigannavar, A. M. (2010) treated seeds of Spanish bunch *(Arachis hypogaea* ssp. *fastigiata* var. *vulgaris*) variety TPG 41 with 200 and 300 Gy of gamma rays during rainy season. The M_2 generation was grown in summer season by advancing M_1 plants as plant to row progenies. They isolated 69 true breeding mutants of TPG 41 for various traits based on the breeding behavior in M_3, M_4 and M_5 generations. Estimation of fatty acids in 69 mutants of TPG 41 indicated greater variability for stearic acid, oleic acid and linoleic acid and lesser variability for palmitic acid, arachidic acid, eicosenoic acid, behenic acid and lignoceric acid. The variability in these mutants was more pronounced in summer than rainy season. They observed 10 mutants (TGM 3, TGM 13, TGM 18, TGM 22, TGM 40, TGM 44, TGM 57, TGM 64, TGM 77, and TGM 83) had increased palmitic acid by 1.3- 2.5% compared to parent (8.8%) in both the seasons. Similarly, seven of the mutants (TGM44, TGM 45, TGM 46, TGM 50, TGM 55 and TGM 59) had increased stearic acid by 1.1- 2.7%. Oleic acid being an important fatty acid was enhanced in seven mutants (TGM12, TGM 19, TGM 48, TGM 54, TGM 62, TGM 71 and TGM 88) at the cost of linoleic acid by 3-6% resulting in an increase in O/L ratio to 4-5 compared to parent. They recorded highest oleic acid and the lowest linoleic acid content in TGM 71 mutant with mean O/L ratio of 5. Among the 69 mutants, TGM 55 in summer and TGM 42 and TGM 62 in rainy season surpassed significantly parent TPG 41 for pod and seed yields. Further, seed size in TGM 13, TGM 18, TGM 35, TGM 36, TGM 42, TGM 48, TGM 67, and TGM 88 during summer and in TGM 12, TGM 35 and TGM 42 during rainy season increased significantly compared to the parent.

Pavadai *et. al.* (2010) treated dry seeds of soybean variety CO 1 with physical mutagen such as gamma rays with a doses of (10, 20, 30, 40, 50 and 60 kR) and Chemical mutagen such EMS with concentrations (0.1, 0.2, 0.3, 0.4, 0.5 and 0.6%) , DES (0.01, 0.02, 0.03, 0.04, 0.05 and 0.06%) and COH (0.01, 0.02, 0.03, 0.04, 0.05 and 0.06%). EMS treatment showed high protein and oil content compared to other mutagenic treatments such as gamma rays, diethyl sulphate and colchicine. According to their results, high content of protein and oil was observed at high mutagenic

treatments. They observed increased level of seed protein and oil content at 0.5% and 0.6%of EMS treatments and 50kR of gamma rays.

Lee *et. al.* (2014) treated seeds of 'Tamla' variety of rapeseed (*Brassica napus* L.) with 1% EMS to induce mutations in the fatty acid biosynthesis pathway. M_1 plants were selfed and subsequent generations (M_2, M_3 and M_4 mutants) were analyzed to identify mutants having increased levels of oleic acid. They observed that M_2 mutants showed changes in oleic acid content ranging from 13.5% to 76.9% with some mutants (TR-458 and TR-544) having up to 74.7% and 76.9% oleic acid, which was an increase of nearly 5% and 7%, respectively, compared to untreated cv ' Tamla'. They selected two M_3 mutants with > 75% oleic acid content. One mutant (TR-458-2) had increased oleic acid (75.9%) and decreased linoleic acid (12.5%) and linolenic acid (4.4%) contents. The other mutant (TR-544-1) showed increased oleic acid content (75.7%) and decreased linoleic acid (13.5%) and linolenic acid (3.3%) contents. The accumulation or reduction of oleic acid content in the selected M_4 mutants was also accompanied by a simultaneous decrease or increase in linoleic and linolenic acid.

Begum, T. and Dasgupta, T. (2015) treated pure and uniform dry seeds of each of the three genotypes of sesame *(Sesamum indicum* L.) *viz.,* Rama, SI 1666 and IC 21706 with 200 Gy, 400 Gy and 600 Gy doses of gamma rays (physical mutagen) and 0.5%, 1.0%, 1.5% and 2.0% concentrations of EMS. The M_1 generation was bulk harvested and M_2 was grown. They selected thirty mutant lines from 3 widely adapted genotypes of sesame *viz.,* Rama , SI 1666 and IC 21706 were evaluated against their respective control genotype for yield and its important attributes in M_4 generation. All selected mutant lines showed increase in seed yield and most of the yield components in comparison to respective controls. Combining all mutagenic lines, mutant line no. 10 of each of the 3 genotypes induced by 0.5% EMS produced highest yield. They identified a very promising high yielding mutagenic lines namely, lines nos. 5, 9 and 10 of Rama; lines nos. 3, 4, 8 and 10 of SI 1666 and line nos. 7, 9 and 10 of IC 21706. The oil content of the mutants varied from 46.63 to 53.25% indicating 0.09 to 29.42% improvement over respective controls. Highest oil content was recorded in selection no.8, followed by selection no. 9 which were developed from the population of IC 21706 induced by 0.5% EMS. They recorded substantial genetic variation in fatty acid profile among the selected mutants. The result revealed

that linoleic acid was the major component ranging from 42.21 to 46.29% followed by oleic (35.35 to 38.56%), palmitic (7.05 to 10.27%) and stearic (2.98 to 3.44%) acid. Four mutants namely selection no.1 (selected from mutant line no.5 of Rama irradiated by 400 Gy of gamma rays), selection no.5 (derived from mutant line no. 4 of SI 1666 treated by 200 Gy dose of gamma rays), selection no. 7 (selected from mutant line no.10 of SI 1666 induced by 0.5% EMS) and selection no. 8 (developed from mutant line no.7 of IC 21706 treated by 0.5% dose of EMS), were characterized by improvement in both oleic and linoleic acid content over their respective controls.

Rampure *et.al*. (2015) carried out investigation to widen the variability for isolating high oleic acid mutants of an Indian variety 'Bhima' through induced mutagenesis in safflower (*Carthamus tinctorius* L.). The 50 seeds each were treated with 0.005%, 0.010% and 0.015% sodium azide (SA); 0.1%, 0.2% and 0.3% ethyl methane sulphonate (EMS) and 400, 500 and 600 Gy gamma ray after determining the LD_{50} dose / concentrations. They reported that the isolation of high oleic acid mutants of safflower induced by EMS treatment only. No mutant with variation in fatty acid content was induced by sodium azide and gamma rays. They isolated three putative mutants with high oleic acid from the 15,403 M_2 progenies of safflower. Of these three mutant, one (plant no. 48-17) was isolated from 0.1% EMS 3h PSW treatment and other two (Plant nos. 55-2 and 55-8) was isolated from 0.2% EMS 3h PSW treatment. The oleic acid content in 48-17, 55-2 and 55-8 was 63%, 25% and 86% respectively, which was higher than that found in the parent variety Bhima (15%). The mutants segregated in M_3 and M_4 generations. Increased oleic acid content of the mutants was associated with an obvious decrease in their linoleic acid content. They also isolated two high oleic acid progenies in M_4 generation *viz.,* 48-17-13-1 and 48-17-14-3, having high palmitic acid content *viz.,* 11% and 14% respectively, in their oil as compared with 6% in the parent variety Bhima.

Cvejic *et. al.* (2016) carried out investigation to increase the genetic variability of sunflower in terms of oil quality and productivity using induced mutations. They performed a preliminary sensitivity test to establish optimal EMS doses for seed treatment. The results showed that high EMS concentrations (0.5- 2.5%) caused low survival rates, therefore lower EMS doses were used. Thousand seeds of the sunflower high oleic inbred line L 31 were treated with 0.1% solution of EMS to induce mutations. In the M_2 generation, seeds were screened for fatty acid

composition and alterations occurred in individual plants. In the next generation a putative mutant line, ML 31-1, was isolated with significantly lower oleic acid content compared to the wild type L31 grown in the same year. They assumed that heterozygous mutation occurred, manifested by changing a dominant allele *Ol* to the recessive *ol*. After self-pollination in the next generation (M_3) the segregation of oleic acid was from 346.6 to 949.1 g/kg and of linoleic acid from 39.9 to 339.3g /kg. In subsequent generations (M_4), individual selection and evaluation of progenies continued in several directions depending on the content of oleic acid: low, increased or high. They identified three subsequent mutants, designated ML31-11, ML31-12 and ML31-13. In M_6 generation subsequent mutants ML31-11, ML31-12 and ML31-13 were evaluated and showed significant differences in one or more characteristics in regards to wild type. Due to fatty acid content, mutant lines ML31-11 and ML31-12 had significantly lower concentration of oleic acid and significantly higher concentration of linoleic acid compared to the wild type.

Lee *et. al.* (2018) treated seeds of the rapeseed cultivar 'Tamla' *(B. napus* L.) with a 1% EMS solution. The selection of mutants with high oleic acid contents (>75%) in M_3 to M_7 generation plants was carried out. They isolated two mutant (M_7) populations (TR-218 and TR-325) with an average values of oleic acid content were 76.6 and 76.2%, respectively, in comparison to 69.5% in Tamla plants. The levels of linoleic and linolenic acid were reduced slightly in the seeds of the M_7 mutant population (10.6 and 5.8%, respectively) in comparison to 16 and 8.1%, respectively, in untreated Tamla variety. In two M_7 mutant populations, the highest oleic acid content ranged from 79% and the lowest oleic acid content was 73%. Yield components between two mutant populations and untreated Tamla plants were not substantially different, although the mutants in the vegetative stage were slightly smaller in size than Tamla. Genomic analyses of six fatty acid desaturase (four *FAD*2 and two *FAD*6) genes revealed that elevated oleic acid content in the mutants is the result of single gene mutations. Changes in DNA sequence were observed in two genes out of six fatty acid desaturase (four *FAD*2 and two *FAD*6). *FAD*2-2 exhibited a 2-bp deletion in the upstream region of the gene in the two mutants, resulting in a severely truncated polypeptide (57 aa instead of 469 aa), while six point mutyations in the other gene did not result in changes in the amino acid sequence. Based on these results, *FAD*2-2, an endoplasmic reticulum (ER) oleic acid desaturase, is affected in

the mutants, resulting in a ~7% increase in oleic acid content in comparison to untreated Tamla plants.

Hadebe *et. al.* (2019) carried out investigation to determine whether ethyl methyl sulphonate (EMS) mutagenesis significantly altered seed oil content and fatty acid compositions in selected vernonia accessions. Prior to this study, 60000 seeds per accession from two vernonia accessions (vge-1 and vge-4) were subjected to 0.372% (v/v) EMS solution. Seeds were harvested from mutant plants with and without visual chlorophyll mutations from the vge-1 and vge-4 vernonia accessions, subjected to seed oil content and fatty acid composition analyses and compared with untreated controls. Visual chlorophyll mutations confirmed EMS mutation in harvested plants. EMS mutagenesis significantly reduced vernolic acid composition, and significantly increased linoleic, oleic, palmitic, stearic and arachidic acid composition in the vge-1 accession. In vge-4, palmitic acid composition was significantly increased. Results obtained suggested that the effect of EMS mutagenesis on fatty acid composition in vernonia could be accession- specific and influenced by mutation level. The significant but negative association between vernolic acid and other fatty acids indicates that there is potential to increase vernolic acid while at the same time reducing the contents of other fatty acids through EMS mutagenesis in vernonia.

2.6 Induced polygenic variability for quantitative traits

Any crop improvement program's effectiveness is largely determined by the amount of genetic variability present in a character and the extent to which it is heritable. As a result, knowledge of the estimates of variability in yield and its heritable components in the material with which the breeder is working becomes essential for any breeding programme. As a result, using genetic parameters like genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic gain, it became necessary to divide total variability into heritable and non-heritable components. Only a portion of continuous variation is due to heredity (Galton, 1889). However, Johnson (1909) study of a self-pollinated French bean crop highlighted the contribution of genetic and environmental components to total variance, revealing that the genetic component remained essentially stable through generations. Fisher (1918) was the first to distinguish three types of genetic variance: additive x additive, additive x dominance, and dominance x dominance. In a

broad sense, Lush (1940) defined heritability as the ratio of genotypic variance to phenotypic variance. The additive, dominance, and epistatic effects are all part of the genotypic variance. The ratio of additive genetic variance to phenotypic variance is described as ‘narrow sense' heritability (Lush, 1949).

Burton and Devane (1953) went on to suggest that the amount of genetic gain a characteristic can achieve through selection is determined by its heritability, phenotype standard deviation, and selection differential.

The following is a review and summary of the literature on genetic variability, heritability, and genetic advance in safflower and other oilseed crops.

Chavan, G.V. and Chopde, P. R. (1981) carried out investigation to study polygenic variability, heritability and genetic advance in irradiated sesame. A study of 82 M_2 progenies retained in M_1 generation of three gamma irradiated varieties *viz.,* No.58-2, No.85 and D7-11-1 and three controls have indicated that large polygenic variability has been induced due to four irradiation treatments (25, 50, 75 and 100 kR) in all the three varieties. Among the characters studied, number of capsule/ plant, seed yield/ plant, number of primary branches, plant height up to first branch and number of capsules on main shoot has shown greatest variability. Thousand seed weight exhibited minor variation. High heritability was accompanied by higher genetic advance in number of capsules/ plant, number of primary branches, plant height up to first capsule and number of capsules on main shoot. Days to 50 % flowering has highest heritability with moderate genetic advance. These characters, therefore, should be given weightage in selection for high yield in sesame.

Vasline *et. al.* (2000) carried out investigation to study the nature and amount of induced genetic variability in *Sesamum indicum* L. The study consisted of three genotypes treated with physical (gamma rays) and chemical (EMS and DES) mutagens. The maximum variability was observed in characters such as plant height, number of branches per plant, number of capsules per plant and seed yield per plant in M_2 and M_3 generations. A high heritability associated with a high genetic advance as a percentage of mean was observed for plant height, number of branches per plant, number of capsules per plant, number of seeds per capsule and seed yield per plant in M_2 and M_3 generations.

Azzam *et. al.* (2005) carried out investigation to induce new genetic variability in peanut using gamma ray doses in an attempt to improve yield and yield components, oil content and protein content. Three peanut genotypes *viz.,* Giza 4, Giza 6 and R92 were exposed to 0, 100, 200, 300 and 400 Gy of gamma rays at a dose rate of 7.62 Gy/ min. Mean squares due to doses, genotypes and interaction between them were significant for most studied characters in M_1 and M_2 generations. The highest mean values were observed with the 400 Gy gamma ray dose for most studied characters in M_1, while were observed with 300 Gy in M_2 generation. The highest oil percentages were found with 300 Gy and 200 Gy in M_1 and M_2 generations, respectively. The estimates of phenotypic and genotypic coefficient of variability, broad sense heritability and the expected genetic advance from selection were increased in all irradiated populations compared with the non- irradiated genotypes, indicating usefulness of gamma rays to induce variation that help for practicing selection to improve peanut characters.

Sarwar, G. and Haq, M.A. (2005) carried out investigation to induced variability for the improvement of yield and yield components in sesame (*Sesamum indicum* L.) through radiation. The seeds of two local varieties of sesame *viz.,* Til 89 and TS 3 were irradiated with split doses of gamma rays ranging from 100 to 800 Gy. Germination % and Plant height were recorded for determination of LD50 in the M_1 generation. The M_2 generation was observed for estimation of variability, heritability and genetic advance. The highest heritability, along with maximum values of genetic advance regarding seed yield / plant , were estimated in the treated population of TS3 while variety Til 89 showed high values of heritability combined with high values of genetic advance in the branches per plant, capsule number and seed yield per plant. It may be concluded that positive mutations can be obtained safely by irradiating sesame varieties below 600 Gy and improvement in seed yield may be achieved by direct selection of plants based on a larger number of branches, larger number of capsules and higher seed yield per plant, because these characters were governed by an additive type of gene action.

Abd El- Mohsen *et. al.* (2008) carried out investigation to study the effect of some mutagens on morphological and yield traits of sesame and it estimate the genotypic and phenotypic coefficient of variation, broad sense heritability and genetic advance from selection for several important traits in sesame mutant populations (M_2

and M_3 generations). Two commercial cultivars *viz.,* Giza 32 and Toshka 1 were treated with 400 Gy and 500 Gy doses of gamma rays and 0.5% and 1.0% concentration of EMS mutagens. Coefficient of variability indicated that seed yield per plant, number of capsules per plant, number of fruiting branches, flowering date and fruiting zone length were greatly affected by mutagens than oil content and 1000-seed weight. Estimates of phenotypic coefficient of variability (PCV) was generally higher than the genotypic coefficient of variability (GCV) for all studied traits but the difference was small, indicating little influence of environment in the expression of these characters. The PCV and GCV estimates were the highest for number of capsules per plant and seed yield per plant. Low values in this respect were recorded for days to flowering, 1000- seed weight and seed oil content. Estimates of correlation coefficients revealed that highly significant and positive correlations were found between seed yield per plant and each of number of capsules per plant, fruiting zone length, number of fruiting branches and plant height. High heritability and genetic advance estimates were observed for plant height, number of branches per plant, number of capsules per plant and seed yield per plant in M_2 and M_3 generations, indicating the effectiveness of selection for the improvement of these traits.

Siddiqui *et. al.* (2009) carried out investigation to induced quantitative variability by gamma rays and EMS alone and in combination in rapeseed (*Brassica napus* L.). The seeds of rapeseed (*Brassica napus* L.) c.v. Waster treted with two doses of gamma rays *viz.,* 750 Gy and 1000 Gy, two concentrations of EMS *i.e.*, 0.75 % and 1.00% and in combinations (750 Gy + 0.75% EMS, 750 Gy+ 1.00% EMS, 1000 Gy+ 0.75% EMS and 1000 Gy+ 1.00 % EMS). The maximum coefficient of variation was observed for grain yield per plant (37.87%) followed by siliques per plant (29.99%) and thousands grain yield per plant weight (28.36%). The highest heritability values were shown by siliques per plant (81.78%), primary branches (81.06%) and grain yield (79.49%). The grain yield also showed the highest genetic advance (62.28%) followed by silique per plant (50.45%) and primary branches (45.79%). Combinations of physical and chemical mutagen have shown enhancing effect on primary branches. The highest coefficient of variation (36.08%) and genetic advance (59.03%) showed in 750 Gy of gamma rays while the maximum heritability (86.82%) was observed in 1.00 % EMS. The induced variation can be exploited in the evolution of new varieties of rapeseed with improved agronomic traits.

Shivani *et. al.* (2011) conducted experiment with 60 genotypes of safflower to assess variability, heritability, genetic advance, direct and indirect effects of different characters on seed yield and genetic diversity. Wide variability was observed for seed yield and other yield attributes. High phenotypic and genotypic coefficients of variation were found for number of seeds per capitulum followed by seed yield. The high heritability with high genetic advance as per cent of mean for seed yield, plant height and test weight revealed that these characters were controlled by additive gene action.

Belete *et. al.* (2012) carried out investigation to evaluate the performance of different genotypes of Ethiopian mustard and to estimate the heritability and genetic advance of agronomic traits of these genotypes. The material for the present investigation consisted of 33 genotypes and 3 standard checks. Wide ranges of mean values were observed for traits such as days to flowering (61-101), days to maturity (155-182), plant height (177-235), number of secondary branches per plant (5-25), number of pods per plant (123-279), number of seeds per pod (6-14), number of seeds per plant (3-11), seed yield per plot (334-1300 g), oil yield per plot (141-584 g) and 1000- seed weight (2.4-4.6 g). High genotypic and phenotypic coefficient of variation was shown in traits such as seed yield per plot and oil yield per plot. Low to high heritability values were recorded for the traits studied. High heritability values were recorded for traits such as days to flowering (79.3%), plant height (62.8%), 1000 seed weight (57.9%) and days to maturity (57.5%). Number of seeds per pod, seed yield per plot and oil yield per plot was found to have high genetic advance along with moderate heritability. Thirteen genotypes had days to maturity less than the grand mean as well as the standard checks which may be used for developing early maturing varieties.

Emrani *et. al.* (2012) carried out investigation for evaluation of induced genetic variability in agronomic traits by Gamma irradiation in canola (*Brassica napus* L.). The 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, GCV, PCV and GAM were also estimated. Results of analysis of variance indicated highly significant effect of mutagenic doses, genotypes and genotype x 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. The highest variations induced with treatment of 1000 Gy of gamma rays in most of the traits in RGS003 cultivar, while 800 Gy gamma rays induced similar conditions in 'Sarigol' cultivar. The relationship between traits revealed major contribution of number of fruits per plant on justifying seed yield variation in both M_2 and M_3 generations. These results indicate that this yield component is the major determinants for fruits- yield differences among plants which also positively influences by irradiation mutagen.

Ahmed *et.al.* (2013) carried out investigation to develop direct or indirect relationship among the qualitative traits for ultimate improvement in yield and quality. Thirty five advance *brassica* mutant lines and one check were evaluated for genetic variability and phenotypic correlations for some qualitative traits. High genetic variability was recorded for erucic acid and glucosinolates while low genetic variability was recorded for protein and oil contents. Phenotypic variances were recorded higher than the genotypic variances for all the observed traits. Heritability and genetic advance were higher for glucosinolates and erucic acid while oil content showed the lowest values of heritability and genetic advance. Generally, low correlations were recorded among different characters. However, some of the connected traits like protein, glucosinolates and erucic acid showed significantly positive correlation with each other.

Bahmankar *et. al.* (2014) carried out investigation to assess the broad sense heritability and genetic advance in 20 safflower genotypes. The results of broad sense heritability indicated that main capitula diameter, number of seeds per capitula, 1000 seed weight and plant height traits had the highest value. The main capitula diameter and plant height revealed higher values of genetic advance. High genetic advance coupled with heritability was observed for main capitula diameter and plant height traits. Thus selection will be useful in safflower breeding programs.

Begum, T. and Dasgupta, T. (2014) carried out investigation to induced genetic variability, heritability and genetic advance in Sesame (*Sesamum indicum* L.). The seeds of three widely adopted sesame genotypes- Rama, SI-1666 and IC 21706 were induced by 200 Gy, 400 Gy and 600 Gy doses of gamma rays as well as by

0.5%, 1.0%, 1.5% and 2.0% concentrations of ethyl methane sulphonate (EMS) separately. Mutant generations from M_1 to M_2 were raised to assess the extent of variability, heritability, and genetic advance for yield and important yield components in mutant populations. Lower doses of mutagens were more proficient for induction of mutations. The chemical mutagen (EMS) was much more effective than the physical mutagen in producing polygenic variability. The genotype IC 21706 and the treatment using 0.5% concentration of EMS appeared to be the best for engendering variability, highlighting their potentiality for selecting higher yielding plants in early generations. In M_2 generation, there was considerable increase in genetic estimates for all the metric traits, as compared with that in the M_1. In general, estimates of genetic variability and heritability dwindled with increasing doses of gamma rays and EMS. All genotypes showed a promising increase in genotypic variability, heritability and genetic advance for all traits, implying that these characters can be transmitted to future generations.

Rai *et. al.* (2014) carried out investigation to induce of genetic variability for yield and its component traits in two varieties of linseed *(Linum usitatissimum* L.) *viz.,* T-397 and shekhar through mutagenesis. The seeds of these two varieties were exposed to different doses of gamma rays 40, 50 and 60 kR. The present findings clearly indicated the significant differences between the mean values recorded for different populations of mutagenic treatments and the control for all the characters studied as well as, mean sum of square due to treatments were also significant. The magnitude of induced genetic variability in term of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control in both T-397 and Shekhar varieties in the M_2 generation. Although the estimates of heritability were low to moderate for all of the treatments in both the varieties but it is apparent from the foregoing observations that sufficient amount of genetic variability exists for some of the traits such as number of pods per plant in both the varieties of linseed for further crop improvement.

Sanghani *et. al.* (2016) carried out investigation to study the nature and magnitude of induced genetic variability in sesame (*Sesamum indicum* L.). Seeds of three sesame genotypes, Gt-2, Param and Vikrant were treated with four concentrations of ethyl methane sulphonate (0.5%, 1.0%, 1.5% and 2.0%), separately. Mutant generations from M_1 and M_2 were raised to study the extent of variability,

heritability and genetic advance in mutant populations. Mutations surpassed the magnitude of variability over control population in both the generations. Genotypic and phenotypic variances were higher for sterility % and 1000 seed weight in both M_1 and M_2 generations. Regardless of the genotype, M_1 generation professed maximum genotypic and phenotypic coefficients of variability (GCV and PCV) for number of seeds per capsule. On the contrary, in M_2 generation induced populations of all the three genotypes engendered maximum GCV and PCV for seed yield per plant. High heritability for sterility percentage and 1000 seed weight coupled with high genetic advance inferred that additive gene effects were important in determining these characters and could be improved through mass selection.

Uzair *et. al.* (2016) carried out investigation to study the genetic variability and heritability in relation to seed yield and its components traits in mustard (*Brassica juncea* L.). In this research there are eight quantitative parameters were observed *viz.,* Days to 50% flowering, Days to 70% maturity, plant height, number of primary branches, silique length, number of seeds per silique, 1000 seed weight and seed yield were noted. Extremely substantial changes ($p< 0.05$) remained taken in all characters which demonstrated substantial difference. The high heritability in aggregation with high genetic development was noted in plant height, silique length and seed yield which gave the indication that these traits were under the control of additive gene which will be more useful in expecting the gain under collection than heritability alone, while days taken to flowering, days taken to maturity, number of branches per plant, number of seeds per silique and 1000 seed weight revealed capricious trends. Hence, it was observed that adequate scope of genetic variability is present for selection of superior genotypes, which can be exploited in future breeding programs.

Pushpavalli, S.N.C.V.L. and Kumar, G. (2017) carried out investigation to study genetic variability, correlation and path analysis in sixty three safflower genotypes. Seed yield followed by 100- seed weight contributed to maximum genetic divergence. Broad sense heritability estimates was highest for seed yield followed by 100 seed weight. Significant and positive correlation was observed between seed yield and number of capitula/ plant, number of seeds/capitulum and 100- seed weight. Path coefficient analysis indicated that 100- seed weight exhibited maximum direct effect followed by number of seeds/ capitulum.

Sikarwar *et. al.* (2017) carried out investigation to assess the genetic variability, heritability and genetic advance in 21 diverse genotypes of yellow sarson *(Brassica rapa* var. yellow sarson) for ten yield and its contributing characters. Analysis of variance for the design of the experiment indicated highly significant differences for all the characters. High PCV and GCV were observed for number of secondary branches per plant followed by seed yield per plant, number of primary branches per plant and number of siliqua on main raceme. Hence, direct selection of these traits will prove effective. Days to flowering, plant height and length of siliqua showed low PCV and GCV. Higher estimates of broad sense heritability were observed for all the characters. High heritability coupled with high genetic advance was observed for number of secondary branches per plant, seed yield per plant, length of main raceme, number of siliqua on main raceme, number of seeds per siliqua and number of primary branches per plant. High heritability with moderate genetic advance in case of length of siliqua and 1000 seed weight whereas, high heritability and low genetic advance was observed for days to flowering and plant height.

Khattab M.N. (2018) carried out investigation to study the variance, heritability, genetic advance and correlation of some Phonological, Morphological and Productivity traits in six safflower (*Carthamus tinctorius* L.) Genotypes *viz.,* local, thick orange 480, Acar 6, Syrian-1, Gila and Son 11. The values of mean and range revealed that there is wide variability among genotypes for most of the characters. The biological yield per plant, seed yield per plant, number of seeds per capitulum, number of capitulum per plant, number of branches per plant and harvest index exhibited wide range and high PCV and GCV giving an opportunity for improvement through selection. Besides, these characters also had narrow differences between the values of PCV and GCV showing least influence of environment. High heritability coupled with high genetic advance observed for seed yield per plant, biological yield per plant, 100 seed weight, plant height and number of seeds per capitulum indicated that these traits are governed by additive gene action. Hence, there are good chances of improvement of these traits through direct selection. The highest phenotypic correlations were observed between seed yield with some traits such as, biological yield/ plant and No. of capitula/ plant, thus these traits, may be used for selecting high yielding genotypes.

Leelavati, T. M. and Mogali, S.C. (2018) carried out investigation to assess the induced genetic variability, interrelationship among yield components and their direct and indirect effect on yield. The seeds of two linseed varieties *viz.,* Indira Alsi and NL-115 were treated with five doses of chemical mutagen, EMS at five doses 0.1% to 0.5% respectively. Amongst the 240 mutants high magnitude of GCV and PCV was obtained for stem girth, number of primary branches per plant, number of secondary branches per plant, number of capsules per plant and seed yield per plant and moderate for number of seeds per capsule, 1000 seed weight, days to flower initiation, days to 50 % flowering and plant height in M_4 population and low for days to maturity. All characters recorded high heritability with moderate to high level of genetic advance. Phenotypic correlation was found to be significant and positive for all characters except for days to flower initiation, days to fifty percent flowering and days to maturity where they recorded non significant positive association with yield. The phenotypic path coefficients revealed high positive direct effect for number of capsule per plant, stem girth, number of primary branches per plant, seeds per capsules and 1000 seed weight in both mutants populations. Negative direct effect was obtained for days to 50 percent flowering and secondary branches per plant.

Patil, M.K. and Lokesh, R. (2018) carried out investigation for estimation of genetic variability, Heritability, Genetic advance, correlations and path analysis in advanced mutant breeding lines of sesame (*Sesamum indicum* L.). Analysis of variance revealed highly significant differences for seven characters except number of branches per plant, capsule length, capsule weight, test weight and seed yield per plant. Higher estimates of PCV were observed for all the traits but the difference between PCV and GCV was narrow indicating lowest environmental influence and predominance of genetic factors controlling these traits. High heritability coupled with high genetic advance was observed for plant height and distance from ground to first capsule indicate that these traits are controlled by additive genes and phenotypic selections would be effective. Number of capsules per plant, number of branches per plant, capsule length, number of seeds per capsule, capsule weight and test weight had strong and significant positive association with seed yield per plant at both genotypic and phenotypic levels. Path coefficient analysis indicated that number of seeds per plant followed by number of capsules per plant were important traits to be considered for realizing the improvement in yield in sesame owe to their positive contribution.

Days to maturity and capsule length were negative. Capsule weight influence seed yield negatively through most characters.

Phanindra *et. al.* (2018) carried out investigation to induced genetic variability in mutant confectionary sunflower (*Helianthus annuus* L.). The seeds of sunflower genotypes *viz.,* EC 625693, EC 318761 and SCG 62 were treated with sodium azide (NaN3) at concentrations of 100 ppm, 200 ppm and 300 ppm. The analysis of variances revealed significant differences between treatments for all ten characters under study. There was a close correspondence between GCV and PCV for all characters. High GCV, PCV, heritability and genetic advance as per cent of mean were exhibited by seed filling percentage, 100 grain weight, sugar content and seed yield / plant. The 300 ppm showed high genetic parameters for head diameter, seed filling percentage, seed yield / plant, 100 ppm for 100 grain weight. On the basis of per se performance, EC 625693 of 100 ppm showed positive shift in mean for seed yield / plant compared to control. While other genotypes showed negative response to mutagenic treatment.

Kalaiyarasi *et. al*. (2019) carried out investigation to evaluate the morphological characterization and variability of fifteen sesame genotypes including one local variety and three checks varieties. Eight biometrical and morphological traits were recorded for fifteen genotypes. High PCV and GCV are recorded for the traits *viz.,* number of branches per plant, seed yield per plant and total number of capsules per plant. High heritability and genetic advance was observed for the characters, number of branches per plant, number of capsules per plant, seed yield per plant, plant height, plot yield, 1000 seed weight and number of seeds per capsules. The traits with high heritability and high genetic advance as percent of mean are governed by the additive gene action where simple selection is effective for breeding programmes.

Umamaheshwari *et. al.* (2019) carried out investigation to analyze the genetic variability, correlation and path coefficient analysis of yield and yield attributing characters in 30 genotypes of sesame. Analysis of variance indicated the existence of significant genotypic differences among the genotypes. Considering genetic parameters, high GCV and PCV was observed for number of branches per plant. High heritability coupled with high genetic advances percent of mean was observed for

plant height at maturity, number of branches per plant, number of capsules per plant, length of the capsule, number of seeds per capsule, 1000 seed weight and seed yield per plant indicating the influence of additive and non additive gene action, as such simple selection would likely to be effective for improvement of these traits. Seed yield per plant showed positive association with number of capsules per plant, number of seeds per capsule, number of branches per plant and 1000 seed weight. Path analysis revealed that traits plant height at maturity, number of capsules per plant and number of seeds per capsule was directly influencing the seed yield per plant.

Dogra *et. al*. (2020) carried out investigation to study the magnitude of variation and association for seed yield and to identify promising genotypes. The experimental material comprising of 30 linseed genotypes were evaluated in randomized block design with three replication and data were recorded on thirteen morphometric traits. High PCV and GCV were observed for aerial biomass, primary branches per plant, capsules per plant, and seed yield per plant. For rest of the traits PCV and GCV was moderate to low. High heritability with high genetic advance was observed for aerial biomass, capsules per plant, primary branches per plant, seed yield per plant, secondary branches per plant, technical height and harvest index. Seed yield per plant showed positive and significant correlation with length of flowering period, seeds per capsule, harvest index, primary branches, secondary branches, capsules per plant, aerial biomass and 1000 seed weight while, plant height and technical height showed negative correlation. On the basis of path coefficient analysis, capsules per plant followed by 1000 seed weight exhibited the highest direct effects on seed yield per plant.

Kamdi *et. al.* (2020) carried out investigation to create genetically variable population for yield and its contributing characters. The seeds of soybean variety TAMS-38 were irradiated with three doses of gamma rays *i.e.* 200, 250 and 300 Gy. Significant differences were observed between the progenies for all the five characters studied in M_2 and M_3 generations. The estimates of genotypic coefficient of variation were lesser than the estimates of phenotypic coefficient of variation in M_3 generation indicating the environmental influence over the characters studied. The medium to high GCV and PCV were observed for seed yield/ plant and their contributing trait which indicates there is substantial variation is present. High heritability was recorded for all the characters under study. High estimate of heritability suggested less

influence of environmental factor in the expression for yield and its related traits. Similarly, genetic advance as a percentage of mean were medium to high for all the characters in M_3 generation. In the present study only four characters *viz.,* seed yield per plant, number of pods per plant, number of branches per plant and plant height which showed medium to high GCV, high heritability and medium to high genetic advance as percentage of mean were considered for selection in M_3 generation. This revealed that the above mentioned four characters were influenced by additive gene action and selection would be effective in improving these traits.

Meena *et. al.* (2020) carried out investigation to assess the induced genetic variability, interrelationship among yield components and their direct and indirect effect on yield. Thirty six genotypes of linseed (*Linum usitatissimum* L.) were evaluated. Substantial amount of genetic variations were observed with low influence of environment indicated consistence performance of the genotypes. GCV and PCV were highest for number of capsules per plant followed by number of primary branches per plant. Greater magnitude of heritability coupled with high to moderate genetic advance as per cent of mean was observed for number of capsules per plant, number of primary branches per plant, plant height, seed yield per plant and 1000 seed weight. Seed yield per plant had positive and significant correlation with plant height, number of capsules per plant, 1000 seed weight and protein content, while highly correlate with number of capsules per plant. Path coefficient analysis revealed that number of capsules per plant has strong positive direct effect on seed yield per plant. Number of capsules per plant, number of primary branches per plant, 1000 seed weight and plant height were identified as important traits for selection in linseed breeding program.

Minnie *et. al.* (2020) carried out investigation to study genetic variability, character association and genetic divergence for yield and its attributing traits among 70 genotypes of safflower (*Carthamus tinctorius* L.). The results pertaining to genetic parameters *viz.,* PCV, GCV, heritability and GAM for the seven characters. The genotypic coefficients of variation (GCV) were less compared to the phenotypic coefficients of variation (PCV) for all the characters. High GCV was observed for seed yield followed by test weight and high PCV values were observed for oil content, test weight, seed yield and number of effective capitula/ plant. High heritability coupled with high genetic advance was observed for seed yield, number of

seeds/ capitulum, number of effective capitula/ plant and days to maturity. Seed yield was significantly and positively correlated with days to 50 % flowering, days to maturity, number of seeds/ capitulum and test weight. Path coefficient analysis indicated that days to maturity exhibited maximum direct effect followed by test weight and number of seeds/ capitulum on seed yield.

Rajanna *et. al.* (2020) carried out investigation to examine the nature and magnitude of variability, heritability and genetic advance of yield components and oil quality parameter by evaluating one hundred linseed *(Linum usitatissimum* L.) genotypes and four checks. Analysis of variance revealed that the differences among genotypes were significant for all the characters studied. Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. High PCV and GCV values exhibited for number of branches per plant, number of capsules per plant, yield per plant, palmitic acid and linoleic acid indicating wide range of variability with substantial environmental influence on the expression of these traits and provide better opportunity for improvement of these traits through selection. Small difference between GCV and PCV were recorded for all the characters studied which indicated less influence of environment on these characters. High heritability coupled with high genetic advance as per cent of mean (GAM>20%) observed for plant height, technical plant height, number of branches per plant, number of capsules per plant, yield per plant, palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid indicated that these characters are highly heritable.

Singh *et. al.* (2020) carried out investigation to estimate of genetic variability, heritability and genetic advance in mutant breeding lines of sesame (*Sesamum indicum* L.) variety Gujarat Til-1. The seeds were treated with different doses of gamma rays such as 15 kR, 20 kR, 25 kR, 30 kR, 45 kR and 60 kR and with different chemical mutagen such as 0.1% HA, 0.1% MH, 0.2 HA, 0.2% MH and their combination 0.1% HA + 0.1% MH and 0.2% HA+ 0.2% MH and also treated with combination of gamma rays and chemical mutagens such as 15 kR+ 0.1% HA, 15 kR+0.1% MH, 20 kR+ 0.2% HA and 20 kR +0.2% MH. Analysis of variance revealed significant difference for all the characters studied except test weight. The highest GCV and PCV were observed for character *viz.,* number of capsule per plant, seed yield per plant and number of seed per capsule. High heritability was recorded

for days to maturity , seed yield per plant and number of capsules per plant, indicating that these characters are controlled by additive gene effect and phenotypic selection of these characters would be effective for further breeding purpose.

Thakur *et. al.* (2020) carried out investigation to study the nature and magnitude of genetic variability with a view to identify promising genotypes for yield and related traits in linseed (*Linum usitatissimum* L.). Eighteen diverse linseed genotypes were evaluated for twelve agro morphological characters to assess the genetic parameters of variability. Analysis of variance indicated presence of a wide range of genetic variability among genotypes for all the traits. The higher phenotypic coefficient values than corresponding genotypic coefficient values depicted influence of environment in the expression of traits. Technical height exhibited highest GCV value while the lowest GCV was observed for days to maturity. High estimates of PCV and GCV indicate sufficient variability, signifying the effectiveness of the selection of desirable types for improvement of such characters. The high expected genetic advance expressed as percentage of mean were recorded for technical height, aerial biomass per plant, plant height, primary branches per plant and secondary branches per plant. High heritability with moderate genetic advance was observed for technical height indicating the presence of additive and non- additive gene action. Path analysis revealed, direct and indirect effects of genotypic path coefficient were higher in magnitude than the corresponding phenotypic path coefficients. Highest positive direct effect on seed yield was shown harvest index followed by aerial biomass, plant height, secondary branches per plant and days to maturity.

Rathod *et. al.* (2021) carried out investigation to evaluate the genetic variability, heritability and genetic advance estimates in sixty two genotypes along with two local checks PBNS-12 and A-1 of safflower. Analysis of variance involving 64 genotypes of safflower for eleven quantitative characters. The results revealed highly significant mean sum of squares for all the characters indicating greater diversity among the genotypes. Phenotypic coefficient of variation was higher in magnitude than the genotypic coefficient of variation in respect of all the characters indicating the effect of the environment. Number of secondary branches per plant, seed yield per plant, number of primary branches per plant, number of effective capitula per plant, number of seeds per capitula shown high phenotypic and genotypic coefficient of variation. Heritability in broad sense was higher for almost all the

characters except hull content and oil content. High heritability coupled with high genetic advance as percent of mean was observed for number of secondary branches per plant followed by seed yield per plant, number of seeds per capitula, number of primary branches/ plant, number of effective capitula per plant, plant height, 100 seed weight indicating the role of additive genes in governing the inheritance of these traits which could be improved through simple selection.

2.7 Correlation and path analysis

Seed yield is a function of two or more component traits. The genetic associations between yield and its components are useful for determining the impact of selecting for one or more traits.

The correlation coefficient analysis aids in determining the nature and extent of any relationship between two measurable variables. It does not, however, take into account the dependence of one variable on the other. Furthermore, simple correlations cannot distinguish the direct contribution of each component. This gap is filled by path coefficient analysis. Wright (1921) was the first to use it to estimate the direct and indirect effects of a group of variables that were all related to one another. This technique requires cause and effect situation of the variables.

The available literature on correlation and path analysis on seed yield with their component traits in safflower and other oilseed crops is briefly reviewed.

Khan *et. al.* (2000) carried out investigation to determine correlations and path coefficients among different parameters, to differentiate the contribution made by each parameter in the final seed yield. Thirty genotypes of diverse origin of *Brassica napus* L. were grown for estimation of correlation and path coefficient. Branches per plant had the highest correlation (0.397) followed by pods per plant (0.282) and plant height (0.030). Path coefficient analysis revealed that branches per plant had a direct effect (0.649) on seed yield followed by 1000 seed weight (0.338) and pods per plant (0.066). 1000 seed weight has a negative indirect effect via branches per plant (-0.263) and pod length (-0.295) on seed yield. The important characters effecting seed yield in this study were branches per plant, 1000 seed weight and pods per plant.

Bidgoli *et. al.* (2006) carried out investigation to study the path analysis and association between seed yield and some morphological and phenological traits in

safflower (*Carthamus tinctorius* L.). Seed yield was significantly correlated with the traits *viz.,* total biomass, stem yield, capitulum diameter, 1000 seed weight, seed weight/ capitulum, distance between ground level and the first fertile branch, number of days to the beginning of branching and flowering duration. Total biomass, seed weight/ capitulum, distance between ground level and the first fertile branch, 1000 seed weight and flowering duration had substantial direct effects, in that order, on enhancement of seed yield. The significant positive correlation coefficient of capitulum diameter with seed yield resulted from positive indirect effects of total biomass, seed weight/ capitulum and 1000 seed weight. Conversely, the significant negative correlations between number of days to the beginning of branching and distance between ground level and the first fertile branch and seed yield resulted from negative indirect effects of the same three traits. Stepwise multiple regression analysis showed that 94% of the total variation in seed yield could be explained by variation in total biomass and by number of days to the beginning of branching (84 and 10%, respectively). Results suggest that total biomass and number of days to the beginning of branching are primary selection criteria for improving seed yield in safflower.

Arslan B. (2007) carried out investigation to determine the relations among yield and some characters of safflower using correlations and path coefficient analysis. Simple correlation analysis and path analysis were applied to the means of 15 genotypes in order to determine the relationships between agronomic characters and estimate the direct and indirect effects of agronomic characters on seed yield. Based on the results, positive and significant correlations were found between seed yield and all investigated traits excepts primary branches/ plant (r= -0.466**) and 1000 seed weight (r= -0.220*). According to the path analysis, it can be also that seed yield was determined by head diameter, heads/ plant and seeds/ head since these characters had highly positive significant direct effects on seed yield.

Topal *et. al.* (2010) carried out investigation to study the path analysis of seed yield components using different correlation coefficient in safflower (*Carthemus tinctorius* L.). Direct and indirect effects estimated with parametric and nonparametric path analysis exhibited similarly but parametric path analysis was preferred to non parametric path analysis. Because, residual effects of paracentric path analysis are lower than that of nonparametric path analysis. Furthermore, determination coefficients of parametric path analysis were higher than that of non parametric path

analysis in both years. The direct effect of oil yield and indirect effect of number of seed / head on seed yield via oil yield were found large by parametric and non parametric path analysis. It was concluded that oil content, number of seed / head and plant height were important selection characters for seed yield of safflower under drought conditions.

Yasin, A.B. and Singh, S. (2010) carried out investigation to study the correlation and path coefficient analyses in twenty four diverse genotypes of safflower in order to understand the relationship and contribution on eight characters towards the grain yield. The seed yield per plant exhibits highly significant and positive correlation with number of seeds per head, head length in diameter and 1000 seed weight at both genotypic and phenotypic level. Path coefficient analysis revealed that number of seeds per head, 1000- seed weight and head length in diameter had the highest and positive direct effect with yield kg per plant. Hence, the study revealed the importance of number of seeds per head, head length in diameter and 1000- seed weight as selection criteria for improvement of yield in sunflower.

Ahire *et. al.* (2012) carried out investigation to study the correlation and coefficient of variation in soybean to estimates the best selection criteria of mutants for improving oil quality through determination of interrelationships between fatty acid and oil quality parameters. Correlation analysis showed that a highly significant ($P< 0.01$) negative correlation of oleic (MUFA) with linoleic (r=-0.847) and linolenic acid (r= -0.692) (PUFAs) contents is important for selection of mutants with high oleic and low linoleic acid content to improve the oxidative stability index (OSI) of soybean oil. A strong significant but negative correlation was found between linoleic acid and the omega6/ omega3 ratio (r=-0.764) and a strong significant positive correlation between OSI and oleic acid (r= 0.938) content indicating improved oxidative stability of the oil while retaining nutritional quality. Mutagenic treatments produced significant genetic variation in fatty acid composition and oil quality without altering the population means. Among all quality parameters, OSI (50.0%) and steric acid (62.8%) exhibited maximum variation compared to other traits among the fatty acids.

Behnam *et. al.* (2012) carried out experiment to evaluate the correlation between yield and other quantitative traits in safflower (*Carthamus tinctorius* L.)

using six genotypes under three water stress conditions *i.e.* normal, stress at stem elongation and flowering stages. Correlation analysis revealed significant correlation between oil and seed yield in normal and stress conditions. The result indicated that the stress tolerance index, geometric mean productivity and arithmetic mean productivity could be used for selection of drought tolerant genotypes. According to the path analysis in a normal and stressed conditions seed yield had highest and positive direct effect on seed yield through number of head per plant and 1000 seed weight, while in stressed conditions, 1000 seed weight and number of seed per head showed the highest direct effect on seed yield.

Bahmankar *et. al.* (2014) carried out investigation to study phenotypic correlation, multiple stepwise regressions and path analysis to evaluate the relationship between yield and components yield using 20 different safflower genotypes. Phenotypic correlation indicated that seed yield per plants had highly positive correlation with 1000 seed weight (r= 0.79**), main head diameter (r= 0.77**) and heads per plants (r= 0.49*). Stepwise multiple linear regression interpretation also indicated that 90% of variation in seed yield attributed to variation which arose from 1000 seed weight, heads per plants, main head diameter and plant height characters. The results of path analysis strongly suggested that 1000 seed weight; heads per plants and main head diameter contain positive direct effect on seed yield. Therefore, it could be concluded that number of head per plant, 1000 seed weight, main head diameter and plant height are putative morphological markers which can be considered as the desirable tools for screening elite safflower genotype under the field conditions.

Tariq *et. al.* (2014) conducted an experiment to examine the genotypic and phenotypic correlation coefficients, as well as the path effects of yield-related characteristics on seed yield by using 20 genotypes of safflower. Plant height, boll diameter, number of seeds per boll, 1000 seed weight and days to maturity all had significant and positive correlations with seed yield (kg/ ha). As a result, these are the primary yield contributing traits that should be subjected to selection pressure in order to improve yield. The number of seeds per boll had the greatest and most favorable direct effect on seed yield (kg/ha), followed by 1000 seed weight and plant height.

Bhakre *et. al.* (2015) carried out investigation to study the correlation and path analysis in 150 germplasm lines of safflower. The yield / plant was positively and significantly correlated with number of capitula/ plant, plant height, number of seed/ capitula and 100 seed weight. Seed yield was also negatively correlated with height of insertion of first primary branch from ground level. Number of capitula per plant inserted highest positive direct effect on seed yield / plant followed by number of seeds/ capitulum, plant height and 100 seed weight. The high residual effect of 0.578 indicates that there are some other characters, other than these which affect seed yield/ plant.

Baloch *et. al.* (2016) carried out experiment to evaluate the advance sunflower (*Helianthus annus* L.) genotypes (18) for genetic parameters including phenotypic correlation and heritability. The mean squares were differed significantly ($P \leq 0.01$) for all the studied traits. The correlation results depicted that traits such as, plant height, head diameter, seeds head per plant and seed index established positive and significant correlations with seed yield per plant, demonstrating that genotypes having higher extent of these traits may be preferred in selection for evolving high yielding sunflower genotypes. High heritability estimates (broad sense) were detected for all the studied traits except head diameter, which expressed moderate heritability, representing that the variations witnessed was generally under the control of genetical factors than that of environmental factors; therefore, these character may be improved directly on the basis of phenotypic selection.

Pavithra *et. al.* (2016) carried out experiment to determine the relationships among yield and yield components in safflower (*Carthamus tinctorius* L.). One hundred and fifty safflower germplasm accessions were evaluated to study the correlation and path coefficients for 15 quantitative traits. Correlation analysis revealed significant positive correlation between seed yield per plant and other characters like plant height, capitula per plant, number of seed per capitulum, biological yield and harvest index and significant negative with rosette period, days to 50% flowering and days to maturity. Path analysis revealed that all significantly correlated traits exhibited positive direct effect on seed yield except days to maturity.

Kadam *et. al.* (2018) carried out investigation to study the character association and path analysis in summer groundnut (*Arachis hypogaea* L.). The thirty

elite genotypes of groundnut were evaluated and the observation of fifteen characters was recorded. The association between dry pod yield per plant and other quantitative characters showed significant and positive correlation with number of mature pods per plant, dry biomass, number of pegs per plant, fresh pod yield per plant, fresh biomass, fresh fodder yield per plant and immature pods per plant. Path coefficient analysis revealed that traits *viz.,* dry biomass, fresh fodder yield, number of mature pods and fresh pod yield per plant exhibited high direct effect as well as strong association with dry pod yield per plant indicating true and perfect relationship between them. On the basis of relative contribution the fresh biomass, plant height, dry pod yield, fresh pod yield, plant spread were the main characteristic contributing to the genetic divergence.

Singh *et. al.* (2018) carried out investigation to analyze correlation for seed yield and its component traits in fifty sunflower genotypes. Correlation studies revealed that seed yield per plant was positively and significantly associated with 100-seed weight, seed volume weight, head diameter, duration of reproductive phase and oil content. Oil content was positively associated with duration of reproductive phase, head diameter and seed volume weight, whereas the association between hull content and oil content was found to be highly significant and negative.

Dhage *et. al.* (2020) carried out investigation to estimates the association of yield and yield contributing characters in Safflower (*Carthamus tinctorius* L.) The set of 63 genotypes along with three check *viz.,* A-1, PBNS-12 and PKV-pink were evaluated. Correlation studies revealed that, the seed yield per plant was significantly and positively correlated with plant height, number of branches per plant, number of capitula per plant, number of seeds per capitulum, 100 seed weight and volume weight whereas negatively and non significantly with days to 50% flowering, days to maturity and oil content.

Pattar, V. K. and Patil, R. (2020) carried out investigation to evaluate the association among yield components and their direct and indirect influence on grain yield of Safflower (*Carthamus tinctorius* L.) using 11 genotypes. The phenotypic correlation among the traits and their path coefficients were estimated. Positive and significant correlations were observed between grain yield and number of capitula per plant and 100 seed weight. Plant height, number of seeds per capitulum and oil

content exhibited significant negative correlation with seed yield. Positive direct effects were exhibited for number of capitula per plant and 100 seed weight. Negative direct effects were observed for plant height, number of seeds per capitulum and oil content. Therefore, improvement of the seed yield will be efficient via selection for number of capitula per plant and 100 seed weight.

CHAPTER-III

MATERIALS AND METHODS

CHAPTER - III

MATERIALS AND METHODS

The current study, titled "Genetic improvement of safflower (*Carthamus tinctorius* L.) through induced mutation," was conducted during *Rabi* 2019-20 in M_1 generation and *Rabi* 2020-21 in M_2 generation at the All India Coordinated Research Project on Safflower, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. This chapter mainly focuses on the details of the materials and the methods used during the research.

The All India Coordinated Research Project on Safflower, VNMKV, Parbhani, is located at latitude 190^0 16' N, longitude 670^0 47' E and an altitude of 409.0 m above mean sea level (msl), with a shallow to medium black soil type. Appendix l contains data on meteorological parameters such as rainfall, minimum and maximum temperature and relative humidity obtained from Metrological Department, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani during the crop growing period.

3.1 Experimental materials

3.1.1 Genotypes

For mutagenic treatments, the experimental material used PBNS-12 (Parbhani Kusum), a widely used and popular variety of safflower (*Carthamus tinctorius* L.). The pure seeds of PBNS-12 variety were obtained from the safflower breeder, AICRP on Safflower, VNMKV, Parbhani. In India, this variety is suggested for cultivation. A brief summary of this variety is given in Table- 1

Table 3.1: Salient features of Safflower genotypes used in the study

Characteristics	Variety PBNS-12
	Description
Plant Height (cm)	95-100 cm
Days to 50% flowering (days)	83-90 day
Maturity duration (days)	135-140 day
Corolla colour at bloom	Yellow
Corolla colour at drying	Orange
Leaf texture	Thick
Seed colour	Creamish white
100 seed weight(g)	5.6 to 6.2 gm.
Oil content (%)	28-29%
Oleic acid content (%)	13.9%
Linoleic acid content (%)	72.2%
Palmatic acid content (%)	6.2%
Steric acid content (%)	2.4%
Seed Yield	Rainfed- 12-15 q/ha. Irrigated- 20q/ha.
Oil Yield	5.4 to 5.6 q/ha.

3.1.2 Mutagens

Physical mutagen (gamma ray), chemical mutagen (ethyl methyl sulphonate) and their combinations were used to treat experimental material in this study. Table-2 describes the source and mode of action of this mutagen.

Table 3.2: Source and mode of action of mutagens

Sr. No.	Mutagen	Source	Mode of action
1)	**Physical mutagen**		
a)	Gamma rays	Cobalt (CO^{60}) (Dose rate 2.39 kR min^{-1})	Ionization
2)	**Chemical mutagen**		
a)	Ethyl Methane Sulphonate (EMS) C_2H_5 O SO_2 CH_3	Eastman Kodak Chemical Rochester, New York 14650 USA Loba chemicals, India	Alkylation

3.2 Methods

3.2.1 Mutagenic treatment with gamma rays.

200 uniform, pure, dry and well-filled seeds of variety PBNS-12 with about 8-10 percent moisture were exposed to 100, 200, 300, 400 and 500 Gy doses of gamma rays (CO^{60}) at a dose rate of 23.9 Gy per minute at the Nuclear and Agriculture Division, B.A.R.C., Trombay, while the same number of untreated seeds of this variety served as a control.

3.2.2 Method of preparation of chemical mutagen.

Chemical mutagen specificity is determined by treatment conditions, the most crucial of which are temperature and hydrogen ion concentration. In this investigation, ethyl methane sulphonate solution was made by dissolving a suitable amount of chemical in a phosphate buffer with a pH of 7.0 and adjusting the final pH to 7.0 with a few drops of standard NaOH.

3.2.2.1 Mutagenic treatment with EMS.

The uniform, pure, dry and well filled 200 seeds of variety PBNS-12 were presoaked in distilled water for 3 hours and then dipped in enough mutagenic solution of chemical mutagens of different concentrations and durations as show in Table 3. All of the treatments were done for 18 hours in a shaker at 200 rpm at 25+2 ^{o}C. It should be noted that the seed for the control corresponding to the various chemical

mutagenic treatments was treated in the same way as the control corresponding to the different chemical mutagenic treatments, with the exception that the chemical solutions were replaced by the buffer solution. As a result, the control seeds were exposed to similar physiological conditions before sowing as the treated seeds, although not having been exposed to chemical mutagens.

Table 3.3: Details of mutagenic treatments given to safflower seeds.

Mutagens	Dose/ concentration	Duration of pre-soaking (hrs)	Duration of treatment (hrs)	P^H buffer solution	Number of seeds treated
Gamma rays	100Gy	--	-	-	200
	200Gy	-	-	-	200
	300Gy	-	-	-	200
	400Gy	-	-	-	200
	500 Gy	-	-	-	200
EMS	0.1%	3	18	7.0	200
	0.2%	3	18	7.0	200
	0.3%	3	18	7.0	200
	0.4%	3	18	7.0	200
Gamma rays and EMS	200Gy+0.1% EMS	3	18	7.0	200
	200Gy+ 0.2% EMS	3	18	7.0	200
	300Gy + 0.1% EMS	3	18	7.0	200
	300Gy + 0.2% EMS	3	18	7.0	200
Dry control	-	-	-	-	200
Wet control	Phosphate buffer	-	-	7.0	200

3.3 Experimental Details

The experimental material consisted of 15 treatments, 13 of which were treated and two were untreated controls. The field experiment on Safflower was conducted on the AICRP research farm, VNMKV, Parbhani during *Rabi* 2019-20 in M_1 generation and 2020-21 in M_2 generation.

The details of experimental layout were as under.

1. Design	: Randomized Block Design
2. Treatments	: 15 (13 treated + 2 untreated control)
3. Replications	: 3 (Three)
4. Plot size	: 5.00 m x 2.25 m
5. Spacing	: Row to Row – 45 cm Plant to Plant- 20 cm
6. Method of sowing	: Dibbling
7. Fertilizer dose	: 60 kg N: 30 kg P: 00 kg K (kg/ha)

3.4 Studies in M_1 generation

Post treatment handling of seeds material and raising M_1 Generation.

Seeds treated with chemical mutagens were thoroughly washed in tap water to remove any traces of mutagens before being dibbling one seed $hill^{-1}$ at a distance of 45 cm between rows and 20 cm between seeds in the experimental field at AICRP on Safflower, Vasantrao Naik Marathawada Krishi Vidyapeeth, Parbhani during *Rabi* 2019-20 on dated 13 November 2019. The experiment was set up in a three-replication randomized block design (RBD). To raise a good crop, recommended package of practices were followed.

The treated seeds were space planted in M_1 generation and individual M_1 surviving plants were selfed by nylon net bags before initiation of flowering. From each plant, first formed three capsules were selfed and selfed capsule of an individual was threshed and seeds of each plant were kept separately for raising M_2 generation.

3.4.1 Observation recorded in M_1 generation for estimating mutagenic sensitivity

3.4.1.1 Emergence (%)

Emergence was determined by the appearance of cotyledonary leaves above the ground surface. The observations were recorded on the 10^{th}, 12^{th} and 15^{th} day after sowing and reported in percentages.

Emergence percentage was calculated by using the following formula:

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

3.4.1.2 Plant Survival (%)

The number of seedlings that survived 30 days after sowing was counted. The following formula was used to compute the survival percentage:

$$\text{Survival (\%)} = \frac{\text{Total no. of seeds survived}}{\text{Total no. of seeds emerged}} \times 100$$

3.4.1.3 Plant height (cm):

Plant height was recorded in centimeters at maturity stage from base of the plant to main capitula.

3.4.1.4 Pollen sterility/ fertility:

Pollen sterility/ fertility were observed by pollen viability test.

3.4.1.5 Days to 50% flowering:

The date of 50 % flowering was recorded and from sowing to 50% flowering, the number days were counted.

3.4.1.6 Days to maturity:

The number of days it took for seeds to mature from the day of sowing was recorded at the time of harvesting.

3.4.1.7 Seed yield per plant (g):

The total weight of the seeds per plant was measured and tabulated in grams.

3.5 Studies in M_2 generation

In each treatment, the M_2 generation was cultivated individually from all the M_1 plants harvested using the plant to row progeny method. Seeds were thoroughly mixed before samples were drawn. Each treatment was sown in a plot size of 6.4 × 5.0 m^2. The seeds were dibbled at the rate of one seed $hill^{-1}$ at a spacing of 45 cm

between rows and 20 cm between seeds at the experimental field at AICRP on Safflower, Vasantrao Naik Marathawada Krishi Vidyapeeth, Parbhani on 10th November 2020. In three replications, about 1000 plants were maintained for each treatment. Plots containing control plants were also kept for observing the results.

3.5.1 Observation in M_2 generation

3.5.1.1 Chlorophyll mutations

The chlorophyll mutations were thoroughly assessed in on M_2 generation. Such mutations were counted and recorded upto 15th day after sowing. They were categorized according to method suggested by Gustafsson (1940) and are presented as indicated below:

a) Albino:

Seedlings that lack chlorophyll or carotenoid pigments are colourless and non-viable.

b) Xantha:

The majority of the pigments are carotenoids, but no chlorophylls are generated; they are yellow and non-viable.

c) Chlorina:

Seedlings that are generally viable and light green to yellow green in colour. They eventually return to their original state.

d) Viridis:

Patches of light yellow and green appear in a regular or irregular pattern. Normally, they are viable.

e) Xanthaviridis:

The leaves had a yellow apex and were green in colour. These mutants were able to survive.

3.5.1.2 Viable mutations

The viable mutations that differed from the control plants up to harvest day, but were not deadly were recorded. Changes in leaf structure, highly branching forms, dwarf plants, sterile plants, seed size, seed coat colour and capsule diameter were all reported as viable mutations.

3.5.1.3 Estimation of mutation frequency

The frequency of both chlorophyll and viable mutations was computed using the formulae recommended by Gaul (1958)

$$\text{Mutation frequency (\%)} = \frac{\text{Number of mutations}}{\text{Total number of plants scored}} \times 100$$

3.5.1.4 Estimation of mutagenic effectiveness and efficiency of mutagens

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 and pollen sterility. Both these were estimated using the formulae suggested by Konzak *et al.* (1965)

$$\text{Mutagenic effectiveness (Physical mutagen)} = \frac{\text{Mutation frequency}}{\text{Dose in kilo roentgens (kR)}} \times 100$$

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

$$\text{Mutagenic efficiency} = \frac{\text{Mutation frequency}}{\text{Pollen sterility (\%)}} \times 100$$

3.5.1.5 Observations recorded in M_2 generation

For assessing the variation created in quantitative characters in M_2 generation, 300 plants were randomly selected from each treatment including control and observations were recorded on the following quantitative and qualitative characters:

A) Quantitative characters:

a) Morphological characters:

1. Days to rosette period:

A rosette is a circular arrangement of leaves or leaf-like structures. From emergence to rosette stage, the number of days was counted.

2. Days to bolt:

Bolting is the production of a flowering stem (or stems) on agricultural and horticultural crops. The number of days was counted from emergence to bolting period.

3. Days to 50 % flowering:

The date of 50 per cent flowering was recorded and number of days was counted from sowing to 50 per cent flowering.

4. Flower colour:

Flower colour of safflower was noted at bloom and faded stage.

5. Leaf dentation:

Leaf dentation is a toothlike projection on leaf. The number dentation on leaf was calculated.

6. Plant height (cm):

Plant height was recorded in centimeters at maturity stage from base of plant to main capitula.

7. Days to maturity:

At the time of harvesting, the number of days it took for seeds to mature from the day of sowing was noted.

8. Number of primary branches per plant:

On the main stem, the total number of primary branches was counted and recorded.

9. Number of secondary branches per plant:

On primary branches, the total number of secondary branches present was counted and recorded.

10. Number of capsules per plant:

At the time of harvesting, the total number of capitula per plant was counted and recorded.

11. Number of spines on leaf (low/ medium/ strong):

At maturity, the total number of spines on each leaf was counted and recorded.

12. Diameter of main capitula (Head size) (cm):

At the time of harvesting, the diameter of the main capitula was measured and recorded.

b) Seed characters:

1. Number of seeds per capsule

Total number of seed per capsule were counted and recorded at the time of harvesting.

2. 100 seed weight (gm):

A randam sample of 100 seeds was taken from the bulk produce of each plant and weight was recorded in grams.

3. Seed width (mm):

The seed width was measured with the help of vernier calliper and recorded in millimetres.

4. Seed length (mm):

Seed length was measured with the help of vernier caliper and recorded in mm.

5. Seed yield per plants (gm):

The total weight of the seeds per plant was calculated and recorded in gram.

6. Hull content (%):

Hull is the outer shell or coating of a seed. The test weight of seeds was recorded and then presoaked in water for 12-15 hours and dry it. The outer shells of seeds were removed and take weight of hull. The percentage of hull content was calculated by using following formula:

$$\text{Percentage of hull content} = \frac{\text{Weight of hull content}}{\text{Test weight of seeds}} \times 100$$

B) Qualitative Characters:

1. Oil content (%):

The percentage of oil content was measured by NMR machine.

2. Oil quality (%) (Oleic, Linoleic, Palmatic and Steric acid):

The percentage of different fatty acid composition were measured by NMR machine and recorded in percent.

3.6 Statistical analysis

3.7.1.1 Determination of LD_{50}

LD_{50} values were determined for germination and survival of M_1 safflower genotypes used in this study by following Probit analysis (Sharma, 1998).

3.6.1.1 Analysis of variance

The mean values obtained for several characters in the M_1 and M_2 generations were employed for further statistical analysis. The statistical analysis for the Randomized Block Design was done using the standard approach of Analysis of Variance (Panse and Sukhatme 1954).

ANOVA

Source	D.F	SS	MSS	F.cal
Replication (r)	(r-1)	------	---------	---------
Varieties (v)	(v-1)	VSS	VSS/VDF	VMSS/EMSS
Treatments (Tr)	(Tr-1)	TrSS	TrSS/TrDF	TrMSS/EMSS
Interaction (I)	(v-1)	ISS	ISS/IDF	IMSS/EMSS
Error(E)	(Tr-1) (e-1)	ESS	ESS/EDF	----------
Total				

Following formulae are also used

1. SE of Variety SE= (VMSS/ n x r) $1^{/2}$
2. SE for treatment SE= (TrMSS / n x r) ^{½}
3. SE for Interaction SE= (EMSS/n x r) $^{1/2}$
4. CD = (2 x SE) $^{1/2}$ x t at 5%
5. SD= SS/ n
6. CV%= SD/ m x 100

Where, n = no. of observation
r = no. of replication

3.6.1.2 Variability studies

The induced variation in polygenic characteristics was evaluated using statistical parameters such as mean, standard error and variance for each treatment for all the traits studied in different generations based on observations recorded in M_1 and M_2 generations.

The following formulae were used to determine genotypic variance, phenotypic variance, genotypic coefficient of variation, phenotypic coefficient of variation, genetic advance, and heritability in a broad sense.

1. Genotypic variance ($\sigma^2 g$) = $\frac{\text{Treatment MSS - Error MSS}}{\text{No. of replications}}$

2. Phenotypic variance ($\sigma^2 p$) = Genotypic variance + Error variance.

According to Burton (1952), the genotypic and phenotypic coefficients of variation (GCV and PCV) were determined.

3. Genotypic coefficient of variation (GCV) = $\frac{\sigma^2 g}{\bar{X}} \times 100$

4. Phenotypic coefficient of variation (PCV) = $\frac{\sigma^2 p}{\bar{X}} \times 100$

Where,

$\sigma^2 g$ = genotypic variance

$\sigma^2 p$ = phenotypic variance

$\bar{X}$ = general mean of character

5. Heritability in broad sense.

Heritability (broad sense) was calculated according to the method suggested by Hanson *et. al.* (1956).

$$\text{Heritability } (h^2) \text{ B. S.} = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Where,

$\sigma^2 g$ = genotypic variance

$\sigma^2 p$ = phenotypic variance

6. Genetic advance (GA)

The formula was used to calculate the amount of genetic advance that may be expected for each quantitative attribute (Allard, 1960)

$$GA = K.\ \sigma_p\ h^2\ (bs)$$

Where,

GA = Genetic advance

K = Standardized selection differential

{K = 2.06 assuming 5 per cent selection intensity}

h^2= Heritability

σ_p = Phenotypic standard deviation

7. Genetic advance as per cent of mean (GAM)

$$GAM = \frac{GA}{\bar{X}} \times 100$$

Where,

GA = genetic advance

$\overline{X}$ = general mean of character

3.6.2 Association analysis

3.6.2.1 Correlation coefficients

Phenotypic correlation coefficients were estimated from the variance and covariance components by following the method given by Al-Jibouri *et. al.* (1958)

$$\text{Phenotypic correlation} = r_{xy} \qquad \frac{\text{Cov. (x.y.)}}{\sqrt{\sigma\ 2x.\sigma\ 2y.}}$$

Where,

Cov. (x.y.) = Phenotypic covariance between character x and y

σ^2x and σ2y = respective variances of x and y

The significance of phenotypic correlation coefficients was tested against 'r' value given by Fisher and Yates (1963).

3.7.2.2 Path coefficient analysis

In path coefficient analysis, the cause and effect relationship is well defined. The path coefficient analysis is simply a standardized partial regression coefficient

that splits the correlation coefficient into measures of direct and indirect effects, i.e. it measures the direct and indirect contributions of various independent characters on the dependent character.

Wright (1921) proposed path coefficient analysis, which elaborated by Deway and Lu (1959). The direct path coefficients were determined using the simplified Doolittle technique to solve the following set of 'P' simultaneous equations.

$$P_{01} + P_{02}\, r_{12} + \ldots\ldots\ldots\ldots P_{0p}\, r_{1p} = r_{01}$$

$$P_{01}\, r_{12} + P_{02} + \ldots\ldots\ldots\ldots P_{0p}\, r_{2p} = r_{02}$$

$$P_{01}\, r_{10} + P_{02}\, r_2\, P + \ldots\ldots\ldots\ldots P_{0p} = r_{0p}$$

Where,

$P_{01,}\ P_{02}$ ..... P_{0p} are the path effects of 1, 2, ... P variables on '0' variable.

$r_{12,}\ r_{13,}$ ..... r_{1p} ..... r_p (P-1) are the possible correlation coefficients between various independent variable and $r_{01,}\ r_{02}$ ..... r_{0p} are the correlations of independent variables with dependent variable. The different effects of 'i' th variable *via* 'j' th variable was worked out as (P_{oj} x P_{ij}).

From the simultaneous equation it is clear that the correlation coefficient is the sum of direct and indirect path coefficients.

Residual effect was calculated as under

$$P^2_{0x} = 1 - (P^2_{01} + 2P_{01}P_{02}\, r_{12} + 2P_{01}\, P_{03} r_{13} + \ldots\ldots P^2_{02} + 2P_{02}\, P_{03}\, r_{23} + \ldots\ldots P^2_{0p})$$

Residual factor = $\sqrt{P20x}$

CHAPTER-IV

RESULTS AND DISCUSSION

CHAPTER - IV

RESULTS AND DISCUSSION

The presence of genetic variability for economic traits is a critical factor in enhancing locally adapted varieties for specific attributes. The experimental results and their consequences of the current study "Genetic improvement of Safflower (*Carthamus tinctorius* L.) through induced mutation" are presented under the following subheadings:

4.1. Studies in M_1 generation

4.1.1 Mutagenic sensitivity studies in M_1 generation.

4.1.1.1 Emergence (%)

4.1.1.2 Plant survival (%)

4.1.1.3 Pollen sterility (%)

4.1.1.4 Estimation of LD_{50} based on Plant survival (%):

4.1.2 Induced polygenic variance studies in M_1 generation for various traits.

4.2 Studies in M_2 generation

4.2.1 Chlorophyll mutations studies in M_2 generation

4.2.1.1 Frequency of chlorophyll mutations

4.2.1.2 Spectrum of chlorophyll mutation in M_2 generation

4.2.2 Viable mutations studies in M_2 generation

4.2.2.1 Frequency of viable mutations

4.2.2.2 Spectrum of viable mutations

4.2.3 Estimates of mutagenic effectiveness and efficiency

4.2.4 Induced polygenic variability studies in M_2 generations for various traits.

4.2.5 Correlation studies in M_2 generation.

4.2.6 Path coefficient analysis studies in M_2 generation.

4.1 Studies in M_1 generation

4.1.1 Mutagenic sensitivity studies in M_1 generation.

Mutagenic sensitivity in general is known to be influenced by group of factors which include moisture content, temperature, storage of the seed, gaseous composition, P^H, concentration of catalytic ions, various pre and post treatment conditions, genetic constitution of the material treated, strength of the mutagen used, duration of the treatment etc. (Konzak *et. al.*, 1965, Blixt *et. al.*, 1967 and Narayanan and Konzak, 1969). Mutagenic sensitivity was determined in the present study using various criteria such as percent emergence and plant survival in the M_1 generation, chlorophyll mutants, and viable mutation frequency in the M_2 generation.

4.1.1.1 Emergence (%)

During the M_1 generation, the influence of various doses of gamma rays, ethyl methane sulphonate (EMS) and their combinations on seed emergence in the PBNS-12 variety of Safflower was investigated and the results are provided in Table 4.1.

The results demonstrated significant impacts of varying mutagen dosages on seed emergence for all of the mutagens examined. When compared to control, the seed emergence percentage of PBNS-12 was decreased in all mutagenic treatments. The highest percentage reduction in seed emergence was recorded with a 500 Gy gamma ray dose followed by a 300Gy +0.2 % EMS dose of combination. The lowest emergence percentage (17.6%) was achieved with a 500 Gy gamma ray treatment, followed by a combination dose of 300 Gy + 0.2% EMS (29.6%). The maximum emergence percentage (83.4%) was found in the 0.1% EMS concentration followed by a 100 Gy (80.4%) dose of gamma rays.

The degree of radio sensitivity and the extent of genetic as well as physiological damage caused by the mutagen are determined by inhibition of emergence. In the current study, seed emergence rate declined with increasing doses/concentrations under both physical and chemical mutagenic treatments. Boureima *et. al.* (2009) in African Sesame, Kharade *et. al.* (2016) in Groundnut, Kumari *et. al.* (2016) in Sesame, Bhoite *et. al.* (2019) in Soybean, Sandhiya *et. al.* (2020) in Sesame and Emrani *et. al.* (2011) in *B. napus* has all shown similar results.

Table 4.1: Effect of different mutagens on emergence, plantsurvival and pollen sterility in M_1generation of safflower variety PBNS-12.

Sr. No.	Treatments	Emergence (%)	Plant Survival (%)	Pollen sterility (%)
1	100 Gy	80.4	78.15	2.45
2	200 Gy	70.4	69.23	2.70
3	300 Gy	68.2	65.06	3.71
4	400 Gy	62.8	60.86	4.72
5	500 Gy	17.6	1	-
6	0.1% EMS	83.4	75.30	2.54
7	0.2% EMS	73.6	72.41	3.45
8	0.3% EMS	65.2	49.61	3.92
9	0.4% EMS	61.6	24.45	4.49
10	200 Gy + 0.1% EMS	78.8	74	3.39
11	200 Gy + 0.2% EMS	59.6	30.67	3.65
12	300 Gy + 0.1% EMS	63.3	54.38	4.64
13	300 Gy + 0.2% EMS	29.6	14.55	4.97
14	Dry Control	90.4	89.13	0.35
15	Wet Control	88.4	87.95	0.29

4.1.1.2 Plant survival (%)

The effect of various dosages of gamma rays, ethyl methane sulphonate (EMS) and their combinations on plant survival in PBNS-12 variety of Safflower were studied during M_1generation and results are given in Table 4.1.

For all of the mutagens tested, the results showed that different dosages of both physical (gamma rays) and chemical (EMS) and their combinations had significant effects on plant survival. In all of the mutagenic treatments, the percentage of plants that survived was lower than in the control. The 100 Gy gamma ray dosage was followed by 0.1% EMS (75.30 percent) and 200 Gy +0.1 % EMS (74 percent) doses/concentrations of mutagenic treatments, which resulted in the highest plant survival percentage (78.15 percent) of the PBNS-12 safflower variety.

Gamma rays caused the greatest decline in plant survival percentage, followed by combination and EMS treatments. The lowest plant survival percentage (1%) was obtained with a 500 Gy dose of gamma rays followed by doses/concentrations of mutagenic treatments of 300 Gy+ 0.2 % EMS (14.55 percent), 0.4 % EMS (24.45 percent) and 200 Gy+ 0.2% EMS (30.67 percent). In the current study, the plant survival ratio declined as the doses/concentrations of both physical and chemical

mutagenic treatments as well as their combinations were increased over the control in the M_1 generation.Similar types of results have been reported by Boureima *et. al.* (2009) in African Sesame, Satpute and Kothekar (1996) in Safflower, Bhoite *et. al.* (2019) in Soybean, Singh *et. al.*(2018) in Sesame, Kumar *et. al.* (2010) in Sunflower and Diouf *et. al.*(2010) in Sesame.

4.1.1.3 Pollen sterility (%)

The impact of various doses of gamma rays, ethyl methane sulphonate (EMS), and their combinations on pollen fertility in the PBNS-12 variety of Safflower was investigated during M_1 generations and the results of pollen sterility % are mentioned in Table 4.1.

For all of the mutagens studied, the results demonstrated that varied dosages of both physical (gamma rays) and chemical (EMS) and their combinations had significant effects on pollen sterility. The pollen sterility percentage of PBNS-12 was higher in all mutagenic treatments than in the control in this study. Deshpande and Malode (2015) found that pollen fertility was lower in all of the mutagenic treatments compared to the control in Linseed. The 300 Gy + 0.2 percent EMS dose of combination treatment produced the highest pollen sterility percentage (4.97%), followed by 400 Gy (4.72%), 300 Gy+ 0.1 percent EMS (4.64%) and 0.4 percent EMS (4.49%) doses/concentrations of mutagenic treatments.

Gamma rays were used to determine the minimal pollen sterility percentage, which was then followed by EMS treatments. The lowest pollen sterility percentage (2.45%) was found at a 100 Gy gamma ray dose followed by a 0.1 percent EMS (2.45%) mutagenic treatment concentration. In the current study, the pollen sterility rate increased as the dose/concentrations of both physical and chemical mutagenic treatments as well as their combinations were raised in the M_1 generation. Singh *et. al.* (2018) found that increasing the dose of gamma rays singly and in combination treatments reduced pollen fertility % in Sesame (*Sesamum indicum* L.).Also the results are in agreement with the work done by Kumari *et. al.* (2016) in Sesame, Sahaand Paul (2017) in Sesame, Kumar *et.al.*(2010) in Sunflower, Rampure *et. al.*(2017) in Safflower and Kavithamani *et. al.* (2008) in Soybean.

Plate No. 4.1: Plant Survival is 0% in 500 Gy Gamma rays in M_1 generation

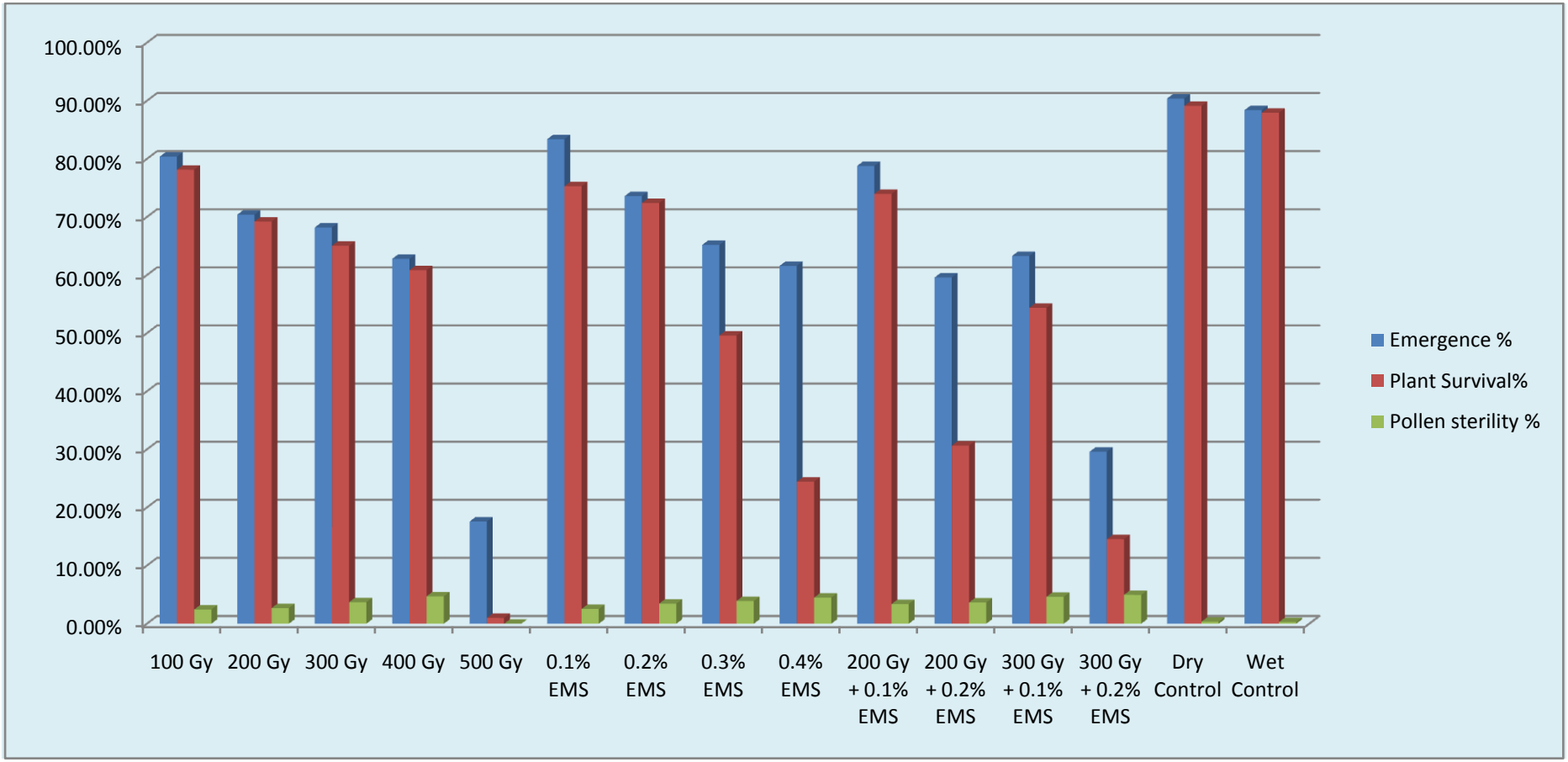


Figure 4.1: Effect of different mutagens on emergence, plant survival and pollen sterility in PBNS-12 variety of safflower in M_1 generation.

4.1.1.4 Estimation of LD_{50} based on Plant survival (%):

The LD_{50} value for both gamma rays and EMS are mentioned in Table 4.2 and 4.3, repectively. Based on mortality percentages and probit values, the LD_{50} value was computed. In the case of gamma rays, the LD_{50} value derived based on survival percentage was 299.5 Gy dose and 0.25 % EMS concentration in the case of EMS mutagenic treatments.

The mutagenic treatment given between 250-350 Gy in the case of gamma rays and 0.2-0.3 % concentration of EMS were appropriate for mutagenic treatment in safflower, according to the obtained LD_{50} values.

The optimal dose for high frequency mutations has been determined to be LD_{50} for artificially induced mutations using physical or chemical mutagens (Anbarasan *et. al.*, 2015). In this investigation the LD_{50} was computed on the basis of plant survival percentage at different doses of gamma rays and EMS. The LD_{50} of safflower (*Carthamus tinctorius* L.) variety PBNS-12 was found at 299.5 Gy and 0.25% of gamma rays and EMS dosage respectively.Similarly, Niu *et. al.,* (2009) estimated the optimum dose (LD_{50}) of gamma rays in safflower to be around 300 Gy, but no data on the optimum concentration (LD_{50}) of EMS was given.Yadav *et. al.* (2016) found that the optimum concentration (LD_{50}) of EMS in *S. alba* is around 0.3 % EMS concentration.

Table 4.2: Estimation of LD_{50} dose based on Plant survival (Gamma rays)

Dose of gamma rays (Gy)	Log_{10} value of dose	Reduction in Plant survival% (Dead %)	Probit value	LD_{50} value	LD_{50} Dose
100	2.00	21.85	4.23	2.4765	Antilog(2.4765) = 299.5 Gy
200	2.30	30.77	4.50		
300	2.48	34.94	4.61		
400	2.60	39.14	4.72		
500	2.70	99.00	6.28		

Table 4.3: Estimation of LD_{50} dose based on Plant survival (EMS)

Concentration of EMS (%)	Concentration of EMS (PPM)	Log_{10} value of concentration (PPM)	Reduction in Plant survival (%) (Dead %)	Probit value	LD_{50} value	LD_{50} dose
0.1	1000	3.00	24.70	4.33	3.4040	Antilog (3.4040) =2536.0 =0.2536%
0.2	2000	3.30	27.49	4.42		
0.3	3000	3.48	50.39	5.03		
0.4	4000	3.60	75.55	5.71		

4.1.2 Induced polygenic variance studies in M_1 generation for various traits.

For four quantitative features in the M_1 generation of the PBNS-12 safflower variety, the range, mean, variance and coefficient of variation were computed. The results showed that mutagenesis treatment raised the value of range, variance and coefficient of variation significantly over control in all mutagenic populations for all characters tested.

4.1.2.1 Plant height

The influence of various doses of gamma rays, ethyl methane sulphonate (EMS) and their combinations on plant height in the PBNS-12 variety of Safflower was investigated in the M_1 generation and the results are displayed in Table 4.4.

In M_1 generation, the range, mean, variance, and coefficient of variation for the plant height trait were calculated. The results showed that the M_1 generation had the greatest range of variance in plant height, indicating that mutagenic treatments had caused more variability within the M_1 generation. These findings are in accordance with those presented in Sesame by Sanghani *et. al.* (2016). The highest range of variation was seen with a 200 Gy gamma ray dosage followed by a 200 Gy+ 0.1 % EMS dose in a combined treatment.

The difference between mean values of all mutagenic treatments and mean values of control suggested that all mutagens tested were effective and caused variation in plant height in all the mutagenic populations in M_1 generation. These findings are largely consistent with Lande *et. al.*(2018) in Soybean and Sanghani *et. al.* (2016) in Sesame. The highest mean value for plant height (80.90) was observed

with a combination treatment of 200 Gy + 0.1% EMS followed by a gamma ray dose of 200 Gy (80.33).

The findings demonstrated a significant increase in variance in all mutagenic treatments as compared to the control. Siddiqui *et. al.* (2009) in Rapeseed and Begum and Dasgupta, (2014) in Sesame found similar observations. The highest value of variance (99.14) was obtained with 200 Gy gamma ray dose followed by 200 Gy + 0.1% EMS (95.14) dose of combination treatment over dry control (25.56) and wet control (12.46). The lowest value of variance (46.50) was obtained with 400 Gy gamma ray dose followed by 0.4 % EMS (52.57) concentration treatment.

The 200 Gy dose of gamma rays had the highest coefficient of variation (12.17 %) followed by 200 Gy + 0.1 % EMS (11.77 %) and 300 Gy + 0.1% EMS (11.06 %) doses of combination treatments as compared to dry control (5.47 %) and wet control (3.66 %). The lowest coefficient of variation (8.46%) was achieved with 400 Gy gamma ray dosage followed by 0.4 % EMS (9.53%) concentration treatment. In the current study, the coefficient of variation in the treated population was significantly higher than in the control population. These findings are consistent with the findings of Rai*et. al.* (2014), Siddiqui *et. al.* (2009) in Rapeseed and Lande *et. al.* (2018) in Soybean.

Table 4.4: Range, mean, variance and coefficient of variance (CV) for Plant height in M_1generation of safflower variety PBNS-12

Sr. No.	Treatments	Range (cm)	Mean ±SE	Variance	CV (%)
1	100 Gy	58-89	78.32±1.48	66.23	10.35
2	200 Gy	54-90	80.33±0.47	99.14	12.17
3	300 Gy	64-89	73.58±0.79	70.55	10.09
4	400 Gy	64-88	76.63±1.90	46.50	8.46
5	0.1% EMS	60-89	78.30±2.20	59.81	10.38
6	0.2% EMS	60-87	78.03±0.72	64.65	10.25
7	0.3% EMS	58-86	72.90±0.52	76.54	10.23
8	0.4% EMS	55-88	74.77±0.37	52.57	9.53
9	200 Gy + 0.1% EMS	54-90	80.90±0.98	95.14	11.77
10	200 Gy + 0.2% EMS	56-91	79.92±1.15	64.90	10.16
11	300 Gy + 0.1% EMS	54-88	72.32±1.85	64.44	11.06
12	300 Gy + 0.2% EMS	59-89	76.83±0.65	71.09	10.97
13	Dry Control	64-87	79.95±0.46	25.56	5.47
14	Wet Control	65-86	79.55±0.35	12.46	3.66

4.1.2.2 Days to 50% flowering

The action of various doses of gamma rays, ethyl methane sulphonate (EMS), and their combinations on days to 50% flowering in the PBNS-12 variety of Safflower was examined during M_1 generation and the results are reported in Table 4.5.

In M_1 generation, the range, mean, variance and coefficient of variation were computed for the days to 50% flowering characteristic. The results illustrated that the M_1 generation had the highest range of variation for days to 50% flowering, indicating that mutagenic treatments had induced more variability within the M_1 generation. These findings are in accordance with those stated in Rapeseed by Siddiqui *et. al.* (2009). The maximum range of variation was found at a 200 Gy gamma ray dose, followed by 0.3 % EMS concentration and a combination treatment of 200 Gy+0.1 % EMS dose.

The difference between the mean values of all mutagenic treatments and the mean values of control indicated that all of the mutagens tested were effective and created variability for days to 50% flowering in all mutagenic populations in the M_1 generation. These findings are consistent with the findings of Lande *et. al.* (2018) in Soybean. A 200 Gy dosage of gamma rays followed by a 200 Gy +0.1 % EMS

dose of combination treatment resulted in a considerable reduction in days to 50% flowering.

The findings showed a significant increase in variance in all the mutagenic treatments as compared to the control. Siddiqui *et. al.*(2009) in Rapeseed and Begum and Dasgupta, (2014) in Sesame found similar observations. The combination treatment of 200 Gy + 0.1 % EMS had the highest value of variance (58.38) followed by the 200 Gy (56.60) dose of gamma rays treatment over dry control (10.02) and wet control (5.89). The 0.2% EMS concentration treatment had the lowest amount of variance (36.94) followed by the 0.3 % EMS (37.03) concentration treatment.

The highest coefficient of variation (11.51 %) was found in the 200 Gy +0.1 % EMS concentration treatment, which was followed by 200 Gy (11.16 %) gamma rays and 300 Gy + % EMS (10.27 %) doses of combination treatments as compared to dry control (4.13 %) and wet control (2.97 %). The 0.2 % EMS concentration treatment had the lowest coefficient of variation (7.97%) followed by the 400 Gy (8.19%) gamma ray dose and the 0.3 % EMS (8.41%) concentration treatments. In the current study, the coefficient of variation in the treated population was significantly higher than in the control population. These results are supported by the findings of Rai *et. al.* (2014) and Lande *et. al.* (2018) in Soybean.

Table 4.5: Range, Mean, variance and coefficient of variance (CV) for days to 50% flowering in M_1 generation of safflower variety PBNS-12.

Sr. No.	Treatments	Range (days)	Mean ±SE	Variance	CV (%)
1	100 Gy	68-90	80.65±0.91	40.95	9.05
2	200 Gy	66-92	78.65±0.18	56.60	11.16
3	300 Gy	68-89	82.33±0.88	47.33	9.42
4	400 Gy	69-90	82.40±2.04	39.71	8.19
5	0.1% EMS	70-89	82.67±0.33	52.81	9.93
6	0.2% EMS	71-88	84.38±0.91	36.94	7.97
7	0.3% EMS	67-87	83.00±1.75	37.03	8.41
8	0.4% EMS	70-88	83.05±1.48	44.27	9.15
9	200 Gy + 0.1% EMS	66-86	79.12±0.64	58.38	11.51
10	200 Gy + 0.2% EMS	71-90	81.67±0.88	48.28	9.93
11	300 Gy + 0.1% EMS	72-90	80.87±0.70	49.83	10.27
12	300 Gy + 0.2% EMS	69-90	82.78±1.49	42.05	8.75
13	Dry Control	76-87	80.15±0.45	10.02	4.13
14	Wet Control	77-86	81.00±0.58	5.89	2.97

4.1.2.3 Days to maturity

The influence of various doses of gamma rays, ethyl methane sulphonate (EMS) and their combinations on days to maturity in the PBNS-12 variety of Safflower was tested during the M_1 generation and the results are given in Table 4.6.

For the days to maturity characteristic in M_1 generation, the range, mean, variance, and coefficient of variation were computed. The results showed that the M_1 generation had the highest range of variation for days to maturity, indicating that mutagenic treatments had caused higher variability within the M_1 generation. These findings are in accordance with those described in Rapeseed by Siddiqui *et. al.* (2009). The highest range of variation was found with a gamma ray dose of 200 Gy followed by a combination treatment of 200 Gy+ % EMS dose.

The difference between the mean values of all mutagenic treatments and the mean values of control suggested that all mutagens examined were effective and caused variability in days to maturity in all mutagenic populations in the M_1 generation. These results are consistent with the findings of Lande *et. al.* (2018) in Soybean. The 200 Gy doses of gamma rays followed by the 200 Gy + 0.1% EMS dose of combination treatment resulted in a considerable reduction in days to maturity.

The findings observed a significant rise in variance in all mutagenic treatments as compared to the control. Siddiqui *et. al.*(2009) in Rapeseed and Begum and Dasgupta, (2014) in Sesame achieved similar remarks. The combined treatment of 200 Gy +0.1 % EMS had the highest value of variance (71.78) followed by 200 Gy (71.19) dose of gamma rays and 0.2% EMS (67.78) concentration treatment over dry control (9.71) and wet control (12.92). The 0.1% EMS concentration treatment had the lowest value of variation (39.95) followed by the 0.4 % EMS (47.29) concentration treatment (47.29).

The highest coefficient of variation (7.74%) was detected at 200 Gy +0.1% EMS dose of combination treatment, followed by 200 Gy (7.42%) and 300 Gy (6.71%) doses of gamma rays treatments, compared to dry control (2.28%) and wet control (2.23 %). The 0.1% EMS concentration treatment had the lowest coefficient of variation (5.51 %), followed by 0.4 % EMS (5.83 %) concentration and 100 Gy

(5.88 %) dose of gamma rays treatments. In the current investigation, the coefficient of variation in the treated population was significantly greater than the control population. These findings are in accordance with findings of Rai *et. al.*(2014) and Lande *et. al.*(2018) in Soybean.

Table 4.6: Range, Mean, variance and coefficient of variance (CV) for days to maturity in M_1 generation of safflower variety PBNS-12.

Sr. No.	Treatments	Range (days)	Mean ±SE	Variance	CV (%)
1	100 Gy	110-142	129.77±2.85	50.12	5.88
2	200 Gy	108-144	119.93±1.44	71.19	7.42
3	300 Gy	110-140	130.72±2.90	67.15	6.71
4	400 Gy	114-141	131.23±2.38	57.51	6.43
5	0.1% EMS	115-140	132.30±2.91	39.95	5.51
6	0.2% EMS	116-139	129.53±1.61	67.78	6.66
7	0.3% EMS	112-137	132.62±0.84	60.72	6.08
8	0.4% EMS	114-139	130.42±1.56	47.29	5.83
9	200 Gy + 0.1% EMS	109-135	119.43±0.68	71.78	7.74
10	200 Gy + 0.2% EMS	117-140	131.20±2.31	60.22	6.46
11	300 Gy + 0.1% EMS	118-141	131.90±1.74	50.87	6.00
12	300 Gy + 0.2% EMS	114-140	132.82±0.74	50.50	5.73
13	Dry Control	128-139	129.22±0.55	9.71	2.28
14	Wet Control	129-140	128.90±0.86	12.92	2.23

4.1.2.4 Grain yield per plant

The effect of different dosages of gamma rays, ethyl methane sulphonate (EMS) and their combinations on grain yield per plant in PBNS-12 variety of Safflower were studied in M_1 generation and theresults are presented in Table 4.7.

The range, mean, variance and coefficient of variation were calculated for grain yield per plant trait in M_1 generation. The results revealed that the range of variation for grain yield per plant was found to be highest in M_1 generation, indicating that mutagenic treatments had created more variability within the M_1 generation. These results are in broad agreement with the reports of Sanghani *et. al.*(2016) in Sesame. Maximum range of variation was recorded at 200 Gy dose of gamma rays followed by 200 Gy+ 0.1% EMS dose of combination treatment.

The deviation of mean values of all mutagenic treatment over mean values of control indicated that all the mutagens tried were found effective and have induced

the variability for grain yield per plant in all the mutagenic population in M_1 generation. These results are in broad agreement with the reports of Lande *et. al.*(2018) in Soybean and Sanghani *et. al.*(2016) in Sesame. A significant increase in grain yield per plant was recorded at 200 Gy dose of gamma rays followed by 300 Gy + 0.2% EMS dose of combination treatment.

The results revealed that the significant increase of variance in all mutagenic treatments over control. Similar observation was reported by Siddiqui *et. al.*(2009) in Rapeseed and Begumand Dasgupta, (2014) in Sesame. Highest value of variance (88.14) was recorded at 200 Gy dose of gamma rays treatment followed by 0.2 % EMS(82.55) concentration treatment and 200 Gy + 0.1% EMS(78.38) dose of combination treatment over dry control (29.73) and wet control (20.95). The lowest value of variance (42.65) was recorded at 0.1% EMS concentration followed by 300 Gy (46.76) and 100 Gy (46.80) doses of gamma rays treatments.

The maximum coefficient of variation (28.85%) was recorded at0.4% EMS concentration treatment followed by 0.2% EMS (27.48%)and 0.3% EMS (25.67%)concentration treatments as against dry control (10.28%) and wet control (12.88%). The minimum coefficient of variation (15.98%) was recorded at300 Gy + 0.1% EMS dose of combination treatment followed by 400 Gy (16.18%) and 300 Gy (16.28%) doses of gamma rays treatments. In the present study, the coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014), Siddiqui *et. al.*(2009) in Rapeseed and Lande *et. al.* (2018) in Soybean.

Table 4.7: Range, Mean, variance and coefficient of variance (CV) for grain yield per plant in M_1 generation of safflower variety PBNS-12.

Sr. No.	Treatments	Range (g)	Mean ±SE	Variance	CV (%)
1	100 Gy	24-50	37.60±1.25	46.80	18.19
2	200 Gy	20-54	49.00±1.71	88.14	19.16
3	300 Gy	24-53	42.00±1.25	46.76	16.28
4	400 Gy	19-47	32.33±1.40	59.20	16.18
5	0.1% EMS	28-54	40.37±1.19	42.65	18.54
6	0.2% EMS	17.50	33.07±1.66	82.55	27.48
7	0.3% EMS	20-48	29.33±1.37	56.71	25.67
8	0.4% EMS	17-47	30.70±1.70	70.17	28.85
9	200 Gy + 0.1% EMS	22.59	40.97±1.62	78.38	21.61
10	200 Gy + 0.2% EMS	19-48	37.37±1.56	72.79	22.83
11	300 Gy + 0.1% EMS	18-48	31.73±1.36	55.79	15.98
12	300 Gy + 0.2% EMS	25-58	45.00±1.35	54.62	16.42
13	Dry Control	22-42	30.30±1.00	29.73	10.28
14	Wet Control	25-41	35.53±0.84	20.95	12.88

4.2 Studies in M_2 generation

4.2.1 Chlorophyll mutations studies in M_2 generation.

4.2.1.1 Frequency of chlorophyll mutations

Chlorophyll mutations are one of the few reliable indicators for assessing the genetic impact of various mutagens and they are commonly utilized as genetic markers in both basic and applied research. The increased frequency of chlorophyll mutations caused by mutagens is owing to these mutagens preferential impact on genes involved in chlorophyll development.

Table 4.8 shows the results of the frequency of chlorophyll mutations in the M_2 generation of the safflower variety PBNS-12. In the M_2 generation, a single xantha type chlorophyll mutant was discovered at 0.3 percent EMS concentration and the rate of chlorophyll mutation was 0.11 percent.

Khan and Tyagi (2010) found that the frequency of chlorophyll mutations was higher in combined treatments than in EMS and gamma rays treatments alonein Soybean (*Glycine max* L.).

Table 4.8: Frequency of Chlorophyll mutations in M_2 generation of Safflower variety PBNS-12.

Treatments	PBNS-12		
	No. of Seedlings scored	No. of chlorophyll mutants	Frequency of chlorophyll mutations (%)
100 Gy	992	0	0
200 Gy	940	0	0
300 Gy	855	0	0
400 Gy	795	0	0
0.1% EMS	985	0	0
0.2% EMS	910	0	0
0.3% EMS	885	1	0.11
0.4% EMS	750	0	0
200 Gy + 0.1% EMS	845	0	0
200 Gy + 0.2% EMS	780	0	0
300 Gy + 0.1% EMS	720	0	0
300 Gy + 0.2% EMS	640	0	0
Dry Control	1030	0	0
Wet Control	1025	0	0
Total	12152	1	0.11

4.2.1.2 Spectrum of chlorophyll mutation in M_2 generation

Different mutagens, such as gamma rays and ethyl methane sulphonate and their combinations, produced various forms of chlorophyll mutations, which were obtained during M_2 generation quickly after emergence.

Table 4.9 shows the impact of mutagens on the spectrum of chlorophyll mutation in the M_2 generation of the safflower genotype variety PBNS-12. According totaxonomy of Gustafsson, (1940) and Blixit, (1961), the following types of chlorophyll mutations have been reported.

a) Albino

The albino seedlings were completely devoid of chlorophyll pigment and were found to be virtually white and reduced in size. These individuals lived for almost 7-8 days before dying.

b) Xantha

The seedling leaves vary in colour from yellowish to white. Carotenoids were present in these mutants, but chlorophyll was not. They were proven to be lethal in

nature after surviving for about 10-12 days.

c) Chlorina

The leaves of these mutants were golden yellowish to green in colour and after 15-20 days, they showed a lethal reaction.

d) Xanthaviridis

Xanthaviridis mutants had green leaves with a yellow apex. These mutants were able to survive.

e) Viridis

The leaves of these mutants were yellow green to pale green in colour before turning normal green. These mutants were able to reproduce and grow normally.

Table 4.9: Spectrum of Chlorophyll mutations in M_2 generations of safflower variety PBNS-12

Genotype	Treatment	Chlorophyll mutants					
		Albina	Xantha	Chlorina	Viridis	Xanthaviridis	Total
PBNS-12	100 Gy	-	-	-	-	-	-
	200 Gy	-	-	-	-	-	-
	300 Gy	-	-	-	-	-	-
	400 Gy	-	-	-	-	-	-
	0.1% EMS	-	-	-	-	-	-
	0.2% EMS	-	-	-	-	-	-
	0.3% EMS	-	1	-	-	-	1
	0.4% EMS	-	-	-	-	-	-
	200 Gy + 0.1% EMS	-	-	-	-	-	-
	200 Gy + 0.2% EMS	-	-	-	-	-	-
	300 Gy + 0.1% EMS	-	-	-	-	-	-
	300 Gy + 0.2% EMS	-	-	-	-	-	-
	Dry Control	0	0	0	0	0	0
	Wet Control	0	0	0	0	0	0

The result revealed that at 0.3 % EMS concentration mutagenic treatment, a single xantha type spectrum of chlorophyll mutant was detected, as shown in Table, 4.9. Manjunath *et. al.* (2020) in Groundnut, Julia *et. al.*(2018) in Indian mustard, Khan and Tyagi (2010) in Soybean and Anbarasan *et. al.* (2015) in Sesame all showed a similar spectrum of chlorophyll mutations. Chlorophyll mutations can be caused by

alterations in chlorophyll structural components, the inability of protoplastids to develop into plastids of normal size and colour, or both (Gustafsson, 1940).

4.2.2 Viable mutations studies in M_2 generation

4.2.2.1 Frequency of viable mutations

The frequency of viable mutations in M_2 generation is mentioned in Table 4.10. Viable mutation frequency suggested that the frequency of mutations increased as mutagen doses were increased. However, exceptions to this trend were also noticed. In comparison to EMS and gamma rays mutagenic treatments, the frequency of viable mutations caused by combination mutagenic treatment was shown to be higher. At 200 Gy + 0.1 % EMS dose of combination treatment, the highest frequency of viable mutation (2.25%) was reported followed by 0.2% EMS (1.87 %) concentration and 200 Gy (1.70 %) dose of gamma rays treatment. The lowest frequency of viable mutations (0.50%) was recorded at 100 Gy dose of gamma rays treatment.

Viable mutations were categorized as macro and micro mutations, while Swaminathan, 1969classified them as macro mutations and systematic mutations. Viable macro mutations, though induced quantitatively very few, would be more valuable in genetic studies since, plants with altered characteristics or phenotype can serve as markers of the mutability of a variety or species. Frequency of such mutations also serves as an index of mutagenic sensitivity of various mutagenic agents and their dose effects (Waghmare and Mehra, 2001). The frequency of viable mutations was higher in combination treatments than in gamma rays and EMS concentration treatments in this study. Similar types of results have been reported byVennakumari *et. al.* (1994) in Soybean, Kassem *et. al.* (1976) in Wheat and Amarnath and Prasad (2000) in Tobacco. According to Wakode *et. al.* (2000), the genotypic background of the material treated in soybean appears to be the most important indicator of mutation generation and recovery of desirable mutations.

Plate No. 4.2: Experimental Field Layout in M_2 Generation

Plate No. 4.3: Xantha chlorophyll mutant found at 0.3% EMS concentration in M_2 generation

Table 4.10: Frequency of viable mutations in M_2 generation of safflower variety PBNS-12.

Treatments	PBNS-12		
	No. of Seedlings scored	No. of Viable mutants	Frequency of viable mutations (%)
100 Gy	992	5	0.50
200 Gy	940	16	1.70
300 Gy	855	9	1.05
400 Gy	795	7	0.88
0.1% EMS	985	6	0.61
0.2% EMS	910	17	1.87
0.3% EMS	885	11	1.24
0.4% EMS	750	9	1.20
200 Gy + 0.1% EMS	845	19	2.25
200 Gy + 0.2% EMS	780	10	1.20
300 Gy + 0.1% EMS	720	7	0.97
300 Gy + 0.2% EMS	640	8	1.25
Dry Control	1030	-	-
Wet Control	1025	-	-
Total	12152	119	14.72

4.2.2.2 Spectrum of viable mutations

The data mentioned in Table 4.11 with respect to the spectrum of viable mutations indicated that the mutagenic treatments with gamma rays, EMS and their combination induced mutations affecting plant habit, leaf morphology, seed and oil characteristics. High spectrum of viable mutations was recorded at 200 Gy + 0.1% EMS mutagenic treatment in PBNS-12 population. Among gamma rays, 200 Gy treatments induced wider spectrum of viable mutations and in case of EMS treatment, 0.2% EMS concentration induced wider spectrum of viable mutations in PBNS-12 population.

The combined mutagenic treatments had a larger spectrum of viable mutations than gamma rays and EMS mutagenic treatments alone. This is in contrast to the earlier findings by Veenakumari*et. al.*(1994) and Paul and Singh (2005), who found a higher frequency and broader spectrum of viable mutations in populations treated with a combination of gamma rays and chemical mutagens than in populations treated with gamma rays and chemical mutagens alone in field pea populations (*Pisun sativum*). Makeen et al. (2013) in Urd bean, on the other hand, described the

superiority of combination treatments over radiations and chemicals that cause functional modifications in genes. Additionally, the findings are consistent with the work done by Vennakumari *et. al.* (1994) in Soybean, Kassem *et. al.*(1976) in Wheat and Amarnath and Prasad (2000) in Tobacco. Below are descriptions of viable mutations caused by gamma rays, EMS and combined mutagenic treatments.

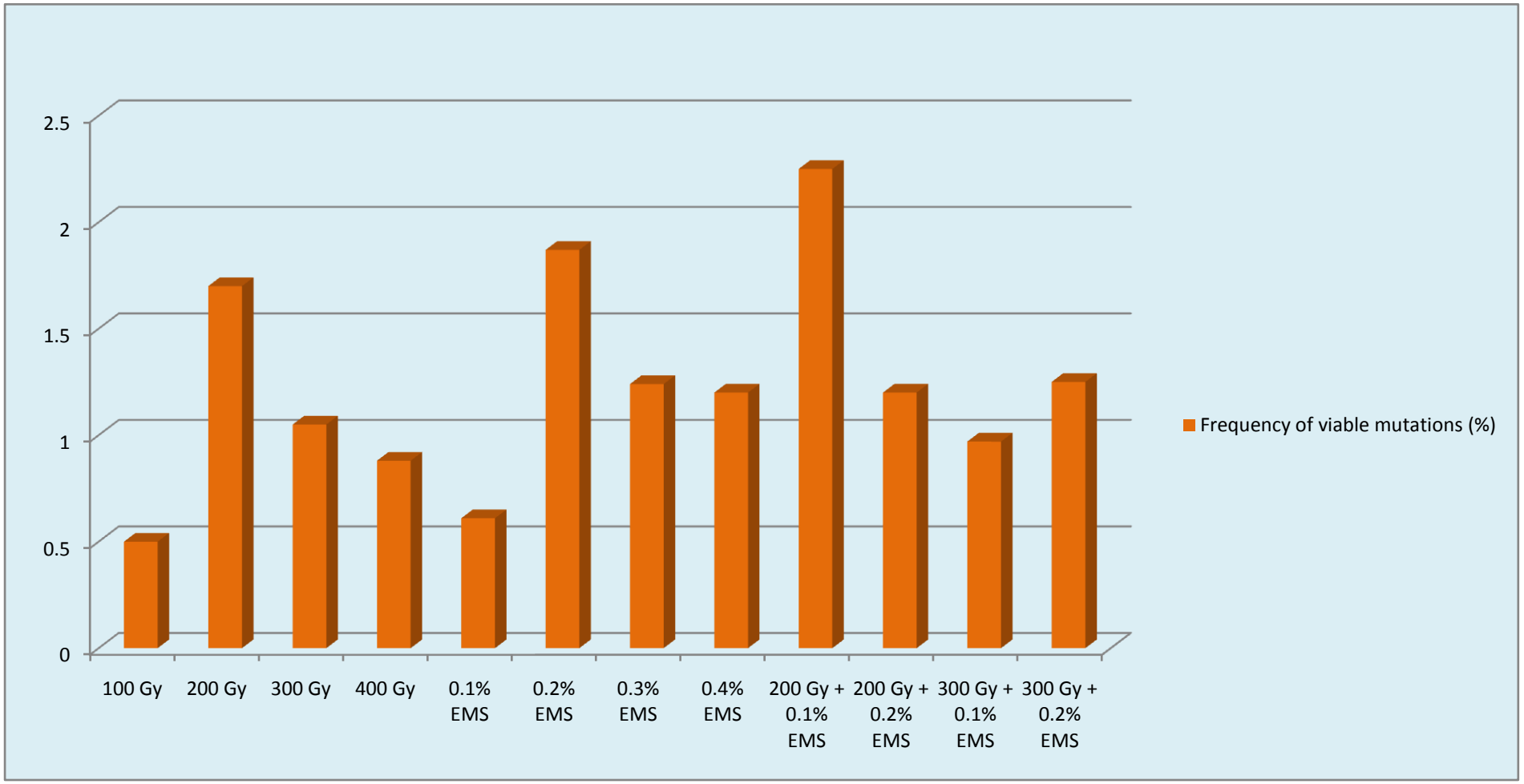


Figure 4.2: Frequency of viable mutations in M_2 generation of safflower variety PBNS-12

Table 4.11 Spectrum of viable mutations in M_2 generation of PBNS-12 variety.

Treatments	Leaf mutant				Mutations for stature and growth							Total no. of mutants.
	Narrow leaves	Broad leaves	Deep serrated leaves	Shrinkage Leaves	Dwarf	Tall	Less Branched	Highly branched	Small Capitula	Large capitula	More Capitula / plants	
Dry Control	0	0	0	0	0	0	0	0	0	0	0	0
Wet Control	0	0	0	0	0	0	0	0	0	0	0	0
100 Gy	0	1	0	1	0	0	1	0	1	0	0	4
200 Gy	1	0	0	0	1	1	0	2	0	1	1	7
300 Gy	0	0	1	0	1	0	2	0	1	0	0	5
400 Gy	1	0	0	1	1	0	0	1	0	0	1	5
0.1% EMS	1	0	0	0	1	0	1	0	0	0	0	3
0.2% EMS	0	2	2	0	0	1	0	2	0	1	2	10
0.3% EMS	0	0	1	0	1	1	0	1	0	1	1	6
0.4% EMS	0	1	0	2	0	0	1	0	0	0	0	4
200 Gy + 0.1% EMS	0	0	3	0	0	1	0	2	0	1	1	8
200 Gy + 0.2% EMS	1	0	1	0	1	0	1	0	1	0	0	5
300 Gy +0.1%EMS	0	1	0	2	0	1	0	0	0	0	0	4
300 Gy+ 0.2% EMS	2	0	0	0	2	0	1	0	0	0	0	5
Total	6	5	8	6	8	5	7	8	3	4	6	66

Continue…

Treatments	Seed mutants					Early mutants						Total no. of mutants
	Bold seed	Small seed	Thin hull	High test weight	Low test weight	Early bolting	Late bolting	Early Flowering	Late flowering	Early Maturing	Late maturing	
Dry Control	0	0	0	0	0	0	0	0	0	0	0 0 0 0	0
Wet Control	0	0	0	0	0	0	0	0	0	0	0	0
100 Gy	0	0	0	0	1	0	0	0	0	0	0	5
200 Gy	2	0	0	1	0	1	0	1	0	1	0	13
300 Gy	0	2	0	0	1	1	0	0	0	0	0	9
400 Gy	1	0	0	1	0	0	0	0	0	0	0	7
0.1% EMS	0	0	0	0	1	0	1	0	1	0	0	6
0.2% EMS	1	1	0	1	0	0	1	0	1	0	1	16
0.3% EMS	0	1	1	0	0	1	0	0	0	0	0	9
0.4% EMS	1	0	1	0	0	0	0	0	0	0	0	6
200 Gy + 0.1% EMS	2	0	2	2	0	0	0	1	0	1	0	16
200 Gy + 0.2% EMS	0	1	0	0	0	1	0	1	0	1	0	9
300 Gy +0.1%EMS	1	0	0	1	0	0	0	0	0	0	0	6
300 Gy+ 0.2% EMS	0	1	0	0	1	0	1	0	0	0	0	8
TOTAL	8	6	4	6	4	4	3	3	2	3	1	110

Continue……

Treatments	Oil mutant				Total no. of mutants
	Low oil content	High oil content	High oleic acid	Low linoleic acid	
Dry Control	0	0	0	0	0
Wet Control	0	0	0	0	0
100 Gy	0	0	0	0	5
200 Gy	0	1	1	1	16
300 Gy	0	0	0	0	9
400 Gy	1	0	0	0	8
0.1% EMS	0	0	0	0	6
0.2% EMS	1	0	0	0	17
0.3% EMS	0	1	1	0	11
0.4% EMS	0	1	1	1	9
200 Gy + 0.1% EMS	0	1	1	1	19
200 Gy + 0.2% EMS	0	0	1	0	10
300 Gy +0.1%EMS	1	0	0	0	7
300 Gy+ 0.2% EMS	0	0	0	0	8
Total	3	4	5	3	125

A) Leaf mutant

1. Narrow leaves mutant

In the mutagenic population, six narrow leaves mutants were found. Two narrow leaf mutants were found at 300 Gy + 0.2 % EMS dose of combination and each narrow leaf mutant was found at 200 Gy, 400 Gy, 0.1% EMS and 200 Gy + 0.2% EMS dose of mutagenic treatments. The combination treatment of 300 Gy + 0.2 % EMS resulted in the highest frequency of narrow leaf mutants. Singh and Singh (2018) found similar mutants in sesame and Veenakumari *et. al.* (1994) found them in soybean.

2. Braod leaves mutant

At a dose of 0.2% EMS, the highest frequency of broad leaf mutant was observed. A total of five broad leaf mutants were identified. At 0.2% EMS concentration treatment, two broad leaves mutants were found. At 100 Gy, 0.4 % EMS and 300 Gy + 0.1 % EMS doses of mutagenic treatments, each broad leaf mutant was detected. Similar mutants were previously identified in Soybean by Ahire *et. al.* (2005).

3. Deep serrated leaves mutant

A total of eight deep serrated leaves mutants were recognized. The deep serrated leaf mutant was found in the highest frequency at 200 Gy+ 0.1% EMS dose of combination treatment.Three deep serrated leaf mutants were found at 200 Gy +0.1 % EMS dose, two deep serrated leaf mutants were realized at 0.2% EMS concentration and each single deep serrated leaf mutant was discovered at 300 Gy, 0.3 % EMS, and 200 Gy + 0.2 % EMS dose of mutagenic treatments. Shrivastava and Kumar (2011) detected a similar type of mutants in Safflower.

4. Shrinkage leaves mutant

Six shrinkage leaves mutant were identified. The highest frequency of shrinkage leaves mutant was found at 0.4% EMS and 300 Gy + 0.1% EMS dose of combination treatment. Amongsix mutants, two mutants were noticed each mutagenic treatment *viz.,* 0.4% EMS and 300Gy + 0.1% EMS dose of combination and each single shrinkage leaves mutant were noticed at 100 Gy and 400 Gy dose of gamma rays treatments.Lande *et. al.* (2018) in Soybean and Ahire *et. al.* (2005) in Soybean had previously found similar mutants.

Stature and growth mutants

1. Dwarf mutant

The combination treatment of 300 Gy + 0.2% EMS resulted in the highest frequency of dwarf mutants. There were a total of eight dwarf mutants identified. Two mutants were found at 300 Gy + 0.2% EMS and each individual mutant was noticed at 300 Gy, 400 Gy, 0.1% EMS, 0.3 % EMS and 200 Gy + 0.2% EMS, respectively. Similar types of mutant were identified previously by Rampure *et. al.*(2017) in Safflower, Julia *et. al.*(2018) in Indian mustard, Pavadai *et. al.* (2009) in Soybean, Cvejic *et. al.* (2011) in Sunflower and Lande *et. al.* (2018) in Soybean.

2. Tall mutant

A total of five tall mutants were recognized. Each tall mutant was detected at doses of mutagenic treatments of200 Gy, 0.2% EMS, 0.3 % EMS, 200 Gy + 0.1% EMS and 300 Gy+ 0.1% EMS, respectively. Similar kinds of mutant were identified previously by Rampure *et. al.* (2017) in Safflower, Lande *et. al.* (2018) in Soybean,

Control

Narrow leaves and dwarf Plant
(300 Gy + 0.2% EMS treatment)

Highly branched plant
(200 Gy treatment)

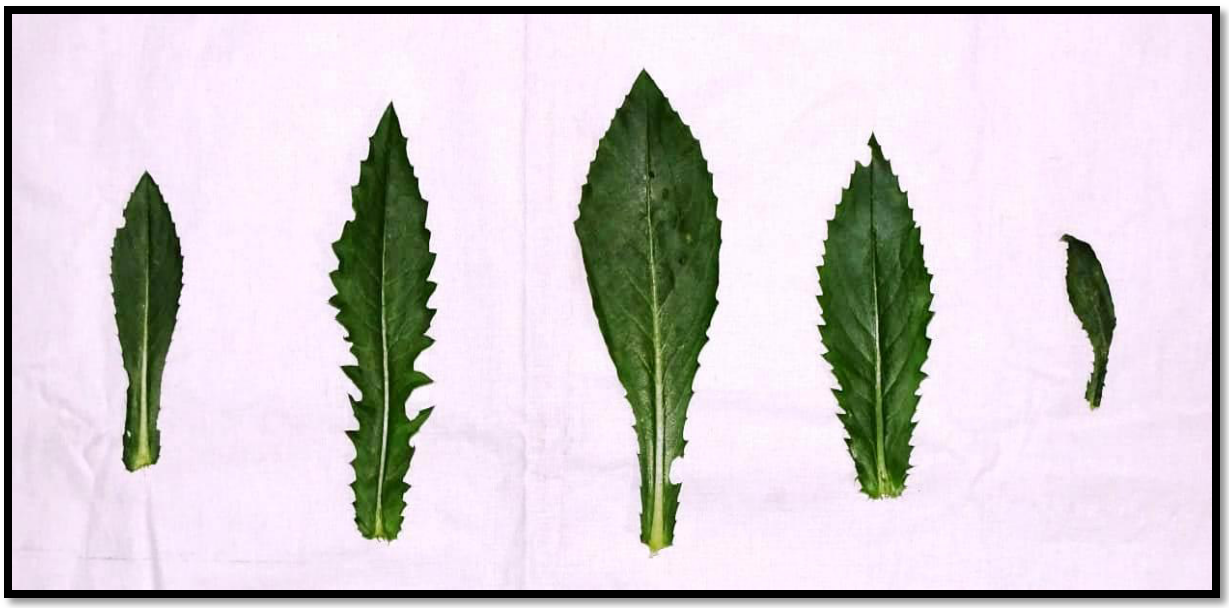
Deep and high serration
(200 Gy + 0.1% EMS treatment)

Plate No. 4.4: Viable mutations for stature and growth in M_2 generation

Shrinkage leaf plant
(0.4% EMS Concentration)

Broad leaf plant
(0.2% EMS Concentration)

Plate No. 4.4: Viable mutations for stature and growth in M_2 generation



Control | Deep and high seriated | Broad leaf | Thin leaf | Narrow leaf

Plate No.4.5: Leaf mutant observed in M_2 generation

Pavadai *et. al.* (2009) in Soybean, Cvejic *et. al.* (2011) in Sunflower and Ahire *et. al.* (2005) in Soybean.

3. Less branched mutant

Seven mutants with fewer branches were identified. Among seven mutants, the largest frequency of less branched mutant was observed at 300 Gy dose of gamma rays. Out of these mutants, two mutant were observed at 300 Gy dose of gamma rays and single mutant each was detected at 100 Gy, 0.1% EMS, 0.4% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of mutagenic treatment respectively. Similar kinds of mutant were observed previouslyby Rampure *et. al.*(2017) in Safflower.

4. Highly branched mutant

There were eight highly branched mutants found. The highest frequency of highly branched mutants was seen among eight mutants at 200 Gy, 0.2% EMS and 200 Gy + 0.1 % EMS doses of mutagenic treatments. Two mutants were found for each of the mutagenic treatments, namely 200 Gy, 0.2% EMS and 200 Gy + 0.1 % EMS doses, while a single mutant was found at 400 Gy and 0.3 percent% EMS concentration mutagenic treatments. Rampure *et. al.* (2017) in Safflower, Lande *et. al.* (2018) in Soybean, Ravichandran and Jayakumar (2015) in Sesame and Cvejic *et. al.* (2011) in Sunflower identified similar mutants.

5. Small size capitula mutant

In the mutagenic population of PBNS -12, three small size capitula mutants were found. At 100 Gy, 300 Gy and 200 Gy +0.2 % EMS doses of mutagenic treatments, each single small size capitula mutant was isolated. Rampure *et. al.* (2017) reported similar mutants in Safflower and Singh and Singh (2018) reported them in Sesame.

6. Large size capitula mutant

Each of single large size capitula mutants were found at 200 Gy, 0.2% EMS , 0.3% EMS and 200 Gy + 0.1% EMS dose of mutagenic treatments. In the mutagenic population of PBNS-12, four large size capitula mutants were identified.Similar kinds of mutant were found earlier by Rampure *et. al.* (2017) in Safflower, Singhand Singh (2018) in Sesame.

7. More capitula per plant mutant

In the mutagenic population of PBNS-12, there were six more capitula per plant mutants. At 200 Gy, 400 Gy, 0.3 % EMS and 200 Gy + 0.1 % EMS doses of mutagenic treatments, single mutants were observed. At a dose of 0.2% EMS, the highest frequency of more capitula per plant mutant was recorded. Rampure *et. al.* (2017) found similar mutants in Safflower, Ravichandran and Jayakumar (2015) in Sesame and Singh and Singh (2018) in Sesame.

C. Seed mutants

1. Bold seeded mutant

Highest frequency of bold seeded mutant was reported at 200 Gy and 200 Gy+ 0.1% EMS dose of mutagenic treatments. In the mutagenic population of PBNS-12, eight bold seeded mutants were found. Among them, two mutants each were observed at 200 Gy and 200 Gy+ 0.1% EMS dose of mutagenic treatments respectively. Also single mutant each was observed at 400 Gy, 0.2% EMS , 0.4 % EMS and 300 Gy +0.1% EMS dose of mutagenic treatments. Similar kinds of mutant were noticed earlier by Rampure *et. al.*(2017) identified similar mutants in Safflower and Julia *et.al.*(2018)identified similar mutants in Indian mustard.

2. Small seeded mutant

The maximum frequency of small seeded mutant was reported at 300 Gy dose of gamma rays. In the mutagenic population of PBNS-12, six tiny seeded mutants were found. Two mutants were observed at a 300 Gy dose of gamma rays treatment, and a single mutant was observed at each of the mutagenic treatments, namely 0.2% EMS, 0.3 % EMS, 200 Gy + 0.2% EMS, and 300 Gy + 0.2% EMS. Similar mutants were previously found by Rampure *et. al.* (2017) in Safflower.

3. Thin hull mutant

The highest frequency of thin hull mutant was found at 200 Gy + 0.1% EMS dose of mutagenic treatment. Four thin hull mutants were observed in mutagenic population of PBNS-12. Among them, single mutant each was found at 0.3% EMS and 0.4% EMS concentration treatments, while two mutants were observed at 200 Gy + 0.1% EMS dose of mutagenic treatments.Similar mutants were previously reported by Rampure *et. al.* (2017) in Safflower.

Control
Seed weight: 5.7 (gm)
SL: 8.96 (mm)
SW: 3.92 (mm)

Small Seed
(200 Gy + 0.1% EMS treatment)
100 seed weight : 3.9 (gm)
SL: 6.03 (mm)
SW: 2.93 (mm)

Bold Seed
(400 Gy treatment)
100 seed weight: 9 (gm)
SL: 10.94 (mm)
SW: 5.92 (mm)

Plate No. 4.6: Seed mutants observed in M_2 generation

Control | Large Size Capitula (200 Gy treatment) | Small Size Capitula (200 Gy + 0.2% EMS treatment)

Plate No. 4.7: Mutants for capitula size observed in M_2 generation

4. High test weight mutant

The combination treatment of 200 Gy + 0.1 percent EMS resulted in the highest frequency of high test weight mutants. In the mutagenic population of PBNS-12, six high test weight mutants were identified. The single mutants were found at 200 Gy, 400 Gy, 0.2 %EMS and 300 Gy+ 0.1% EMS doses of mutagenic treatments and two mutants were observed at 200 Gy + 0.1 % EMS dose of mutagenic treatments.Similar kinds of mutants were previously reported by Rampure *et. al.* (2017) in Safflower, Channaoui *et. al.* (2019) in Rapeseed and Lande *et. al.* (2018) in Soybean.

5. Low test weight mutant

In the mutagenic population of PBNS-12, four low test weight mutants were detected. Single mutant each was noticed at 100 Gy, 300 Gy, 0.2% EMS and 300 Gy + 0.2% EMS dose of mutagenic treatments. Similar kinds of mutant were noticed earlier by Rampure *et. al.* (2017) in Safflower.

D. Earliness mutant

1. Early bolting mutant

Four early bolting mutants were observed in the mutagenic population of PBNS-12. Among them, single mutant each was found at 200 Gy, 300 Gy, 0.3 % EMS and 200 Gy+ 0.2% EMS dose of mutagenic treatments. Rampure *et. al.* (2017) identified a similar type of mutation in Safflower.

2. Late bolting mutant

In mutagenic population of PBNS-12, three late bolting mutants were observed. Among them, single mutant each was observed at 0.1% EMS, 0.2% EMS and 300 Gy + 0.2% EMS dose of mutagenic treatments. Rampure *et. al.* (2017) identified a similar type of mutation in Safflower.

3. Early flowering mutant

Three early flowering mutants were observed in mutagenic population of PBNS-12. Among them, single mutant each was observed at 200 Gy, 200 Gy + 0.1% EMS and 200 Gy + 0.2% EMS dose of mutagenic treatments. Similar types of mutant

were observed earlier by Rampure *et. al.* (2017) in Safflower, Cvejic *et. al.* (2011) in Sunflower, Channaoui *et. al.* (2019) in Rapeseed, Lande *et. al.* (2018) in Soybean, Singh and Singh (2018) in Sesame and Ahire *et. al.* (2005) in Soybean.

4. Late flowering mutant

In the mutagenic population of PBNS-12, two late flowering mutants were discovered.Each single mutant was observed at 0.1% EMS and 0.2% EMS concentration treatments.Rampure *et. al.* (2017) found a similar type of mutant in Safflower, Singhand Singh (2018) in Sesame and Ahire *et. al.* (2005) in Soybean.

5. Early maturing mutant

In the mutagenic population of PBNS-12, three early maturing mutants were identified. At 200 Gy, 200 Gy + 0.1% EMS and 200 Gy + 0.2 % EMS doses of mutagenic treatments, single mutants were found. Similar types of mutant were observed earlier by Rampure *et. al.* (2017) in Safflower, Ahire *et. al.* (2005) in Soybean and Ahmed *et. al.* (2012) in Safflower.

6. Late maturing mutant

Single late maturing mutant was identified at 0.2% EMS concentration treatment. Similar types of mutant were reported by Rampure *et. al.* (2017) in Safflower, Ahire *et. al.* (2005) in Soybean and Ahmed *et. al.* (2012) in Safflower.

E. Oil mutants

1. Low oil content mutant

In the mutagenic population of PBNS-12, three mutants with low oil content were identified. Among them, single mutant each was reported at 400 Gy, 0.2% EMS and 300 Gy + 0.1% EMS dose of mutagenic treatments.Similar types of mutant were observed earlier by Rampure *et. al.* (2017) in Safflower.

2. High oil content mutant

In the mutagenic population of PBNS-12, four mutants with high oil content were detected. Among them, single mutant each was observed at 200 Gy, 0.3 % EMS, 0.4% EMS and 200 Gy + 0.1% EMS dose of mutagenic treatments. Rampure *et.*

al.(2017) found a similar form of mutant in Safflower, Cvejic *et. al.* (2011) in Sunflower and Seeba *et. al.* (2003) in Sesame.

3. High oleic acid mutant

Five high oleic acid mutants were observed in the mutagenic population of PBNS-12. Among them, single mutant each was observed at 200 Gy, 0.3% EMS, 0.4% EMS, 200 Gy + 0.1% EMS and 200 Gy + 0.2% EMS dose of mutagenic treatments. Similar types of mutant were previously observed by Rampure *et. al.* (2017) in Safflower and Khadeer and Anwar (1991) in Safflower.

4. Low linoleic acid

In the mutagenic population of PBNS-12, three low linoleic acid mutants were identified. Among them, each single mutant was observed at 200 Gy, 0.4% EMS and 200 Gy + 0.1% EMS dose of mutagenic treatments. Similar types of mutant were previously reported by Rampure *et. al.* (2017) in Safflower and Khadeer and Anwar (1991) in Safflower.

4.2.3 Estimates of mutagenic effectiveness and efficiency

Table 4.12 shows estimates of mutagenic effectiveness and efficiency for various gamma ray doses, EMS and their combinations based on viable mutation frequency during M_2 generation on a plant basis. The results showed that gamma rays had the most mutagenic effectiveness followed by combination and EMS treatments, and that gamma rays had the highest mutagenic efficiency followed by EMS and combination treatments.

Mutagenic effectiveness is a measure of frequency of mutation induced by a unit dose of mutagen while mutagenic efficiency represents the proportion of mutation in relation to the associated undesirable biological effects (lethality, injury, sterility) induced by mutagen (Konzak *et. al.*, 1965).The mutagenic efficiency was estimated based on lethality.

The 200 Gy dose of gamma rays had the highest mutagenic effectiveness (8.50%), followed by 200 Gy + 0.1% EMS (6.25%) dose of combination treatment and 0.2 % EMS (5.19%) concentration treatment.

Mutagenic efficiency may differ for different plant tissue or plant part or individuals because of the differential test conditions influencing the expression of the true potential of the agent (Konzak *et. al.,* 1965).

Table 4.12: Mutagenic effectiveness and efficiency of mutagens in inducing viable mutations in safflower variety PBNS-12.

Genotype	Treatment	Viable mutants	
		Mutagenic effectiveness (%)	Mutagenic efficiency (%)
PBNS-12	100 Gy	5.00	9.1
	200 Gy	8.50	16.2
	300 Gy	3.50	5.7
	400 Gy	2.20	3.6
	0.1% EMS	3.40	9.9
	0.2% EMS	5.19	14.0
	0.3% EMS	2.30	7.9
	0.4% EMS	1.70	4.2
	200 Gy + 0.1% EMS	6.25	11.5
	200 Gy + 0.2% EMS	1.67	4.7
	300 Gy + 0.1% EMS	1.80	3.1
	300 Gy + 0.2% EMS	1.16	3.2
	Dry Control	-	-
	Wet Control	-	-

The highest mutagenic efficiency (16.2%) was reported at a 200 Gy gamma ray dose followed by 0.2% EMS (14.0%) concentration and 200 Gy + 0.1% EMS (11.5%) dose of combination treatments.

With increasing doses/ concentrations of mutagens, the mutagenic effectiveness and efficiency were steadily reduced in the current study. Similar findings have been reported previously by Anbarasan *et. al.* (2015) in Sesame and Julia *et. al.* (2018) in Indian mustard.

In the current investigation, lower or intermediate doses/concentrations were shown to be more effective and efficient. Similar findings were previously reported by Saha and Paul (2018) in Sesame.

Gamma rays had a higher mutagenic effectiveness and efficiency than EMS and combined treatment in the current study. Sheeba *et. al.* (2003) in Sesame, Khan

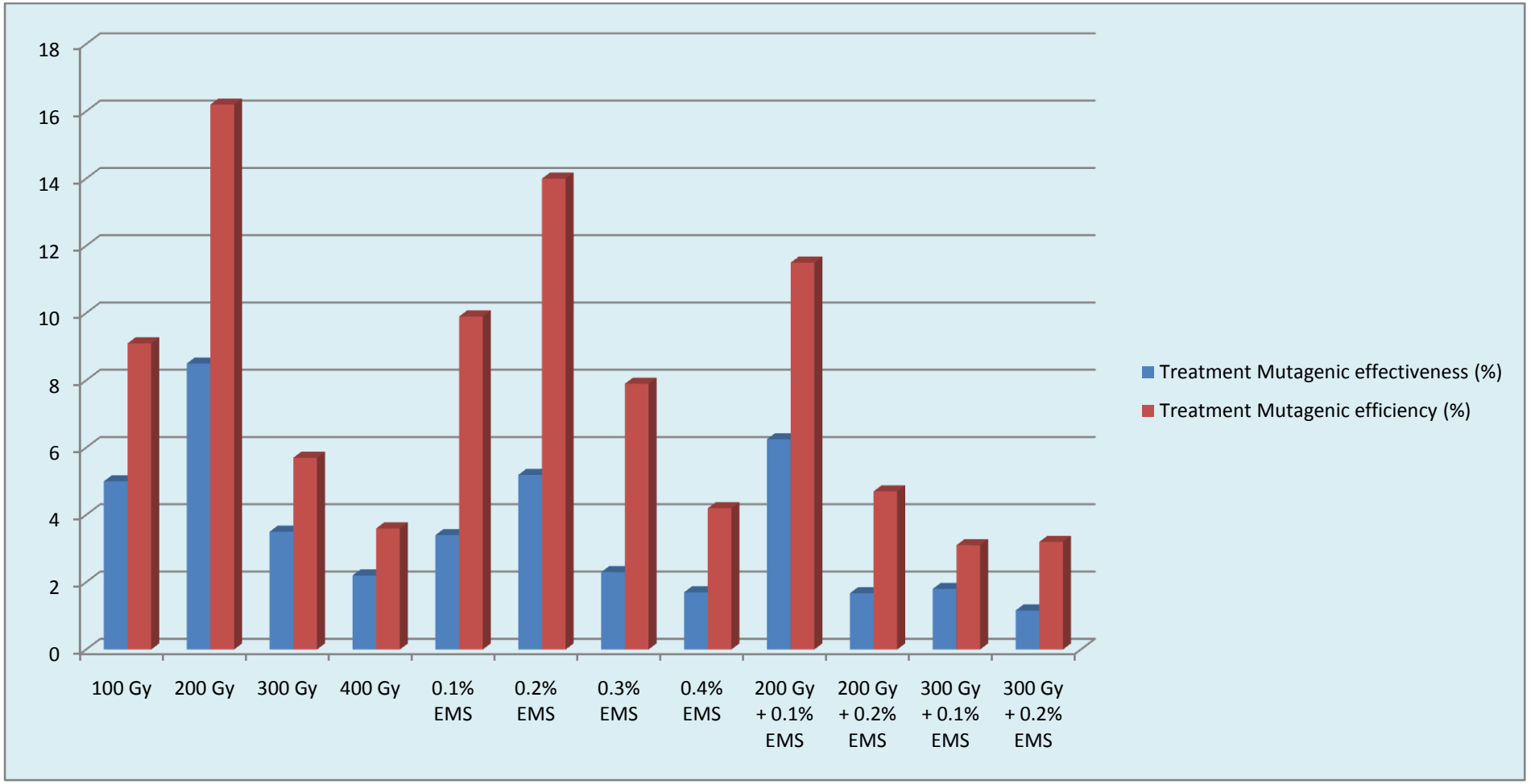


Figure 4.3: Mutagenic effectiveness and efficiency of mutagens in inducing viable mutations in safflower variety PBNS-12 in M_2 generation.

and Tyagi (2010) in Soybean, and Kavithamani *et. al.* (2008) in Soybean has all shown similar results.

4.2.4 Induced polygenic variability studies in M_2 generations for various traits.

Any crop improvement program's effectiveness is largely determined by the amount of genetic diversity present in a character and the extent to which it is heritable. As a result, knowledge of the estimates of variability in yield and its heritable components in the material with which the breeder is working becomes essential for any breeding programme. As a result, using genetic indices like genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic progress, it became necessary to divide total variability into heritable and non-heritable components.Heritability estimates combined with genetic gain are usually more useful than heritability estimates alone in estimating the gain under selection. To acquire a clear overview of the scope of improvement in specific traits through selection, both heritability and genetic gain were determined. Heritability combined with genetic advances would provide a more trustworthy indicator of selection value (Johnson *et. al.,* 1955). Tables 4.13- 4.30 show estimates of these genetic parameters for different attributes for various doses of gamma rays, EMS and their combination.

1) Days to rosette stage

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for days to rosette stage in M_2 generation of PBNS-12 variety of safflower are mentionedin Table 4.13.

The results demonstrated that in all of the mutagenic treatments, the range of variation in M_2 generation was wide when compared to control. The highest range of variation was found at a gamma ray dose of 200 Gy, followed by a 0.2 % EMS concentration and a combination treatment of 200 Gy + 0.1% EMS dose. The difference between the mean values of the mutagenic treatments and the mean value of the control indicated that all of the mutagens tested were effective in inducing genetic variability in all of the mutagenic populations in the M_2 generation for days to rosette stage.

A significant reduction in days to rosette period (25.37) wasrecorded at 200 Gy dose of gamma rays followed by 200 Gy +0.1% EMS dose (25.67) and 0.2% EMS concentration (27.70) treatments. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014).The maximum coefficient of variation (5.37) was recorded at 0.1% EMS concentration treatment. An increase in genotypic (GCV) and phenotypic coefficient of variation (PCV) over respective control population indicated that mutation induced reasonably wider variability in all the treated population. These findings are in the confirmity with the findings of Begum and Dasgupta (2014). The maximum value of PCV (9.00) and GCV (7.37) for days to rosette was recorded at 200 Gy + 0.1% EMS dose of combination treatment followed by 200 Gy dose of gamma rays [PCV(7.91), GCV(6.87)] and 0.2% EMS concentration [PCV (8.18), GCV(6.43)] treatments respectively. In present study, low value of PCV and GCV for days to rosette stage was recorded. A small difference between PCV and GCV was recorded at 200 Gy dose of gamma rays which indicated less influence of environment on this character.A close analysis of PCV and GCV found that GCV values were extremely close to PCV, indicating that polygene mutations were the source of the most variation. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020). Selection success is a reflection of selection response and heritability and genetic advance are significant selection indices. In comparison to the control, all mutagenic treatments had high to moderate heritability and low to moderate genetic advance as a percent of the mean. In all of the mutagenic treatments, there was little genetic gain. At 200 Gy dose of gamma rays, 0.2% EMS concentration and 200 Gy+ 0.1 % EMS dose of combination treatments, high heritability and moderate genetic advance as percent of mean were reported among the mutagenic treatments.In current study, high heritability was observed together with moderate genetic advance as a percent of mean, showing that both additive and non-additive gene action is involved in the inheritance of days to rosette period. The results obtained are in agreement with the reports of Rajanna *et. al.* (2020) in Linseed, Sikarwar *et. al.* (2017) in Yellow Sarson and Begum and Dasgupta (2014) in Sesame.

2) Days to bolting

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for days to bolting in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.14.

The results demonstrated that in all of the mutagenic treatments, the range of variation in M_2 generation was wide when compared to control. The highest range of variation was found with a gamma ray dose of 200 Gy followed by a combination treatment of 200 Gy + 0.1 % EMS dose. The difference between the mean values of mutagenic treatments and the mean value of control indicated that all mutagens tested were successful and caused genetic variability in all mutagenic populations in the M_2 generation for days to bolting.

A significant reduction in days to bolting (40.68) was recorded at 200 Gy + 0.1% EMS dose of combination followed by 200 Gy(41.45) dose of gamma rays and 0.3% EMS concentration (41.93) treatments. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014). The maximum coefficient of variation (7.75) was recorded in 300 Gy +0.2% EMS dose of combination treatment. The magnitude of induced genetic variability in terms of PCV and GCV was greater in the mutagenic treatments as compared to their respective control.These findings are in the confirmity with the findings of Rai *et. al.* (2014). The maximum value of PCV (11.49) and GCV (8.19) for days to bolting was recorded at 300 Gy + 0.1% EMS dose of combination treatment followed by 0.2% EMS concentration [PCV (10.34), GCV (8.10)] treatment. In the present study low value of PCV and GCV for days to bolting was recorded. At 200 Gy of gamma rays, there was a minor difference between PCV and GCV, indicating that the environment had less of an impact on this trait. A close study of PCV and GCV indicated that GCV values were extremely close to PCV, indicating that polygene mutations were the source of the most variation.These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).Selection success is a reflection of selection response and heritability and genetic advance are significant selection factors. In comparison to the control, all mutagenic treatments

had high to moderate heritability and low to moderate genetic gain as a percent of the mean. In all of the mutagenic treatments, there was little genetic gain. Most of the mutagenic treatments showed high heritability with moderate genetic advance as percent of mean, showing the significance of both additive and non-additive gene action in directing the inheritance of days to bolting. The results obtained are in agreement with the reports of Rajanna *et. al.* (2020) in Linseed, Sikarwar *et. al.* (2017) in Yellow Sarson, Begum and Dasgupta (2014) in Sesame.

3) Days to 50 % flowering

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for days to 50% flowering in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.15.

The results revealed that, in M_2 generation the range of variation was wide in all the mutagenic treatmentsas compared to control. Maximum range of variation was recorded at 200 Gy dose of gamma rays followed by 0.2% EMS concentration and 200 Gy + 0.1% EMS dose of combination treatment. The difference between the mean values of the mutagenic treatments and the mean value of the control indicated that all of the mutagens tested were successful and caused genetic variability in all of the mutagenic populations in the M_2 generation for days to 50% flowering.These results are in broad agreement with the reports of Ravichandran and Jayakumar (2015) in Sesame, Lande *et. al.* (2018) in Soybean and Channaoui *et. al.*(2019) in Rapessed .

A significant reduction in days to 50% flowering (76.70) was recorded at 200 Gy + 0.1% EMS dose of combination followed by 200 Gy dose (77.30) of gamma rays treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control.These findings are in the confirmity with the findings of Lande *et. al.* (2018) in Soybean.The maximum coefficient of variation (5.70) was recorded at 0.2% EMS concentration treatment. An increase in genotypic (GCV) and phenotypic coefficient of variation (PCV) over respective control population indicated that mutagens induced reasonably wider variability in all the treated population. These findings are in the confirmity with the findings of Begum and Dasgupta (2014). The maximum value of PCV (9.48) and GCV (7.58) for days to

50% flowering was recorded at 0.2% EMS concentration treatment followed by 200 Gy+0.1% EMS dose of combination [PCV (7.98), GCV (7.35)] treatment. In the present study, low PCV and GCV values were recorded in all the treated population for days to 50% flowering. These results are in broad agreement with the reports of Sikarwar *et. al.* (2017) in Yellow Sarson, Rajanna *et. al.* (2020) in Linseed, Dogra *et. al.*(2020) in Linseed and Khattab *et. al.*(2018) in Safflower. A small difference between PCV and GCV was recorded at 200 Gy + 0.1% dose of combination treatment followed by 200 Gy dose of gamma rays which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020).

Selection success is a reflection of selection response and heritability and genetic advance are significant selection indices. In comparison to the control, all mutagenic treatments had high to moderate heritability and low to moderate genetic advance as a percent of the mean. All of the mutagenic treatments showed a low to moderate genetic advance over the control. High heritability and moderate genetic advance as a percent of mean were reported among the mutagenic treatments at 200 Gy+ 0.1 % EMS dose of combination followed by 200 Gy dose of gamma rays and 0.2 % EMS concentration treatments.Also high heritability was recorded at 200 Gy+ 0.1% EMS dose of combination and 0.2% EMS concentration treatment, together with moderate genetic advance.In the current study, strong heritability was reported in various mutagenesis treatments, together with moderate genetic advance as a percent of mean, showing the importance of additive and non-additive gene activity in determining the inheritance of days to 50% flowering. These results are in broad agreement with the reports of Rajanna *et. al.*(2020) in Linseed, Khattab *et. al.* (2018) in Safflower, Umamaheswari *et. al.*(2019) in Sesame and Patil and Lokesha (2018) in Sesame. In several mutagenic treatments, high heritability was also reported with low genetic advance of percent of mean, showing the importance of non additive gene action in determining the inheritance of days to 50% flowering.These results are in broad agreement with the reports of Dogra *et. al.*(2020) in Linseed, Thakur *et.*

al.(2020) in Linseed, Phanindra *et. al.*(2018) in Sunflower, Bahmankar *et. al.* (2014) in Safflower and Kalaiyarasi *et. al.*(2019) in Sesame.

According to Paul (1978), if heritability in the broad sense is mostly attributable to additive gene effects, then it is only associated with high genetic gain. If heredity is mostly due to both additive and non additive effects, the genetic gain will be moderate, as seen in various mutagenic treatments ranging from days to 50% flowering. If non additive effects (dominance and/or epistasis) account for the majority of the heritability in the broad sense, the genetic gain will be low, as observed in the current study in most of the mutagenic treatments of days to 50% flowering.

4) Days to maturity

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for days to maturity in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.16.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS dose of combination and 0.2% EMS concentration treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for days to maturity in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Ravichandran and Jayakumar (2015) in Sesame, Lande *et. al.*(2018) in Soybean and Channaoui *et. al.*(2019) in Rapessed.

A significant reduction in days to maturity (120.18) was recorded at 200 Gy + 0.1% EMS dose of combination followed by 200 Gy dose (121.58) of gamma rays treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Lande *et. al.* (2018) in Soybean. The maximum coefficient of variation (4.48) was recorded in 100 Gy dose of gamma rays treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded

greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014). The maximum value of PCV (7.04) and GCV (6.03) for days to maturity was recorded at 0.2% EMS concentration treatment. In the present study, low PCV and GCV values were recorded in all the treated population for days to maturity indicating low scope of selection for improvement. These results are in broad agreement with the reports of Thakur *et. al.*(2020) in Linseed, Begumand Dasgupta (2014) in Sesame, Rajanna *et. al.* (2020) in Linseed, Dogra *et. al.*(2020) in Linseed, Phanindra *et. al.*(2018) in Sunflower and Khattab *et. al.* (2018) in Safflower. A small difference between PCV and GCV was recorded at 200 Gy dose of gamma rays which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Selection success is a reflection of selection response and heritability and genetic advance are significant selection indices. In comparison to the control, all mutagenic treatments had high to moderate heritability and low to moderate genetic advance as a percent of mean. All of the mutagenic treatments showed low to moderate genetic advancement. The 0.2 % EMS concentration treatment showed strong heritability and moderate genetic advance as a percent of mean across the mutagenic treatments.In the 200 Gy and 0.2 % EMS concentration treatments, high heritability was observed together with moderate genetic advancement. In the current study, high heritability was detected in various mutagenic treatments, together with moderate genetic advance as a percent of mean, showing the role of additive and non-additive gene action in determining the inheritance of days to maturity.These results are in broad agreement with the reports of Rajanna *et. al.* (2020) in Linseed, Bahmankar *et. al.* (2014) in Safflower and Umamaheswari *et. al.*(2019) in Sesame.In some mutagenic treatments, high heritability was also reported, along with low genetic advance as a percent of mean, showing the role of non additive gene action in determining the inheritance of days to maturity.These results are in broad agreement with the reports of Khattab *et. al.*(2018) in Safflower, Shivani *et. al.*(2011) in

Safflower,Thakur *et. al.*(2020) in Linseed, Meena *et. al.* (2020) in Linseed and Belete *et. al.*(2012) in Ethiopian mustard.

In the present study high heritability along with moderate genetic advance was recorded in some mutagenic treatment. Similar types of results were recorded by earlier work done by Chavanand Chopade (1981) in Sesame.

According to Paul (1978), if heritability in the broad sense is mostly attributable to additive gene effects, then it is only associated with high genetic gain. If heritability is mostly due to both additive and non additive effects, the genetic gain will be moderate, shown in several mutagenic treatments of days to maturity. If non additive effects (dominance and/or epistasis) account for the majority of the heritability in the broad sense, the genetic gain will be modest, as observed in the current study in most of the mutagenic treatments of days to maturity.

5) Number of primary branches per plant

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for number of primary branches per plant in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.17.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. These results are in broad agreements with the reports of Rai *et. al.*(2014) in linseed.Maximum range of variation was recorded at 200 Gy + 0.1% EMS dose of combination followed by 200 Gy dose of gamma rays treatment. The difference between the mean values of the mutagenic treatments and the mean value of the control indicated that all of the mutagens tested were effective and caused genetic variability in the number of primary branches per plant in all mutagenic populations in the M_2 generation.These results are in broad agreement with the reports of Sheeba *et. al.* (2003) in Sesame, Lande *et. al.* (2018) in Soybean, Channaoui *et. al.* (2019) in Rapessed and Ravichandran and Jayakumar (2015) in Sesame.

A significant increase in number of primary branches per plant (11.30) was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS (10.35) dose of combinationtreatment. The coefficient of variation showed marked increases

in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) and Siddiqui *et. al.*(2009). The maximum coefficient of variation (29.18) was recorded at400 Gy dose of gamma rays treatment followed by 0.1% EMS (28.74) concentration treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed, Begum and Dasgupta (2014) in Sesame. The maximum value of PCV (42.28) and GCV (31.31) for number of primary branches per plant was recorded at 0.1% EMS concentration and 200 Gy dose of gamma rays treatment respectively.In the present study, high PCV and GCV values were recorded in all the mutagenic treatments for number of primary branches per plant. These findings are consistent with the reports of Meena *et. al.* (2020) in Linseed, Khattab *et. al.* (2018) in safflower, Leelavatiand Mogali (2018) in Linseed, Patiland Lokesha (2018) in Sesame and Rajanna *et. al.* (2020) in Linseed.A small difference between PCV and GCV was recorded at 200 Gy dose of gamma rays which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Selection success is a reflection of selection response and heritability and genetic advance are significant selection parameters. In comparison to the control, all mutagenic treatments had low to high heritability and high genetic advance as a percentage of mean. All of the mutagenic treatments showed low genetic gain when compared to the control. At 200 Gy of gamma rays, 0.1% EMS, 0.2 % EMS and 0.4 % EMS concentrations, as well as 200 Gy + 0.1 % EMS and 300 Gy+0.2 % EMS doses of combination treatments, strong heritability and genetic advance as percent of mean were observed.At 100 Gy, 300 Gy, 400 Gy doses of gamma rays, 0.3 % EMS concentration and 200 Gy+ 0.2 % dose of combination treatments, there was moderate heritability combined with high genetic advance as percent of the mean. In the current study, high heritability was observed in some mutagenic treatments, along with a high genetic advance percent of the mean, indicating that additive gene action governs the inheritance of the number of primary branches per plant and that improvement of this

trait could be achieved through simple phenotypic selection in mutant populations. These results are consistent with the reports of Thakur *et. al.*(2020) in Linseed, Sikarwar *et. al.*(2017) in Yellow Sarson,Chavanand Chopade (1981) in Sesame and Leelavatiand Mogali (2018) in Linseed. In several mutagenic treatments, substantial heritability was also detected, along with high genetic advance as a percent of mean, showing the importance of both additive and non additive gene action in determining the inheritance of the number of primary branches per plant. These results are in broad agreement with the reports of Uzair *et. al.*(2016) in Mustard. Paul (1978) also stated that if heredity is primarily due to non-additive effects (dominance and/or epistasis), the genetic gain will be low, as seen in the number of primary branches per plant.

6) Number of secondary branches per plant

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for number of secondary branches per plant in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.18.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. These results are in broad agreements with the reports of Rai *et. al.*(2014) in Linseed. Maximum range of variation was recorded at 200 Gy + 0.1% EMS dose of combination followed by 200 Gy dose of gamma rays and 0.2% EMS concentration treatment. The difference between the mean values of the mutagenic treatments and the mean value of the control indicated that all of the mutagens tested were effective and caused genetic variability in the number of secondary branches per plant in all mutagenic populations in the M_2 generation.These results are in accordance with the reports of Sheeba *et. al.*(2003) in Sesame, Lande *et. al.*(2018) in Soybean, Channaoui *et. al.*(2019) in Rapessed and Ravichandran and Jayakumar (2015) in Sesame.

A significant increase in number of secondary branches per plant (28.43) was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS (27.28) dose of combination treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) in Linseed and Lande *et. al.* (2018) in

Soybean. The maximum coefficient of variation (34.30) was recorded at 0.4% EMS concentration treatment followed by 0.3% EMS (32.09) concentration treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) in Linseed, Begum and Dasgupta (2014) in Sesame. The maximum value of PCV (42.02) and GCV (28.47) for number of secondary branches per plant was recorded at 0.4% EMS concentration and 200 Gy + 0.2% EMS dose of combination treatment respectively.In the present study, high PCV and GCV values were recorded in all the mutagenic treatments for number of secondary branches per plant. These results consistent with the reports of Umamaheswari *et. al.* (2019) in Sesame, Rajanna *et. al.* (2020) in Linseed, Sikarwar *et. al.*(2017) in Yellow Sarson and Leelavati and Mogali (2018) in Linseed. A small difference between PCV and GCV was recorded at 200 Gy dose of gamma rays followed by 0.2% EMS concentration treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Selection success is a reflection of selection response and heritability and genetic advance are significant selection criteria. In comparison to the control, all mutagenic treatments had low to high heritability and high genetic advance as a percentage of the mean. All of the mutagenic treatments showed a low to moderate genetic advance over the control. Among the mutagenic treatments, high heritability along with high genetic advance as percent of mean were recorded at 200 Gy, 400 Gy dose of gamma rays, 0.2% EMS concentration and 200 Gy + 0.1% EMS and 200 Gy+0.2% EMS dose of combination treatments. Moderate heritability combined with high genetic advance as percent of mean was recorded at 100 Gy, 300 gy, 400 Gy dose of gamma rays, 0.1% EMS, 0.3% EMS and 0.4% EMS concentration treatments. At 200 Gy of gamma rays, 0.2 % EMS concentration and 200 Gy + 0.1 % EMS dose of combination treatment, high heritability was observed along with moderate genetic advance. In the current study, high heritability along with high genetic advance as percent of mean was observed indicating that additive gene action governs the

inheritance of the number of secondary branches per plant, and that improvement of this trait could be achieved through simple phenotypic selection in mutant populations.These results are in accordance with the reports of Leelavati and Mogali (2018) in Linseed, Sikarwar *et. al.*(2017) in Yellow Sarson, Thakur *et. al.*(2020) in Linseed and Rathod *et. al.*(2021) in Safflower. Moderate heritability was found, along with a high genetic advance as a percentage of the mean, showing that both additive and non additive gene action play a role. These results are in broad agreement with the reports of Kamdi *et. al.*(2020) in soybean and Uzair *et. al.* (2016) in Mustard. In several mutagenesis treatments, high heritability was also observed, along with moderate genetic advance as a percent of mean, showing the importance of both additive and non additive gene action in determining the inheritance of the number of secondary branches per plant. These results are in broad agreement with the reports of Rajanna *et. al.*(2020) in Linseed.

7) Number of capsule per plant

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for number of capsule per plant in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.19.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. These results are in broad agreements with the reports of Rai *et. al.*(2014) in Linseed. Maximum range of variation was recorded at 200 Gy + 0.1% EMS dose of combination followed by 200 Gy dose of gamma rays and 0.2% EMS concentration treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for number of capsule per plant in all the mutagenic populations in M_2 generation.These results are in consistent with the reports of Sheeba *et. al.*(2003) in Sesame, Lande *et. al.*(2018) in Soybean, Channaoui *et. al.*(2019) in Rapessed and Ravichandran and Jayakumar (2015) in Sesame.

A significant increase in number of capsule per plant (26.43) was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS (26.40) dose of combination treatment. The coefficient of variation showed marked increases in the

treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) in Linseed and Lande *et. al.*(2018) in Soybean. The maximum coefficient of variation (31.79) was recorded at 200 Gy+ 0.2 % EMS dose of combination treatment followed by 100 Gy (31.31) dose gamma rays treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) in Linseed, Begum and Dasgupta (2014) in Sesame. The maximum value of PCV (43.42) and GCV (30.64) for number of capsule per plant was recorded at 200 Gy+0.2% EMS dose of combination and 300 Gy + 0.1% EMS dose of combination treatment respectively. In the present study, high PCV and GCV values were recorded in all the mutagenic treatments for number of capsule per plant. These results are in broad agreement with the reports of Kalaiyarasi *et. al.*(2019) in Sesame, Leelavati and Mogali (2018) in Linseed, Rajanna *et. al.* (2020) in Linseed and Khattab *et. al.* (2018) in Safflower. A small difference between PCV and GCV was recorded at 200 Gy + 0.1 % EMS dose of combination followed by 0.2% EMS concentration treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Selection success is a reflection of selection response, and heritability and genetic advance are significant selection variables. In comparison to the control, all mutagenic treatments had low to high heritability and high genetic advance as a percentage of mean. All of the mutagenic treatments showed a low to moderate genetic advance over the control.Among the mutagenic treatments, the 200 Gy, 300 Gy doses of gamma rays, 0.1 % EMS, 0.2 % EMS concentration, 200 Gy + 0.1 % EMS and 300 Gy+0.1 % EMS doses of combination treatments showed strong heritability and genetic advance as percent of mean.Moderate heritability combined with high genetic advance as percent of mean was recorded at 400 Gy dose of gamma rays, 0.3% EMS, 0.4% EMS concentration and 200 Gy+ 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments. At 200 Gy of gamma rays, 0.2 % EMS concentration and 200 Gy + 0.1 % EMS dose of combination treatments, high heritability was observed along with moderate genetic advancement. In the present

investigation, high heritability was detected in various mutagenic treatments, together with high genetic advance as a percent of mean, showing the significance of additive gene action in determining the inheritance of this trait. These results are in accordance with the reports of Kalaiyarasi *et. al.*(2019) in Sesame, Leelavati and Mogali (2018) in Linseed, Rajanna *et. al.* (2020) in Linseed, Meena *et. al.*(2020) in Linseed, Umamaheswari *et.al.* (2019) in Sesame, and Khattab *et. al.*(2018) in Safflower. In several mutagenic treatments, high heritability was reported together with moderate genetic advance as a percent of mean, showing the importance of both additive and non additive gene action in determining the inheritance of this trait. These results are in broad agreement with the reports of Sikarwar *et. al.*(2017) in Yellow Sarson. In several mutagenic treatments, moderate heritability was also detected, along with high genetic advance as a percent of mean, showing the importance of both additive and non additive gene action in determining the inheritance of this trait. These results are consistent with the reports of Shivani *et. al.*(2011) in Safflower, Patil and Lokesha (2018) in Sesame.

8) Leaf dentation

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for leaf dentation in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.20.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS dose of combination treatment.The difference between the mean values of the mutagenic treatments and the mean value of the control revealed that all of the mutagens tested were efficient in inducing genetic variability for leaf dentation in all mutagenic populations in the M_2 generation.

A significant reduction in leaf dentation (30.13) was recorded at 200 Gy+ 0.1% EMS dose of combination followed by 200 Gy (31.22) dose of gamma rays treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. Similar observation was reported by Rai *et. al.*(2014) in Linseed. The maximum coefficient of variation (10.80) was recorded

at 400 Gy dose of gamma rays treatment followed by 200 Gy + 0.2 % EMS (10.10) dose of combination treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. Similar observation was reported by Begum and Dasgupta (2014) in Sesame and Rai *et. al.*(2014) in Linseed. The maximum value of PCV (16.20) and GCV (13.56) for leaf dentation was recorded at 200 Gy dose of gamma rays. A small difference between PCV and GCV was recorded at 200 Gy + 0.1 % EMS dose of combination followed by 200 Gy dose of gamma rays treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation was caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020).

Selection success is a reflection of selection response and heritability and genetic advance are significant selection indices. In comparison to the control, all mutagenic treatments had moderate to high heritability and low to high genetic advance as a percent of mean. All of the mutagenic treatments showed low genetic advance when compared to the control. Among the mutagenic treatments, high heritability along with high genetic advance as percent of mean were recorded at 200 Gy and 200 Gy + 0.1 % EMS dose of combination treatment. High heritability was observed with moderate genetic advance as a percent of mean at 300 Gy, dose of gamma rays, 0.1% EMS, 0.2% EMS concentration and 200 Gy+ 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments. Moderate heritability combined with moderate genetic advance as percent of mean was observed at 100 Gy and 400 Gy dose of gamma rays treatment. While moderate heritability was observed along with low genetic advance as percent of mean at 0.3% EMS, 0.4% EMS and 300 Gy + 0.1% EMS dose of combination treatment.High heritability was found in this study, along with a high genetic advance as a percentage of the mean, showing the importance of additive gene action in the inheritance of this characteristic.These findings are broad agreement with results of Tariq *et. al.*(2014) in Safflower and Bahmankar *et. al.*(2014) in Safflower. High/moderate heritability was detected, along with moderate genetic advance as a percent of mean, showing that both additive and non additive gene action play a significant role in the inheritance of this trait.Similar

observation was reported by Rajanna *et. al.*(2020) in Linseed and Shivani *et. al.*(2011) in Safflower. In addition, moderate heritability was detected, along with low genetic advance as a percentage of the mean, showing the importance of non additive gene action in the inheritance of this characteristic. Similar observation was reported by Sheeba *et. al.*(2003) in Sesame.

9) Number of spines on leaf

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for number of spines on leaf in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.21.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS dose of combination treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for number of spine on leaf in all the mutagenic populations in M_2 generation. Similar observation was reported by Sheeba *et. al.*(2003) in Sesame.

A significant reduction in number of spines on leaf (36.83) was recorded at 200 Gy+ 0.1% EMS dose of combination followed by 200 Gy dose (39.10) of gamma rays treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. Similar observation was reported by Rai. *et. al.*(2014) in Linseed. The maximum coefficient of variation (7.96) was recorded at 0.4% EMS concentration treatment followed by400 Gy (7.91) dose of gamma rays treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. Similar observation was reported by Begumand Dasgupta (2014) in Sesame and Rai *et. al.*(2014) in Linseed. The maximum value of PCV (13.82) and GCV (12.30) for number of spine on leaf was recorded at 200 Gy dose of gamma rays followed by PCV (13.22) and GCV (11.50) was recorded at 200 Gy+ 0.1% EMS dose of combination treatment. A small difference between PCV and GCV was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1 % EMS dose of

combination treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation was caused by mutations for polygenes. These findings are in the conformity with the findings of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Selection success is a reflection of selection response and heritability and genetic advance are significant selection criteria. In comparison to the control, all mutagenic treatments had low to high heritability and low to high genetic advance as percent of mean. In all of the mutagenic treatments, there was low genetic gain. High heritability and genetic advance as a percent of mean was found among the mutagenic treatments at 200 Gy and 200 Gy + 0.1 percent EMS doses of combination treatment. High heritability was observed with moderate genetic advance as percent of mean at 300 Gy of gamma rays, 0.2 % EMS concentration and 200 Gy+ 0.2 % EMS dose of combination treatments. High heritability was observed along with low genetic advance as a percentage of the mean at a 100 Gy gamma ray dose and 0.1 % EMS concentration treatment. While moderate heritability with low genetic advance as percent of mean was recorded at 400 Gy dose of gamma rays 0.3% EMS and 0.4% EMS concentration treatment. Low heritability was observed along with low genetic advance as percent of mean at 300 Gy + 0.1 % EMS and 300 Gy + 0.2% EMS dose of combination treatment. In the current study, high heritability was found along with high genetic advance as percent of mean showing the importance of additive gene action in the inheritance of this character.These findings are in accordance with the findings of Tariq *et. al.*(2014) in Safflower and Bahmankar *et. al.*(2014) in Safflower. High heritability was found, along with moderate genetic advance as a percentage of the mean, showing that both additive and non additive gene action play a huge role in the inheritance of this trait.These findings are in conformity with the findings of Rajanna *et. al.*(2020) in Linseed and Shivani *et. al.*(2011) in Safflower.In addition, high/moderate/low heritability was identified, along with low genetic advance as a percent of mean, showing the importance of non additive gene action in determining the inheritance of this trait.Similar observation was reported by Phanindra *et. al.*(2018) in Sunflower and Sheeba *et. al.*(2003) in Sesame.

10) Diameter of head (cm)

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for diameter of head in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.22.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS dose of combination treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for diameter of head in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Channaoui *et. al.*(2019) in Rapessed, and Cvejic *et. al.*(2011) in Sunflower.

A significant increase in diameter of head (3.19) was recorded at 200 Gy dose of gamma rays followed by 200 Gy+ 0.1% EMS (3.07) dose of combination treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. The maximum coefficient of variation (21.40) was recorded at 0.4% EMS concentration treatment followed by 400 Gy (17.81) dose of gamma rays treatment. The magnitude of induced genetic variability in terms of PCV and GCV was greater in the mutagenic treatments as compared to their respective control. The maximum value of PCV (30.02) and GCV (21.90) for diameter of head was recorded at 0.4% EMS concentration and 400 Gy dose of gamma rays treatment. In the present study, moderate to high value of PCV and GCV was recorded for diameter of head. Similar observation was reported by Tariq *et. al.*(2014) in Safflower and Paikara *et. al.*(2013) in Safflower. A small difference between PCV and GCV was recorded at 200 Gy + 0.1 % EMS dose of combination followed by 200 Gy dose of gamma rays and 0.2% EMS concentration treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation was caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Selection success is a reflection of selection reaction and heritability and genetic advance are significant selection indices. In comparison to the control, all mutagenic treatments had moderate to high heritability and moderate to high genetic advance as a percent of mean. In all of the mutagenic treatments, there was low genetic gain. With the exception of 0.3 % EMS and 0.4 % EMS concentration treatments, most mutagenic treatments had significant heritability as well as high genetic advance as a percentage of mean.At 0.4 percent EMS concentration treatment, moderate heritability was observed, along with a high genetic advance as a percentage of the mean. Moderate heritability was observed, and also moderate genetic advance as a percentage of the mean at 0.3 percent EMS concentration treatment. In the current investigation, high heritability was detected in most mutagenic treatments, together with high genetic advance as a percent of mean, showing the significance of additive gene action in determining the inheritance of this feature.These results are in broad agreement with the reports of Bahmankar *et. al.*(2014) in Safflower and Tariq *et. al.*(2014) in Safflower.

11) Number of seeds per capsule

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for number of seeds per capsule in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.23.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS dose of combination treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for number of seeds per capsule in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Sheeba *et. al.*(2003) in Sesame, Lande *et. al.*(2018) in Soybean, Channaoui *et. al.*(2019) in Rapessed and Ravichandran and Jayakumar (2015) in Sesame.

A significant increase in number of seeds per capsule (32.40) was recorded at 200 Gy dose of gamma rays followed by 200 Gy+ 0.1% EMS(31.03) dose of

combination treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014). The maximum coefficient of variation (24.23) was recorded at 0.4% EMS concentration treatment followed by 0.1% EMS (22.82) concentration treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) in Linseed, Begum and Dasgupta (2014) in Sesame. The maximum value of PCV (32.90) and GCV (24.26) for number of seeds per capsule was recorded at 400 Gy dose of gamma rays and 0.2% EMS concentration treatment. In the present study, high to moderate value of PCV and GCV was observed. High value of PCV and GCV was observed in some mutagenic treatments. These results are in broad agreement with the reports of Begum and Dasgupta (2014) in Sesame and Rathod *et. al.* (2021) in Safflower. Moderate value of PCV and GCV was observed in some other mutagenic treatments. These results are in broad agreement with the reports of Pushpavalli *et. al.*(2017) in safflower and Kalaiyarasi *et. al.*(2019) in Sesame. A small difference between PCV and GCV was recorded at 0.2% EMS concentration followed by 200 Gy dose of gamma rays and 200 Gy +0.1% EMS dose of combination treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had moderate to high heritability and high genetic advance as a percent of mean. All of the mutagenic treatments showed low to moderate genetic advancement. With the exception of 100 Gy dose of gamma rays, 0.1 % EMS and 0.4 % EMS concentration, and 300 Gy + 0.2 % EMS dose of combination treatments, most mutagenic treatments had high heritability and high genetic advance as a percent of mean. There was moderate heritability with high genetic advance as a percent of mean at 100 Gy of gamma rays, followed by 0.1 % EMS, 0.4 % EMS

concentration and 300 Gy + 0.2 % EMS dose of combination treatments. High heritability was observed, along with high genetic advance as a percentage of mean and also with moderate genetic advance at 0.2% EMS concentration treatment. In the current investigation, high heritability was detected in various mutagenic treatments, together with high genetic advance as a percent of the mean, showing the significance of additive gene action in determining the inheritance of this trait.These results are in accordance with the reports of Rathod *et. al.*(2021) in Safflower, Kalaiyarasi *et. al.*(2019) in Sesame, Leelavati and Mogali (2018) in Linseed and Rajanna *et. al.*(2020) in Linseed.

12) 100 seed weight

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for 100 seed weight in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.24.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. These results are in broad agreements with the reports of Rai *et. al.*(2014) in Linseed. Maximum range of variation was recorded at 400 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS dose of combination treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for 100 seed weight in all the

Table 4.13: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for days to rosette in M_2 generation of PBNS-12 variety

Sr. No.	Treatment	Range (days)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	25-31	28.42±0.20	4.17	2.48	4.58	7.18	5.54	59.40	2.50	8.79
2	200 Gy	22-33	25.37±0.19	4.03	3.04	3.93	7.91	6.87	75.34	3.12	12.28
3	300 Gy	26-32	29.27±0.27	3.78	1.74	4.88	6.64	4.50	46.00	1.84	6.29
4	400 Gy	25-30	28.85±0.30	3.66	1.88	4.63	6.63	4.75	51.26	2.02	7.01
5	0.1% EMS	25-31	29.65±0.35	5.76	3.23	5.37	8.10	6.06	56.06	2.77	9.35
6	0.2% EMS	22-32	27.70±0.18	5.14	3.17	5.06	8.18	6.43	61.68	2.88	10.40
7	0.3% EMS	25-30	30.42±0.30	5.08	2.49	5.29	7.41	5.19	49.01	2.28	7.48
8	0.4% EMS	26-32	28.70±0.18	2.99	1.24	4.62	6.03	3.88	41.33	1.47	5.13
9	200 Gy + 0.1% EMS	23-33	25.67±0.20	5.34	3.58	5.18	9.00	7.37	66.95	3.19	12.42
10	200 Gy + 0.2% EMS	27-32	29.27±0.24	2.76	1.47	3.87	5.67	4.15	53.50	1.83	6.25
11	300 Gy + 0.1% EMS	26-29	29.27±0.27	2.97	1.28	4.44	5.89	3.87	43.14	1.53	5.23
12	300 Gy + 0.2% EMS	27-33	29.08±0.24	2.42	1.40	3.47	5.35	4.07	57.92	1.86	6.38
13	Dry Control	27-31	28.20±0.15	0.89	0.26	2.81	3.35	1.82	29.53	0.57	2.04
14	Wet Control	27-30	28.30±0.15	0.87	0.23	2.84	3.30	1.69	26.10	0.50	1.78

Table 4.14: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for days to bolting in M_2 generation of PBNS-12 variety

Sr. No.	Treatment	Range (days)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	39-52	46.73±0.50	19.13	10.17	6.41	9.36	6.82	53.15	4.79	10.25
2	200 Gy	35-56	41.45±0.18	13.74	9.75	4.82	8.94	7.53	70.99	5.42	13.08
3	300 Gy	36-54	47.43±0.66	20.62	12.40	6.04	9.57	7.42	60.12	5.62	11.86
4	400 Gy	42-53	47.33±0.35	18.78	8.24	6.86	9.16	6.06	43.89	3.92	8.28
5	0.1% EMS	41-54	46.08±0.69	20.12	10.2	6.84	9.73	6.93	50.69	4.68	10.16
6	0.2% EMS	40-56	48.53±0.61	25.17	15.46	6.42	10.34	8.10	61.39	6.35	13.07
7	0.3% EMS	36-51	41.93±0.45	16.97	10.73	5.96	9.82	7.81	63.24	5.37	12.80
8	0.4% EMS	38-52	48.22±0.74	18.91	8.44	6.71	9.02	6.03	44.64	3.99	8.29
9	200 Gy + 0.1% EMS	38-55	40.68±0.41	11.07	6.63	5.18	8.18	6.33	59.91	4.11	10.09
10	200 Gy + 0.2% EMS	37-52	44.42±0.65	18.67	8.84	7.06	9.73	6.69	47.35	4.21	9.49
11	300 Gy + 0.1% EMS	39-54	43.57±0.45	25.06	12.72	8.06	11.49	8.19	50.74	5.23	12.01
12	300 Gy + 0.2% EMS	40-53	47.05±0.80	24.81	11.53	7.75	10.59	7.22	46.47	4.77	10.14
13	Dry Control	43-53	46.95±0.42	5.33	1.69	4.06	4.92	2.77	31.74	1.51	3.21
14	Wet Control	43-52	47.07±0.35	5.11	1.63	3.96	4.80	2.71	31.93	1.49	3.16

Table 4.15: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for days to 50% flowering in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (days)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	69-89	80.95±0.54	32.56	16.80	4.90	7.05	5.06	51.59	6.06	7.49
2	200 Gy	62-88	77.30±0.45	37.99	28.72	3.94	7.97	6.93	75.58	9.60	12.42
3	300 Gy	68-90	83.07±0.85	34.39	18.62	4.78	7.06	5.20	54.15	6.54	7.87
4	400 Gy	72-90	80.85±0.67	26.90	14.21	4.41	6.42	4.66	52.80	5.64	6.98
5	0.1% EMS	74-90	85.07±0.47	17.95	7.67	3.77	4.98	3.25	42.71	3.73	4.38
6	0.2% EMS	65-91	80.85±0.98	58.80	37.55	5.70	9.48	7.58	63.87	10.09	12.48
7	0.3% EMS	65-88	81.40±0.88	36.59	18.47	5.23	7.43	5.28	50.47	6.29	7.73
8	0.4% EMS	69-89	80.45±0.75	25.03	11.26	4.61	6.22	4.17	44.98	4.64	5.76
9	200 Gy + 0.1% EMS	63-90	76.70±0.20	37.47	31.74	3.12	7.98	7.35	84.71	10.68	13.93
10	200 Gy + 0.2% EMS	64-87	81.33±0.36	36.48	21.97	4.68	7.43	5.76	60.22	7.49	9.21
11	300 Gy + 0.1% EMS	65-89	82.73±0.87	30.06	15.17	4.66	6.63	4.71	50.47	5.70	6.89
12	300 Gy + 0.2% EMS	70-90	81.33±0.94	40.55	20.15	5.55	7.83	5.52	49.68	6.52	8.01
13	Dry Control	79-87	80.87±0.34	4.93	1.72	2.22	2.75	1.62	34.87	1.59	1.97
14	Wet Control	78-88	81.10±0.23	6.68	2.27	2.59	3.19	1.86	34.02	1.81	2.23

Table 4.16: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for days to maturity in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (days)	Mean±SE	Phenotypic Variance	Genotypic variance	CV %	PCV %	GCV (%)	H_2 (bs) (%)	GA (%)	GAM
1	100 Gy	115-136	129.92±0.80	67.25	33.56	4.48	6.31	4.46	49.91	8.43	6.49
2	200 Gy	107-141	121.58±0.53	48.57	40.75	2.30	5.73	5.25	83.90	12.05	9.91
3	300 Gy	114-140	132.82±0.75	55.72	31.52	3.70	5.62	4.23	56.57	8.70	6.55
4	400 Gy	119-139	129.30±1.28	57.53	26.30	4.32	5.87	3.97	45.72	7.14	5.52
5	0.1% EMS	120-140	133.35±1.00	40.50	20.84	3.33	4.77	3.42	51.46	6.75	5.06
6	0.2% EMS	113-141	130.00±0.67	83.79	61.54	3.63	7.04	6.03	73.45	13.85	10.65
7	0.3% EMS	112-139	132.62±0.84	53.18	26.56	3.89	5.50	3.89	49.93	7.50	5.66
8	0.4% EMS	117-137	131.43±1.20	38.50	23.07	3.00	4.74	3.67	59.93	7.66	5.85
9	200 Gy + 0.1% EMS	108-140	120.18±0.73	29.08	18.82	2.67	4.49	3.61	64.70	7.18	5.98
10	200 Gy + 0.2% EMS	110-136	129.40±1.07	50.69	24.68	3.94	5.50	3.84	48.69	7.14	5.52
11	300 Gy + 0.1% EMS	113-138	131.50±0.85	25.65	10.48	2.96	3.85	2.46	40.86	4.26	3.24
12	300 Gy + 0.2% EMS	114-140	133.25±0.58	49.18	27.81	3.47	5.26	3.96	56.55	8.17	6.13
13	Dry Control	124-135	130.45±0.39	5.90	1.61	1.59	1.86	0.97	27.34	1.37	1.05
14	Wet Control	125-135	130.08±0.41	5.05	1.87	1.37	1.73	1.05	37.06	1.72	1.32

Table 4.17: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Number of Primary branches per plant in M_2 generation of PBNS-12 variety

Sr. No.	Treatment	Range (No.)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	4-17	9.45± 0.55	11.56	5.7	25.61	35.97	25.26	49.32	3.45	36.55
2	200 Gy	3-21	11.30±0.34	16.22	12.52	17.03	35.64	31.31	77.17	6.40	56.66
3	300 Gy	3-15	9.47±0.40	8.37	3.99	22.10	30.57	21.11	47.72	2.84	30.05
4	400 Gy	5-20	9.73±0.50	15.06	6.99	29.18	39.87	27.16	46.42	3.71	38.13
5	0.1% EMS	4-19	9.60±0.28	16.48	8.86	28.74	42.28	31.001	53.78	4.50	46.84
6	0.2% EMS	5-16	9.37±0.19	9.75	5.61	21.71	33.34	25.30	57.57	3.70	39.54
7	0.3% EMS	3-14	8.32±0.11	7.54	3.45	24.30	33.01	22.34	45.79	2.59	31.14
8	0.4% EMS	4-19	7.87±0.13	9.28	4.65	27.35	38.72	27.41	50.11	3.14	39.97
9	200 Gy + 0.1% EMS	2-20	10.35±0.10	13.83	9.67	19.70	35.93	30.05	69.93	5.36	51.76
10	200 Gy + 0.2% EMS	4-14	8.08±0.47	8.43	3.91	26.30	35.91	24.45	46.36	2.77	34.30
11	300 Gy + 0.1% EMS	2-15	7.43±0.23	5.48	1.96	25.21	31.48	18.86	35.87	1.73	23.27
12	300 Gy + 0.2% EMS	3-12	7.28±0.15	7.26	4.01	24.74	36.98	27.49	55.25	3.07	42.09
13	Dry Control	7-12	9.45±0.10	2.80	0.76	15.10	17.70	9.24	27.26	0.94	9.94
14	Wet Control	7-13	9.42±0.11	3.53	0.99	16.93	19.95	10.55	27.98	1.08	11.50

Table 4.18: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Number of Secondary branches per plant in M_2 generation of PBNS-12 genotypes.

Sr. No.	Treatment	Range (No.)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	14-36	20.90±0.71	66.67	28.30	29.64	39.07	25.45	42.45	7.14	34.16
2	200 Gy	6-44	28.43±1.01	82.22	62.26	15.71	31.89	27.75	75.72	14.14	49.74
3	300 Gy	8-38	25.18±0.42	67.40	32.94	23.31	32.60	22.79	48.87	8.27	32.82
4	400 Gy	15-42	24.55±1.13	81.84	42.59	25.52	36.85	26.58	52.04	9.70	39.51
5	0.1% EMS	12-39	25.65±1.36	66.24	27.45	24.28	31.73	20.43	41.44	6.95	27.09
6	0.2% EMS	7-41	24.90±0.32	67.39	49.50	16.98	32.97	28.26	73.46	12.42	49.88
7	0.3% EMS	11-39	19.43±1.28	65.73	26.84	32.09	41.72	26.66	40.83	6.82	35.09
8	0.4% EMS	6-36	17.92±1.18	56.68	18.90	34.30	42.02	24.27	33.35	5.17	28.87
9	200 Gy + 0.1% EMS	7-47	27.28±1.09	64.57	41.67	17.54	29.45	23.66	64.53	10.68	39.15
10	200 Gy + 0.2% EMS	8-34	17.33±0.90	46.51	24.34	27.15	39.35	28.47	52.37	7.36	42.45
11	300 Gy + 0.1% EMS	9-38	17.48±0.91	38.04	12.13	29.12	35.28	19.92	31.88	4.05	23.17
12	300 Gy + 0.2% EMS	5-30	16.08±0.91	31.31	12.01	27.32	34.79	21.54	38.34	4.42	27.48
13	Dry Control	21-31	24.65±0.43	10.44	2.70	11.29	13.11	6.66	25.85	1.72	6.98
14	Wet Control	21-32	24.75±0.06	10.75	3.39	10.96	13.25	7.44	31.57	2.13	8.62

Table 4.19: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for number of Capsule per plant in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (No.)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	13-35	20.58±0.68	66.06	24.53	31.31	39.49	24.06	37.13	6.22	30.20
2	200 Gy	5-43	26.43±1.28	91.73	59.63	21.44	36.23	29.21	65.00	12.82	48.52
3	300 Gy	7-36	23.97±1.03	54.01	29.68	20.58	30.66	22.73	54.96	8.32	34.71
4	400 Gy	14-42	23.33±1.28	63.99	30.25	24.89	34.28	23.57	47.28	7.79	33.39
5	0.1% EMS	10-38	25.15±0.88	49.77	27.77	18.65	28.05	20.95	55.80	8.11	32.24
6	0.2% EMS	6-40	24.85±0.30	71.03	45.76	20.23	33.92	27.22	64.42	11.18	45.01
7	0.3% EMS	10-34	18.00±0.06	50.73	22.97	29.27	39.57	26.63	45.28	6.64	36.91
8	0.4% EMS	5-35	18.10±0.97	38.39	18.07	24.90	34.23	23.49	47.07	6.01	33.19
9	200 Gy + 0.1% EMS	4-45	26.43±0.30	72.67	53.05	16.76	32.25	27.56	73.00	12.82	48.50
10	200 Gy + 0.2% EMS	7-33	16.08±0.58	48.77	22.63	31.79	43.42	29.58	46.41	6.68	41.51
11	300 Gy + 0.1% EMS	8-38	15.55±0.80	41.25	22.70	27.70	41.30	30.64	55.02	7.28	46.82
12	300 Gy + 0.2% EMS	3-30	15.60±0.75	26.63	13.10	23.58	33.08	23.20	49.18	5.23	33.52
13	Dry Control	21-30	24.30±0.39	8.43	2.43	10.07	11.95	6.42	28.89	1.73	7.11
14	Wet Control	21-31	24.33±0.15	8.96	2.19	10.70	12.30	6.08	24.41	1.51	6.18

Table 4.20: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Leaf dentation in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (No.)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	30-49	38.72±0.77	23.34	11.40	8.92	12.48	8.72	48.85	4.86	12.56
2	200 Gy	22-47	31.22±0.60	25.56	17.93	8.85	16.20	13.56	70.13	7.30	23.40
3	300 Gy	31-50	40.47±0.33	24.21	12.34	8.51	12.16	8.68	50.97	5.17	12.77
4	400 Gy	29-49	35.70±0.79	24.86	9.99	10.80	13.97	8.85	40.18	4.13	11.56
5	0.1% EMS	31-48	41.18±0.71	22.09	11.53	7.89	11.41	8.24	52.19	5.05	12.27
6	0.2% EMS	32-52	40.50±0.63	24.10	16.01	7.02	12.12	9.88	66.45	6.72	16.59
7	0.3% EMS	31-52	43.30±0.65	18.07	8.23	7.24	9.82	6.62	45.54	3.99	9.21
8	0.4% EMS	28-43	36.25±0.63	13.37	5.75	7.62	10.09	6.61	42.99	3.24	8.93
9	200 Gy + 0.1% EMS	24-48	30.13±0.38	20.32	13.97	8.36	14.96	12.40	68.77	6.39	21.19
10	200 Gy + 0.2% EMS	28-51	40.87±1.09	40.32	23.27	10.10	15.54	11.80	57.72	7.55	18.47
11	300 Gy + 0.1% EMS	34-50	40.13±0.62	16.25	7.72	7.28	10.04	6.92	47.53	3.95	9.83
12	300 Gy + 0.2% EMS	31-47	38.45±0.61	19.96	10.32	8.07	11.62	8.36	51.73	4.76	12.38
13	Dry Control	35-43	36.70±0.25	3.53	1.18	4.17	5.12	2.96	33.49	1.30	3.53
14	Wet Control	36-44	37.67±0.09	4.88	1.59	4.82	5.87	3.35	32.61	1.49	3.94

Table 4.21: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for number of spines on Leaf in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (No.)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	38-53	44.30±0.44	11.82	5.98	5.45	7.76	5.52	50.61	3.58	8.09
2	200 Gy	28-51	39.10±0.52	29.21	23.12	6.31	13.82	12.30	79.14	8.81	22.53
3	300 Gy	38-55	46.42±0.42	16.51	9.21	5.82	8.76	6.54	55.79	4.67	10.06
4	400 Gy	34-53	42.25±0.71	20.01	8.84	7.91	10.59	7.04	44.15	4.07	9.63
5	0.1% EMS	36-51	44.55±0.54	13.12	7.38	5.38	8.13	6.10	56.22	4.19	9.42
6	0.2% EMS	38-55	46.78±0.34	12.95	8.62	4.45	7.69	6.27	66.54	4.93	10.54
7	0.3% EMS	41-54	46.85±0.52	13.56	6.66	5.61	7.86	5.51	49.14	3.73	7.96
8	0.4% EMS	34-53	44.65±0.64	22.15	9.53	7.96	10.54	6.91	43.01	4.17	9.34
9	200 Gy + 0.1% EMS	28-50	36.83±0.52	23.72	17.94	6.53	13.22	11.50	75.64	7.59	20.60
10	200 Gy + 0.2% EMS	33-53	43.97±0.66	22.94	11.93	7.55	10.89	7.86	52.00	5.13	11.67
11	300 Gy + 0.1% EMS	39-54	46.60±0.45	16.81	6.01	7.05	8.80	5.26	35.76	3.02	6.48
12	300 Gy + 0.2% EMS	37-55	45.55±0.78	21.59	6.77	8.45	10.20	5.71	31.37	3.00	6.59
13	Dry Control	42-48	44.48±0.29	4.08	1.11	3.87	4.54	2.37	27.18	1.13	2.54
14	Wet Control	41-47	43.53±0.14	1.94	0.51	2.75	3.20	1.64	26.24	0.75	1.73

Table 4.22: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Diameter of head in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (cm)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	1.5-3.6	2.38±0.04	0.32	0.17	16.38	23.68	17.11	52.19	0.61	25.46
2	200 Gy	0.8-3.9	3.19±0.05	0.34	0.22	10.63	18.22	14.79	65.92	0.79	24.74
3	300 Gy	1.3-3.6	2.65±0.04	0.28	0.15	14.15	20.35	14.63	51.64	0.57	21.65
4	400 Gy	1.2-3.4	2.12±0.07	0.36	0.21	17.81	28.23	21.90	60.20	0.74	35.01
5	0.1% EMS	1.1-3.5	2.42±0.04	0.36	0.19	17.02	24.66	17.85	52.40	0.64	26.62
6	0.2% EMS	1.3-3.7	2.63±0.04	0.38	0.28	12.22	23.44	20.00	72.84	0.92	35.16
7	0.3% EMS	1.2-3.8	2.70±0.03	0.30	0.14	14.78	20.24	13.82	46.65	0.53	19.45
8	0.4% EMS	1.2-3.6	2.08±0.07	0.39	0.19	21.40	30.02	21.05	49.17	0.63	30.40
9	200 Gy + 0.1% EMS	0.9-3.8	3.07±0.06	0.32	0.23	10.29	18.60	15.49	69.37	0.81	26.58
10	200 Gy + 0.2% EMS	0.9-3.4	2.35±0.08	0.32	0.19	15.79	24.24	18.39	57.54	0.68	28.73
11	300 Gy + 0.1% EMS	1.5-3.6	2.75±0.05	0.28	0.15	13.16	19.34	14.17	53.69	0.59	21.39
12	300 Gy + 0.2% EMS	1.1-3.5	2.46±0.06	0.34	0.20	15.54	23.76	17.98	57.22	0.69	28.01
13	Dry Control	2.1-3.2	2.46±0.01	0.05	0.02	7.37	9.07	5.30	34.05	0.16	6.36
14	Wet Control	2.1-3.3	2.45±0.03	0.06	0.02	7.99	9.64	5.40	31.37	0.15	6.23

Table 4.23: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for number of seeds per capsule in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (No.)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2 (bs) (%)	GA (%)	GAM
1	100 Gy	13-37	25.30±0.83	46.16	18.92	20.63	26.86	17.19	40.97	5.74	22.67
2	200 Gy	5-45	32.40±0.65	32.10	21.38	10.10	17.49	14.27	66.61	7.77	23.99
3	300 Gy	11-40	26.42±0.22	58.96	33.18	19.22	29.07	21.81	56.28	8.90	33.70
4	400 Gy	8-38	20.75±0.66	46.61	24.27	22.78	32.90	23.74	52.07	7.32	35.30
5	0.1% EMS	12-39	23.95±0.44	58.77	28.90	22.82	32.01	22.45	49.17	7.77	32.42
6	0.2% EMS	11-40	25.67±0.69	48.44	38.78	12.11	27.12	24.26	80.07	11.48	44.72
7	0.3% EMS	10-41	26.37±0.87	45.13	23.36	17.70	25.48	18.33	51.76	7.16	27.17
8	0.4% EMS	9-35	21.17±0.73	44.47	18.18	24.23	31.51	20.14	40.87	5.61	26.52
9	200 Gy + 0.1% EMS	3-42	31.03±0.79	41.69	28.82	11.56	20.81	17.30	69.13	9.19	29.63
10	200 Gy + 0.2% EMS	9-36	26.55±0.97	57.95	30.85	19.61	28.67	20.92	53.24	8.35	31.45
11	300 Gy + 0.1% EMS	14-38	27.02±0.91	43.52	24.86	15.99	24.42	18.46	57.12	7.76	28.73
12	300 Gy + 0.2% EMS	12-39	25.77±1.23	37.95	18.06	17.31	23.91	16.49	47.59	6.04	23.44
13	Dry Control	21-34	26.40±0.46	8.18	2.81	8.78	10.84	6.35	34.37	2.03	7.67
14	Wet Control	20-32	25.47±0.39	8.25	1.95	9.86	11.28	5.48	23.64	1.40	5.49

Table 4.24: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for 100 seed weight in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (g)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	2.1-7.1	4.70±0.02	1.20	0.70	15.07	23.31	17.79	58.23	1.31	27.96
2	200 Gy	2.0-7.5	5.03±0.12	1.21	0.86	11.81	21.86	18.39	70.80	1.61	31.88
3	300 Gy	2.3-6.7	4.72±0.06	1.27	0.57	17.78	23.87	15.92	44.51	1.03	21.89
4	400 Gy	2.1- 9.0	4.59±0.04	2.20	1.20	21.75	32.31	23.90	54.68	1.67	36.40
5	0.1% EMS	2.9-7.2	4.80±0.09	1.32	0.67	16.77	23.93	17.07	50.88	1.20	25.08
6	0.2% EMS	2.4-6.9	4.70±0.07	1.42	1.08	12.29	25.29	22.11	76.38	1.87	39.80
7	0.3% EMS	2.1-6.6	4.67±0.15	1.34	0.68	17.42	24.83	17.70	50.78	1.21	25.98
8	0.4% EMS	2.0-7.1	4.80±0.13	1.17	0.54	16.58	22.56	15.30	46.00	1.03	21.38
9	200 Gy + 0.1% EMS	1.3-8.3	5.08±0.09	1.29	0.91	12.09	22.34	18.79	70.72	1.65	32.55
10	200 Gy + 0.2% EMS	3.0-7.4	4.44±0.03	1.40	0.73	18.39	26.64	19.27	52.33	1.28	28.71
11	300 Gy + 0.1% EMS	1.9-7.8	4.38±0.18	1.12	0.57	16.98	24.22	17.28	50.87	1.11	25.38
12	300 Gy + 0.2% EMS	3.1-6.6	4.85±0.03	1.15	0.73	13.32	22.11	17.65	63.69	1.41	29.01
13	Dry Control	3.9-5.5	4.74±0.03	0.14	0.04	6.81	7.97	4.14	0.27	0.21	4.44
14	Wet Control	3.6-5.7	4.75±0.01	0.20	0.06	7.93	9.36	4.98	28.31	0.26	5.46

Table 4.25: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for seed width in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (mm)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV %	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	2.62-5.35	3.64±0.10	0.49	0.24	13.94	19.30	13.36	47.87	0.69	19.04
2	200 Gy	2.16-5.82	4.75±0.08	0.81	0.58	9.91	18.90	16.09	72.52	1.34	28.23
3	300 Gy	2.74-5.37	3.93±0.11	0.58	0.31	13.14	19.38	14.25	54.07	0.85	21.59
4	400 Gy	2.48-5.92	3.17±0.10	0.43	0.23	14.19	20.67	15.02	52.84	0.71	22.50
5	0.1% EMS	2.42-5.48	3.38±0.08	0.56	0.26	16.11	22.10	15.13	46.87	0.72	21.35
6	0.2% EMS	2.59-5.66	3.39±0.06	0.51	0.42	9.02	21.09	19.06	81.70	1.20	35.49
7	0.3% EMS	2.22-5.24	3.65±0.09	0.45	0.24	12.31	18.31	13.56	54.84	0.75	20.69
8	0.4% EMS	2.93-5.76	4.23±0.10	0.60	0.25	13.94	18.34	11.92	42.22	0.67	15.95
9	200 Gy + 0.1% EMS	2.19-5.93	4.68±0.04	0.76	0.57	9.13	18.58	16.18	75.85	1.36	29.03
10	200 Gy + 0.2% EMS	2.20-5.48	3.78±0.13	0.59	0.26	15.16	20.31	13.51	44.25	0.70	18.51
11	300 Gy + 0.1% EMS	2.85-5.69	4.25±0.06	0.62	0.33	12.71	18.56	13.53	53.15	0.86	20.32
12	300 Gy + 0.2% EMS	2.56-5.72	3.67±0.13	0.53	0.22	15.00	19.80	12.93	42.64	0.63	17.39
13	Dry Control	2.65-3.88	3.33±0.04	0.11	0.04	7.82	9.97	6.17	38.37	0.26	7.88
14	Wet Control	2.43-3.92	3.32±0.03	0.11	0.04	7.68	9.92	6.27	40.02	0.27	8.18

Table 4.26: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Seed length in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (mm)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	5.28-9.86	7.46±0.16	1.99	0.84	14.37	18.91	12.29	42.26	1.23	16.46
2	200 Gy	5.11-10.92	8.82±0.7	2.24	1.55	9.41	16.98	14.14	69.28	2.14	24.24
3	300 Gy	5.18-10.04	6.92±0.10	1.46	0.64	13.10	17.45	11.54	43.71	1.09	15.72
4	400 Gy	5.68-10.94	6.19±0.16	1.04	0.37	13.28	16.52	9.82	35.34	0.74	12.02
5	0.1% EMS	5.14-9.88	7.80±0.18	1.69	0.76	12.31	16.65	11.21	45.32	1.21	15.54
6	0.2% EMS	5.52-10.12	8.35±0.19	1.26	0.72	8.75	13.43	10.18	57.50	1.33	15.91
7	0.3% EMS	5.34-9.96	6.87±0.11	1.10	0.62	10.10	15.29	11.48	56.34	1.22	17.75
8	0.4% EMS	6.03-10.68	8.24±0.16	1.27	0.67	9.45	13.69	9.90	52.30	1.21	14.74
9	200 Gy + 0.1% EMS	5.10-10.86	8.85±0.08	2.14	1.61	8.28	16.54	14.32	74.96	2.26	25.54
10	200 Gy + 0.2% EMS	5.23-9.48	7.64±0.20	1.82	1.05	11.53	17.67	13.39	57.41	1.60	20.90
11	300 Gy + 0.1% EMS	5.36-10.75	8.27±0.20	1.67	0.83	11.04	15.61	11.04	49.96	1.33	16.07
12	300 Gy + 0.2% EMS	5.41-10.82	6.95±0.16	1.22	0.55	11.79	15.89	10.66	45.00	1.02	14.74
13	Dry Control	5.87-8.96	7.51±0.08	0.36	0.12	6.49	7.98	4.65	33.90	0.42	5.57
14	Wet Control	6.01-8.96	7.48±0.12	0.45	0.18	7.00	8.98	5.63	39.26	0.42	5.58

Table 4.27: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Grain yield per plant in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (g)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	7.33-46.23	26.71±1.45	105.02	40.38	30.10	38.37	23.79	38.45	8.12	30.39
2	200 Gy	5.74-52.86	37.36±0.94	118.22	79.41	16.67	29.10	23.85	67.17	15.05	40.27
3	300 Gy	8.42-38.89	29.97±1.16	91.04	45.49	22.52	31.83	22.50	49.96	9.82	32.76
4	400 Gy	8.06-48.89	24.63±1.82	92.95	29.28	32.40	39.15	21.97	31.50	6.26	25.40
5	0.1% EMS	9.89-48.92	28.88±0.49	111.92	68.68	22.77	36.63	28.69	61.36	13.37	46.30
6	0.2% EMS	5.20-41.31	31.10±1.23	97.15	43.82	23.48	31.69	21.29	45.10	9.16	29.45
7	0.3% EMS	9.98-47.44	22.58±1.13	79.11	30.82	30.78	39.40	24.59	38.95	7.14	31.62
8	0.4% EMS	6.05-41.24	18.55±0.65	61.35	19.43	34.91	42.23	23.77	31.66	5.11	27.55
9	200 Gy + 0.1% EMS	4.95-51.93	36.70±1.66	136.52	77.74	20.89	31.84	24.02	56.94	13.71	37.34
10	200 Gy + 0.2% EMS	10.56-48.13	20.79±0.86	87.88	52.14	28.76	45.10	34.74	59.33	11.46	55.12
11	300 Gy + 0.1% EMS	9.54-46.29	21.01±1.11	60.65	19.65	30.48	37.07	21.10	32.39	5.20	24.74
12	300 Gy + 0.2% EMS	10.12-41.50	20.71±1.25	93.56	45.58	33.44	46.69	32.60	48.72	9.71	46.87
13	Dry Control	16.92-39.78	28.91±0.31	27.01	7.48	15.28	17.97	9.46	27.71	2.97	10.26
14	Wet Control	21.40-38.22	28.47±0.38	21.89	7.06	13.45	16.34	9.28	32.26	3.11	10.86

Table 4.28: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Plant height in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (cm)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	58-89	73.42±1.43	79.03	37.32	8.80	12.11	8.32	47.23	8.65	11.78
2	200 Gy	53-91	81.82±0.89	107.88	68.44	7.68	12.69	10.11	63.44	13.57	16.59
3	300 Gy	55-88	72.68±1.24	79.54	40.54	8.59	12.27	8.76	50.96	9.36	12.88
4	400 Gy	57-87	73.10±1.23	71.79	37.76	7.98	11.59	8.41	52.59	9.18	12.56
5	0.1% EMS	56-89	73.07±1.09	71.58	39.81	7.71	11.58	8.64	55.62	9.69	13.27
6	0.2% EMS	54-95	75.17±1.49	86.49	41.18	8.96	12.37	8.54	47.61	9.12	12.14
7	0.3% EMS	58-88	76.08±1.39	70.70	34.15	7.95	11.05	7.68	48.31	8.37	10.99
8	0.4% EMS	59-91	75.58±1.66	97.04	40.20	9.97	13.03	8.39	41.43	8.41	11.12
9	200 Gy + 0.1% EMS	56-96	81.33±0.77	100.15	65.01	7.29	12.30	9.91	64.91	13.38	16.45
10	200 Gy + 0.2% EMS	57-90	77.22±1.47	85.93	35.59	9.19	12.00	7.73	41.41	7.91	10.24
11	300 Gy + 0.1% EMS	61-95	78.70±1.11	60.93	22.39	7.89	9.92	6.01	36.76	5.91	7.51
12	300 Gy + 0.2% EMS	56-93	75.65±1.45	83.21	40.81	8.61	12.06	8.44	49.04	9.22	12.18
13	Dry Control	70-85	76.60±0.21	17.78	4.28	4.80	5.50	2.70	24.08	2.09	2.73
14	Wet Control	69-85	75.52±0.41	21.17	6.65	5.05	6.09	3.42	31.43	2.98	3.94

Table 4.29: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Hull content in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (%)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	38.18-54.15	45.49±0.21	17.85	8.63	6.67	9.29	6.46	48.38	4.21	9.26
2	200 Gy	35.11-54.48	39.95±0.29	14.52	9.06	5.85	9.54	7.53	62.36	4.90	12.25
3	300 Gy	35.45-53.78	47.93±0.65	18.97	8.76	6.67	9.09	6.17	46.18	4.14	8.64
4	400 Gy	36.26-53.26	44.58±0.57	22.09	12.10	7.09	10.54	7.80	54.80	5.31	11.90
5	0.1% EMS	34.48-52.54	44.75±0.62	21.73	10.84	7.38	10.42	7.36	49.87	4.79	10.70
6	0.2% EMS	35.95-55.48	46.60±0.65	25.53	15.50	6.80	10.84	8.45	60.71	6.32	13.56
7	0.3% EMS	37.16-52.94	42.58±0.19	18.54	9.61	7.02	10.11	7.28	51.83	4.60	10.80
8	0.4% EMS	34.11-55.26	41.67±0.66	23.53	12.46	7.98	11.64	8.47	52.96	5.29	12.70
9	200 Gy + 0.1% EMS	37.48-53.78	46.40±0.50	21.20	15.23	5.27	9.92	8.41	71.83	6.81	14.68
10	200 Gy + 0.2% EMS	35.26-55.52	43.55±0.76	25.99	14.05	7.94	11.71	8.61	54.04	5.68	13.03
11	300 Gy + 0.1% EMS	42.25-56.24	49.62±0.44	13.50	6.72	5.25	7.40	5.22	49.79	3.77	7.59
12	300 Gy + 0.2% EMS	35.26-55.85	42.70±0.46	19.51	7.80	8.01	10.34	6.54	39.99	3.64	8.52
13	Dry Control	42.15-50.62	44.33±1.05	7.08	2.04	4.95	5.87	3.15	28.79	1.58	3.48
14	Wet Control	41.33-50.75	45.47±0.38	7.88	2.85	4.93	6.17	3.71	36.14	2.09	4.60

Table 4.30: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for oil content in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (%)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV%	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	26.80-31.40	28.47±0.20	1.40	0.60	3.14	4.15	2.72	42.98	1.05	3.68
2	200 Gy	25.45-34.20	31.32±0.11	6.64	4.26	4.93	8.23	6.59	64.14	3.41	10.87
3	300 Gy	26.02-30.35	27.65±0.24	2.07	0.77	4.12	5.20	3.17	37.22	1.10	3.99
4	400 Gy	27.04-31.87	29.50±0.20	2.05	0.99	3.50	4.86	3.37	48.19	1.42	4.82
5	0.1% EMS	26.42-30.82	28.60±0.26	3.18	1.87	4.00	6.24	4.79	58.86	2.16	7.56
6	0.2% EMS	24.14-29.98	26.43±0.21	3.27	1.74	4.69	6.84	4.99	53.10	1.98	7.48
7	0.3% EMS	25.81-32.50	30.82±0.36	7.95	5.62	4.96	9.15	7.69	70.66	4.11	13.32
8	0.4% EMS	25.27-33.17	31.20±0.35	9.65	6.83	5.38	9.96	8.37	70.76	4.53	14.51
9	200 Gy + 0.1% EMS	28.27-32.20	27.05±0.23	4.29	2.07	5.51	7.66	5.32	48.21	2.06	7.61
10	200 Gy + 0.2% EMS	25.94-30.50	29.97±0.14	8.28	4.16	6.85	9.71	6.88	50.22	2.98	10.05
11	300 Gy + 0.1% EMS	26.12-31.48	28.310.09	3.31	1.33	4.97	6.43	4.08	40.26	1.51	5.33
12	300 Gy + 0.2% EMS	27.10-30.50	28.64±0.07	1.41	0.47	3.39	4.15	2.39	33.24	0.81	2.84
13	Dry Control	27.58-29.47	28.83±0.12	0.38	0.12	1.78	2.15	1.20	31.03	0.40	1.37
14	Wet Control	27.55-29.54	28.91±0.03	0.34	0.11	1.65	2.01	1.14	32.33	0.39	1.34

Table 4.31: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for Palmitic acid in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (%)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV %	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	4.50-6.98	6.46±0.08	0.31	0.20	5.26	8.64	6.85	62.89	0.72	11.19
2	200 Gy	4.61-5.95	5.49±0.05	0.15	0.07	5.29	7.06	4.68	43.97	0.35	6.40
3	300 Gy	4.87-5.97	5.31±0.04	0.10	0.06	3.99	5.97	4.44	55.33	0.36	6.81
4	400 Gy	4.6-6.50	5.79±0.02	0.30	0.24	4.26	9.41	8.39	79.52	0.89	15.42
5	0.1% EMS	4.97-6.02	5.20±0.02	0.05	0.02	3.13	4.10	2.64	41.45	0.18	3.50
6	0.2% EMS	4.40-7.01	6.57±0.06	0.25	0.16	4.42	7.59	6.17	66.11	0.68	10.33
7	0.3% EMS	4.37-5.41	5.02±0.05	0.10	0.04	4.86	6.18	3.82	38.27	0.24	4.87
8	0.4% EMS	4.44-6.55	6.03±0.04	0.21	0.15	4.17	7.63	6.38	70.04	0.66	11.00
9	200 Gy + 0.1% EMS	4.90-5.96	5.56±0.04	0.08	0.04	3.75	5.18	3.58	47.63	0.28	5.08
10	200 Gy + 0.2% EMS	4.88-5.90	5.66±0.03	0.07	0.04	3.06	4.79	3.69	59.26	0.33	5.85
11	300 Gy + 0.1% EMS	4.12-5.12	4.79±0.03	0.07	0.04	3.84	5.65	4.15	53.87	0.30	6.27
12	300 Gy + 0.2% EMS	4.80-5.94	5.50±0.08	0.14	0.07	4.67	6.78	4.91	52.58	0.40	7.34
13	Dry Control	4.92-5.45	5.12±0.02	0.02	0.01	2.25	2.64	1.38	27.21	0.08	1.48
14	Wet Control	5.02-5.55	5.42±0.02	0.02	0.01	1.89	2.16	1.05	23.55	0.06	1.05

Table 4.32: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for stearic acid in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range (%)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV %	GCV (%)	H_2(bs) (%))	GA (%)	GAM
1	100 Gy	1.01-1.29	1.17±0.03	0.006	0.003	4.28	6.43	4.81	55.82	0.09	7.40
2	200 Gy	1.05-1.40	1.25±0.06	0.010	0.004	5.98	7.91	5.17	42.70	0.09	6.96
3	300 Gy	1.11-1.62	1.52±0.09	0.011	0.007	4.02	6.91	5.62	66.15	0.14	9.41
4	400 Gy	1.15-1.47	1.36±0.06	0.008	0.004	4.68	6.63	4.70	50.15	0.09	6.85
5	0.1% EMS	1.03-2.22	1.88±0.18	0.109	0.084	8.46	17.61	15.44	76.92	0.52	27.90
6	0.2% EMS	1.04-1.29	1.12±0.03	0.003	0.001	4.23	5.24	3.08	34.58	0.04	3.73
7	0.3% EMS	1.01-1.80	1.41±0.12	0.035	0.021	8.34	13.18	10.21	59.98	0.23	16.29
8	0.4% EMS	1.18-1.62	1.45±0.06	0.019	0.009	6.84	9.54	6.64	48.47	0.14	9.52
9	200 Gy + 0.1% EMS	1.02-2.54	2.00±0.12	0.175	0.132	10.35	20.92	18.18	75.52	0.65	32.55
10	200 Gy + 0.2% EMS	1.21-1.72	1.48±0.06	0.024	0.010	7.94	10.47	6.83	42.57	0.14	9.18
11	300 Gy + 0.1% EMS	1.10-2.32	1.67±0.12	0.134	0.095	11.89	21.92	18.41	70.55	0.53	31.85
12	300 Gy + 0.2% EMS	1.22-1.63	1.48±0.06	0.010	0.006	4.53	6.89	5.19	56.82	0.12	8.06
13	Dry Control	1.32-1.49	1.40±0.03	0.003	0.001	3.07	3.94	2.46	39.15	0.04	3.18
14	Wet Control	1.27-1.45	1.34±0.03	0.003	0.001	3.22	4.07	2.49	37.32	0.04	3.13

Table 4.33: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for oleic acid in M_2 generation of PBNS-12 variety

Sr. No.	Treatment	Range (%)	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV %	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	13.5-16.49	15.43±0.03	0.83	0.35	4.50	5.92	3.85	42.28	0.80	5.16
2	200 Gy	13.14-18.26	16.78±0.03	2.59	1.70	5.61	9.57	7.77	65.76	2.18	12.99
3	300 Gy	14.02-15.97	15.00±0.06	0.43	0.19	3.29	4.38	2.88	43.45	0.59	3.92
4	400 Gy	13.67-16.32	14.36±0.04	0.68	0.38	3.81	5.74	4.29	55.91	0.95	6.61
5	0.1% EMS	13.23-16.87	15.72±0.15	0.97	0.44	4.62	6.27	4.23	45.61	0.93	5.89
6	0.2% EMS	13.52-15.97	14.93±0.15	0.55	0.13	4.36	4.98	2.40	23.28	0.36	2.39
7	0.3% EMS	13.12-.18.04	16.04±0.09	2.38	1.61	5.44	9.61	7.92	67.97	2.16	13.46
8	0.4% EMS	13.17-18.20	16.83±0.03	2.24	1.69	4.42	8.90	7.72	75.29	2.32	13.80
9	200 Gy + 0.1% EMS	13.04-18.38	17.20±0.06	1.85	1.31	4.29	7.91	6.65	70.54	1.98	11.50
10	200 Gy + 0.2% EMS	13.52-18.09	16.35±0.06	2.15	1.36	5.43	8.97	7.14	63.33	1.91	11.71
11	300 Gy + 0.1% EMS	14.12-16.27	15.14±0.13	0.49	0.19	3.62	4.62	2.87	38.60	0.56	3.68
12	300 Gy + 0.2% EMS	13.97-16.55	15.66±0.16	0.54	0.24	3.47	4.67	3.13	44.85	0.68	4.32
13	Dry Control	13.80-15.12	14.34±0.01	0.19	0.08	2.35	3.04	1.94	40.52	0.36	2.54
14	Wet Control	13.96-15.25	14.67±0.04	0.16	0.05	2.30	2.76	1.54	30.97	0.26	1.76

Table 4.34: Range, Mean, Phenotypic and Genotypic coefficient of variation, Heritability and Genetic advance for linoleic acid in M_2 generation of PBNS-12 variety.

Sr. No.	Treatment	Range	Mean±SE	Phenotypic Variance	Genotypic variance	CV%	PCV (%)	GCV (%)	H_2(bs) (%)	GA (%)	GAM
1	100 Gy	74.25-79.72	77.04±0.04	3.19	1.11	1.87	2.32	1.37	34.78	1.28	1.66
2	200 Gy	72.17-79.94	76.12±0.04	4.99	3.69	1.49	2.93	2.52	74.07	3.41	4.48
3	300 Gy	74.75-79.82	77.56±0.09	2.30	0.98	1.48	1.96	1.28	42.74	1.34	1.72
4	400 Gy	76.36-80.24	78.43±0.21	1.58	0.43	1.36	1.60	0.84	27.47	0.71	0.91
5	0.1% EMS	74.92-80.08	77.59±0.19	2.73	1.39	1.49	2.13	1.52	50.80	1.73	2.23
6	0.2% EMS	76.45-79.97	78.56±0.04	0.96	0.26	1.06	1.25	0.65	27.36	0.55	0.70
7	0.3% EMS	75.09-80.16	77.41±0.04	2.36	1.23	1.37	1.98	1.43	52.31	1.65	2.14
8	0.4% EMS	70.62-80.07	75.99±0.04	7.92	5.55	2.03	3.70	3.10	70.07	4.06	5.35
9	200 Gy + 0.1% EMS	70.44-79.87	75.60±0.06	6.17	4.81	1.54	3.28	2.90	78.01	3.99	5.28
10	200 Gy + 0.2% EMS	72.56-78.09	76.15±0.21	3.24	1.36	1.80	2.36	1.53	41.79	1.55	2.04
11	300 Gy + 0.1% EMS	75.28-79.84	78.29±0.22	1.89	0.81	1.33	1.76	1.15	42.59	1.21	1.54
12	300 Gy + 0.2% EMS	75.95-78.93	77.32±0.14	1.16	0.44	1.10	1.39	0.86	37.78	0.84	1.08
13	Dry Control	76.87-78.84	78.02±0.05	0.42	0.15	0.66	0.83	0.50	35.57	0.48	0.61
14	Wet Control	77.89-79.08	78.28±0.04	0.15	0.03	0.44	0.49	0.22	20.46	0.16	0.21

mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Sheeba *et. al.*(2003) in Sesame, Lande *et. al.*(2018) in Soybean and Channaoui *et. al.*(2019) in Rapessed.

A significant increase in 100 seed weight (5.08) was recorded at 200 Gy+ 0.1% EMS dose of combination followed by 200 Gy (5.03) dose of gamma rays treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) in Linseed and Lande *et.al.* (2018) in Soybean. The maximum coefficient of variation (21.75) was recorded at 400 Gy dose of gamma rays treatment followed by 200 Gy+0.2% EMS (18.39) dose of combination treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) in Linseed, Begum and Dasgupta (2014) in Sesame. The maximum value of PCV (32.31) and GCV (23.90) for 100 seed weight was recorded at 400 Gy dose of gamma rays followed by 200 Gy + 0.2% EMS [PCV (26.64) and GCV (19.27)] dose of combination treatment. In the present study, high to moderate value of PCV and GCV was observed in mutagenic population for 100 seeed weight. These results are in broad agreement with reports of Umamaheswari *et. al.* (2019) in Sesame, Leelavati and Mogali (2018) in Linseed, Rajanna *et. al.*(2020) in Linseed and Rathod *et. al.* (2021) in Safflower. A small difference between PCV and GCV was recorded at 0.2% EMS concentration followed by 200 Gy dose of gamma rays and 200 Gy +0.1% EMS dose of combination treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had moderate to high heritability and high genetic advance as a percent of the mean. In all of the mutagenic treatments, there was low genetic gain. With the exception of 300 Gy dose of gamma rays and 0.4 % EMS concentration treatment, most mutagenic treatments had significant heritability as well

as high genetic advance as a percent of the mean. At 300 Gy of gamma rays and 0.4 % EMS concentration treatment, there was moderate heritability and high genetic advance as a percent of the mean.High heritability was found in this study, along with a high genetic advance as a percentage of the mean, showing the importance of additive gene action in the inheritance of this characteristic. These results are in accordance with the reports ofPhanindra *et. al. (*2018) in Sunflower, Pushpavalli and Kumar (2017) in Safflower, Khattab *et. al.* (2018) in Safflower, Leelavatiand Mogali (2018) in Linseed and Rajanna *et. al.*(2020) in Linseed. The presence of moderate heritability and low genetic advance suggests that non additive gene action is involved in the inheritance of this trait. These results are in broad agreement with the reports of Thakur *et. al.*(2020) in Linseed and Jagadeesan *et. al.*(2008) in Sunflower.

13) Seed width

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for seed width in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.25.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy+ 0.1% EMS dose of combination followed by 200 Gy dose of gamma rays treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for seed width in all the mutagenic populations in M_2 generation.

A significant increase in seed width (4.75) was recorded at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS(4.68) dose of combination treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. Similar observation was reported by Lande *et. al.*(2018) in Soybean and Rai *et. al.*(2014) in Linseed. The maximum coefficient of variation (16.11) was recorded at 0.1% EMS concentration treatment followed by 200 Gy+ 0.2% EMS(15.16) dose of combination treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. Similar observation was reported

by Rai *et. al.*(2014) in Linseed and Begum and Dasgupta (2014) in Sesame. In the present study, moderate PCV and GCV value was recorded. The maximum value of PCV (22.10) and GCV (19.06) for seed width was recorded at 0.1% EMS and 0.2% EMS concentration treatment respectively. A small difference between PCV and GCV was recorded at 0.2% EMS concentration followed by 200 Gy +0.1% EMS dose of combination and 200 Gy dose of gamma rays treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had moderate to high heritability and moderate to high genetic advance as a percent of the mean. In all of the mutagenic treatments, there was low genetic gain. With the exception of 100 Gy dose of gamma rays, 0.1 % EMS, 0.4 % EMS concentration, 200 Gy + 0.2 % EMS, and 300 Gy + 0.2 % EMS dose of combination treatments, most mutagenic treatments had high heritability and high genetic advance as percent of the mean. Moderate heritability was observed, along with a high genetic advance as a percentage of the mean at 0.1 % EMS concentration treatment, While moderate heritability was found with moderate genetic advance as percent of mean at 100 Gy dose of gamma rays followed by 0.4% EMS concentration, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments.High heritability was found in this study, along with a high genetic advance as a percentage of the mean, showing the role of additive gene action in governing this feature. Similar observation was reported by Khattab *et.al.*(2018) in Safflower and Pushpavalli and Kumar (2017) in Safflower.

14) Seed length

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for seed length in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.26.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy dose of gamma followed by rays 200 Gy+ 0.1% EMS dose of combination treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for seed length in all the mutagenic populations in M_2 generation.

A significant increase in seed length (8.85) was recorded at 200 Gy + 0.1 % EMS dose of combination followed by 200 Gy (8.82) dose of gamma rays treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. Similar observation was reported by Rai *et. al.*(2014) in Linseed and Lande *et. al.*(2018) in Soybean. The maximum coefficient of variation (14.37) was recorded at 100 Gy dose of gamma rays treatment followed by 400 Gy(13.28) dose of gamma rays treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. Similar observation was reported by Rai *et. al.*(2014) in Linseed and Begumand Dasgupta (2014) in Sesame. The maximum value of PCV (18.91) and GCV (14.32) for seed length was recorded at 100 Gydose of gamma rays and 200 Gy +0.1% EMS dose of combination treatment respectively. In the present study, moderate value of PCV and GCV was recorded. Similar observation was reported in Adewale *et. al.*(2010) in African Yam Bean. A small difference between PCV and GCV was recorded at 200 Gy +0.1% dose of combination followed 200 Gy dose of gamma rays treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had low to high heritability and moderate to high genetic advance as a percent of mean. In all of the mutagenic treatments, there was low genetic advance. Among the mutagenic treatments, the 200 Gy dose of gamma

rays had the highest heritability as well as the high genetic advance as a percent of the mean, followed by the 200 Gy+ 0.1 % EMS and the 200 Gy+ 0.2 % EMS doses of combination treatment.High heritability was found along with moderate genetic advance as percent of mean at 0.2% EMS followed by 0.3% EMS and 0.4% EMS concentration treatment. While moderate heritability was observed along with moderate genetic advance as percent of mean was recorded at 100 Gy dose of gamma rays followed by 300 Gy dose, 0.1% EMS concentration, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments.At a 400 Gy dose of gamma rays treatment, low heritability was observed along with moderate genetic advance as a percentage of the mean. High heritability was found in this study, along with a high genetic advance as a percentage of the mean, showing the importance of additive gene action in the inheritance of this characteristic. These findings are in accordance with the findings of Khattab *et.al.*(2018) in Safflower and Pushpavalli and Kumar (2017) in Safflower.

15) Seed yield per plant

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for grain yield per plant in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.27.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. These results are in broad agreements with the reports of Rai *et. al.* (2014) in Linseed and Lande *et. al.*(2018) in Soybean. Maximum range of variation was recorded at 200 Gy + 0.1% EMS dose of combination followed by 200 Gy dose of gamma rays treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for grain yield per plant in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Sheeba *et. al.*(2003) in Sesame, Channaoui *et. al.*(2019) in Rapessed, Lande *et. al.*(2018) in Soybean, and Ravichandran and Jayakumar (2015) in Sesame.

A significant increase in grain yield per plant (37.36) was recorded at 200 Gy dose of gamma rays followed by 200 Gy +0.1% EMS(36.70) dose of combination

treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed and Lande *et. al.*(2018) in Soybean. The maximum coefficient of variation (34.91) was recorded at 0.4% EMS concentration treatment followed by 300 Gy + 0.2 % EMS (33.44) dose of combination treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed, Begum and Dasgupta (2014) in Sesame. The maximum value of PCV (46.69) and GCV (34.74) for grain yield per plant was recorded at 300 Gy +0.2% EMS dose of combination and 200 Gy +0.2% EMS dose of combination treatment respectively. In the present study, high value of PCV and GCV was observed in all mutagenic treatments. These results are in broad agreement with the reports of Rathod *et. al.* (2021) in Safflower, Rajanna *et. al.* (2020) in Linseed, Leelavati and Mogali (2018) in Linseed, Siddiqui *et. al.* (2009) in Rapeseed and Khattab *et. al.* (2018) in Safflower. A small difference between PCV and GCV was recorded at 200 Gy dose of gamma rays treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. Low to high heritability and high genetic advance as percent of mean were recorded in all the mutagenic treatments as compared to control. Low to moderate genetic advance was observed in all the mutagenic treatments. Among the mutagenic treatments, high heritability along with high genetic advance as percent of mean was recorded at 200 Gy dose of gamma rays followed by 0.1% EMS, 200 Gy+ 0.1% EMS and 200 Gy+ 0.2% EMS dose of combination treatment. Moderate heritability was found along with high genetic advance as percent of mean at 300 Gy dose of gamma rays followed by 0.2% EMS, 300 Gy + 0.2% EMS dose of combination treatment. Low heritability was found at 100 Gy dose of gamma rays, with high genetic advance as a percent of mean,

followed by 400 Gy dose, 0.3 percent EMS, 0.4 percent EMS concentration, and 300 Gy + 0.1 percent EMS dose of combination treatments. High heritability was identified along with moderate genetic advance at 200 Gy dose of gamma rays, 0.1% EMS concentration, 200 Gy + 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments. In the current study, high heritability was detected in various mutagenesis treatments, along with high genetic advance as a percent of mean, showing the importance of additive gene action in determining the inheritance of seed yield per plant.These results are in broad agreement with the reports of Rajanna *et. al.*(2020) in Linseed, Leelavati and Mogali (2018) in Linseed, Khattab *et. al.* (2018) in Safflower and Sanghani *et. al.* (2016) in Sesame. Moderate heritability was identified, along with a high genetic advance as a percentage of the mean, showing the importance of both additive and non additive gene action in determining the inheritance of grain yield per plant.These results are in broad agreement with the reports of Jagadeesan *et. al.* (2008) in Sunflower. Low heritability was observed in some mutagenic treatments. These results are in broad agreement with the reports of Rai *et. al.*(2014) in Linseed. Paul (1978) also stated that if heritability is mostly attributable to both additive and non additive effects, then it is only associated with moderate genetic advance, shown in seed yield per plant.

16) Plant height

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for plant height in M_2 generation of PBNS-12 genotype of safflower are presented in Table 4.28.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. These results are in broad agreements with the reports of Rai *et. al.* (2014) in Linseed. Maximum range of variation was recorded at 0.2% EMS concentration followed by 200 Gy + 0.1% EMS dose of combination and 200 Gy dose of gamma rays treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for plant height in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Sheeba *et. al.* (2003) in Sesame, Channaoui *et.*

al.(2019) in Rapessed, Lande *et. al.* (2018) in Soybean and Ravichandran and Jayakumar (2015) in Sesame.

A significant increase in plant height (81.82) was recorded at 200 Gy dose of gamma rays followed by 200 Gy +0.1% EMS(81.33) dose of combination treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed and Lande *et. al.*(2018) in Soybean. The maximum coefficient of variation (9.97) was recorded at 0.4% EMS concentration treatment followed by 200 Gy + 0.2 % EMS (9.19) dose of combination treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.*(2014) in Linseed, Begum and Dasgupta (2014) in Sesame. The maximum value of PCV (13.03) and GCV (10.11) for plant height was recorded at 0.4% EMS concentration and 200 Gy dose of gamma rays treatment respectively. In the present study, moderate value of PCV and GCV was observed in some mutagenic treatments for plant height. These results are in broad agreement with the reports of Kamdi *et. al.* (2020) in Soybean, Rajanna *et. al.* (2020) in Linseed, Leelavati and Mogali (2018) in Linseed and Khattab *et. al.* (2018) in Safflower. Low value of PCV and GCV was observed in some mutagenic treatments for plant height. These results are in broad agreement with the reports of Rai *et. al.*(2014) in Linseed, Sikarwar *et al.*(2017) in Yellow Sarson and Belete *et. al.*(2012) in Ethiopian mustard. A small difference between PCV and GCV was recorded at 200 Gy dose of gamma rays treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. Low to high heritability and low to moderate genetic advance as percent of mean were recorded in all the mutagenic treatments as compared to control. Low to moderate genetic advance was observed in all the mutagenic treatments. Among the mutagenic treatments, high

heritability along with moderate genetic advance as percent of mean was recorded at 200 Gy followed by 300 Gy, 400 Gy dose of gamma rays, 0.1% EMS and 200 Gy+ 0.1% EMS dose of combination treatment. Moderate heritability was identified along with with moderate genetic advance as percent of mean at 100 Gy dose of gamma rays followed by 0.2% EMS , 0.3% EMS, 0.4% EMS concentration, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatment. While low heritability was detected along withlow genetic advance as percent of mean at 300 Gy + 0.1% EMS dose of combination treatment. High heritability was detected along with moderate genetic advance at 200 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS dose of combination treatment. In this study, high heritability was observed together with moderate genetic advance as a percent of mean, showing the importance of both additive and non additive gene action in determining inheritance of plant height.These results are in broad agreement with the reports of Sanghani *et. al.* (2016) in Sesame, Siddiqui *et. al.* (2009) in rapeseed, Belete *et. al.* (2012) in Ethiopian mustard, Bahmankar *et. al.* (2014) in Safflower and Phanindra *et. al.* (2018) in Sunflower. Plant height inheritance is governed by both additive and non additive gene activity, as evidenced by moderate heritability and moderate genetic advance as a percent of the mean. These results are in broad agreement with the reports of Siddiqui*et. al.*(2009) in Rapeseed.

17) Hull content (%)

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for hull content percent in M_2 generation of PBNS-12 variety of safflower are presented in Table 4.29

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 0.4% EMS concentration followed by 300 Gy + 0.2 % EMS dose of combination treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for hull content (%) in all the mutagenic populations in M_2 generation.

A significant reduction in hull content percent (39.95) was recorded at 200 Gy dose of gamma rays followed by 0.4% EMS(41.67) and 0.3% EMS (42.58) concentration treatments. The coefficient of variation showed marked increases in the treated population as compared to respective control.The maximum coefficient of variation (8.01) was recorded at 300 Gy + 0.2% EMS dose of combination treatment followed by 0.4 % EMS(7.98) concentration treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control.These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed, Begum and Dasgupta (2014) in Sesame. The maximum value of PCV (11.71) and GCV (8.61) for hull content percent was recorded at 200 Gy + 0.2% EMS dose of combinationtreatment. In the present study, low value of PCV and GCV was observed in all mutagenic treatments. These results are in broad agreement with the results of Phanindra *et. al.* (2018) in Sunflower and Rathod *et. al.*(2021) in Safflower. A small difference between PCV and GCV was recorded at 200 Gy + 0.1 % EMS dose of combination and 200 Gy dose of gamma rays treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had low to high heritability and low to moderate genetic advance as a percent of mean.Low genetic advance was observed in all the mutagenic treatments. Among the mutagenic treatments, high heritability was identified along with moderate genetic advance as percent of mean at 200 Gy followed by 400 Gy dose of gamma rays, 0.2% EMS, 0.3% EMS, 0.4% EMS concentration, 200 Gy+ 0.1% EMS and 200 Gy+ 0.2% EMS dose of combination treatment. Moderate heritability was observed along with moderate genetic advance as a percentage of the mean at 0.1 percent EMS concentration treatment.While moderate heritability combined with low genetic advance as percent of mean at 100 Gy dose of gamma rays followed by 300 Gy and 300 Gy + 0.1% EMS dose of combination treatment. At 300 Gy + 0.2 percent EMS dose of combination treatment, low heritability was

observed, along with low genetic advance as a percentage of the mean. In this study, high/moderate heritability was observed, along with moderate genetic advance as a percent of the mean, demonstrating the importance of both additive and non-additive gene action in hull content inheritance.These results are in broad agreement with the reports of Rathod *et. al.* (2021) in Safflower. While high/moderate/low heritability was identified, along with low genetic advance as a percent of mean, showing the role of non additive gene action in hull content inheritance.These results are in broad agreement with the reports of Phanindra *et. al.* (2018) in Sunflower.

18) Oil content (%)

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for oil content percent in M_2 generation of PBNS-12 variety of safflower are presented in Table 4.30.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy dose of gamma rays followed by 0.4% EMS concentration and 0.3% EMS concentration treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for oil content percent in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Sheeba *et. al.* (2003) in Sesame, Khadeer and Anwar (1991) in Safflowerand Pawadai *et. al.* (2010) in Soybean.

A significant increase in oil content percent (31.32) was recorded at 200 Gy dose of gamma rays followed by 0.4% EMS(31.20) and 0.3% EMS (30.82) concentration treatments. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed and Lande *et. al.* (2018) in Soybean. The maximum coefficient of variation (6.85) was recorded at 200 Gy + 0.2% EMS dose of combination treatment followed by 200 Gy + 0.1 % EMS (5.51) dose of combination treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai

et. al. (2014) in Linseed, Begum and Dasgupta (2014) in Sesame and Jagadeesan *et. al.* (2008) in Sunflower.The maximum value of PCV (9.96) and GCV (8.37) for oil content percent was recorded at 0.4% EMS concentration treatment. In the present study, low value of PCV and GCV was recorded in all mutagenic treatments. These results are in broad agreement with the reports of Jagadeesan *et. al.*(2008) in Sunflower, Phanindra *et. al.* (2018) in Sunflower and Rathod *et. al.* (2021) in Safflower. A small difference between PCV and GCV was recorded at 0.4% EMS concentration treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had low to high heritability and low to moderate genetic advance as a percent of mean. In all of the mutagenic treatments, there was low genetic gain. Among the mutagenic treatments, high heritability along with moderate genetic advance as percent of mean was recorded at 200 Gydose of gamma rays followed by 0.3% EMS, 0.4% EMS concentration and 200 Gy+ 0.2% EMS dose of combination treatment. At 100 Gy of gamma rays, there was moderate heritability with low genetic advance as a percent of the mean, followed by 400 Gy, 200 Gy + 0.1 % EMS, and 300 Gy + 0.1 % EMS doses of combination treatment. At 0.1 % and 0.2 % EMS concentration treatments, high heritability was observed together with low genetic advance as a percent of the mean. Low heritability and low genetic advance as a percent of mean were observed at 300 Gy of gamma rays followed by 300 Gy + 0.2 % EMS dose of combination treatment. High heritability was observed in this study, along with moderate genetic progress, showing the importance of both additive and non additive gene activity in determining the transmission of oil content. These results are in broad agreement with the reports of Phanindra *et. al.* (2018) in Sunflower, Meena *et. al.*(2020) in Linseed and Rathod *et. al.*(2021) in Safflower. The presence of high/moderate/low heritability, as well as low genetic advance as a percent of the mean, suggests that non-additive gene action governs the inheritance of oil content.These results are in broad agreement with the reports of Jagadeesan *et. al.*

(2008) in Sunflower, Siddiqui *et. al.*(2009) in Rapeseed and Singh *et. al.*(2020) in Sesame.

19) Palmitic acid

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for palmitic acid content in M_2 generation of PBNS-12 variety of safflower are presented in Table 4.31

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 0.2% EMS concentration followed by 100 Gy dose of gamma rays and 0.4% EMS concentration treatments. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for palmitic acid content in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Rajanna *et. al.* (2020) in Linseed and Khadeer and Anwar (1991) in Safflower.

A significant increase in palmitic acid content percent (6.57) was recorded at 0.2% EMS concentration followed by 100 Gy (6.46) dose of gamma rays and 0.4% EMS (6.03) concentration treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed and Lande *et. al.*(2018) in Soybean. The maximum coefficient of variation (5.29) was recorded at 200 Gy dose of gamma rays treatment followed by 100 Gy (5.26) dose of gamma rays treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed, Begum and Dasgupta (2014) in Sesame, Jagadeesan *et. al.* (2008) in Sunflower and Rajanna *et. al.* (2020) in Linseed. The maximum value of PCV (9.41) and GCV (8.39) for palmitic acid content percent was recorded at 400 Gy dose of gamma rays treatment. In the present study, low value of PCV and GCV was recorded in all mutagenic treatments. These findings are controversy with the finding of Rajanna *et. al.* (2020) in Linseed. A small difference between PCV and GCV was

recorded at 0.4% EMS concentration treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.* (2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had low to high heritability and low to moderate genetic advance as a percent of mean. In all of the mutagenic treatments, there was low genetic gain. Among the mutagenic treatments, the 100 Gy dose of gamma rays produced high heritability and moderate genetic advance as a percent of the mean, followed by the 400 Gy dose of gamma rays, 0.2 % EMS concentration, and 0.4 % EMS concentration treatments. High heritability was observed together with low genetic advance as percent of mean at 300 Gy dose of gamma rays followed by 200 Gy + 0.1% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatment. While moderate heritability was detected along with low genetic advance as percent of mean was recorded at 200 Gy, 0.1% EMS concentration and 200 Gy + 0.1% EMS dose of combination treatment. At 0.3 percent EMS concentration treatment, low heritability was observed, as well as low genetic advance as a percentage of the mean. High heritability was observed in this study, along with moderate genetic advance, demonstrating the significance of both additive and non additive gene action in determining palmitic acid content inheritance. These results are in broad agreement with the reports of Phanindra *et. al.* (2018) in Sunflower, Meena *et. al.* (2020) in Linseed and Rathod *et. al.*(2021) in Safflower. High/moderate/low heritability was observed, along with low genetic advance as a percent of the mean, showing the importance of non-additive gene action in determining palmitic acid content inheritance.These findings condradict with the finding of Rajanna *et. al.* (2020) in Linseed.

20) Stearic acid

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations

for stearic acid content in M_2 generation of PBNS-12 variety of safflower are presented in Table 4.32.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy + 0.1% EMS combination treatment followed by 0.1% EMS concentration treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for stearic acid content in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Rajanna *et. al.* (2020) in Linseed and Khadeer and Anwar (1991) in Safflower.

A significant increase in stearic acid content percent (2.00) was recorded at 200 Gy + 0.1% EMS combination treatment followed by 0.1% EMS(1.88) concentration and 300 Gy + 0.1% EMS(1.67) combination treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed and Lande *et. al.*(2018) in Soybean. The maximum coefficient of variation (11.89) was recorded at 300 Gy + 0.1% EMS combination treatment followed by 200 Gy + 0.1% EMS(10.35) combination treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed, Begum and Dasgupta (2014) in Sesame, Jagadeesan *et. al.* (2008) in Sunflower and Rajanna *et. al.* (2020) in Linseed. The maximum value of PCV (21.92) and GCV (18.41) for stearic acid content percent was recorded at 300 Gy + 0.1% EMScoimbination treatment. In the present study, low to high value of PCV and GCV was recorded in all mutagenic treatments. These findings are broad agreement with the finding of Rajanna *et. al.* (2020) in Linseed. A small difference between PCV and GCV was recorded at 0.4% EMS concentration treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020).

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had low to high heritability and low to high genetic advance as a percent of the mean. In all of the mutagenic treatments, there was low genetic gain. The 200 Gy + 0.1% EMS combination treatment had the highest heritability and genetic progress as a percent of mean among the mutagenic treatments, followed by the 300 Gy + 0.1 % EMS combination and 0.1 % EMS concentration treatments.High heritability was observed together with moderate genetic advance as percent of mean at 0.3% EMS concentration treatment. At 100 Gy, 300 Gy, 400 Gy doses of gamma rays, and 300 Gy + 0.2 % EMS dose of combination treatment, high heritability was observed with low genetic advance as a percentage of the mean.At 200 Gy, 0.4 percent EMS and 200 Gy + 0.1 percent EMS, there was moderate heritability combined with low genetic advance as a percentage of the mean. In currentstudy, high heritability was reported along with high genetic advance, showing the importance of additive gene action in stearic acid content inheritance.These results are in broad agreement with the reports of Rajanna *et. al.* (2020) in Linseed and Ahmed *et. al.* (2013) in Winter Rapeseed. High/moderate heritability was observed, together with low genetic advance as a percent of the mean, showing the importance of non-additive gene action in stearic acid content inheritance.These findings contradict with the finding of Rajanna *et. al.* (2020) in Linseed and Ahmed *et. al.* (2013) in Winter Rapeseed.

21) Oleic acid

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for oleic acid content in M_2 generation of PBNS-12 variety of safflower are presented in Table 4.33.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 200 Gy + 0.1% EMS combination treatment followed by 200 Gy dose of gamma rays treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for oleic acid content in all the mutagenic

populations in M_2 generation. These results are in broad agreement with the reports of Rajanna *et. al.* (2020) in Linseed and Khadeer and Anwar (1991) in Safflower.

A significant increase in oleic acid content percent (16.83) was recorded at 200 Gy + 0.1% EMS combination treatment followed by 200 Gy (16.78) dose of gamma rays and 200 Gy + 0.2% EMS(16.35) combination treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed and Lande *et. al.*(2018) in Soybean. The maximum coefficient of variation (5.61) was recorded at 200 Gy dose of gamma rays treatment followed by 0.3% EMS (5.44) concentration treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed, Begum and Dasgupta (2014) in Sesame, Jagadeesan *et. al.* (2008) in Sunflower and Rajanna *et. al.*(2020) in Linseed. The maximum value of PCV (9.61) and GCV (7.92) for oleic acid content percent was recorded at 0.3% EMS concentration treatment. In the present study, low value of PCV and GCV was recorded in all mutagenic treatments. These findings are controversy with the finding of Rajanna *et. al.* (2020) in Linseed and Ahmed *et. al.* (2013) in Winter Rapeseed. A small difference between PCV and GCV was recorded at 0.4% EMS concentration treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020) in Linseed.

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had low to high heritability and low to moderate genetic advance as a percent of mean. In all of the mutagenic treatments, there was low genetic gain. The 200 Gy dose of gamma rays treatment had the highest heritability and moderate genetic advance as a percent of the mean, followed by 0.3 % EMS, 0.4 % EMS, 200 Gy + 0.1 % EMS, and 200 Gy + 0.2 % EMS combination treatments.At 400 Gy of gamma treatment, there was a high heritability combined

with low genetic advance as a percentage of the mean. Moderate heritability was observed with low genetic advance as a percentage of the mean at 100 Gy, 300 Gy, 0.1 percent EMS, and 300 Gy + 0.2 percent EMS doses of combination treatment. Low heritability was detectedalong with low genetic advance as percent of mean was recorded at 0.2% EMS and 300 Gy + 0.1% EMS combination treatment. High heritability was reported in this study, along with moderate genetic advance, showing the importance of both additive and non additive gene action in determining the inheritance of oleic acid content.These findings contradict with the finding of Rajanna *et. al.* (2020) in Linseed and Ahmed *et. al.* (2013) in Winter Rapeseed. The presence of high/moderate/low heritability, as well as low genetic advance as a percentage of the mean, suggests that non-additive gene action governs the inheritance of oleic acid content. These findings contradict with the finding of Rajanna *et. al.* (2020) in Linseed and Ahmed *et. al.* (2013) in Winter Rapeseed.

22) Linoleic acid

Estimation of range, mean, coefficient of variation, GCV, PCV, heritability and genetic advance for different doses of gamma rays, EMS and their combinations for linoleic acid content in M_2 generation of PBNS-12 variety of safflower are presented in Table 4.34.

The results revealed that, the range of variation was wide in M_2 generation as compared to control in all the mutagenic treatments. Maximum range of variation was recorded at 0.4% EMS concentration treatment followed by 200 Gy + 0.1% EMS dose of combination treatment. The deviation of mean values of mutagenic treatments over mean value of control indicated that all the mutagens tried were found effective and have induced the genetic variability for linoleic acid content in all the mutagenic populations in M_2 generation. These results are in broad agreement with the reports of Rajanna *et. al.* (2020) in Linseed and Khadeer and Anwar (1991) in Safflower.

A significant reduction in linoleic acid content percent (75.60) was recorded at 200 Gy + 0.1% EMS combination treatment followed by 0.4% EMS (75.99) and200 Gy (76.12) dose of gamma rays treatment. The coefficient of variation showed marked increases in the treated population as compared to respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed and Lande *et. al.*(2018) in Soybean. The maximum coefficient of variation (2.03) was

recorded at 0.4% EMS concentration treatment followed by 100 Gy (1.87) dose of gamma rays treatment. The magnitude of induced genetic variability in terms of PCV and GCV was recorded greater in the mutagenic treatments as compared to their respective control. These findings are in the confirmity with the findings of Rai *et. al.* (2014) in Linseed, Begum and Dasgupta (2014) in Sesame, Jagadeesan *et. al.* (2008) in Sunflower and Rajanna *et. al.* (2020) in Linseed. The maximum value of PCV (3.70) and GCV (3.10) for linoleic acid content percent was recorded at 0.4% EMS concentration treatment. In the present study, low value of PCV and GCV was recorded in all mutagenic treatments. These findings are broad agreement with the finding of Ahmed *et. al.* (2013) in Winter Rapeseed. A small difference between PCV and GCV was recorded at 0.4% EMS concentration treatment which indicated less influence of environment on this character. A close observation of PCV and GCV revealed that the values recorded for GCV were very close to PCV indicating thereby that maximum variation were caused by mutations for polygenes. These findings are in the confirmity with the finding of Sharma and Sharma (1986), Rai *et. al.* (2014) and Rajanna *et. al.*(2020) in Linseed.

Heritability and genetic advance are important selection parameters and selection success is a reflectance of selection response. In comparison to the control, all mutagenic treatments had low to high heritability and low genetic advance as percentage of mean. In all of the mutagenic treatments, there was low genetic gain. Among the mutagenic treatments, the 200 Gy+ 0.1 percent EMS dose of combination treatment had the highest heritability and the lowest genetic advance as a percent of the mean, followed by 200 Gy + 0.2 percent EMS, 200 Gy, 0.1 percent EMS, 0.3 percent EMS, and 0.4 percent concentration treatments. At 300 Gy dose of gamma rays, 200 Gy + 0.2 percent EMS and 300 Gy + 0.1 percent EMS combination treatment, moderate heritability was found together with low genetic advance as a percent of the mean. At 100 Gy, 400 Gy, 0.2 percent EMS and 300 Gy + 0.2 percent EMS doses of combination treatment, low heritability was observed, as well as low genetic advance as a percentage of the mean. High/moderate/low heritability, as well as low genetic advance as a percent of the mean, was found in this study, showing the importance of non-additive gene action in linoleic acid content inheritance.These findings are controversy with the finding of Rajanna *et. al.* (2020) in Linseed and Ahmed *et. al.* (2013) in Winter Rapeseed.

4.2.5 Correlation studies in M_2 generation.

Genetic improvement of any crop heavily depends upon the nature and extent of genetic variability and also on the magnitude of interrelationship of yield and its major contributing characters. Genetic variability and correlation among seed yield and yield attributes helps in identifying a suitable genotype with desired characteristics. The success of selection depends on the choice of selection criteria for improvement of seed yield. Correlation coefficient analysis could distinguish significant relationship between evaluated traits.

4.2.5.1 Phenotypic correlation coefficient analysis

The phenotypic correlation were estimated out among the characters studied to determine the effect of mutagens on associations patterns in M_2 generations of safflower populations and the results are presented below. Estimates of phenotypic correlation coefficient among seed yield and yield attributed characters in mutagenic treatments for safflower populations are depicted in Table. 4.35.

1) Plant height (cm)

The phenotypic correlation coefficient analysis revealed that plant height exhibited non significant and positive correlation with seed yield per plantat 0.2% EMS concentration, 200 Gy + 0.1 EMS dose of combination and 200 Gy + 0.2% EMS dose of combination mutagenic treatment. Similarly, correlation coefficient analysis revealed a significant and positive relationship between plant height and the traits i.e. days to rosette at 300 Gy dose, days to 50% flowering at 100 Gy dose and 0.2 % EMS concentration, days to maturity at 100 Gy dose, 300 Gy dose, 0.3 % EMS concentration and 200 Gy +0.2 % EMS dose of combination and hull content at 0.1% EMS concentration at the phenotypic level. Also correlation coefficient analysis showed the significant and negative relationship at phenotypic level that existed between plant height and the traits such as 100 seed weight at 100 Gy, primary branches per plant at 400 Gy dose, 0.1% EMS concentration and 300 Gy +0.1% EMS dose of combination, diameter of head at 300 Gy dose, no. of seeds per capsule at 300 Gy dose and secondary branches per plant at 0.1% EMS concentration. In the present study, phenotypic correlation analysis indicated that seed yield exhibited positive non-significant association with plant height. These findings are broad agreement with the

finding of Umamaheshwari *et. al.* (2019) in Sesame, Bidgoli *et. al.*(2006) in Safflower and Singh *et. al.*(2018) in Sunflower. Plant height had a positive significant association with parameters such as days to rosette, days to 50% flowering, days to maturity and hull content at the phenotypic level, according to correlation analysis. These findings are consistant with the finding of Leelavathi *et. al.* (2018) in Linseed, Bahmankar *et. al.* (2014) in Safflower, Bidgoli *et.al* (2006) in Safflower and Pavithra *et. al.* (2016) in Safflower. Similarly, correlation analysis revealed a negative significant relationship between plant height and attributes such as 100 seed weight, primary branches per plant, secondary branches per plant and head diameter. These findings are in accordance with the findings of Khattab *et. al.* (2018) in Safflower and Dogra *et. al.* (2020) in Linseed.

2) Days to rosette

The phenotypic correlation coefficient analysis revealed that days to rosette exhibited non significant and negative association with seed yield per plant was recorded at 100 Gy, 200 Gy, 300 Gy , 400 Gy, 0.1% EMS, 0.4% EMS, 200 Gy+ 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments. Days to rosette and trait days to 50 % flowering at 300 Gy + 0.1% EMS dose, Days to maturity at 100 Gy, 300 Gy, and 200 Gy+ 0.2 % EMS dose, 100 seed weight at 100 Gy dose, No. of capsule per plant at 0.1% EMS and 200 Gy + 0.1% EMS dose and Diameter of head at 200 Gy + 0.1 % EMS dose of combination treatments all showed significant and negative associations at the phenotypic level. At phenotypic level, days to rosette showed significant positive correlations with day to maturity at 0.2% EMS concentration, 100 seed weight at 0.2% EMS concentration, oil content at 0.2% EMS concentration and primary branches per plant at 300 Gy +0.2% EMS dose of combination treatments. Days to rosette had a negative non significant relationship with seed yield per plant in the current study, according to phenotypic correlation analysis. These findings are in accordance with those findings of Mathur *et. al.* (1976), Khattab *et. al.* (2018), and Dhage *et. al.*(2020) in Safflower. Days to rosette had a positive significant association with days to maturity, according to phenotypic correlation analysis. These findings are consistent with findings of Pavithra *et. al.* (2016) and Bhakre *et. al.* (2015) in Safflower.

3) Days to 50% flowering

The phenotypic correlation coefficient analysis revealed that days to 50% flowering exhibited significant and negative association with seed yield per plant was recorded at 0.3% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments. Similarly a correlation coefficient analysis showed significant and negative relationship between days to 50% flowering and the trait such as primary branches per plant at 300 Gy and 200 Gy+ 0.1%EMS, secondary branches per plant at 0.3% EMS, 200 Gy+ 0.1% EMS and 300 Gy+ 0.2% EMS, no. of capsule per plant at 200 Gy+ 0.1% EMS and 300 Gy+ 0.2% EMS, diameter of head at 100 Gy, 300 Gy, 0.3% EMS, 200 Gy+ 0.1% EMS and 300 Gy+ 0.2% dose, no. of seed per capsule at 100 Gy, 300 Gy, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose, 100 seed weight at 300 Gy and 400 Gy and oil content at 0.2% EMS concentration treatments. At the phenotypic level, correlation coefficient analysis revealed significant and positive relationship between days to 50% flowering and the trait such as days to maturity at 100 Gy, 300 Gy, 0.2% EMS, 0.3% EMS and 200 Gy + 0.1% EMS dose, no. of seeds per capsule at 300 Gy, 0.1% EMS and 200 Gy + 0.2% EMS and hull content at 300 Gy + 0.2% EMS dose of combination treatments. In the present study, phenotypic correlation analysis indicated that seed yield exhibited negative significant association with days to 50% flowering. These findings are broad agreement with the finding of Pavithra *et. al.* (2016) in Safflower and Singh *et. al.*(2018) in Sunflower. Days to 50% flowering had a positive significant relationship with features such as days to maturity, number of seeds per capsule and hull content at the phenotypic level, according to correlation analysis.These findings are consistent with the finding ofSingh *et. al.* (2018) in Sunflower, Khattab *et. al.* (2018) in Safflower and Pavithra *et. al.* (2016) in Safflower.Similarly, phenotypic correlation analysis revealed a negative significant association between days to 50% flowering and traits such as primary branches per plant, secondary branches per plant, number of capsules per plant, head diameter, number of seeds per capsule, 100 seed weight and oil content.These findings are consistent with the finding of Bhakre *et. al.*(2015) in Safflower, Bahmankar *et. al.*(2014) in Safflower, Bidgoli *et. al.* (2006) in Safflower and Pavithra *et.al.*(2016) in Safflower.

4) Days to maturity

The phenotypic correlation coefficient analysis revealed that days to maturity exhibited significant and negative association with seed yield per plant was recorded at 100 Gy, 200 Gy, 300 Gy, 400 Gy, 0.3% EMS and 200 Gy+ 0.1% EMS dose of combination treatments. At the phenotypic level, correlation coefficient analysis revealed a significant and negative relationship between days to maturity and trait primary branches per plant at 100 Gy, 200 Gy, 300 Gy, 0.1% EMS, 0.2% EMS, 200 Gy + 0.1% EMS and 200 Gy + 0.2% EMS, secondary branches per plant at 200 Gy, 400 Gy, 0.2% EMS, 0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 gy + 0.1% EMS, no. of capsule per plant at 200 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 200 Gy+ 0.1% EMS and 300 Gy+ 0.1% EMS, diameter of head at 100 Gy, 300 Gy, 400 Gy, 0.2% EMS, 0.4% EMS and 200 Gy+ 0.1% EMS, no. of seeds per capsule at 100 Gy,300 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 0.4% EMS, 200 Gy+ 0.1% EMS, 200 Gy+ 0.2% EMS and 300 Gy+ 0.1% EMS, 100 seed weight at 100 Gy, 400 Gy, 200 Gy+ 0.1% EMS, 200 Gy+ 0.2% EMS and 300 Gy+ 0.1% EMS andoil content at 200 Gy+ 0.1% EMS, dose of combination treatments. In the current study, phenotypic correlation analysis indicated that days to maturity exhibited significant and negative association with seed yield per plant. These findings are consistent with the finding of Pavithra *et. al.*(2016) in Safflower and Singh *et. al.* (2018) in Sunflower. According to correlation analysis, days to maturity had a negative significant association with other traits such as primary branches per plant, secondary branches per plant, number of capsules per plant, diameter of head, number of seeds per capsule, 100 seed weight and oil content at the phenotypic level. These findings are consistent with the finding of Bhakre *et. al.*(2015) in Safflower, Bahmankar *et. al.*(2014) in Safflower and Pavithra *et.al.*(2016) in Safflower.

5) Primary branches per plant

The phenotypic correlation coefficient analysis revealed that primary branches per plant had a significant and positive relationship with seed yield per plant in the majority of the mutagenic treatments except for 400 Gy and 0.1% EMS treatments.At the phenotypic level, correlation coefficient analysis revealed a significant and positive relationship between primary branches per plant and trait secondary branches per plant at all mutagenic treatments except 400 Gy gamma rays treatment,no. of

capsule per plant at most of the mutagenic treatments except 400 Gy gamma rays treatment, diameter of head at 100 Gy, 400 Gy, 0.2% EMS, 200 Gy + 0.1% EMS and 300 Gy +0.2% EMS dose, no. of seeds per capsule at 100 Gy, 300 Gy, 0.1% EMS, 0.2% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS, 100 seed weight at 0.4% EMS and 300 Gy + 0.1% EMS dose, oil content at 200 Gy + 0.1% EMS and 300 Gy +0.1% EMS dose of combination treatments. Phenotypic correlation analysis revealed that primary branches per plant had a significant and positive relationship with seed yield per plant in the current study.These findings are consistent with the finding of Dhage *et. al.* (2020) in Safflower, Dogra *et. al.* (2020) in Linseed, Khattab *et. al.* (2018) in Safflower, Bhakre *et. al.* (2015) in Safflower and Leelavati *et. al.* (2018) in Linseed. Correlation study revealed that primary branches per plant had a positive and significant relationship with secondary branches per plant, number of capsules per plant, diameter of head, number of seeds per capsule, 100 seed weight and oil content at the phenotypic level.These findings are consistent with the finding of Dogra *et. al.* (2020) in Linseed, Dhage *et. al.* (2020) in Safflower, Leelavati *et. al.* (2018) in Linseed, Bhakre *et. al.* (2015) in Safflower and Arslan, B.(2007) in Safflower.

6) Secondary branches per plant

The phenotypic correlation coefficient analysis revealed that secondary branches per plant exhibited significant and positive association with seed yield per plant was recorded at all mutagenic treatments. At the phenotypic level, correlation coefficient analysis revealed a significant and positive relationship between secondary branches per plant and trait no. of capsules per plant across all mutagenic treatments, diameter of head at 400 Gy, 0.2% EMS, 0.4% EMS and 200 Gy+ 0.1% EMS dose, no. of seeds per capsule at 200 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 0.3% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose, 100 seed weight at 400 Gy, 0.2% EMS, 0.4% EMS and 200 Gy + 0.2% EMS dose combination treatment. Similarly, correlation coefficient analysis showed significant and negative association at phenotypic level between secondary branches per plant and trait hull content at 0.2% EMS concentration treatment.Phenotypic correlation analysis revealed that secondary branches per plant had a significant and positive relationship with seed yield per plant in the current study.These findings are broad agreement with the finding of Dhage *et. al.* (2020) in Safflower, Dogra *et. al.* (2020) in Linseed, Khattab *et. al.* (2018) in Safflower and Leelavati *et. al.* (2018) in Linseed.At the

phenotypic level, correlation analysis revealed that secondary branches per plant had a positive and significant relationship with other attributes such as the number of capsules per plant, the diameter of the head, the number of seeds per capsule and the weight of 100 seeds.These findings are consistent with the finding of Dogra *et. al.* (2020) in Linseed, Dhage *et. al.* (2020) in Safflower, Leelavati *et. al.* (2018) in Linseed.

7) Number of capsule per plant

The phenotypic correlation coefficient analysis revealed that secondary branches per plant exhibited significant and positive association with seed yield per plant was recorded at all mutagenic treatments except 0.1% EMS concentration treatment. At the phenotypic level, correlation coefficient analysis showed significant and positive association between number of capsule per plant and trait diameter of head at 400 Gy, 0.2% EMS, 200 Gy + 0.1% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose, no. of seeds per capsule at 300 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 0.3% EMS, 200 Gy + 0.1% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose, 100 seed weight at 200 Gy, 400 Gy, 0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.1% EMS dose, oil content at 300 Gy + 0.1% EMS dose of combination treatment. Similarly, phenotypic correlation coefficient analysis revealed a significant and negative relationship between number of capsules per plant and trait hull contentat 0.2% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose, oil content at 200 Gy dose of gamma rays treatment at the phenotypic level. Phenotypic correlation analysis revealed that the number of capsules per plant had a significant and positive relationship with seed yield per plant in the current study.These findings are in accordance with the finding of Pavithra *et. al.* (2016) in Safflower, Pushpavalli *et. al.* (2017) in Safflower, Dhage *et. al.* (2020) in Safflower, Dogra *et. al.* (2020) in Linseed, Khattab *et. al.* (2018) in Safflower and Leelavati *et. al.* (2018) in Linseed. Correlation analysis revealed that secondary branches per plant had a positive and significant relationship with other phenotypic features such as head diameter, number of seeds per capsule, 100 seed weight and oil content.These findings are in accordance with the finding of Dogra *et. al.* (2020) in Linseed, Dhage *et. al.* (2020) in Safflower, Arslan *et. al.* (2007) in Safflower, Leelavati *et. al.* (2018) in Linseed and Minnie *et. al.* (2020) in Safflower.

Table 4.35 : Effect of mutagens on phenotypic coefficient of correlation in M_2 generation

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Plant height (cm)	100 Gy	-0.0600	0.3434*	0.3631**	-0.1187	-0.0260	-0.1183	-0.1380	-0.0586	-0.3234*	0.1039	-0.1729	-0.0859
	200 Gy	0.1899	0.0443	-0.0203	-0.0805	-0.1211	-0.1678	-0.0485	-0.1297	-0.1093	0.0295	0.0847	-0.2282
	300 Gy	0.2595*	0.0583	0.3028*	-0.2400	-0.2150	-0.2181	-0.3395**	-0.3178*	-0.0010	-0.1107	0.0704	-0.3034*
	400 Gy	-0.2063	0.1147	0.0653	-0.4010**	-0.0660	-0.1458	-0.1685	-0.1705	-0.0570	0.1535	-0.1381	-0.0227
	0.1% EMS	0.2190	-0.0759	0.1674	-0.2891*	-0.3208*	-0.0201	-0.0027	0.1723	0.0599	*0.2445	-0.0536	-0.1617
	0.2 % EMS	-0.0035	0.3478**	0.0625	-0.0392	0.1042	0.1803	0.0754	-0.0407	0.0411	0.0793	-0.1593	0.2078
	0.3% EMS	0.0826	0.0313	0.3992**	0.1334	0.1013	0.0366	0.1424	0.1307	-0.0297	-0.1339	0.1195	-0.0266
	0.4% EMS	0.0290	0.0415	0.0681	0.0642	0.1056	0.0380	-0.0104	-0.0398	0.2021	-0.0536	-0.0061	-0.0353
	200Gy+0.1 % EMS	0.0073	-0.0656	-0.0500	0.0320	-0.1060	-0.0618	0.1003	0.0437	0.0599	0.0055	0.2319	0.0965
	200 Gy + 0.2% EMS	-0.0338	-0.0218	0.2744*	0.1171	-0.1569	-0.0070	-0.0704	-0.1445	-0.1966	0.0746	-0.1892	0.0257
	300 Gy + 0.1% EMS	-0.0981	0.1171	0.0869	-0.2561*	-0.1177	-0.1658	-0.0337	-0.1953	-0.0110	-0.0306	-0.1060	-0.1024
	300 Gy +0.2% EMS	-0.0435	-0.0499	-0.0550	-0.0936	-0.0374	0.0412	0.0103	-0.0794	0.1707	-0.1310	0.1926	-0.1853
	Dry control	-0.0033	0.0923	0.1517	-0.1507	0.0020	0.0758	0.0972	0.0893	-0.0683	-0.1350	-0.2386	0.1388
	Wet control	-0.2464	0.0842	0.0633	-0.3140*	-0.1545	-0.2264	0.2193	0.2736*	-0.2308	-0.0348	-0.2296	-0.0331

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Days to rosette (Days)	100 Gy		0.0455	-0.2099	0.2085	0.0182	-0.0255	-0.0109	0.1346	0.0718	-0.2686*	-0.1830	-0.0237
	200 Gy		-0.1637	-0.2609*	0.0641	0.2483	0.0354	0.0555	0.0020	-0.1260	0.0216	0.0254	-0.2282
	300 Gy		0.1968	0.0374	0.0409	-0.0351	0.0502	-0.1251	-0.0971	0.0783	0.1557	-0.1040	-0.1045
	400 Gy		-0.0419	0.0208	0.0436	0.0270	0.0030	0.0139	-0.0686	0.0340	-0.2074	0.2219	-0.0255
	0.1% EMS		-0.0580	0.0708	-0.1785	-0.1617	-0.2557*	0.1301	-0.0040	-0.0887	-0.0010	-0.1824	-0.0259
	0.2 % EMS		0.0334	0.2717*	-0.0820	0.0390	0.0431	0.0364	-0.0605	0.3107*	-0.0911	0.2859*	0.1553
	0.3% EMS		-0.0508	0.0018	0.1127	0.0410	0.0628	-0.0221	-0.0414	0.0749	-0.0040	0.2059	0.1194
	0.4% EMS		-0.1194	-0.0526	-0.1443	-0.0822	-0.0494	0.0186	-0.1036	0.0796	0.0689	0.0727	-0.1074
	200 Gy+0.1% EMS		0.0170	0.1528	-0.1818	-0.1148	-0.0401	-0.3511**	-0.3265*	-0.0334	0.0092	-0.2503	-0.1799
	200 Gy + 0.2% EMS		-0.0143	-0.2772*	0.0563	-0.0324	-0.0096	0.1232	0.0921	0.1153	0.1128	0.0823	-0.0330
	300 Gy + 0.1% EMS		-0.2668*	-0.1442	-0.0827	0.0317	-0.0455	0.1625	0.0744	-0.0174	0.1105	0.0181	0.0594
	300 Gy +0.2% EMS		0.0397	0.1796	0.2627*	0.1611	0.1087	0.0053	0.1250	-0.0213	0.1631	-0.1536	0.1793
	Dry control		-0.2254	-0.1006	-0.0217	-0.0512	-0.1525	0.0650	0.0740	0.0288	-0.0429	-0.0044	0.0098
	Wet control		0.0000	-0.0340	0.2348	0.1354	0.1388	-0.3551**	-0.1988	0.0739	0.0298	0.1545	-0.0382

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Days to 50% flowering (Days)	100 Gy			0.4214**	-0.1909	0.1033	-0.0154	-0.3939**	-0.3833**	-0.2509	-0.0562	-0.1274	-0.1714
	200 Gy			0.2038	-0.1613	-0.0751	-0.1506	0.0686	-0.1211	0.0768	0.0961	0.0423	0.0348
	300 Gy			0.3083*	-0.2807*	-0.1788	-0.2028	-0.4292**	-0.4217**	-0.3791**	0.0778	-0.1796	-0.1447
	400 Gy			0.1043	-0.0572	-0.1179	-0.1894	-0.0821	-0.1035	-0.2815*	0.0584	0.0941	-0.1989
	0.1% EMS			0.2372	-0.1872	0.0039	-0.0978	0.0466	-0.1053	-0.1777	0.1147	-0.0270	-0.2307
	0.2 % EMS			0.2627*	-0.0630	-0.1152	-0.1274	-0.1007	-0.1475	-0.0060	0.0092	-0.3160*	0.0367
	0.3% EMS			0.3154*	-0.0951	-0.3012*	-0.2804-	-0.2842*	-0.1583	-0.0925	0.1110	-0.0413	-0.3393*
	0.4% EMS			0.1863	-0.1901	-0.2067	-0.1286	-0.0433	-0.0190	-0.1779	0.1735	0.0704	-0.1310
	200Gy+0.1 % EMS			0.4034**	-0.3878**	-0.3421**	-0.3630**	-0.4050**	-0.4295**	-0.1744	0.0118	-0.1125	-0.3366
	200 Gy + 0.2% EMS			-0.0116	-0.1865	-0.1991	0.0598	-0.0564	-0.2841*	-0.1007	0.0253	-0.0163	-0.1027
	300 Gy + 0.1% EMS			0.0797	-0.1305	-0.1849	-0.0978	-0.1397	-0.1894	-0.2202	-0.1303	0.0495	-0.3034*
	300Gy+0.2 % EMS			0.0321	-0.0886	-0.3146*	-0.5361**	-0.4914**	-0.4961**	-0.1190	0.3228*	0.1039	-0.5160**
	Dry control			0.2182	0.0869	-0.0585	-0.0569	0.0997	0.0926	-0.1651	0.1106	-0.0099	0.0011
	Wet control			0.2311	-0.1730	-0.0607	-0.1615	-0.0865	-0.1251	0.0683	-0.0406	-0.1218	-0.2739*

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Days to maturity (Days)	100 Gy				-0.3795**	-0.2318	-0.2518	-0.4476**	-0.4746**	-0.3929**	-0.0100	-0.1629	-0.4676**
	200 Gy				-0.3039*	-0.3541**	-0.2988*	-0.2304	-0.0085	-0.2140	-0.1022	0.1015	-0.2784*
	300 Gy				-0.3932**	-0.1587	-0.1994	-0.3524**	-0.3192*	-0.1615	-0.0608	0.2180	-0.3381**
	400 Gy				-0.2399	-0.4195**	-0.3461**	-0.3358**	-0.2706*	-0.3660**	0.1262	-0.1931	-0.3473**
	0.1% EMS				-0.3877**	-0.1998	-0.2672*	0.0813	-0.4025**	-0.0269	0.0011	0.1421	0.0964
	0.2 % EMS				-0.2903*	-0.2951*	-0.2921*	-0.3910**	-0.5252**	-0.0114	-0.0344	-0.0356	-0.1960
	0.3% EMS				0.0497	-0.1256	-0.1397	-0.1922	-0.1698	0.0701	0.0258	0.0580	-0.3417**
	0.4% EMS				-0.2117	-0.3073*	-0.1601	-0.4256**	-0.3642**	0.1286	-0.0841	-0.1205	-0.1666
	200 Gy+0.1% EMS				-0.6363**	-0.5235**	-0.4471**	-0.5491**	-0.5051**	-0.3505**	-0.0969	-0.5097**	-0.5525**
	200 Gy + 0.2% EMS				-0.4027**	-0.3422**	-0.1673	-0.1545	-0.2737*	-0.3033*	0.0345	-0.2325	-0.2089
	300 Gy + 0.1% EMS				-0.0852	-0.3132*	-0.2632*	0.0068	-0.0759	-0.3044*	-0.2401	0.0705	-0.0895
	300 Gy +0.2% EMS				0.0854	0.0051	-0.0917	-0.0283	-0.0652	0.0404	0.1150	0.1022	-0.1278
	Dry control				-0.0123	0.2355	-.0.0953	0.0047	-0.0874	0.0224	0.0202	0.0492	0.0764
	Wet control				-0.1971	-0.1029	-0.2237	0.0397	-0.0322	0.3022*	0.0478	-0.1006	-0.1953

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
No. of Primary branches per plant	100 Gy					0.2570*	0.2836*	0.4517**	0.4759**	0.1096	0.0302	-0.1383	0.3997**
	200 Gy					0.6798**	0.5536**	0.1709	0.2497	0.2191	0.0774	-0.0224	0.5201**
	300 Gy					0.7392**	0.7350**	0.2364	0.3214*	0.2014	0.0609	-0.0743	0.6980**
	400 Gy					0.1474	0.0405	0.2790*	0.2111	0.2262	-0.0501	0.0669	0.1571
	0.1% EMS					0.5390**	0.4155**	-0.0212	0.4215**	0.0083	-0.0413	0.0325	0.2147
	0.2 % EMS					0.6702**	0.7424**	0.3415**	0.3914**	0.1332	-0.1711	-0.2009	0.4855**
	0.3% EMS					0.4718**	0.5564**	0.2497	0.1764	-0.1166	0.0206	-0.0014	0.4782**
	0.4% EMS					0.8370**	0.7653**	0.2146	0.1632	0.3405**	0.0880	0.0848	0.4317**
	200 Gy+0.1% EMS					0.8898**	0.7887**	0.4270**	0.5521**	0.2245	0.0887	0.2604*	0.7049**
	200 Gy + 0.2% EMS					0.5560**	0.5407**	0.1089	0.1920	0.2418	-0.2160	0.0197	0.4675**
	300 Gy + 0.1% EMS					0.3787**	0.8205**	0.1773	0.1715	0.3624**	0.2029	0.3908**	0.5356**
	300 Gy +0.2% EMS					0.4169**	0.3318**	0.3051*	0.4276**	-0.1427	0.0766	-0.1277	0.4361**
	Dry control					0.4965**	0.1628	0.1335	0.0305	-0.1066	0.2033	0.0456	0.2399
	Wet control					0.3940**	0.5976**	-0.0422	0.0190	-0.0979	0.0960	0.1505	0.2732*

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
No. of secondary branches per plant	100 Gy						0.7986**	0.1450	0.1534	0.0425	-0.0184	0.1238	0.6198**
	200 Gy						0.4871**	0.1949	0.2836*	0.0982	-0.0368	0.0003	0.4753**
	300 Gy						0.8501**	0.1049	0.1795	0.0501	0.0797	-0.0729	0.5812**
	400 Gy						0.6099**	0.4293**	0.5107**	0.3956**	0.0366	0.1813	0.6549**
	0.1% EMS						0.5362**	-0.1004	0.3801**	0.2446	0.0137	-0.1491	0.3447*
	0.2 % EMS						0.8877**	0.4131**	0.4869**	0.3881**	-0.3062*	0.0183	0.4515**
	0.3% EMS						0.8184**	0.2459	0.3952**	-0.1980	0.0841	-0.0592	0.7487**
	0.4% EMS						0.7368**	0.3302**	0.1953	0.3613**	0.0256	0.0304	0.5611**
	200 Gy+0.1% EMS						0.8515**	0.2874*	0.4660**	0.2033	0.0582	0.1390	0.6867**
	200 Gy + 0.2% EMS						0.6095**	0.1396	0.2750*	0.3638**	-0.1580	0.0697	0.5668**
	300 Gy + 0.1% EMS						0.4980**	0.1434	0.0555	0.1926	0.0527	0.2061	0.3730**
	300 Gy +0.2% EMS						0.3411**	0.2259	0.3388**	0.0594	0.1245	-0.0433	0.4508**
	Dry control						0.4878**	0.0809	-0.0525	-0.1884	0.2463	0.2221	0.5551**
	Wet control						0.7362**	-0.0090	-0.1604	0.0208	0.1426	0.1211	0.4913**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
No. of capsule per plant	100 Gy							0.2388	0.2430	0.0568	-0.0537	0.0511	0.6764**
	200 Gy							-0.0753	0.0351	0.2978*	0.0657	-0.2753*	0.4816**
	300 Gy							0.1563	0.2606*	0.2201	0.0465	-0.1313	0.6995**
	400 Gy							0.3477**	0.3745**	0.3656**	-0.0514	0.1592	0.4938**
	0.1% EMS							-0.1298	0.3851**	0.1630	0.1073	-0.1658	0.2712
	0.2 % EMS							0.5006**	0.5022**	0.2196	-0.2927*	-0.0283	0.5337**
	0.3% EMS							0.2249	0.3677**	-0.0988	0.0072	-0.1131	0.8671**
	0.4% EMS							0.2313	0.2108	0.3898**	0.0161	-0.0558	0.5546**
	200 Gy+0.1% EMS							0.3225*	0.4774**	0.3055*	0.0285	0.1930	0.7444**
	200 Gy + 0.2% EMS							0.0849	0.0899	0.2877*	-0.4262**	0.0522	0.6640**
	300 Gy + 0.1% EMS							0.3134*	0.3011*	0.3224*	0.0863	0.2726*	0.6722**
	300 Gy +0.2% EMS							0.6368**	0.6088**	-0.0306	-0.3289*	-0.0530	0.6561**
	Dry control							-0.0864	-0.1653	-0.0703	0.1254	0.1335	0.2884*
	Wet control							0.0049	-0.1523	-0.0832	0.1818	0.2490	0.5223**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Diameter of head (cm)	100 Gy								0.8218**	0.3335**	0.0070	0.1113	0.6371**
	200 Gy								0.6618**	-0.0129	0.3000*	0.3841**	0.3668**
	300 Gy								0.9170**	0.1168	0.2593*	-0.2493	0.5413**
	400 Gy								0.9156**	0.5133**	0.0577	-0.0777	0.7176**
	0.1% EMS								0.0689	0.0164	0.1677	-0.0966	-0.0767
	0.2 % EMS								0.8242**	0.1507	-0.2047	0.0814	0.4563**
	0.3% EMS								0.7542**	0.0518	0.2472	0.1141	0.4293**
	0.4% EMS								0.8914**	0.1312	-0.1336	0.0099	0.4857**
	200 Gy+0.1% EMS								0.7051**	0.3268*	0.1050	0.3692**	0.4921**
	200 Gy + 0.2% EMS								0.4152**	0.0776	-0.3871**	-0.0307	0.1491
	300 Gy + 0.1% EMS								0.6591**	0.1541	-0.1787	0.2268	0.3616**
	300 Gy +0.2% EMS								0.8391**	-0.0526	-0.3320**	-0.1330	0.5955**
	Dry control								0.6751**	0.0510	-0.0398	-0.1234	0.5290**
	Wet control								0.6361**	-0.1884	-0.0199	-0.0074	0.4687**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
No. of seed per capsule	100 Gy									0.1961	-0.0591	0.0058	0.6037**
	200 Gy									0.0469	0.1483	0.2883*	0.4531**
	300 Gy									0.1787	0.2256	-0.2411	0.6063**
	400 Gy									0.5885**	0.0447	-0.0961	0.8015**
	0.1% EMS									0.2207	0.0155	-0.2512	0.4403**
	0.2 % EMS									0.2292	-0.1259	0.0567	0.4188**
	0.3% EMS									-0.1349	0.2829*	-0.0910	0.4972**
	0.4% EMS									0.1524	-0.1770	0.0012	0.5207**
	200Gy+0.1 % EMS									0.2656*	0.0408	0.3360**	0.5488**
	200 Gy + 0.2% EMS									0.2337	-0.0180	-0.1390	0.3931**
	300 Gy + 0.1% EMS									0.0529	-0.2062	0.1242	0.4058**
	300 Gy +0.2% EMS									-0.0185	-0.3352**	-0.1310	0.6704**
	Dry control									0.1992	-0.2016	-0.1789	0.5585**
	Wet control									-0.1513	-0.1388	-0.0625	0.4748**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
100 seed weight (g)	100 Gy										-0.0697	0.2244	0.3990**
	200 Gy										-0.2629*	-0.2843*	0.5395**
	300 Gy										-0.0558	0.0169	0.3823**
	400 Gy										-0.0882	0.0755	0.6979**
	0.1% EMS										-0.0227	0.0746	0.2825*
	0.2 % EMS										-0.3044*	0.0585	0.2062
	0.3% EMS										-0.1249	0.4642**	-0.0310
	0.4% EMS										0.1102	-0.3064*	0.4686**
	200 Gy+0.1% EMS										0.0635	0.1332	0.5407**
	200 Gy + 0.2% EMS										0.0101	-0.0904	0.3398**
	300 Gy + 0.1% EMS										0.1802	0.1754	0.2707*
	300 Gy +0.2% EMS										-0.0193	0.3257*	0.1097
	Dry control										-0.1959	-0.0579	0.0571
	Wet control										-0.0602	-0.1663	-0.0660

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Hull content (%)	100 Gy											0.0368	0.0500
	200 Gy											0.2212	0.0243
	300 Gy											-0.3047*	0.1160
	400 Gy											0.1171	0.2579
	0.1% EMS											-0.1435	0.0416
	0.2 % EMS											-0.0084	-0.1277
	0.3% EMS											-0.1616	0.0791
	0.4% EMS											0.0577	-0.0226
	200 Gy+0.1% EMS											-0.0098	-0.0293
	200 Gy + 0.2% EMS											-0.1272	-0.2500
	300 Gy + 0.1% EMS											0.0302	0.0764
	300 Gy +0.2% EMS											-0.0010	-0.1895
	Dry control											0.0559	-0.0329
	Wet control											0.1009	0.1112

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Oil content (%)	100 Gy												0.1192
	200 Gy												-0.0935
	300 Gy												-0.1187
	400 Gy												0.1910
	0.1% EMS												0.0247
	0.2 % EMS												-0.0706
	0.3% EMS												-0.0341
	0.4% EMS												-0.1491
	200 Gy+0.1% EMS												0.2462
	200 Gy + 0.2% EMS												-0.0588
	300 Gy + 0.1% EMS												0.2864*
	300 Gy +0.2% EMS												-0.1025
	Dry control												0.0681
	Wet control												0.1387

8) Diameter of head

The phenotypic correlation coefficient analysis revealed that diameter of head had a significant and positive relationship with seed yield per plant for all the mutagenic treatments except 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments.At the phenotypic level, correlation coefficient analysis revealed a significant and positive relationship between head diameter and trait no. of seeds per capsule for all mutagenic treatments, with the exception of0.1% EMS concentration, 100 seed weight at 100 Gy, 400 Gy and 200 Gy + 0.1% EMS dose, hull content at 200 Gy and 300 Gy dose, oil content at 200 Gy and 200 Gy + 0.1% EMS dose of combination treatment. At the phenotypic level, correlation coefficient analysis revealed a significant and negative relationship between head diameter and trait hull content at 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatment. According to phenotypic correlation coefficient analysis, the diameter of the head had a positive and significant relationship with seed yield per plant in the current study.These findings are in accordance with the finding of Arslan (2007) in Safflower, Bidgoli *et. al.*(2006) in Safflower and Bahmankar *et. al.* (2014) in Safflower.At the phenotypic level, correlation analysis showed that the diameter of the head had a positive and significant relationship with other parameters such as the number of seeds per capsule, the weight of 100 seeds, the hull content and the oil content.These findings are in the confirmity with the finding of Bidgoli *et. al.* (2006) in Safflower, Arslan (2007) in Safflower, Bahmankar *et. al.* (2014) in Safflower and Pavithra *et. al.* (2016) in Safflower.

9) Number of seeds per capsule

The phenotypic correlation coefficient analysis revealed that number of seeds per capsule exhibited significant and positive association with seed yield per plant was recorded at all the mutagenic treatments. At phenotypic level, correlation coefficient analysis showed significant and positive association between number of seeds per capsule and trait 100 seed weight at 400 Gy and 200 Gy + 0.1% EMS, hull content at 0.3% EMS, oil content at 200 Gy and 200 Gy + 0.1% EMS dose of combination treatment. Similarly, correlation coefficient analysis showed significant and negative association at phenotypic level exist between number of seeds per capsule and trait hull content at 300 Gy + 0.2% EMS dose of combination

treatment.According to phenotypic correlation coefficient analysis, the number of seeds per capsule had a positive and significant relationship with seed yield per plant in the current study. These findings are in accordance with the finding of Arslan (2007) in Safflower, Pavithra *et. al.* (2016), Pushpavalli *et.al.* (2017) in Safflower, Dhage *et.al.* (2020) and Minnie *et. al.* (2020) in Safflower. A correlational study revealed that the number of seeds per capsule had a positive and significant relationship with other attributes such as 100 seed weight, hull content and oil content at the phenotypic level. These findings are consistent with the finding of Minnie *et. al.* (2020) in Safflower and Shivani *et. al.* (2011) in Safflower.

10) 100 seed weight (g)

The phenotypic correlation coefficient analysis revealed that 100 seed weight (g) exhibited significant and positive association with seed yield per plant in majority of the mutagenic treatments with the exception of 0.2% EMS, 0.3% EMS and 300 Gy + 0.2% EMS dose of combination. At phenotypic level, correlation coefficient analysis showed significant and positive association exist between 100 seed weight and trait oil content at 0.3% EMS and 300 Gy+ 0.2% EMS dose of combination treatments. Similarly, correlation coefficient analysis showed significant and negative association at phenotypic level exist between 100 seed weight and trait hull content at 200 Gy and 0.2% EMS concentration, oil content at 200 Gy and 0.4% EMS concentration treatment.Phenotypic correlation coefficient analysis revealed that 100 seed weight had a positive and significant relationship with seed yield per plant in the current study.These findings are consistent with the finding of Pavithra*et. al.* (2016) in Safflower, Pushpavalli *et.al.*(2017) in Safflower, Dhage *et.al.* (2020) in Safflower and Minnie *et. al.*(2020) in Safflower. A correlation study revealed that 100 seed weight had a positive and significant relationship with other features such as oil content at the phenotypic level. These findings are in accordance with the finding of Minnie *et. al.* (2020) in Safflower and Bhakre *et. al.* (2015) in Safflower. Similarly, correlation coefficient analysis showed significant and negative association at phenotypic level exist between 100 seed weight and traits *viz.,* hull content and oil content. These findings are in the confirmity with the finding of Pavithra *et. al.* (2016) in Safflower and Dhage *et.al.* (2020) in Safflower.

11) Hull content

The phenotypic correlation coefficient analysis revealed that hull content exhibited non significant and negative association with seed yield per plant was recorded at 0.2% EMS, 0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy+ 0.2% EMS dose of combination treatment. At the phenotypic level, correlation coefficient analysis revealed a significant and negative relationship between hull content and trait oil content following treatment with 300 Gy of gamma rays. Phenotypic correlation analysis revealed that hull content had a negative non significant relationship with seed yield per plant and a negative significant relationship with oil content in the current study. These findings are controversy with the finding of Pavithra *et. al.* (2016) in Safflower and Patter *et. al.*(2020) in Safflower.

12) Oil content (%)

The phenotypic correlation coefficient analysis revealed that oil content exhibited significant and positive association with seed yield per plant at 300 Gy + 0.1% EMS dose of combination treatment. Correlation coefficient analysis showed non-significant and positive association at phenotypic level exist between oil content and seed yield per plant at 100 gy, 400 Gy, 0.1% EMS and 200 Gy + 0.1% EMS dose of combination treatment. According to phenotypic correlation analysis, Oil content had a positive significant relationship with seed yield per plant in the current study. These findings are in accordance with the finding of Topal *et. al.* (2010) in Safflower. Further, phenotypic correlation study revealed that oil content had a non-significant positive relationship with seed yield per plant.These findings consistent with the finding of Bhakre *et. al.* (2015) in Safflower, Pavithra *et. al.* (2016) in Safflower and Minnie *et. al.*(2020) in Safflower.

4.2.5.2 Genotypic correlation coefficient analysis

The Genotypic correlation were estimated out among the characters studied to determine the effect of mutagens on associations patterns in M_2 generations of safflower populations and the results are presented below. Estimates of genotypic correlation coefficient among seed yield and yield attributed characters in mutagenic treatments for safflower populations are depicted in Table 4.36.

1) Plant height (cm)

According to genotypic correlation coefficient analysis, plant height displayed a significant and positive relationship with seed yield per plant at100 Gy, 0.2% EMS, 200 Gy+ 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments. At Genotypic level, correlation coefficient analysis showed significant and positive association between plant height and trait days to rosette at 200 Gy, 300 Gy, 0.3% EMS and 300 Gy + 0.2% EMS dose, days to 50% flowering at 100 Gy and 0.2% EMS concentration, days to maturity at 100 Gy, 300 Gy, 0.2% EMS and 200 Gy+ 0.2% EMS dose, primary branches per plant at 300 Gy, 0.2% EMS, 0.3% EMS and 300 Gy+ 0.2% EMS dose, secondary branches per plant at 100 Gy, 300 Gy, 0.4% EMS and 300 Gy + 0.1% EMS dose, no. of capsule per plant at 0.2% EMS, 0.4% EMS and 300 Gy + 0.2% EMS dose, diameter of head at 0.4% EMS and 300 Gy + 0.2% EMS dose, no. of seeds per capsule at 0.1% EMS, 0.3% EMS and 300 Gy + 0.2% EMS dose, 100 seed weight at 0.1% EMS, 0.3% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose, hull content at 100 Gy, 400 Gy and 300 Gy + 0.1% EMS dose, oil content at 300 Gy, 0.3% EMS and 200 Gy + 0.1% EMS dose of combination treatments. Similarly, correlation coefficient analysis showed significant and negative association at genotypic level between plant height and trait days to rosette at 400 Gy, 200 Gy+ 0.2% EMS and 300 Gy+ 0.1% EMS dose, days to 50% flowering at 0.4% EMS, 200 Gy+ 0.1% EMS, 200 Gy+ 0.2% EMS, 300 Gy + 0.1 EMS and 300 Gy + 0.2% EMS dose,primary branches per plant at 400 Gy dose, secondary branches per plant at 0.1% EMS and 200 Gy + 0.1% EMS dose, diameter of head at 300 Gy dose, no. of seeds per capsule at 300 Gy dose, 100 seed weight at 100 Gy and 200 Gy+ 0.2% EMS dose, hull content at 0.1% EMS, 0.2% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose, oil content at 100 Gy,0.2% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatments.According to genotypic correlation analysis, Plant height had a positive significant relationship with seed yield per plant in the current study.These finding are consistent with the findings of Begum and Dasgupta (2011) in Sesame, Pavithra *et. al.* (2016) in Safflower, Arslan *et. al.* (2007) in Safflower and Dhage *et. al.* (2020) in Safflower. Plant height showed a positive significant association with other traits such as days to rosette, days to 50% flowering, days to maturity, primary branches per plant, secondary branches per plant, number of capsules per plant, the diameter of head, number of seeds per capsule, 100

seed weight, hull content and oil content at the genotypic level.These findings are in accordance with the findings of Dhage *et.al.*(2020) in Safflower, Meena *et. al.* (2020) in Linseed, Pavithra *et. al.* (2016) in Safflower and Bahmankar *et. al.* (2014) in Safflower.

2) Days to rosette

The genotypic correlation coefficient analysis revealed that days to rosette demonstrated significant and negative correlation with seed yield per plant at 400 Gy, 0.4% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments. At genotypic level, correlation coefficient analysis showed significant and negative association between days to rosette and trait days to 50% flowering at 200 Gy, 400 Gy, 0.2% EMS, 0.4% EMS and 300 Gy + 0.1% EMS dose, days to maturity at 200 Gy and 200 Gy + 0.2% EMS dose, primary branches per plant at 0.2% EMS and 300 Gy + 0.1% EMS dose, no. of capsule per plant at 0.1% EMS and 300 Gy + 0.1% EMS, diameter of head at 400 Gy, 0.3% EMS, 0.4% EMS and 300 Gy + 0.2% EMS dose, no. of seeds per capsule at 400 Gy, 0.2% EMS, 0.3% EMS, 0.4% EMS, 200 Gy+ 0.1% EMS and 300 Gy + 0.2% EMS dose, 100 seed weight at 200 Gy, 400 Gy, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose, hull content at 100 Gy, 400 Gy and 200 Gy + 0.2% EMS dose, oil content at 100 Gy, 300 Gy, 0.1% EMS and 200 Gy + 0.1% EMS dose of combination treatments. Similarly, correlation coefficient analysis showed significant and positive relationship at genotypic level between days to rosette and trait days to 50% flowering at 100 Gy and 300 Gy + 0.2% EMS dose, days to maturity at 0.1% EMS, 0.3% EMS, 0.4% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose, primary branches per plant at 300 Gy, 0.3% EMS, 0.4% EMS and 300 Gy + 0.2% EMS dose, secondary branches per plant at 100 Gy, 200 Gy, 0.3% EMS and 300 Gy + 0.2% EMS dose, no. of capsule per plant at 100 Gy, 400 Gy and 0.3% EMS concentration, diameter of head at 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.1% EMS dose, no. of seeds per capsule at 100 Gy , 0.1% EMS and 300 Gy + 0.1% EMS dose, 100 seed weight at 0.1 % EMS, 0.2% EMS and 0.4% EMS concentration, hull content at 200 Gy, 300 Gy and 0.4% EMS concentration, oil content at 400 Gy and 0.3% EMS concentration treatment.According to genotypic correlation analysis,days to rosette had a negative significant relationship with seed yield per plant in the current study. These finding are consistent with the findings of Pavithra *et. al.* (2016) in Safflower, Sarang *et. al.* (2004) in Safflower, Mozaffari and

Asadi (2006) in Safflower and Bidgoli *et. al.*(2006) in Safflower. Days to rosette had a positive significant correlation with days to 50% flowering and days to maturity, according to genotypic correlation study.These findings are in accordance with the findings of Pavithra *et. al.*(2016) in Safflower and Bidgoli *et. al.* (2006) in Safflower.

3) Days to 50% flowering

The genotypic correlation coefficient analysis revealed that days to 50% flowering exhibited significant and negative correlation with seed yield per plant was recorded at 300 Gy,400 Gy, 0.3% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS, 300 Gy+ 0.1% EMS and 300 Gy+ 0.2% EMS dose of combination treatments. At genotypic level, correlation coefficient analysis showed significant and negative association between days to 50% flowering and trait days to maturity at 0.3% EMS concentration, primary branches per plant at 100 Gy,300 Gy, 400 Gy, 0.1% EMS, 0.4% EMS, 200 Gy+ 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments, secondary branches per plant at 300 Gy, 400 Gy, 0.3% EMS, 0.4% EMS, 200 Gy + 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments, no. of capsule per plant at 300 Gy, 400 Gy, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, diameter of head at 100 Gy, 300 Gy, 0.3% EMS, 0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments, no. of seeds per capsule at 100 Gy, 300 Gy, 400 Gy, 0.1% EMS, 0.3% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments, 100 seed weight at 400 Gy and 0.1% EMS concentration, hull content at 0.3% EMS and 300 Gy + 0.1% EMS dose of combination treatments, oil content at 300 Gy and 0.2% EMS concentration treatments. Similarly, correlation coefficient analysis showed significant and positive association at genotypic level between days to 50% flowering and trait days to maturity at 100 Gy, 400 Gy, 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, secondary branches per plant at 100 Gy, 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatment, no. of capsule per plant at 100 Gy and 0.2% EMS concentration, diameter of head at 0.1% EMS and 0.2% EMS concentration, no of seed per capsule at 0.2% EMS concentration, 100 seed weight at 0.2% EMS, 0.3% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments, hull content at 200 Gy, 0.4% EMS and 200 Gy + 0.2% EMS dose of combination treatments and oil content at 300 Gy + 0.2% EMS dose of

combination treatment.In the current study, genotypic correlation analysis revealed a negative significant relationship between days to 50% flowering and seed yield per plant. These finding are broad agreement with the findings of Pavithra *et. al.*(2016) in Safflower, Minnie *et. al.*(2020) in Safflower and Singh *et. al.* (2018) in Sunflower. According to genotypic correlation analysis, days to 50% flowering had a negative significant association with other traits such as primary branches per plant, secondary branches per plant, number of capsules per plant, diameter of head, number of seeds per capsule, 100 seed weight, hull content and oil content. These findings are in accordance with the findings of Bhakre *et. al.*(2015) in Safflower, Bahmankar *et. al.* (2014) in Safflower, Bidgoli *et. al.* (2006) in Safflower and Pavithra *et.al.* (2016) in Safflower. Days to 50 % flowering had a positive significant relationship with days to maturity, according to genotypic correlation study.These finding are broad agreement with the findings of Pavithra *et.al.* (2016) in Safflower and Minnie *et. al.* (2020) in Safflower.

4) Day to maturity (days)

The genotypic correlation coefficient analysis revealed that days to maturity exhibited significant and negative correlation with seed yield per plant at 100 Gy, 200Gy, 300 Gy, 400 Gy and 200 Gy + 0.1% EMS dose of combination treatments. At genotypic level, correlation coefficient analysis showed significant and negative association exists between days to maturity and trait primary branches per plant at 100 Gy, 200 Gy, 300 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 200 Gy+ 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments, secondary branches per plant at 100 Gy, 200 Gy, 300 Gy, 400 Gy, 0.2% EMS, 0.4% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.1% EMS dose of combination treatments, no. of capsule per plant at 100 Gy, 200 Gy, 300 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 200 Gy + 0.1% EMS, 300 Gy+ 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, diameter of head at 100 Gy, 200 Gy, 300 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments, no. of seeds per capsule at 100 Gy, 300 Gy, 0.2% EMS, 0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments, 100 seed weight at 200 Gy, 400 Gy and 300 Gy+ 0.1% EMS dose of combination treatments, hull content at 0.1% EMS, 0.3% EMS and 300 Gy + 0.1% EMS dose of combination treatments, oil content at 100 Gy and 200 Gy +0.2% EMS

dose of combination treatments. Similarly, correlation coefficient analysis showed significant and positive association at genotypic level between days to maturity and trait secondary branches per plant at 0.1% EMS concentration treatment, diameter of head at 0.3% EMS concentration, no of seed per capsule at 300 Gy +0.1% EMS dose of combination treatment, 100 seed weight at 300 Gy and 0.2% EMS concentration treatments, hull content at 100 Gy, 400 Gy, 200 Gy+ 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments and oil content at 200 Gy, 0.3% EMS and 300 Gy + 0.1% EMS dose of combination treatments.According to genotypic correlation analysis, days to maturity had a negative significant relationship with seed yield per plant in the current study.These finding are consistent with the findings of Pavithra *et. al.*(2016) in Safflower, Minnie *et. al.* (2020) in Safflower and Singh *et. al.* (2018) in Sunflower. Days to maturity also had a negative significant association with other traits such as primary branches per plant, secondary branches per plant, number of capsules per plant, diameter of head, number of seeds per capsule, 100 seed weight, hull content and oil content, according to genotypic correlation analysis. These findings are in accordance with the findings of Shivani *et. al.* (2011) in Safflower, Bhakre *et. al.*(2015) in Safflower, Bahmankar *et. al.* (2014) in Safflower and Pavithra *et.al.* (2016) in Safflower. Similarly genotypic correlation analysis indicated that days to maturity displayed positive significant association with other traits *viz.,* secondary branches per plant, diameter of head, no. of seeds per capsule, 100 seed weight, hull content and oil content.These findings are in the confirmity with the findings of Minnie *et. al.* (2020) in Safflower, Pavithra *et. al.* (2016) in Safflower and Dhage *et. al.* (2020) in Safflower.

5) Primary branches per plant

The genotypic correlation coefficient analysis revealed that primary branches per plant demonstrated significant and positive correlation with seed yield per plant in most of the mutagenic treatments except 400 Gy, 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments. At genotypic level, correlation coefficient analysis showed significant and positive association between primary branches per plant and trait secondary branches per plant at all mutagenic treatments except 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatments, no. of capsule per plant at all mutagenic treatments except 400 Gy and 300 Gy + 0.2% EMS dose of combination treatments, diameter of head at 100 Gy, 200 Gy, 300 Gy, 0.2%

EMS,0.3% EMS, 200 Gy + 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments, no. of seeds per capsule at 100 Gy, 200 Gy, 300 Gy, 0.2% EMS, 0.3% EMS and 200 Gy + 0.1% EMS dose of combination treatments, 100 seed weight at 200 Gy, 0.2% EMS, 0.4% EMS, 200 Gy+ 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy+ 0.1% EMS dose of combination treatments, hull content at 0.3% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, oil content at 200 Gy +0.1% EMS and 300 Gy + 0.1% EMS dose of combination treatments. Similarly, correlation coefficient analysis showed significant and negative association at genotypic level exist between primary branches per plant and trait diameter of head at 400 Gy, 0.1% EMS and 300 Gy + 0.1% EMS dose of combination treatments, no of seed per capsule at 400 Gy dose of gamma rays treatment, 100 seed weight at 0.3% EMS and 300 Gy + 0.2% EMS dose of combination treatments, hull content at 0.2% EMS and 200 Gy+ 0.2% EMS dose of combination treatments and oil content at 0.1% EMS and 0.2% EMS concentration treatments.In this study, genotypic correlation analysis revealed a positive significant relationship between primary branches per plant and seed yield per plant. These finding are in accordance with the findings of Dhage *et. al.* (2020) in Safflower, Dogra *et. al.* (2020) in Linseed, Khattab *et. al.* (2018) in Safflower, Bhakre *et. al.* (2015) in Safflower and Leelavati *et. al.* (2018) in Linseed. Primary branches per plant also had a positive significant relationship with secondary branches per plant, number of capsules per plant, diameter of head, number of seeds per capsule, 100 seed weight, hull content and oil content, according to genotypic correlation analysis. These findings are consistent with the findings of Dogra *et. al.* (2020) in Linseed, Dhage *et. al.* (2020) in Safflower, Leelavati *et. al.* (2018) in Linseed, Patil *et. al.* (2018) in Sesame, Bhakre *et. al.* (2015) in Safflower and Arslan (2007) in Safflower.

6) Secondary branches per plant

The genotypic correlation coefficient analysis revealed that primary branches per plant exhibited significant and positive correlation with seed yield per plant was recorded at all the mutagenic treatments except 300 Gy + 0.1% EMS dose of combination treatments. At the genotypic level, correlation coefficient analysis revealed a significant and positive relationship between secondary branches per plant and trait no. of capsule per plant at all mutagenic treatments except300 Gy + 0.1% EMS dose of combination treatments, diameter of head at 200 Gy, 300 Gy, 400 Gy,

0.2% EMS, 0.3% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, no. of seeds per capsule at 200 Gy, 300 Gy, 400 Gy, 0.2% EMS, 0.3% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, 100 seed weight at 400 Gy, 0.2% EMS, 200 Gy+ 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments, hull content at 200 Gy, 0.1% EMS, 0.3% EMS and 300 Gy + 0.2% EMS dose of combination treatments, oil content at 400 Gy, 200 Gy +0.1% EMS and 300 Gy + 0.1% EMS dose of combination treatments. Similarly, correlation coefficient analysis showed significant and negative association at the genotypic level between secondary branches per plant and trait no. of capsule per plant at 300 Gy + 0.1% EMS dose of combination treatment, diameter of head at 0.1% EMS and 300 Gy + 0.1% EMS dose of combination treatments, no of seed per capsule at 300 Gy + 0.1% EMS dose of combination treatments, 100 seed weight at 300 Gy, 0.1% EMS and 0.3% EMS concentration treatments, hull content at 100 Gy, 0.2% EMS, 200 Gy+ 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatments and oil content at 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments.In current study, genotypic correlation analysis demonstrated a positive relation between secondary branches per plant and seed yield per plant.These finding are broad agreement with the findings of Dhage *et. al.* (2020) in Safflower, Dogra *et. al.* (2020) in Linseed, Khattab *et. al.* (2018) in Safflower and Leelavati *et. al.* (2018) in Linseed. Correlation analysis revealed that secondary branches per plant had a positive and substantial relationship with other parameters such as the number of capsules per plant, head diameter, number of seeds per capsule, 100 seed weight, hull content, and oil content at the genotypic level. These findings are in accordance with the finding of Dogra *et. al.* (2020) in Linseed, Dhage *et. al.* (2020) in Safflower, Leelavati *et. al.*(2018) in Linseed.

7) Number of capsule per plant

At all mutagenic treatments except the 0.1 % EMS concentration treatments, the genotypic correlation coefficient study revealed that the number of capsules per plant had a substantial and positive association with seed yield per plant.At the genotypic level, correlation coefficient study revealed a significant and positive relationship between the number of capsules per plant and the trait diameter of the headat 300 Gy, 0.2% EMS, 0.3% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2%

EMS dose of combination treatments, no. of seeds per capsule at 300 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 0.3% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, 100 seed weight at 200 Gy, 400 Gy, 0.2% EMS, 0.4% EMS, 200 Gy+ 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatments, hull content at 0.3% EMS concentration treatments, oil content at 400 Gy, 200 Gy +0.1% EMS and 300 Gy + 0.1% EMS dose of combination treatments. Similarly, correlation coefficient study revealed significant and negative association between the number of capsules per plant and trait diameter of head at 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments, 100 seed weight at 0.1% EMS, 0.3% EMS and 300 Gy + 0.2% EMS dose of combination treatments, hull content at 100 Gy, 0.2% EMS, 0.4% EMS, 200 Gy+ 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments and oil content at 200 Gy, 0.1% EMS, 0.2% EMS, 0.3% EMS and 300 Gy + 0.2% EMS dose of combination treatments.According to genotypic correlation analysis, the number of capsules per plant had a positive significant relationship with seed yield per plant in the current study. These finding are consistent with the findings of Bahmankar *et. al.*(2014) in Safflower, Khattab *et. al.* (2018) in Safflower, Dhage *et. al.* (2020) in Safflower, Patter *et. al.* (2020) in Safflower, Minnie *et. al.* (2020) in Safflower and pavithra *et. al.* (2016) in Safflower. A correlational study revealed that the number of capsules per plant had a positive and significant relationship with other parameters such as head diameter, number of seeds per capsule, 100 seed weight, hull content and oil content at the genotypic level. These findings are in the confirmity with the finding of Minnie *et. al.*(2020) in Safflower, Shivani *et. al.* (2011) in Safflower, Bidgoli *et. al.* (2006) in Safflower and Pavithra *et. al.* (2016) in Safflower.

Table 4.36 : Effect of mutagens on genotypic coefficient of correlation in M_2 generation

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Plant height (cm)	100 Gy	-0.2354	0.8340**	0.4489**	0.1008	0.4220**	0.0540	0.1200	0.1367	-0.3495*	0.8652**	-0.6829**	0.6067**
	200 Gy	0.3816**	-0.1659	-0.0747	-0.0222	-0.0122	-0.2231	-0.0250	-0.0871	-0.0431	-0.1568	-0.0383	-0.0111
	300 Gy	0.5216**	0.0136	0.4132**	0.3096*	0.2966*	0.0635	-0.3922**	-0.4545**	0.0416	-0.0655	0.3824**	-0.2970*
	400 Gy	-0.4907**	-0.1813	-0.1937	-0.6163**	0.0636	0.0335	0.1722	0.0751	-0.2405	0.3370*	-0.2531	0.1645
	0.1% EMS	-0.1042	-0.1359	0.1772	0.1978	-0.2974**	0.1196	-1.9011	0.3685**	0.7619**	-0.7463**	-0.0333	0.1851
	0.2 % EMS	0.2147	0.9959**	0.5231**	0.3087*	0.2155	0.3399*	0.1196	0.0059	0.0419	-0.3219*	-0.6536**	0.4541**
	0.3% EMS	0.3010*	0.1997	1.0860	0.3952**	0.2492	0.0507	0.1598	0.3063*	0.3457*	0.1772	0.5744**	-0.0026
	0.4% EMS	-0.1651	-0.3894**	-0.0456	1.1613	0.8398**	0.7688**	0.3783**	-0.1090	0.2140	0.1630	0.0997	0.0175
	200Gy+0.1 % EMS	-0.0024	-0.3560*	-0.0775	-0.2156	-0.3456*	-0.1165	0.2042	0.1123	0.4546**	0.1709	0.3565*	0.0781
	200 Gy + 0.2% EMS	-0.4646**	-0.4659**	0.8631**	-0.1210	0.1766	-0.1481	0.1202	-0.0790	-0.3288*	-0.5608**	-0.6058**	0.2851*
	300 Gy + 0.1% EMS	-0.5185**	-0.3372*	-0.0389	-0.0880	0.2754*	0.0288	0.1603	0.1334	0.0029	0.5491**	-0.6804**	0.2260
	300 Gy +0.2% EMS	0.7530**	-0.3615**	-0.0863	0.3298*	0.0987	0.6138**	0.7607**	0.8449**	0.3015*	-0.5514**	0.1606	0.5702**
	Dry control	-0.5349**	-0.1521	0.5830**	-0.3579**	-0.0634	-0.1859	0.1091	0.1354	0.8346**	-0.2465	-0.7340**	-0.0584
	Wet control	-0.5524**	0.4376**	0.3822**	-0.3243*	-0.3217*	-0.5585**	0.0923	0.0508	1.9063	0.4441**	-0.7897**	-0.4821**

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Days to rosette (Days)	100 Gy		0.3263*	-0.1201	-0.1134	0.3738**	0.4049**	-0.0921	0.4594**	-0.1580	-0.7721**	-0.5505**	0.1396
	200 Gy		-0.5113**	-0.3928**	0.1746	0.2577*	0.0061	0.2473	-0.1910	-0.2779*	0.3238*	0.1107	0.2274
	300 Gy		0.2538	-0.0851	0.3964**	0.0688	-0.0516	-0.0698	-0.0978	0.2495	0.4031**	-0.5071**	-0.1475
	400 Gy		-0.4077**	-0.0615	0.1943	0.0525	0.3286*	-0.7195**	-0.9041**	-0.3082*	-0.4815**	0.3103*	-0.4152**
	0.1% EMS		0.0400	0.5667**	-0.1000	-0.1327	-0.2824*	1.3546*	0.4597**	0.5651**	-0.0440	-0.2733*	0.2303
	0.2 % EMS		-0.4549**	1.0615	-0.2849*	-0.1760	-0.1992	-0.1764	-0.4200**	0.7384**	0.2278	0.4197**	-0.1762
	0.3% EMS		-0.0248	0.5313**	0.6354**	0.4433**	0.4117**	-0.3854**	-0.7167**	-0.0414	0.1963	0.2979*	0.2362
	0.4% EMS		-0.2946*	0.7902**	0.2869*	-0.0945	0.0661	-0.5368**	-0.5551**	0.7149**	0.3733**	0.0329	-0.4598**
	200 Gy+0.1% EMS		0.1408	0.2719*	-0.1336	-0.0944	-0.2017	-0.1852	-0.2869*	-0.2746*	-0.0997	-0.6493**	-0.4279**
	200 Gy + 0.2% EMS		-0.1077	-0.4256**	0.2411	-0.1928	0.0137	0.6310**	0.2474	-0.0461	-0.3079*	-0.0570	0.1078
	300 Gy + 0.1% EMS		-0.3001*	0.1110	-0.4062**	-0.0031	-0.3433**	0.3470*	0.2648*	0.0604	0.1702	-0.1693	0.0489
	300 Gy +0.2% EMS		0.6678**	0.2578*	0.7324**	0.4277**	-0.1005	-0.2578*	-0.3221*	-0.4829**	0.5794	-0.5371	-0.4651**
	Dry control		-0.5851**	-0.4879**	0.3817**	0.3634**	-0.1618	0.8709**	0.0341	0.1790	0.0938	0.5019	0.6569**
	Wet control		-0.0758	-0.6834**	0.5545**	0.1074	0.3211*	-0.4714**	-0.1538	-1.6133**	-0.1072	0.8862	0.6067**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Days to 50% flowering (Days)	100 Gy			0.9490**	-0.9425**	0.3818**	0.4338**	-0.6820**	-0.8289**	-0.1819	0.0252	-0.0060	-0.0271
	200 Gy			0.0647	0.1917	-0.0663	0.0127	0.1245	0.0281	0.0938	0.6647**	0.0836	0.2684*
	300 Gy			0.0792	-0.4656**	-0.5221**	-0.7415**	-0.5746**	-0.4423**	-0.0390	0.0294	-0.6279**	-0.6257**
	400 Gy			0.4096**	-0.3486*	-0.4572**	-0.2965*	-0.1332	-0.1850	-0.7866**	0.1029	-0.1660	-0.4987**
	0.1% EMS			0.9008**	-0.4425**	0.0075	0.2368	0.3954**	-0.2647*	-0.5465**	0.0181	0.1104	-0.0788
	0.2 % EMS			-0.0161	0.2251	0.6991**	0.4330**	0.2983*	0.4519**	0.3931**	-0.1737	-0.5954**	0.4789**
	0.3% EMS			-0.2950*	0.0814	-0.3915**	-0.1365	-0.3361*	-0.5345**	0.4423**	-0.2877*	0.0390	-0.3639**
	0.4% EMS			0.0287	-0.3570*	-0.2672*	-0.0365	-0.3261*	-0.0469	-0.0752	0.9655**	0.2001	0.2581*
	200Gy+0.1 % EMS			0.2249	-0.7811**	-0.7557**	-0.9691**	-0.5350**	-0.8702**	0.0930	0.0297	-0.0285	-0.7036**
	200 Gy + 0.2% EMS			-0.1512	-0.8050**	-0.3706**	-0.0074	-0.5286**	-0.4300**	0.2637*	0.4091**	-0.0442	-0.4308**
	300 Gy + 0.1% EMS			-0.8335**	0.1499	0.3638**	0.2106	0.1044	0.1024	-0.0505	-0.5831**	-0.1596	-0.6410**
	300Gy+0.2 % EMS			0.4905**	-0.1068	-0.1120	-0.7131**	-0.7088**	-0.9265**	0.7282**	1.1018	0.4973**	-0.8962**
	Dry control			0.7497**	0.6124**	0.6129**	0.2508	0.2467	0.1739	-0.4469**	0.4644**	-0.0731	0.2169
	Wet control			0.5708**	-1.0023	-0.6076**	-0.4235**	-0.0344	-0.6614**	-0.6019**	0.5749**	-0.3293*	-0.7863**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Days to maturity (Days)	100 Gy				-0.6142**	-0.4503**	-0.2726*	-0.4553**	-0.6352**	-0.1951	0.3091*	-0.4855**	-0.5476**
	200 Gy				-0.6545**	-0.6655**	-0.4382**	-0.2884*	-0.0001	-0.5997**	0.0205	0.3701**	-0.6246**
	300 Gy				-0.3030*	-0.4594**	-0.4288**	-0.4655**	-0.6482**	0.2737*	-0.1849	0.0790	-0.3617**
	400 Gy				-0.4459**	-0.5214**	-0.7533**	-0.3809**	-0.2450	-0.8162**	0.2749*	-0.2518	-0.4502**
	0.1% EMS				-0.8426**	0.3043*	-0.4669**	-1.3879**	-0.1373	-0.0118	-0.3719**	-0.0993	0.4287**
	0.2 % EMS				-0.5825**	-0.3113*	-0.2547*	-0.4002**	-0.6111**	0.3721**	-0.1017	0.1730	0.4789**
	0.3% EMS				0.0191	0.0140	0.1644	0.4221**	0.3283	1.0048	-0.3512*	0.7029**	0.2339
	0.4% EMS				-0.1061	-0.5143**	0.0110	-0.9420**	-0.6420**	0.0009	0.2029	0.0258	-0.0716
	200 Gy+0.1% EMS				-0.6048**	-0.5751**	-0.8014**	-0.7979**	-0.8531**	-1.0991	-0.1942	-0.8440**	-0.8938**
	200 Gy + 0.2% EMS				-0.5333**	-0.1880	-0.1180	-0.7942**	-0.3563*	0.0886	0.2987*	-0.2753*	0.1422
	300 Gy + 0.1% EMS				0.0801	-0.5411**	-0.2692*	0.0600	0.6602**	-0.3580**	-0.5266**	0.2861*	0.3524*
	300 Gy +0.2% EMS				0.3227	-0.1657	-0.4835**	-0.3284*	-0.2944*	-0.2228	0.3243*	0.2422	-0.2333
	Dry control				0.4610**	1.0633**	0.8250**	0.1175	-0.1956	-0.3270*	0.6608**	-0.6181**	0.2596*
	Wet control				-0.8253**	-0.8063**	-0.8383**	0.3845**	0.0493	0.1184	-0.2102	-0.7309**	-0.5829**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
No. of Primary branches per plant	100 Gy					0.8194**	0.7776**	0.4667**	0.6820**	0.2468	0.0324	-0.1595	0.9949**
	200 Gy					0.8735**	0.6247**	0.4374**	0.6305**	0.4280**	-0.1113	0.0314	0.5717**
	300 Gy					0.9796**	0.9958**	0.6106**	0.6398**	-0.2082	0.1138	0.0015	0.8194**
	400 Gy					0.3054*	-0.2537	-0.5028**	-0.4385**	0.1625	-0.2146	0.0524	-0.2696*
	0.1% EMS					0.9028**	0.9776**	-1.0929**	0.1896	-0.0593	0.0085	-0.4161**	0.0989
	0.2 % EMS					1.1413	1.0049**	0.5180**	0.6946**	0.6955**	-0.5053**	-0.3771**	0.9739**
	0.3% EMS					0.4387**	0.5122**	0.9727**	0.8881**	-0.5298**	0.7710**	0.1502	0.5955**
	0.4% EMS					1.0274**	1.1250**	0.0533	-0.1589	0.6066**	-0.1234	-0.0791	0.5902**
	200 Gy+0.1% EMS					0.9697**	1.0515**	0.6827**	0.8040**	0.6249**	0.2615*	0.4859**	0.7909**
	200 Gy + 0.2% EMS					0.9293**	0.3590**	0.3184*	0.2408	0.5096**	-0.4071**	0.0755	0.5155**
	300 Gy + 0.1% EMS					-0.1606	0.8811**	-0.2917*	-0.2484	1.0235**	0.1163	0.7001**	0.4941**
	300 Gy +0.2% EMS					0.9180**	-0.2347	0.1390	0.0734	-0.5684**	0.4174**	-0.1362	0.2225
	Dry control					0.8299**	0.1520	0.5034**	0.0698	-0.7495**	0.5216**	0.1550	0.0841
	Wet control					0.5055**	0.8004**	-0.1586	-0.2039	-0.9205**	0.3509*	0.8413**	0.3516*

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
No. of secondary branches per plant	100 Gy						0.9985**	-0.2323	-0.0362	-0.0958	-0.5455**	0.0989	0.6405**
	200 Gy						0.7553**	0.4625**	0.5868**	-0.0527	0.3250*	0.0424	0.4627**
	300 Gy						0.9698**	0.5573**	0.5863**	-0.3623**	-0.0179	-0.1166	0.7412**
	400 Gy						1.1431**	0.3081*	0.3903**	0.8172**	0.0426	0.4299**	0.7402**
	0.1% EMS						0.8825**	-1.5679**	0.2019	-0.4001**	0.3725**	0.1764	0.5873**
	0.2 % EMS						0.9889**	0.6648**	0.7533**	0.7488**	-0.7624**	-0.2970*	0.6700**
	0.3% EMS						1.1387**	0.5781**	0.9651**	-0.6558**	0.6845**	-0.1778	1.0809**
	0.4% EMS						0.8205**	0.1302	0.0140	0.0303	-0.0060	-0.0226	0.4939**
	200 Gy+0.1% EMS						0.9467**	0.5351**	0.7280**	0.4358**	0.1391	0.2676*	0.7894**
	200 Gy + 0.2% EMS						0.8033**	-0.1493	0.0207	0.3995**	-0.3704**	0.0426	0.7394**
	300 Gy + 0.1% EMS						-0.3737**	-0.7556**	-0.7536**	0.1777	-0.2897*	0.5165**	-0.5156**
	300 Gy +0.2% EMS						0.3148*	0.3874**	0.4811**	0.0652	0.4058**	-0.3065*	0.8563**
	Dry control						0.8896**	0.3810**	-0.1482	-0.4737**	0.1200	0.0664	0.4458**
	Wet control						1.0015**	0.4311**	0.1670	-0.7011**	-0.0630	1.1012**	0.8511**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
No. of capsule per plant	100 Gy							-0.2454	-0.0179	-0.0918	-0.7964**	0.1653	0.5202**
	200 Gy							-0.2260	0.0962	0.4346**	-0.1965	-0.3679**	0.6157**
	300 Gy							0.7367**	0.7234**	0.1170	-0.0668	0.0201	0.9371**
	400 Gy							0.1976	0.4880**	0.8159**	0.1903	0.7068**	0.9630**
	0.1% EMS							-1.6725**	0.3107*	-0.2937*	0.1831	-0.4274**	0.0467
	0.2 % EMS							0.6826**	0.6930**	0.4713**	-0.7219**	-0.2717*	0.7151**
	0.3% EMS							1.0239**	1.2395**	-0.7006**	0.9243**	-0.2759*	1.1081**
	0.4% EMS							0.2119	0.1404	0.5218**	-0.3196*	-0.1263	0.5136**
	200 Gy+0.1% EMS							0.9066**	0.8999**	0.5737**	0.0843	0.7171**	0.8104**
	200 Gy + 0.2% EMS							-0.5263**	-0.1994	0.5774**	-0.6615**	0.1141	0.5842**
	300 Gy + 0.1% EMS							-0.0744	0.0644	1.0034**	-0.0446	0.4394**	0.3189*
	300 Gy +0.2% EMS							0.7677**	0.9227**	-0.7167**	-0.8569**	-0.3276*	0.6795**
	Dry control							-0.2386	-0.6087**	-0.4086**	0.0875	0.9883**	0.4217**
	Wet control							-0.0034	-0.3627**	-1.5699**	0.2405	1.0452**	0.4850**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Diameter of head (cm)	100 Gy								0.8090**	0.4391**	-0.2078	0.2008	0.5793**
	200 Gy								0.9887**	-0.0176	0.4777**	0.4346**	0.6957**
	300 Gy								1.0274**	-0.0779	0.2284	-0.1558	0.9144**
	400 Gy								0.9090**	1.0633**	0.1055	-0.2498	0.8166**
	0.1% EMS								1.1500**	-0.2814*	1.3886**	-1.2867*	-0.0301
	0.2 % EMS								0.9191**	0.1349	-0.2826*	-0.1478	0.5463**
	0.3% EMS								0.8244**	-0.0728	0.9228**	-0.0771	0.7766**
	0.4% EMS								0.9806**	-0.0124	-0.2396	0.0979	0.1904
	200 Gy+0.1% EMS								1.1268**	0.9413**	-0.0478	0.9648**	0.9687**
	200 Gy + 0.2% EMS								1.0975**	-0.1988	-0.3524*	0.2032	0.0909
	300 Gy + 0.1% EMS								1.0956**	0.3437*	-0.6286**	-0.0474	0.1546
	300 Gy +0.2% EMS								1.1021**	-0.7379**	-0.7608**	-0.4894**	0.9137**
	Dry control								0.9889**	-0.3617**	-0.1126	-0.2538	1.0269**
	Wet control								0.8590**	1.2232**	0.1250	-0.1206	0.5717**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
No. of seed per capsule	100 Gy									0.1693	-0.3670**	-0.1413	0.5793**
	200 Gy									-0.4342**	0.9287**	0.4330**	0.5923**
	300 Gy									-0.0969	0.1549	-0.1299	0.6151**
	400 Gy									0.9847**	0.0787	-0.2148	0.9662**
	0.1% EMS									0.5050**	0.2122	-0.2981*	0.8487**
	0.2 % EMS									-0.1063	-0.1064	0.0711	0.6530**
	0.3% EMS									-0.6776**	0.9771**	-0.5401**	0.6895**
	0.4% EMS									-0.0102	-0.3537*	0.0739	0.9581**
	200Gy+0.1 % EMS									0.7377**	0.0293	0.6617**	0.4724**
	200 Gy + 0.2% EMS									0.1734	-0.1168	-0.3316*	0.9977**
	300 Gy + 0.1% EMS									-0.2315	-0.8819**	0.0070	0.1702
	300 Gy +0.2% EMS									-0.7666**	-0.7843**	-0.7243**	0.4169**
	Dry control									-0.1283	-0.7369**	-0.4761**	0.9412**
	Wet control									1.0840**	0.0881	0.1055	0.7241**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
100 seed weight (g)	100 Gy										-0.1465	0.4966**	0.3453*
	200 Gy										0.0485	-0.6061**	0.6452**
	300 Gy										0.0230	0.2568*	0.1869
	400 Gy										-0.1176	0.3420*	1.0556**
	0.1% EMS										0.3236*	-0.4902**	0.1614
	0.2 % EMS										-0.6646**	-0.1659	0.4071**
	0.3% EMS										-0.1925	0.7556**	-0.4451**
	0.4% EMS										0.3539*	-0.5802**	0.1499
	200 Gy+0.1% EMS										-0.3314*	1.1249**	0.8504**
	200 Gy + 0.2% EMS										-0.4603**	-0.4545**	0.5303**
	300 Gy + 0.1% EMS										0.5216**	0.3056*	0.5193**
	300 Gy +0.2% EMS										0.2723*	0.7285**	-0.7135**
	Dry control										-1.4019**	0.0600	-0.0853
	Wet control										-0.8156**	-2.4220**	0.8581**

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Hull content (%)	100 Gy											-0.3375*	-0.5528**
	200 Gy											0.6843**	0.6489**
	300 Gy											-0.5134**	0.0461
	400 Gy											-0.1334	0.2968*
	0.1% EMS											-0.1230	-0.1170
	0.2 % EMS											-0.1338	-0.3362*
	0.3% EMS											-0.4030**	0.7327**
	0.4% EMS											0.0554	0.0556
	200 Gy+0.1% EMS											0.3688**	-0.1821
	200 Gy + 0.2% EMS											-0.3701**	-0.1747
	300 Gy + 0.1% EMS											-0.1329	-0.1171
	300 Gy +0.2% EMS											-0.1014	-0.4281**
	Dry control											-0.1261	-0.5360**
	Wet control											0.1131	-0.0691

Continue

Character	Treatment	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)
Oil content (%)	100 Gy												0.3379*
	200 Gy												-0.0685
	300 Gy												-0.0186
	400 Gy												0.1756
	0.1% EMS												-0.2193
	0.2 % EMS												-0.5664**
	0.3% EMS												-0.1779
	0.4% EMS												-0.3010*
	200 Gy+0.1% EMS												0.7618**
	200 Gy + 0.2% EMS												-0.3602**
	300 Gy + 0.1% EMS												0.8783**
	300 Gy +0.2% EMS												-0.2409
	Dry control												0.1261
	Wet control												0.5991**

8) Diameter of head (cm)

The genotypic correlation coefficient study demonstrated that all mutagenic treatments except 0.1% EMS, 0.4% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatments had a significant and positive correlation with seed yield per plant.At the genotypic level, correlation coefficient analysis showed significant and positive association between diameter of head and trait no. of seeds per capsule at all mutagenic treatments, 100 seed weight at 100 Gy, 400 Gy, 200 Gy+ 0.1% EMSand 300 Gy + 0.1% EMS dose of combination treatments, hull content at 200 Gy and 0.3% EMS concentration treatments, oil content at 200 Gy and 200 Gy +0.1% EMS dose of combination treatments. Similarly, correlation coefficient analysis demonstrated significant and negative association at genotypic level between diameter of head and trait 100 seed weight at 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, hull content at 0.2% EMS, 200 Gy+ 0.2% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments and oil content at 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments.According to genotypic correlation analysis, the diameter of the head had a positive significant relationship with seed yield per plant in the current study. These finding are broad agreement with the findings of Bidgoli *et. al.* (2006) in Safflower, Arslan (2007) in Safflower and Bahmankar *et. al.* (2014) in Safflower. Also at genotypic level, correlation analysis showed that diameter of head demonstrated positive and significant association with other traits *viz.,* no. seeds per capsule, 100 seed weight, hull content and oil content. These findings are in accordance with the finding of Bidgoli *et. al.* (2006) in Safflower, Arslan (2007) in Safflower, Bahmankar *et. al.* (2014) in Safflower and Pavithra *et. al.* (2016) in Safflower.

9) Number of seed per capsule

At all of the mutagenic treatments except 300 Gy + 0.1 % EMS dose of combination treatments, the genotypic correlation coefficient analysis revealed that the number of seeds per capsule demonstrated a substantial and positive correlation with seed yield per plant.At genotypic level, correlation coefficient study showed significant and positive relationship between no. of seed per capsule and trait 100 seed weight at 400 Gy, 0.1% EMS and 200 Gy+ 0.1% EMS dose of combination treatments, hull content at 200 Gy and 0.3% EMS concentration treatments, oil

content at 200 Gy and 200 Gy +0.1% EMS dose of combination treatments. Similarly, correlation coefficient analysis showed significant and negative association at genotypic level between no. of seed per capsule and trait 100 seed weight at 200 Gy, 0.3% EMS and 300 Gy + 0.2% EMS dose of combination treatments, hull content at 200 Gy, 0.4% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments and oil content at 0.1% EMS, 0.3% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.2% EMS dose of combination treatments.In the current study, the number of seeds per capsule had a positive and substantial relationship with seed yield per plant, according to genotypic correlation coefficient analysis.These findings are broad agreement with the finding of Arslan (2007) in Safflower, Pavithra *et. al.* (2016), Pushpavalli *et. al.* (2017) in Safflower, Dhage *et. al.* (2020) and Minnie *et. al.* (2020) in Safflower. Correlation analysis revealed that the number of seeds per capsule had a positive and substantial relationship with other attributes such as 100 seed weight, hull content and oil content at the genotypic level. These findings are in accordance with the finding of Minnie *et. al.*(2020) in safflower and Shivani *et. al.* (2011) in Safflower.Similarly, a genotypic correlation study revealed a negative significant relationship between the number of seeds per capsule and features such as 100 seed weight, hull content and oil content.These finding are in the confirmity with the findings of Arslan *et. al.* (2007) in Safflower and Pushpavalli *et. al.* (2017) in Safflower.

10) 100 seed weight (g)

The genotypic correlation coefficient analysis revealed that 100 seed weight demonstrated significant and positive correlation with seed yield per plant at 100 Gy, 200 Gy, 400 Gy, 0.2% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatments. At the genotypic level, correlation coefficient analysis revealed a significant and positive relationship between 100 seed weight and trait hull content at 0.1% EMS, 0.4% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments, oil content at 100 Gy, 300 Gy, 400 Gy, 0.3% EMS, 200 Gy +0.1% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% EMS dose of combination treatments. Similarly, correlation coefficient analysis showed significant and negative association at genotypic level between 100 seed weight and trait hull content at 0.2% EMS, 200 Gy + 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments and oil content at 200 Gy, 0.1% EMS, 0.4% EMS and 200

Gy + 0.2% EMS dose of combination treatments.The genotypic correlation coefficient analysis revealed that 100 seed weight had a positive and significant relationship with seed yield per plant in the current study.These findings are consistent with the finding of Bidgoli *et. al.*(2006) in Safflower, Pavithra *et. al.* (2016) in Safflower, Pushpavalli *et. al.* (2017) in Safflower, Dhage *et. al.* (2020) in Safflower and Minnie *et. al.* (2020) in Safflower. Correlation analysis revealed that 100 seed weight had a positive and significant relationship with characteristics such as hull content and oil content at the genotypic level. These findings are broad agreement with the finding of Minnie *et. al.* (2020) in Safflower, Pattar *et. al.* (2020) in Safflower and Bhakre *et. al.* (2015) in Safflower. Similarly, correlation coefficient analysis revealed a substantial and negative connection between 100 seed weight and attributes such as hull content and oil content at the genotypic level. These findings are in the confirmity with the finding of Pavithra *et. al.* (2016) in Safflower and Dhage *et. al.* (2020) in Safflower.

11) Hull content

The genotypic correlation coefficient analysis revealed that hull content exhibited significant and positive correlation with seed yield per plant at 200 Gy, 400 Gy and 0.3% EMS concentration treatments. At genotypic level, correlation coefficient analysis showed significant and positive association between hull content and trait oil content at 200 Gy and 200 Gy +0.1% EMS dose of combination treatments. Similarly, correlation coefficient analysis showed a significant and negative relationship exist between hull content weight and trait oil content at 100 Gy, 300 Gy, 0.3% EMS and 200 Gy + 0.2% EMS dose of combination treatments at the genotypic level.In the current study, genotypic correlation analysis revealed a positive significant relationship between hull content and traits such as seed yield per plant and oil content. These findings are controversy with the finding of Pavithra *et. al.*(2016) in Safflower and Patter *et. al.*(2020) in Safflower.

12) Oil content

The genotypic correlation coefficient analysis revealed that oil content demonstrated significant and positive correlation with seed yield per plant was recorded at 100 Gy, 200 Gy + 0.1% EMS, and 300 Gy + 0.1% EMS dose of combination treatments. Similarly, genotypic correlation analysis showed that oil content had apositive non significant association with seed yield per plant at 400 Gy

dose of gamma rays treatment.In the current study, oil content had a positive significant relationship with seed yield per plant, according to genotypic correlation analysis. These findings are in accordance with the finding of Topal *et. al.*(2010) in safflower. Similarly, correlation analysis at the genotypic level revealed that oil content had a positive but non-significant relationship with seed yield per plant.These findings are consistent with the finding of Bhakre *et. al.* (2015) in Safflower, Pavithra *et. al.* (2016) in Safflower, Shivani *et. al.* (2011) in Safflower and Minnie *et. al.* (2020) in Safflower.

4.2.6 Path coefficient analysis studies in M_2 generation.

Seed yield is a complex trait that is determined by the interaction of several yield contributing variables. Although the relationship between yield and yield contributing characters might be either negative or positive, it is critical to understand the overall outcome of the direct effect of that feature and indirect effects via other traits. Plant breeders have employed path analysis to aid in the identification of relevant features during selection. As a result, path coefficients must be determined, which split the observed correlation into direct and indirect effects and disclose the cause-and-effect relationship between yields and related attributes.

4.2.6.1 Phenotypic path coefficient analysis

The phenotypic correlation coefficients were divided into direct and indirect effects using phenotypic path coefficient analysis. The following Table 4.37 shows the direct and indirect effects of component attributes on seed yield in M_2 populations of the safflower variety PBNS-12.

1) Plant height (cm)

The phenotypic path coefficients indicated high positive direct effect of plant height on seed yield per plant was recorded at 200 Gy, 0.1% EMS, 0.4% EMS, 300 Gy + 0.1% EMS and 300 Gy + 0.2% dose of combination treatments.The indirect effect of plant height on seed yield per plant *via.* days to rosette, primary branches per plant, secondary branches per plant and 100 seed weight.Plant height had a positive correlation and direct effect on seed yield per plant in the current study. This suggests that increasing the plant height can enhance seed yield. Similar results were recordedby Pavithra *et. al.* (2016) in Safflower, Arslan *et. al.* (2007) in Safflower,

Bahmankar *et. al.* (2014) in Safflower, Bhakre *et. al. (*2015) in Safflower and Shivani *et. al.* (2011) in Safflower.

2) Days to rosette stage

The phenotypic path coefficients indicated high negative direct effect of days to rosette on seed yield per plantat 100 Gy, 200 Gy, 300 Gy,0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatments. The phenotypic path coefficients indicated high positive direct effect of day to rosette on seed yield per plant was recorded at 400 Gy, 0.1% EMS, 0.2% EMS, 0.3% EMS and 300 Gy + 0.2% EMS dose of combination treatments. Days to rosette stage, days to 50% flowering, days to maturity, diameter of head, 100 seed weight and hull content have an indirect effect on seed yield per plant.Days to rosette period had a negative association and a positive direct influence on seed yield per plant in the current study. This suggests that decreasing the days to the rosette period can enhance seed yield. These findings are in accordance with the findings of Pavithra *et. al.*(2016) in Safflower, Sarang *et. al.*(2004) in Safflower, Mathur *et. al.* (1976) and Mozaffari and Asadi (2006) in Safflower.

3) Days to 50% Flowering

The phenotypic path coefficients showed high negative direct impact of days to 50% flowering on seed yield per plant was recorded at 400 Gy, 0.1% EMS, 0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS, 300 Gy + 0.1% and 300 Gy+ 0.2% EMS dose of combination treatments. Similarly positive direct effect of days to 50% flowering on seed yield per plant was recorded at 100 Gy, 200 Gy, 300 Gy, 0.2% EMS and 0.3% EMS concentration treatments. Days to 50% flowering, days to maturity, hull content and oil content have an indirect effect on seed yield per plant. In the current study, days to 50% flowering had a negative direct effect on seed yield per plant.The findings are similar with results of Shivani *et. al.* (2011) in Safflower and Minnie *et. al.*(2020) in Safflower. Days to 50% flowering, on the other hand, showed a negative correlation and a positive direct influence on seed yield per plant. This suggests that by shortening days to 50% flowering, seed yield might be increased. These findings are similar with results of Pavithra *et. al.* (2016) in Safflower, Sarang *et. al.*(2004) in Safflower, Thombre and Joshi (1981) in Safflower and Mozaffari and Asadi (2006) in Safflower.

4) Days to maturity

The phenotypic path coefficients suggested a high negative direct influence of days to maturity on seed yield per plant was recorded at 400 Gy, 0.1% EMS, 0.4% EMS, 200 Gy + 0.1% EMS, 200 Gy + 0.2% EMS, 300 Gy + 0.1% and 300 Gy+ 0.2% EMS dose of combination treatments. Similarly positive direct effect of days to maturity on seed yield per plant was recorded at 100 Gy, 200 Gy, 300 Gy, 0.2% EMS and 0.3% EMS concentration treatments.Plant height, days to rosette stage, days to 50% flowering, primary branches per plant, secondary branches per plant, number of capsules per plant, number of seeds per capsule and hull content have an indirect effect on seed yield per plant. In current study, days to maturity had a negative direct effect on seed yield per plant. Similar types of results were found by Pavithra *et. al.* (2016) in Safflower and Leelavathi *et. al.* (2018) in Linseed.Days to maturity, on the other hand, showed a negative association and a positive direct influence on seed yield per plant. This suggests that reducing the days to maturity shortens the time it takes for seeds to mature.These results are consistent with the results of Sarang *et. al.*(2004) in Safflower, Thombre and Joshi (1981) in Safflower, Mathur *et. al.* (1976) in Safflower and Mozaffari and Asadi (2006) in Safflower.

5) Primary branches per plant

According to phenotypic path coefficients, high positive direct effect of number of primary branches per plant on seed yield per plant was recorded at 200 Gy, 300 Gy, 0.2% EMS, 0.3% EMS, 200 Gy + 0.1% EMS and 300 Gy+ 0.2% EMS dose of combination treatments. Number of primary branches per plant through days to 50 % flowering, secondary branches per plant, number of capsule per plant, diameter of head, number of seed per capsule and 100 seed weight have an indirect impact on seed yield per plant. In the current investigation, the number of primary branches per plant had a positive association and direct effect on seed yield per plant. This indicates that increasing the number of primary branches per plant can improve seed yield. These findings are broad agreement with the findings of Leelavathi *et. al.*(2018) in Linseed, Patil *et. al.*(2018) in Sesame and Bhakre *et. al.*(2015) in Safflower.

Table 4.37: Effect of mutagens on phenotypic path coefficient in M_2 generation

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Plant height (cm)	100 Gy	**0.0858**	-0.0052	0.0295	0.0312	-0.0102	-0.0022	-0.0102	-0.0118	-0.0050	-0.0278	0.0089	-0.0148	-0.0859	-0.0074
	200 Gy	**-0.1039**	-0.0197	-0.0046	0.0021	0.0084	0.0126	0.0174	0.0050	0.0135	0.0114	-0.0031	-0.0088	-0.2282	0.0237
	300 Gy	**0.0553**	0.0144	0.0032	0.0167	-0.0133	-0.0119	-0.0121	-0.0188	-0.0176	-0.0001	-0.0061	0.0039	-0.3034	-0.0168
	400 Gy	**0.1574**	-0.0325	0.0181	0.0103	-0.0631	-0.0104	-0.0229	-0.0265	-0.0268	-0.0090	0.0242	-0.0217	-0.0227	-0.0036
	0.1% EMS	**-0.1545**	-0.0338	0.0117	-0.0259	0.0447	0.0496	0.0031	0.0004	0.0266	-0.0093	0.0378	0.0083	-0.1617	0.0250
	0.2 % EMS	**0.0837**	-0.0003	0.0291	0.0052	-0.0033	0.0087	0.0151	0.0063	-0.0034	0.0034	0.0066	-0.0133	0.2078	0.0174
	0.3% EMS	**0.0220**	0.0018	0.0007	0.0088	0.0029	0.0022	0.0008	0.0031	0.0029	-0.0007	-0.0029	0.0026	-0.0266	-0.0006
	0.4% EMS	**-0.0034**	-0.0001	-0.0001	-0.0002	-0.0002	-0.0004	-0.0001	0.0000	0.0001	-0.0007	0.0002	0.0000	-0.0353	0.0001
	200 Gy+0.1% EMS	**0.1320**	0.0010	-0.0087	-0.0066	0.0042	-0.0140	-0.0082	0.0132	0.0058	0.0079	0.0007	0.0306	0.0965	0.0127
	200 Gy + 0.2% EMS	**0.1086**	-0.0037	-0.0024	0.0298	0.0127	-0.0170	-0.0008	-0.0076	-0.0157	-0.0213	0.0081	-0.0205	0.0257	0.0028
	300 Gy + 0.1% EMS	**-0.0486**	0.0048	-0.0057	-0.0042	0.0124	0.0057	0.0081	0.0016	0.0095	0.0005	0.0015	0.0051	-0.1024	0.0050
	300 Gy +0.2% EMS	**-0.2022**	0.0088	0.0101	0.0111	0.0189	0.0076	-0.0083	-0.0021	0.0160	-0.0345	0.0265	-0.0389	-0.1853	0.0375
	Dry control	**0.0058**	0.0000	0.0005	0.0009	-0.0009	0.0000	0.0004	0.0006	0.0005	-0.0004	-0.0008	-0.0014	0.1388	0.0008
	Wet control	**-0.0948**	0.0234	-0.0080	-0.0060	0.0298	0.0146	0.0215	-0.0208	-0.0259	0.0219	0.0033	0.0218	-0.0331	0.0031

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Days to rosette	100 Gy	0.0016	**-0.0265**	-0.0012	0.0056	-0.0055	-0.0005	0.0007	0.0003	-0.0036	-0.0019	0.0071	0.0048	-0.0237	0.0006
	200 Gy	-0.0041	**-0.0218**	0.0036	0.0057	-0.0014	-0.0054	-0.0008	-0.0012	0.0000	0.0027	-0.0005	-0.0006	0.0242	-0.0005
	300 Gy	-0.0438	**-0.1689**	-0.0332	-0.0063	-0.0069	0.0059	-0.0085	0.0211	0.0164	-0.0132	-0.0263	0.0176	-0.1045	0.0177
	400 Gy	-0.0008	**0.0037**	-0.0002	0.0001	0.0002	0.0001	0.0000	0.0001	-0.0003	0.0001	-0.0008	0.0008	-0.0255	-0.0001
	0.1% EMS	0.0141	**0.0645**	-0.0037	0.0046	-0.0115	-0.0104	-0.0165	0.0084	-0.0003	-0.0057	-0.0001	-0.0118	-0.0259	-0.0017
	0.2 % EMS	-0.0003	**0.0937**	0.0031	0.0254	-0.0077	0.0037	0.0040	0.0034	-0.0057	0.0291	-0.0085	0.0268	0.1553	0.0145
	0.3% EMS	0.0077	**0.0933**	-0.0047	0.0002	0.0105	0.0038	0.0059	-0.0021	-0.0039	0.0070	-0.0004	0.0192	0.1194	0.0111
	0.4% EMS	-0.0011	**-0.0364**	0.0043	0.0019	0.0052	0.0030	0.0018	-0.0007	0.0038	-0.0029	-0.0025	-0.0026	-0.1074	0.0039
	200 Gy+0.1% EMS	-0.0007	**-0.0888**	-0.0015	-0.0136	0.0161	0.0102	0.0036	0.0312	0.0290	0.0030	-0.0008	0.0222	-0.1799	0.016
	200 Gy + 0.2% EMS	0.0037	**-0.1102**	0.0016	0.0305	-0.0062	0.0036	0.0011	-0.0136	-0.0102	-0.0127	-0.0124	-0.0091	-0.0330	0.0036
	300 Gy + 0.1% EMS	0.0052	**-0.0530**	0.0141	0.0076	0.0044	-0.0017	0.0024	-0.0086	-0.0039	0.0009	-0.0059	-0.0010	0.0594	-0.0031
	300 Gy +0.2% EMS	-0.0064	**0.1463**	0.0058	0.0263	0.0384	0.0236	0.0159	0.0008	0.0183	-0.0031	0.0239	-0.0225	0.1793	0.0262
	Dry control	0.0000	**-0.0042**	0.0009	0.0004	0.0001	0.0002	0.0006	-0.0003	-0.0003	-0.0001	0.0002	0.0000	0.0098	0.0000
	Wet control	-0.0174	**0.0708**	0.0000	-0.0024	0.0166	0.0096	0.0098	-0.0251	-0.0141	0.0052	0.0021	0.0109	-0.0382	-0.0027

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Days to 50 % flowering (Days)	100 Gy	0.0358	0.0047	**0.1043**	0.0440	-0.0199	0.0108	-0.0016	-0.0411	-0.0400	-0.0262	-0.0059	-0.0133	-0.1714	-0.0179
	200 Gy	0.0079	-0.0292	**0.1784**	0.0364	-0.0288	-0.0134	-0.0269	0.0122	-0.0216	0.0137	0.0171	0.0075	0.0348	0.0062
	300 Gy	0.0034	0.0114	**0.0579**	0.0178	-0.0162	-0.0103	-0.0117	-0.0248	-0.0244	-0.0219	0.0045	-0.0104	-0.4147	-0.0240
	400 Gy	-0.0101	0.0037	**-0.0878**	-0.0092	0.0050	0.0104	0.0166	0.0072	0.0091	0.0247	-0.0051	-0.0083	-0.1989	0.0175
	0.1% EMS	0.0159	0.0121	**-0.2089**	-0.0495	0.0391	-0.0008	0.0204	-0.0097	0.0220	0.0371	-0.0240	0.0056	-0.2307	0.0482
	0.2 % EMS	0.0058	0.0006	**0.0166**	0.0044	-0.0010	-0.0019	-0.0021	-0.0017	-0.0024	-0.0001	0.0002	-0.0052	0.0367	0.0006
	0.3% EMS	0.0004	-0.0007	**0.0135**	0.0043	-0.0013	-0.0041	-0.0038	-0.0038	-0.0021	-0.0013	0.0015	-0.0006	-0.3393	-0.0046
	0.4% EMS	-0.0047	0.0135	**-0.1128**	-0.0210	0.0214	0.0233	0.0145	0.0049	0.0021	0.0201	-0.0196	-0.0079	-0.1310	0.0148
	200 Gy+0.1% EMS	0.0002	-0.0001	**-0.0036**	-0.0015	0.0014	0.0012	0.0013	0.0015	0.0016	0.0006	0.0000	0.0004	-0.3366	0.0012
	200 Gy + 0.2% EMS	0.0001	0.0001	**-0.0063**	0.0001	0.0012	0.0013	-0.0004	0.0004	0.0018	0.0006	-0.0002	0.0001	-0.1027	0.0006
	300 Gy + 0.1% EMS	-0.0117	0.0267	**-0.1001**	-0.0080	0.0131	0.0185	0.0098	0.0140	0.0190	0.0220	0.0130	-0.0050	-0.3034	0.0304
	300 Gy +0.2% EMS	0.0077	-0.0061	**-0.1544**	-0.0050	0.0137	0.0486	0.0828	0.0759	0.0766	0.0184	-0.0498	-0.0160	-0.5160	0.0797
	Dry control	0.0008	-0.0019	**0.0083**	0.0018	0.0007	-0.0005	-0.0005	0.0008	0.0008	-0.0014	0.0009	-0.0001	0.0011	0.0000
	Wet control	-0.0075	0.0000	**-0.0887**	-0.0205	0.0153	0.0054	0.0143	0.0077	0.0111	-0.0061	0.0036	0.0108	-0.2739	0.0243

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Days to maturity (Days)	100 Gy	-0.0178	0.0103	-0.0207	**-0.0491**	0.0186	0.0114	0.0124	0.0220	0.0233	0.0193	0.0005	0.0080	-0.4676	0.023
	200 Gy	0.0019	0.0249	-0.0195	**-0.0955**	0.0290	0.0338	0.0285	0.0220	0.0008	0.0204	0.0098	-0.0097	-0.2784	0.0266
	300 Gy	-0.0033	-0.0004	-0.0034	**-0.0110**	0.0043	0.0018	0.0022	0.0039	0.0035	0.0018	0.0007	-0.0024	-0.3381	0.0037
	400 Gy	-0.0002	-0.0001	-0.0003	**-0.0025**	0.0006	0.0011	0.0009	0.0008	0.0007	0.0009	-0.0003	0.0005	-0.3473	0.0009
	0.1% EMS	0.0720	0.0305	0.1021	**0.4304**	-0.1669	-0.0860	-0.1150	0.0350	-0.1733	-0.0116	0.0005	0.0611	0.0964	0.0415
	0.2 % EMS	-0.0013	-0.0059	-0.0057	**-0.0216**	0.0063	0.0064	0.0063	0.0084	0.0113	0.0002	0.0007	0.0008	-0.1960	0.0042
	0.3% EMS	-0.0722	-0.0003	-0.0570	**-0.1809**	-0.0090	0.0227	0.0253	0.0348	0.0307	-0.0127	-0.0047	-0.0105	-0.3417	0.0618
	0.4% EMS	0.0076	-0.0059	0.0208	**0.1116**	-0.0236	-0.0343	-0.0179	-0.0475	-0.0406	0.0143	-0.0094	-0.0134	-0.1666	-0.0186
	200 Gy+0.1% EMS	-0.0011	0.0035	0.0093	**0.0230**	-0.0146	-0.0120	-0.0103	-0.0126	-0.0116	-0.0081	-0.0022	-0.0117	-0.5525	-0.0127
	200 Gy + 0.2% EMS	-0.0149	0.0151	0.0006	**-0.0543**	0.0219	0.0186	0.0091	0.0084	0.0149	0.0165	-0.0019	0.0126	-0.2089	0.0113
	300 Gy + 0.1% EMS	0.0269	-0.0447	0.0247	**0.3097**	-0.0264	-0.0970	-0.0815	0.0021	-0.0235	-0.0943	-0.0744	0.0218	-0.0895	-0.0277
	300 Gy +0.2% EMS	0.0092	-0.0301	-0.0054	**-0.1675**	-0.0143	-0.0009	0.0154	0.0047	0.0109	-0.0068	-0.0193	-0.0171	-0.1278	0.0214
	Dry control	0.0023	-0.0015	0.0033	**0.0151**	-0.0002	0.0035	-0.0014	0.0001	-0.0013	0.0003	0.0003	0.0007	0.0764	0.0012
	Wet control	-0.0074	0.0040	-0.0271	**-0.1170**	0.0231	0.0120	0.0262	-0.0046	0.0038	-0.0354	-0.0056	0.0118	-0.1953	0.0229

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
No. of Primary branches per plant	100 Gy	0.0003	-0.0005	0.0005	0.0010	**-0.0026**	-0.0007	-0.0007	-0.0012	-0.0012	-0.0003	-0.0001	0.0004	0.3997	-0.0010
	200 Gy	-0.0258	0.0205	-0.0517	-0.0974	**0.3204**	0.2178	0.1774	0.0548	0.0800	0.0702	0.0248	-0.0072	0.5201	0.1666
	300 Gy	-0.0808	0.0138	-0.0945	-0.1324	**0.3368**	0.2490	0.2475	0.0796	0.1082	0.0678	0.0205	-0.0250	0.6980	0.2351
	400 Gy	0.0183	-0.0020	0.0026	0.0109	**-0.0456**	-0.0067	-0.0018	-0.0127	-0.0096	-0.0103	0.0023	-0.0031	0.1571	-0.0072
	0.1% EMS	0.0001	0.0000	0.0000	0.0001	**-0.0002**	-0.0001	-0.0001	0.0000	-0.0001	0.0000	0.0000	0.0000	0.2147	0.0000
	0.2 % EMS	-0.0080	-0.0168	-0.0129	-0.0595	**0.2051**	0.1374	0.1522	0.0700	0.0803	0.0273	-0.0351	-0.0412	0.4855	0.0996
	0.3% EMS	0.0018	0.0015	-0.0013	0.0007	**0.0135**	0.0063	0.0075	0.0034	0.0024	-0.0016	0.0003	0.0000	0.4782	0.0064
	0.4% EMS	-0.0253	0.0568	0.0749	0.0834	**-0.3939**	-0.3297	-0.3014	-0.0845	-0.0643	-0.1341	-0.0347	-0.0334	0.4317	-0.1701
	200 Gy+0.1% EMS	0.0083	-0.0472	-0.1007	-0.1652	**0.2597**	0.2311	0.2048	0.1109	0.1434	0.0583	0.0230	0.0676	0.7049	0.1831
	200 Gy + 0.2% EMS	-0.0093	-0.0045	0.0148	0.0320	**-0.0796**	-0.0442	-0.0430	-0.0087	-0.0153	-0.0192	0.0172	-0.0016	0.4675	-0.0372
	300 Gy + 0.1% EMS	0.0315	0.0102	0.0160	0.0105	**-0.1228**	-0.0465	-0.1008	-0.0218	-0.0211	-0.0445	-0.0249	-0.0480	0.5356	-0.0658
	300 Gy +0.2% EMS	-0.0070	0.0197	-0.0066	0.0064	**0.0749**	0.0312	0.0249	0.0229	0.0320	-0.0107	0.0057	-0.0096	0.4361	0.0327
	Dry control	-0.0034	-0.0005	0.0020	-0.0003	**0.0229**	0.0114	0.0037	0.0031	0.0007	-0.0024	0.0047	0.0010	0.2399	0.0055
	Wet control	0.0632	-0.0473	0.0348	0.0397	**-0.2013**	-0.0793	-0.1203	0.0085	-0.0038	0.0197	-0.0193	-0.0303	0.2732	-0.0550

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
No. of secondary branches per plant	100 Gy	-0.0019	0.0013	0.0074	-0.0166	0.0184	**0.0717**	0.0573	0.0104	0.0110	0.0031	-0.0013	0.0089	0.6198	0.0445
	200 Gy	-0.0019	0.0038	-0.0012	-0.0054	0.0104	**0.0153**	0.0075	0.0030	0.0044	0.0015	-0.0006	0.0000	0.4753	0.0073
	300 Gy	0.0019	0.0003	0.0016	0.0014	-0.0066	**-0.0089**	-0.0076	-0.0009	-0.0016	-0.0004	-0.0007	0.0007	0.5812	-0.0052
	400 Gy	-0.0134	0.0055	-0.0240	-0.0853	0.0300	**0.2033**	0.1240	0.0873	0.1038	0.0804	0.0074	0.0369	0.6549	0.1331
	0.1% EMS	-0.0508	-0.0256	0.0006	-0.0317	0.0854	**0.1585**	0.0850	-0.0159	0.0602	0.0388	0.0022	-0.0236	0.3447	0.0546
	0.2 % EMS	0.0044	0.0016	-0.0049	-0.0125	0.0283	**0.0422**	0.0375	0.0175	0.0206	0.0164	-0.0129	0.0008	0.4515	0.0191
	0.3% EMS	0.0058	0.0024	-0.0173	-0.0072	0.0271	**0.0575**	0.0470	0.0141	0.0227	-0.0114	0.0048	-0.0034	0.7487	0.0430
	0.4% EMS	0.0579	-0.0451	-0.1134	-0.1685	0.4590	**0.5484**	0.4041	0.1811	0.1071	0.1982	0.0140	0.0167	0.5611	0.3077
	200 Gy+0.1% EMS	-0.0008	-0.0009	-0.0027	-0.0041	0.0070	**0.0078**	0.0067	0.0022	0.0036	0.0016	0.0005	0.0011	0.6867	0.0054
	200 Gy + 0.2% EMS	-0.0222	-0.0046	-0.0282	-0.0484	0.0786	**0.1415**	0.0862	0.0197	0.0389	0.0515	-0.0223	0.0099	0.5668	0.0802
	300 Gy + 0.1% EMS	-0.0139	0.0037	-0.0219	-0.0370	0.0448	**0.1183**	0.0589	0.0170	0.0066	0.0228	0.0062	0.0244	0.3730	0.0441
	300 Gy +0.2% EMS	-0.0033	0.0141	-0.0276	0.0004	0.0366	**0.0877**	0.0299	0.0198	0.0297	0.0052	0.0109	-0.0038	0.4508	0.0395
	Dry control	0.0010	-0.0250	-0.0286	0.1150	0.2424	**0.4882**	0.2381	0.0395	-0.0256	-0.0920	0.1202	0.1084	0.5551	0.2710
	Wet control	-0.0393	0.0344	-0.0154	-0.0262	0.1002	**0.2544**	0.1873	-0.0023	-0.0408	0.0053	0.0363	0.0308	0.4913	0.1250

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
No. of Capsule per Plant	100 Gy	-0.0566	-0.0122	-0.0074	-0.1206	0.1358	0.3823	**0.4787**	0.1143	0.1163	0.0272	-0.0257	0.0245	0.6764	0.3238
	200 Gy	-0.0070	0.0015	-0.0063	-0.0125	0.0232	0.0204	**0.0420**	-0.0032	0.0015	0.0125	0.0028	-0.0116	0.4816	0.0202
	300 Gy	-0.0744	0.0171	-0.0692	-0.0680	0.2509	0.2901	**0.3413**	0.0534	0.0889	0.0751	0.0159	-0.0448	0.6995	0.2388
	400 Gy	-0.0034	0.0001	-0.0044	-0.0081	0.0009	0.0143	**0.0234**	0.0082	0.0088	0.0086	-0.0012	0.0037	0.4938	0.0116
	0.1% EMS	-0.0025	-0.0323	-0.0124	-0.0338	0.0525	0.0678	**0.1263**	-0.0164	0.0487	0.0206	0.0136	-0.0209	0.2712	0.0343
	0.2 % EMS	0.0389	0.0093	-0.0275	-0.0631	0.1603	0.1917	**0.2159**	0.1081	0.1084	0.0474	-0.0632	-0.0061	0.5337	0.1152
	0.3% EMS	0.0251	0.0431	-0.1922	-0.0958	0.3814	0.5610	**0.6856**	0.1542	0.2521	-0.0678	0.0049	-0.0775	0.8671	0.5944
	0.4% EMS	0.0134	-0.0174	-0.0452	-0.0563	0.2691	0.2590	**0.3516**	0.0813	0.0741	0.1370	0.0057	-0.0196	0.5546	0.1950
	200 Gy+0.1% EMS	-0.0304	-0.0197	-0.1782	-0.2194	0.3871	0.4179	**0.4908**	0.1583	0.2343	0.1500	0.0140	0.0947	0.7444	0.3654
	200 Gy + 0.2% EMS	-0.0037	-0.0050	0.0310	-0.0868	0.2807	0.3164	**0.5191**	0.0441	0.0467	0.1494	-0.2213	0.0271	0.6640	0.3447
	300 Gy + 0.1% EMS	-0.1286	-0.0352	-0.0758	-0.2040	0.6360	0.3861	**0.7752**	0.2429	0.2334	0.2499	0.0669	0.2113	0.6722	0.5211
	300 Gy +0.2% EMS	0.0109	0.0288	-0.1421	-0.0243	0.0880	0.0904	**0.2651**	0.1688	0.1614	-0.0081	-0.0872	-0.0141	0.6561	0.1739
	Dry control	0.0021	-0.0041	-0.0015	-0.0026	0.0044	0.0132	**0.0271**	-0.0023	-0.0045	-0.0019	0.0034	0.0036	0.2884	0.0078
	Wet control	-0.0906	0.0556	-0.0647	-0.0895	0.2392	0.2946	**0.4002**	0.0020	-0.0609	-0.0333	0.0728	0.0996	0.5223	0.2090

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Diameter of head (cm)	100 Gy	-0.0267	-0.0021	-0.0761	-0.0865	0.0873	0.0280	0.0461	**0.1932**	0.1588	0.0645	0.0013	0.0215	0.6371	0.1231
	200 Gy	-0.0091	0.0104	0.0128	-0.0431	0.0320	0.0364	-0.0141	**0.1870**	0.1238	-0.0024	0.0561	0.0718	0.3668	0.0686
	300 Gy	-0.1203	-0.0443	-0.1521	-0.1248	0.0837	0.0372	0.0554	**0.3542**	0.3248	0.0414	0.0919	-0.0883	0.5413	0.1917
	400 Gy	-0.0184	0.0015	-0.0090	-0.0366	0.0304	0.0468	0.0379	**0.1091**	0.0999	0.0560	0.0063	-0.0085	0.7176	0.0783
	0.1% EMS	0.0001	-0.0065	-0.0023	-0.0041	0.0011	0.0050	0.0065	**-0.0502**	-0.0035	-0.0008	-0.0084	0.0049	-0.0767	0.0039
	0.2 % EMS	0.0273	0.0132	-0.0365	-0.1417	0.1237	0.1497	0.1814	**0.3623**	0.2986	0.0546	-0.0742	0.0295	0.4563	0.1653
	0.3% EMS	0.0206	-0.0032	-0.0411	-0.0278	0.0362	0.0356	0.0326	**0.1448**	0.1092	0.0075	0.0358	0.0165	0.4293	0.0622
	0.4% EMS	0.0013	-0.0023	0.0053	0.0518	-0.0261	-0.0402	-0.0281	**-0.1217**	-0.1085	-0.0160	0.0163	-0.0012	0.4857	-0.0591
	200 Gy+0.1% EMS	0.0139	-0.0486	-0.0560	-0.0760	0.0591	0.0398	0.0446	**0.1384**	0.0976	0.0452	0.0145	0.0511	0.4921	0.0681
	200 Gy + 0.2% EMS	0.0063	-0.0111	0.0051	0.0139	-0.0098	-0.0126	-0.0077	**-0.0901**	-0.0374	-0.0070	0.0349	0.0028	0.1491	-0.0134
	300 Gy + 0.1% EMS	0.0077	-0.0370	0.0318	-0.0015	-0.0404	-0.0327	-0.0714	**-0.2279**	-0.1502	-0.0351	0.0407	-0.0517	0.3616	-0.0824
	300 Gy +0.2% EMS	0.0018	0.0009	-0.0839	-0.0048	0.0521	0.0386	0.1087	**0.1707**	0.1433	-0.0090	-0.0567	-0.0227	0.5955	0.1017
	Dry control	0.0161	0.0107	0.0165	0.0008	0.0221	0.0134	-0.0143	**0.1652**	0.1115	0.0084	-0.0066	-0.0204	0.529	0.0874
	Wet control	0.0431	-0.0699	-0.0170	0.0078	-0.0083	-0.0018	0.0010	**0.1967**	0.1251	-0.0371	-0.0039	-0.0015	0.4687	0.0922

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
No. of seed per Capsule	100 Gy	-0.0144	0.0330	-0.0939	-0.1162	0.1165	0.0376	0.0595	0.2013	**0.2449**	0.0480	-0.0145	0.0014	0.6037	0.1478
	200 Gy	-0.0369	0.0006	-0.0344	-0.0024	0.0710	0.0807	0.0100	0.1882	**0.2843**	0.0133	0.0422	0.0820	0.4531	0.1288
	300 Gy	-0.0118	-0.0036	-0.0157	-0.0119	0.0120	0.0067	0.0097	0.0341	**0.0372**	0.0067	0.0084	-0.0090	0.6063	0.0226
	400 Gy	-0.0716	-0.0288	-0.0435	-0.1137	0.0887	0.2146	0.1574	0.3847	**0.4202**	0.2473	0.0188	-0.0404	0.8015	0.3368
	0.1% EMS	-0.0830	-0.0019	-0.0507	-0.1939	0.2030	0.1831	0.1855	0.0332	**0.4816**	0.1063	0.0074	-0.1210	0.4403	0.2121
	0.2 % EMS	0.0026	0.0039	0.0095	0.0337	-0.0251	-0.0312	-0.0322	-0.0528	**-0.0641**	-0.0147	0.0081	-0.0036	0.4188	-0.0268
	0.3% EMS	0.0071	-0.0022	-0.0085	-0.0092	0.0095	0.0213	0.0198	0.0407	**0.0539**	-0.0073	0.0153	-0.0049	0.4972	0.0268
	0.4% EMS	-0.0226	-0.0588	-0.0108	-0.2066	0.0926	0.1108	0.1196	0.5058	**0.5674**	0.0865	-0.1004	0.0007	0.5207	0.2954
	200 Gy+0.1% EMS	0.0003	-0.0023	-0.0031	-0.0036	0.0039	0.0033	0.0034	0.0050	**0.0071**	0.0019	0.0003	0.0024	0.5488	0.0039
	200 Gy + 0.2% EMS	-0.0347	0.0222	-0.0683	-0.0658	0.0462	0.0661	0.0216	0.0998	**0.2404**	0.0562	-0.0043	-0.0334	0.3931	0.0945
	300 Gy + 0.1% EMS	-0.0242	0.0092	-0.0235	-0.0094	0.0213	0.0069	0.0374	0.0818	**0.1241**	0.0066	-0.0256	0.0154	0.4058	0.0504
	300 Gy +0.2% EMS	-0.0004	0.0006	-0.0023	-0.0003	0.0020	0.0016	0.0028	0.0039	**0.0046**	-0.0001	-0.0016	-0.0006	0.6704	0.0031
	Dry control	0.0496	0.0411	0.0514	-0.0485	0.0170	-0.0292	-0.0918	0.3748	**0.5551**	0.1106	-0.1119	-0.0993	0.5585	0.3100
	Wet control	0.1309	-0.0951	-0.0599	-0.0154	0.0091	-0.0767	-0.0729	0.3044	**0.4785**	-0.0724	-0.0664	-0.0299	0.4748	0.2272

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
100 seed weight (g)	100 Gy	-0.0991	0.0220	-0.0769	-0.1204	0.0336	0.0130	0.0174	0.1022	0.0601	**0.3065**	-0.0214	0.0688	0.3990	0.1223
	200 Gy	-0.0394	-0.0454	0.0277	-0.0772	0.0790	0.0354	0.1074	-0.0047	0.0169	**0.3606**	-0.0948	-0.1025	0.5395	0.1945
	300 Gy	-0.0002	0.0144	-0.0695	-0.0296	0.0369	0.0092	0.0404	0.0214	0.0328	**0.1833**	-0.0102	0.0031	0.3823	0.0701
	400 Gy	-0.0151	0.0090	-0.0748	-0.0973	0.0601	0.1051	0.0971	0.1363	0.1563	**0.2656**	-0.0234	0.0200	0.6979	0.1853
	0.1% EMS	0.0109	-0.0162	-0.0324	-0.0049	0.0015	0.0446	0.0297	0.0030	0.0402	**0.1823**	-0.0041	0.0136	0.2825	0.0515
	0.2 % EMS	0.0024	0.0183	-0.0004	-0.0007	0.0078	0.0229	0.0129	0.0089	0.0135	**0.0589**	-0.0179	0.0034	0.2062	0.0122
	0.3% EMS	-0.0011	0.0027	-0.0033	0.0025	-0.0042	-0.0071	-0.0035	0.0018	-0.0048	**0.0357**	-0.0045	0.0166	-0.031	-0.0011
	0.4% EMS	0.0353	0.0139	-0.0311	0.0225	0.0595	0.0632	0.0681	0.0229	0.0266	**0.1748**	0.0193	-0.0536	0.4686	0.0819
	200 Gy+0.1% EMS	0.0139	-0.0077	-0.0403	-0.0810	0.0519	0.0470	0.0706	0.0755	0.0614	**0.2312**	0.0147	0.0308	0.5407	0.1250
	200 Gy + 0.2% EMS	-0.0224	0.0132	-0.0115	-0.0346	0.0276	0.0415	0.0329	0.0089	0.0267	**0.1142**	0.0012	-0.0103	0.3398	0.0388
	300 Gy + 0.1% EMS	-0.0011	-0.0017	-0.0218	-0.0302	0.0360	0.0191	0.0320	0.0153	0.0053	**0.0992**	0.0179	0.0174	0.2707	0.0269
	300 Gy +0.2% EMS	0.0307	-0.0038	-0.0214	0.0073	-0.0257	0.0107	-0.0055	-0.0095	-0.0033	**0.1799**	-0.0035	0.0586	0.1097	0.0197
	Dry control	-0.0007	0.0003	-0.0018	0.0002	-0.0012	-0.0021	-0.0008	0.0006	0.0022	**0.0109**	-0.0021	-0.0006	0.0571	0.0006
	Wet control	-0.0189	0.0061	0.0056	0.0248	-0.0080	0.0017	-0.0068	-0.0155	-0.0124	**0.0820**	-0.0049	-0.0136	-0.066	-0.0054

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Hull content (%)	100 Gy	0.0105	-0.0272	-0.0057	-0.0010	0.0031	-0.0019	-0.0054	0.0007	-0.0060	-0.0071	**0.1013**	0.0037	0.0500	0.0051
	200 Gy	-0.0017	-0.0013	-0.0057	0.0060	-0.0046	0.0022	-0.0039	-0.0177	-0.0087	0.0155	**-0.0589**	-0.0130	0.0243	-0.0014
	300 Gy	-0.0008	0.0011	0.0005	-0.0004	0.0004	0.0005	0.0003	0.0018	0.0015	-0.0004	**0.0068**	-0.0021	0.1160	0.0008
	400 Gy	0.0312	-0.0422	0.0119	0.0257	-0.0102	0.0074	-0.0104	0.0117	0.0091	-0.0179	**0.2033**	0.0238	0.2579	0.0524
	0.1% EMS	-0.0149	-0.0001	0.0070	0.0001	-0.0025	0.0008	0.0065	0.0102	0.0009	-0.0014	**0.0608**	-0.0087	0.0416	0.0025
	0.2 % EMS	0.0089	-0.0102	0.0010	-0.0038	-0.0191	-0.0342	-0.0327	-0.0229	-0.0141	-0.0340	**0.1118**	-0.0009	-0.1277	-0.0143
	0.3% EMS	-0.0056	-0.0002	0.0046	0.0011	0.0009	0.0035	0.0003	0.0103	0.0118	-0.0052	**0.0418**	-0.0068	0.0791	0.0033
	0.4% EMS	-0.0052	0.0067	0.0168	-0.0082	0.0085	0.0025	0.0016	-0.0130	-0.0172	0.0107	**0.0970**	0.0056	-0.0226	-0.0022
	200 Gy+0.1% EMS	-0.0003	-0.0006	-0.0007	0.0059	-0.0054	-0.0035	-0.0017	-0.0064	-0.0025	-0.0038	**-0.0606**	0.0006	-0.0293	0.0018
	200 Gy + 0.2% EMS	-0.0003	-0.0005	-0.0001	-0.0002	0.0010	0.0007	0.0020	0.0018	0.0001	0.0000	**-0.0047**	0.0006	-0.2500	0.0012
	300 Gy + 0.1% EMS	-0.0028	0.0101	-0.0119	-0.0218	0.0185	0.0048	0.0078	-0.0163	-0.0188	0.0164	**0.0910**	0.0028	0.0764	0.0070
	300 Gy +0.2% EMS	0.0004	-0.0005	-0.0010	-0.0003	-0.0002	-0.0004	0.0010	0.0010	0.0010	0.0001	**-0.0030**	0.0000	-0.1895	0.0006
	Dry control	-0.0053	-0.0017	0.0044	0.0008	0.0080	0.0097	0.0049	-0.0016	-0.0080	-0.0077	**0.0394**	0.0022	-0.0329	-0.0013
	Wet control	-0.0036	0.0030	-0.0041	0.0049	0.0098	0.0145	0.0185	-0.0020	-0.0142	-0.0061	**0.1020**	0.0103	0.1112	0.0113

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Oil content (%)	100 Gy	-0.0022	-0.0024	-0.0016	-0.0021	-0.0018	0.0016	0.0007	0.0014	0.0001	0.0029	0.0005	**0.0129**	0.1192	0.0015
	200 Gy	-0.0138	-0.0041	-0.0069	-0.0166	0.0037	0.0000	0.0450	-0.0627	-0.0471	0.0465	-0.0361	**-0.1634**	-0.0935	0.0153
	300 Gy	0.0054	-0.0080	-0.0139	0.0168	-0.0057	-0.0056	-0.0101	-0.0192	-0.0186	0.0013	-0.0235	**0.0772**	-0.1187	-0.0092
	400 Gy	-0.0255	0.0410	0.0174	-0.0357	0.0124	0.0335	0.0295	-0.0144	-0.0178	0.0140	0.0217	**0.1850**	0.191	0.0353
	0.1% EMS	-0.0062	-0.0211	-0.0031	0.0164	0.0038	-0.0173	-0.0192	-0.0112	-0.0291	0.0086	-0.0166	**0.1158**	0.0247	0.0029
	0.2 % EMS	0.0132	-0.0236	0.0261	0.0029	0.0166	-0.0015	0.0023	-0.0067	-0.0047	-0.0048	0.0007	**-0.0826**	-0.0706	0.0058
	0.3% EMS	-0.0024	-0.0041	0.0008	-0.0012	0.0000	0.0012	0.0022	-0.0023	0.0018	-0.0092	0.0032	**-0.0198**	-0.0341	0.0007
	0.4% EMS	0.0000	-0.0004	-0.0004	0.0006	-0.0004	-0.0002	0.0003	-0.0001	0.0000	0.0016	-0.0003	**-0.0052**	-0.1491	0.0008
	200 Gy+0.1% EMS	-0.0162	0.0175	0.0079	0.0356	-0.0182	-0.0097	-0.0135	-0.0258	-0.0235	-0.0093	0.0007	**-0.0699**	0.2462	-0.0172
	200 Gy + 0.2% EMS	0.0173	-0.0075	0.0015	0.0212	-0.0018	-0.0064	-0.0048	0.0028	0.0127	0.0083	0.0116	**-0.0913**	-0.0588	0.0054
	300 Gy + 0.1% EMS	-0.0084	0.0014	0.0039	0.0056	0.0308	0.0163	0.0215	0.0179	0.0098	0.0138	0.0024	**0.0788**	0.2864	0.0226
	300 Gy +0.2% EMS	-0.0063	0.0050	-0.0034	-0.0034	0.0042	0.0014	0.0017	0.0044	0.0043	-0.0107	0.0000	**-0.0328**	-0.1025	0.0034
	Dry control	-0.0207	-0.0004	-0.0009	0.0043	0.0040	0.0192	0.0116	-0.0107	-0.0155	-0.0050	0.0048	**0.0866**	0.0681	0.0059
	Wet control	0.0046	-0.0031	0.0024	0.0020	-0.0030	-0.0024	-0.0050	0.0001	0.0012	0.0033	-0.0020	**-0.0199**	0.1387	-0.0028

6) Secondary branches per plant.

The high positive direct influence of number of secondary branches per plant on seed yield per plantaccording tothe phenotypic path coefficientswas reportedinall the mutagenic treatments. The indirect effect of seed yield per plant on the number of secondary branches per plant *via* primary branches per plant, secondary branches per plant, head diameter, number of seeds per capsule, 100 seed weight, hull content and oil content.The number of secondary branches per plant had a positive association and direct impact on seed yield per plant in the current study. This demonstrates that increasing the number of secondary branches per plant can enhance seed yield.Similar results were recorded by Patil *et. al.* (2018) in Sesame, Dogra *et. al.* (2020) in Linseed, Thakur *et. al.* (2020) in Linseed and Bhakre *et. al.* (2015) in Safflower.

7) Number of capsule per plant.

According to phenotypic path coefficients, the high positive direct impact of number of capsule per plant on seed yield per plant was recorded at all the mutagenic treatments except 300 Gy dose of gamma rays treatments. The indirect effect of the number of capsules per plant on seed yield per plant *via* primary branches per plant, secondary branches per plant, head diameter, number of seed per capsule and 100 seed weight.In the current study, the number of capsules per plant had a positive relationship and a direct influence on seed yield per plant. This reveals that increasing the number of capsules per plant can raise seed yield. These results are in accordance with the results of Pavithra *et. al.* (2016) in Safflower, Minnie *et. al.* (2020) in Safflower, Arslan *et. al.* (2007) in Safflower, Pushpavalli *et. al.* (2017) in Safflower and Bahmankar *et. al.* (2014) in Safflower.

8) Diameter of head.

The phenotypic path coefficients demonstrated high positive direct impact of diameter of head on seed yield per plant was recorded at all the mutagenic treatments except 0.1% EMS, 0.4% EMS, 200 Gy + 0.2% EMS and 300 Gy + 0.1% EMS dose of combination treatments.The diameter of the head has an indirect effect on seed yield per plant due to primary branches per plant, secondary branches per plant, number of seed per capsule, hull content and oil content.The diameter of the head had a positive relationship and a direct effect on seed yield per plant in the current study. This means

that increasing the diameter of the head can help to increase seed yield.These results are consistent with the results of Bidgoli *et. al.* (2006) in Safflower, Yasin *et. al.* (2010) in Sunflower, Topal *et. al.* (2010) in Safflower and Bahmankar *et. al.*(2014) in Safflower.

9) Number of seeds per capsule.

The high positive direct influence of number of seed per capsule on seed yield per plant was recorded at all the mutagenic treatments except 0.2% EMS concentration treatments, according to phenotypic path coefficient study. The indirect influence of number of seeds per capsuleon seed yield per plant through primary branches per plant, secondary branches per plant, number of capsule per plant, diameter of head, 100 seed weight and hull content. In the current study, number of seeds per capsule showed positive correlation and positive direct influence on seed yield per plant. This indicates that improvement of seed yield can be achieved through increasing the number of seeds per capsule. These findings are in accordance with the results ofTopal *et. al.* (2010) in Safflower, Bhakre *et.al*. (2015) in Safflower, Pavithra *et. al.* (2016) in Safflower and Minnie*et. al.* (2020) in Safflower

10) 100 seed weight

The phenotypic path coefficients showed high positive direct effect of 100 seed weight on seed yield per plant was recorded at all the mutagenic treatments.The indirect effect of 100 seed weighton seed yield per plant through primary branches per plant, secondary branches per plant, number of capsule per plant, diameter of head and number of seeds per capsule.In the current study, 100 seed weight had a positive relationship and direct impact on seed yield per plant. This indicated that improving the 100 seed weight can enhance seed yield.These findings are consistent with the findings ofby Bidgoli *et. al.* (2006) in Safflower, Shivani *et. al.* (2011) in Safflower, Pattar *et. al.* (2020) in Safflower, Bahmankar *et. al.* (2014) in Safflower, Bhakre *et.al*. (2015) in Safflower and Minnie *et. al.* (2020) in Safflower

11) Hull content

The phenotypic path coefficients indicated high negative direct effect of hull content on seed yield per plant was recorded at all the mutagenic treatments except 200 Gy, 200 Gy + 0.1% EMS, 200 Gy + 0.2% and 300 Gy + 0.2% EMS dose of

combination treatments.The hull content has an indirect effect on seed yield per plant due to plant height, days to rosette stage, days to maturity, primary branches per plant, number of capsule per plant, diameter of head, number of seeds per capsule, 100 seed weight and oil content. In the present study, hull content exhibited negative correlation and negative direct effect on seed yield per plant. This indicates that improvement of seed yield can be achieved through reducing the hull content. These results are broad agreement with the results of Gopal *et. al.* (2014) in Safflower, Cerrotta *et. al.* (2020) in Safflower and Rathod *et. al.* (2021) in Safflower.

12) Oil content

The phenotypic path coefficients indicated high positive direct effect of oil content on seed yield per plant was recorded at 100 Gy, 300 Gy ,400 Gy, 0.1% EMS and 300 Gy + 0.1% dose of combination treatments. The oil content has an indirect effect on seed yield per plant due to number of secondary branches per plant, number of capsule per plant and 100 seed weight. Oil content had a positive association and direct effect on seed yield per plant in the current study. This demonstrates that improving seed yield can be accomplished by increasing oil content. These results are consistent with the findings of Shivani *et. al.* (2011) in Safflower, Topal *et. al.* (2010) in Safflower and Bhakre *et.al*. (2015) in Safflower.

4.2.6.2 Genotypic path coefficient analysis

The genotypic correlation coefficients were divided into direct and indirect effects using genotypic path coefficient analysis. The following Table 4.38 shows the direct and indirect effects of component attributes on seed yield in M_2 populations of the safflower variety PBNS-12.

1) Plant height (cm)

The high positive direct influence of plant height on seed yield per plant was recorded at all mutagenic treatments except 400 Gy and 0.4% EMS concentration treatments, according tothe genotypic path coefficients. The indirect effect of plant height on seed yield per plant through days to rosette, days to 50% flowering, days to maturity, primary branches per plant, secondary branches per plant and 100 seed weight.Plant height had a positive connection and direct effect on seed yield per plant in the current study. This means that increasing the plant height can enhance seed

yield. These results are broad agreement with the results of Nair *et. al.*(2006) in Safflower, Pavithra *et. al.* (2016) in Safflower, Bahmankar *et. al.* (2014) in Safflower, Bhakre *et. al. (*2015) in Safflower and Shivani *et. al.* (2011) in Safflower.

2) Days to rosette stage

The genotypic path coefficients suggested high negative direct influence of days to rosette on seed yield per plant was recorded at 300 Gy, 0.1% EMS, 200 Gy + 0.1% EMS and 200 Gy + 0.2% EMS dose of combination treatments. Similarly, all mutagenic treatments except 300 Gy, 0.1 percent EMS, 200 Gy + 0.1% EMS and 200 Gy + 0.2 % EMS dose of combination treatments showed a strong positive direct influence of days to rosette on seed yield per plant.The indirect effect of days to rosette stage on seed yield per plant *via* plant height, days to 50% flowering, days to maturity, head diameter, and number of seeds per capsule.Days to rosette period had a negative association and a positive direct influence on seed yield per plant in this study. This implies that decreasing the days to rosette period can enhance seed yield.These findings are broad agreement with the findings of Pavithra *et. al.*(2016) in Safflower, Sarang *et. al.*(2004) in Safflower, Mathur *et. al.* (1976) and Mozaffari and Asadi (2006) in Safflower.

3) Days to 50% Flowering

The genotypic path coefficients revealed a strong negative direct effect of days to 50% flowering on seed yield per plant at 200 Gy + 0.1% EMS dose of combination treatment. Similarly, all mutagenic treatments, with the exception of 200 Gy + 0.1% EMS dose of combination treatment, showed a strong positive direct influence of days to 50% flowering on seed yield per plant.The days to 50% flowering has an indirect effect on seed yield per plant due to days to rosette, days to maturity and 100 seed weight. In the current study, days to 50% flowering showed negative directs effect on seed yield per plant. These results are in accordance with the findings of Diwakar *et. al.* (2006) in Safflower, Shivani *et. al.* (2011) in Safflower and Minnie *et. al.* (2020) in Safflower. Days to 50% flowering, on the other hand, showed a negative correlation and a positive direct influence on seed yield per plant. This indicates that by shortening flowering days to 50%, seed yield might be increased. These results are in confirmity with the results of Dambal *et. al.* (2015) in Safflower, Pavithra *et.*

al.(2016) in Safflower, Sarang *et. al.*(2004) in Safflower, Thombre and Joshi (1981) in Safflower and Mozaffari and Asadi (2006) in Safflower.

4) Days to maturity

The genotypic path coefficients revealed a strong negative direct influence of days to maturity on seed yield per plant was recorded at 200 Gy, 0.2% EMS, 0.3% EMS, 200 Gy + 0.1% EMS and 300 Gy + 0.1% dose of combination treatments. Similarly, all mutagenic treatments except 200 Gy, 0.2% EMS, 0.3 % EMS, 200 Gy +0.1 % EMS, and 300 Gy + 0.1% dosage of combination treatments showed a strong positive direct influence of days to maturity on seed yield per plant.The indirect effect of days to maturityon seed yield per plant through plant height, days to rosette stage, diameter of head, number of seed per capsule and hull content.Days to maturity had a negative direct effect on seed yield per plant in current study. These findings are in broad agreement with results of Pavithra *et. al.* (2016) in Safflower and Leelavathi *et. al.*(2018) in Linseed. Days to maturity, on the other hand, showed a negative association and a positive direct influence on seed yield per plant. This suggests that decreasing the days to maturity shortens the time it takes for seeds to mature. These findings are broad agreement with results of Sarang*et. al.*(2004) in Safflower, Thombre and Joshi (1981) in Safflower, Mathur *et. al.* (1976) in Safflower and Mozaffari and Asadi (2006) in Safflower.

5) Primary branches per plant

The genotypic path coefficients showed a strong positive direct impact of number of primary branches per plant on seed yield per plant was recorded at 100 Gy, 200 Gy, 300 Gy, 200 Gy + 0.1% EMS and 300 Gy+ 0.1% EMS dose of combination treatments. The number of primary branches per plant has an indirect effect on seed yield per plant due to days to diameter of head and 100 seed weight.The number of primary branches per plant had a positive relationship and direct effect on seed yield per plant in the current study. This suggests that increasing the number of primary branches per plant can enhance seed yield. These findings are in accordance with results of Reddy *et. al.* (2004) in Safflower, Golkar *et. al.* (2014) in Safflower, Leelavathi *et. al.* (2018) in Linseed, Patil *et. al.* (2018) in Sesame and Bhakre *et. al.* (2015) in Safflower.

6) Secondary branches per plant.

Thestrong positive direct influence of number of secondary branches per plant on seed yield per plant was recorded at 200 Gy, 400 Gy, 0.1% EMS, 0.2% EMS, 0.3% EMS, 0.4% EMS and 300 Gy + 0.2% EMS dose of combination treatments according to the genotypic path coefficients. The indirect effect of number of secondary branches per planton seed yield per plant through primary branches per plant, number of seeds per capsule, diameter of head and number of seed per capsule.The number of secondary branches per plant had a strong relation and direct effect on seed yield per plant in the current study. This suggests that increasing the number of secondary branches per plant can increase seed yield.These findings are consistent with results of Reddy *et. al.* (2004) in Safflower, Patil *et. al.* (2018) in Sesame, Dogra *et. al.*(2020) in Linseed, Thakur *et. al.* (2020) in Linseed and Bhakre*et. al.* (2015) in Safflower.

7) Number of capsule per plant.

The genotypic path coefficients revealed a strong positive direct effect of number of capsule per plant on seed yield per plant was recorded at all the mutagenic treatments except 200 Gy, 400 Gy, 0.1% EMS and 300 Gy + 0.1% EMS dose of combination treatments. The number of capsule per planthas an indirect effect on seed yield per plant due to primary branches per plant, secondary branches per plant, diameter of head, number of seed per capsule and 100 seed weight. The number of capsules per plant had a positive relationship and a direct effect on seed yield per plant in the current study. This suggests that increasing the number of capsules per plant can enhance seed yield.These findings are broad agreement with results of Diwakar*et. al.* (2006) in Safflower, Khalili *et. al.* (2013) in Safflower, Pavithra *et. al.* (2016) in Safflower, Minnie *et. al.* (2020) in Safflower, Arslan *et. al.* (2007) in Safflower, Pushpavalli *et. al.* (2017) in Safflower and Bahmankar *et. al.* (2014) in Safflower.

8) Diameter of head.

At all mutagenic treatments except 100 Gy, 200 Gy, 0.1% EMS and 0.3 % EMS concentration treatments, the genotypic path coefficients revealed a strong positive direct effect of head diameter on seed yield per plant.The diameter of head

has an indirect effect on seed yield per plant through secondary branches per plant, number of capsule per plant and number of seed per capsule.The diameter of the head had a positive association and a direct effect on seed yield per plant in the current study. This suggests that increasing the diameter of the head can help to increase seed yield. These findings are consistent with results of Bidgoli *et. al.* (2006) in Safflower, Topal *et. al.* (2010) in Safflower, Khalili *et. al.* (2013) in Safflower and Bahmankar *et. al.* (2014) in Safflower.

9) Number of seed per capsule.

The genotypic path coefficients indicated high positive direct effect of number of seed per capsule on seed yield per plant was recorded at 200 Gy, 300 Gy, 0.4% EMS and 200 Gy + 0.2% EMS dose of combination treatment. The indirect effect of number of seeds per capsuleon seed yield per plant through primary branches per plant, secondary branches per plant, number of capsule per plant, diameter of head and hull content.In the current study, the number of seeds per capsule had a positive association and direct effect on seed yield per plant. This demonstrates that increasing the number of seeds per capsule can improve seed yield. These results are in accordance with the findings of Diwakar *et. al.* (2006) in Safflower, Golkar *et. al.* (2011) in Safflower, Topal *et. al.* (2010) in Safflower, Bhakre *et.al*. (2015) in Safflower, Pavithra *et. al.* (2016) in Safflower and Minnie *et. al.* (2020) in Safflower.

10) 100 seed weight

The genotypic path coefficients suggested high positive direct influence of 100 seed weight on seed yield per plant was recordedat all the mutagenic treatments except 0.2%, 0.3%, 0.4% and 300 Gy + 0.2% EMS dose of combination treatments.The 100 seed weighthas an indirect effect on seed yield per plant through primary branches per plant and number of capsule per plant.In the current study, 100 seed weight had a positive association and direct effect on seed yield per plant. This indicated that improving the 100 seed weight can enhance seed yield.These results are broad agreement with the results of Sreenivasa*et. al.* (2011) in Safflower,Khalili *et. al.* (2013) in Safflower, Shivani *et. al.* (2011) in Safflower, Pattar *et. al.* (2020) in Safflower, Bahmankar *et. al.* (2014) in Safflower, Bhakre *et.al*. (2015) in Safflower and Minnie *et. al.* (2020) in Safflower.

Table 4.38 : Effect of mutagens on genotypic path coefficient in M_2 generation

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Plant height (cm)	100 Gy	**-20.1812**	4.751	-16.8317	-9.0597	-2.0343	-8.5157	-1.0903	-2.4223	-2.7581	0.0453	-17.4613	13.7826	0.6067	-12.2444
	200 Gy	**-1.0512**	-0.4012	0.1744	0.0785	0.0233	0.0128	0.2345	0.0263	0.0916	-0.0231	0.1648	0.0403	-0.0111	0.0117
	300 Gy	**-0.5561**	-0.2901	-0.0076	-0.2298	-0.1722	-0.1649	-0.0353	0.2181	0.2528	-0.1009	0.0364	-0.2127	-0.2970	0.1652
	400 Gy	**0.4195**	-0.2058	-0.0761	-0.0812	-0.2585	0.0267	0.0140	0.0722	0.0315	-0.1116	0.1414	-0.1062	0.1645	0.0690
	0.1% EMS	**-0.1465**	0.0153	0.0199	-0.0260	-0.0290	0.0436	-0.0175	0.2784	-0.0540	-0.0162	0.1093	0.0049	0.1851	-0.0271
	0.2 % EMS	**-0.3864**	-0.0830	-0.3848	-0.2021	-0.1193	-0.0833	-0.1313	-0.0462	-0.0023	-0.0349	0.1244	0.2526	0.4541	-0.1755
	0.3% EMS	**-0.1010**	-0.0304	-0.0202	-0.1097	-0.0399	-0.0252	-0.0051	-0.0161	-0.0309	0.0253	-0.0179	-0.0580	-0.0026	0.0003
	0.4% EMS	**0.1181**	-0.0195	-0.0460	-0.0054	0.1371	0.0992	0.0908	0.0447	-0.0129	-0.4117	0.0192	0.0118	0.0175	0.0021
	200 Gy+0.1% EMS	**-0.9057**	0.0022	0.3224	0.0702	0.1953	0.3130	0.1055	-0.1849	-0.1017	0.0500	-0.1548	-0.3228	0.0781	-0.0707
	200 Gy + 0.2% EMS	**-0.1521**	0.0707	0.0709	-0.1313	0.0184	-0.0269	0.0225	-0.0183	0.0120	-0.0007	0.0853	0.0922	0.2851	-0.0434
	300 Gy + 0.1% EMS	**-0.2329**	0.1208	0.0785	0.0090	0.0205	-0.0641	-0.0067	-0.0373	-0.0311	-0.4504	-0.1279	0.1585	0.2260	-0.0526
	300 Gy +0.2% EMS	**-1.4939**	-1.1248	0.5401	0.1289	-0.4926	-0.1474	-0.9169	-1.1363	-1.2622	0.0397	0.8237	-0.2400	0.5702	-0.8518
	Dry control	**0.0476**	-0.0254	-0.0072	0.0277	-0.0170	-0.0030	-0.0088	0.0052	0.0064	-0.3877	-0.0117	-0.0349	-0.0584	-0.0028
	Wet control	**-0.2034**	0.1124	-0.0890	-0.0777	0.0660	0.0654	0.1136	-0.0188	-0.0103	0.0453	-0.0903	0.1606	-0.4821	0.0981

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Days to rosette	100 Gy	-0.1172	**0.4979**	0.1625	-0.0598	-0.0565	0.1861	0.0202	-0.0459	0.2288	-0.0787	-0.3845	-0.2741	0.1396	0.0695
	200 Gy	0.0932	**0.2443**	-0.1249	-0.0959	0.0427	0.0629	0.0015	0.0604	-0.0467	-0.0679	0.0791	0.0270	0.2274	0.0556
	300 Gy	-0.3807	**-0.7298**	-0.1852	0.0621	-0.2893	-0.0502	0.0377	0.0510	0.0714	-0.1820	-0.2941	0.3701	-0.1475	0.1077
	400 Gy	-0.0103	**0.0209**	-0.0085	-0.0013	0.0041	0.0011	0.0069	-0.0151	-0.0189	-0.0064	-0.0101	0.0065	-0.4152	-0.0087
	0.1% EMS	0.0801	**-0.7689**	-0.0307	-0.4357	0.0769	0.1020	0.2172	-1.0415	-0.3534	-0.4345	0.0338	0.2101	0.2303	-0.1771
	0.2 % EMS	0.0346	**0.1611**	-0.0733	0.1710	-0.0459	-0.0284	-0.0321	-0.0284	-0.0677	0.1190	0.0367	0.0676	-0.1762	-0.0284
	0.3% EMS	0.1025	**0.3407**	-0.0085	0.1810	0.2165	0.1510	0.1403	-0.1313	-0.2442	-0.0141	0.0669	0.1015	0.2362	0.0805
	0.4% EMS	-0.0469	**0.2840**	-0.0837	0.2244	0.0815	-0.0268	0.0188	-0.1524	-0.1576	0.2030	0.1060	0.0093	-0.4598	-0.1306
	200 Gy+0.1% EMS	0.0016	**-0.6590**	-0.0928	-0.1792	0.0880	0.0622	0.1329	0.1220	0.1891	0.1810	0.0657	0.4279	-0.4279	0.2820
	200 Gy + 0.2% EMS	0.1298	**-0.2794**	0.0301	0.1189	-0.0674	0.0539	-0.0038	-0.1763	-0.0691	0.0129	0.0860	0.0159	0.1078	-0.0301
	300 Gy + 0.1% EMS	-1.1082	**2.1371**	-0.6414	0.2372	-0.8682	-0.0066	-0.7336	0.7416	0.5660	0.1291	0.3638	-0.3618	0.0489	0.1045
	300 Gy +0.2% EMS	0.5828	**0.7740**	0.5169	0.1995	0.5669	0.3311	-0.0778	-0.1995	-0.2493	-0.3738	0.4484	-0.4157	-0.4651	-0.3600
	Dry control	-1.0941	**2.0455**	-1.1969	-0.9980	0.7808	0.7434	-0.3309	1.7815	0.0697	0.3661	0.1918	1.0266	0.6569	1.3437
	Wet control	0.1213	**-0.2195**	0.0166	0.1500	-0.1217	-0.0236	-0.0705	0.1035	0.0338	0.3541	0.0235	-0.1945	-0.1792	0.0393

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Days to 50 % flowering (Days)	100 Gy	44.7330	17.4991	**53.6349**	50.9013	-50.5523	20.4793	23.2642	-36.5773	-44.4586	-9.7580	1.3515	-0.3218	-0.0271	-1.4549
	200 Gy	-0.1075	-0.3314	**0.6482**	0.0420	0.1243	-0.0429	0.0082	0.0807	0.0182	0.0608	0.4308	0.0542	0.2684	0.1740
	300 Gy	0.0007	0.0131	**0.0517**	0.0041	-0.0241	-0.0270	-0.0383	-0.0297	-0.0229	-0.0020	0.0015	-0.0325	-0.6257	-0.0323
	400 Gy	-0.0126	-0.0284	**0.0698**	0.0286	-0.0243	-0.0319	-0.0207	-0.0093	-0.0129	-0.0549	0.0072	-0.0116	-0.4987	-0.0348
	0.1% EMS	-0.0280	0.0082	**0.2058**	0.1854	-0.0911	0.0015	0.0487	0.0814	-0.0545	-0.1125	0.0037	0.0227	-0.0788	-0.0162
	0.2 % EMS	0.0712	-0.0325	**0.0715**	-0.0012	0.0161	0.0500	0.0310	0.0213	0.0323	0.0281	-0.0124	-0.0426	0.4789	0.0343
	0.3% EMS	0.0486	-0.0060	**0.2432**	-0.0718	0.0198	-0.0952	-0.0332	-0.0817	-0.1300	0.1076	-0.0700	0.0095	-0.3639	-0.0885
	0.4% EMS	-0.1401	-0.1060	**0.3598**	0.0103	-0.1284	-0.0961	-0.0131	-0.1173	-0.0169	-0.0271	0.3473	0.0720	0.2581	0.0929
	200 Gy+0.1% EMS	0.2152	-0.0852	**-0.6046**	-0.1360	0.4722	0.4569	0.5859	0.3235	0.5261	-0.0562	-0.0180	0.0172	-0.7036	0.4253
	200 Gy + 0.2% EMS	-0.0889	-0.0205	**0.1907**	-0.0288	-0.1535	-0.0707	-0.0014	-0.1008	-0.0820	0.0503	0.0780	-0.0084	-0.4308	-0.0822
	300 Gy + 0.1% EMS	-0.8729	-0.7769	**2.5887**	-2.1576	0.3881	0.9417	0.5452	0.2702	0.2650	-0.1308	-1.5094	-0.4131	-0.6410	-1.6592
	300 Gy +0.2% EMS	-1.3152	2.4293	**3.6379**	1.7844	-0.3885	-0.4074	-2.5942	-2.5786	-3.3705	2.6490	4.0083	1.8092	-0.8962	-3.2601
	Dry control	0.2706	1.0407	**-1.7786**	-1.3334	-1.0892	-1.0901	-0.4460	-0.4389	-0.3093	0.7949	-0.8259	0.1300	0.2169	-0.3857
	Wet control	-0.0672	0.0116	**-0.1536**	-0.0877	0.1540	0.0933	0.0651	0.0053	0.1016	0.0925	-0.0883	0.0506	-0.7863	0.1208

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Days to maturity (Days)	100 Gy	13.7714	-3.6835	29.1135	**30.6770**	-18.8407	-13.8147	-8.3624	-13.9685	-19.4868	-5.9845	9.4815	-14.8946	-0.5476	-16.7985
	200 Gy	0.0308	0.1621	-0.0267	**-0.4127**	0.2701	0.2747	0.1809	0.1190	0.0000	0.2475	-0.0084	-0.1527	-0.6246	0.2578
	300 Gy	0.2243	-0.0462	0.0430	**0.5429**	-0.1645	-0.2494	-0.2328	-0.2527	-0.3519	0.1486	-0.1004	0.0429	-0.3617	-0.1964
	400 Gy	-0.1114	-0.0354	0.2355	**0.5750**	-0.2564	-0.2998	-0.4332	-0.2190	-0.1409	-0.4693	0.1581	-0.1448	-0.4502	-0.2589
	0.1% EMS	0.2185	0.6986	1.1105	**1.2329**	-1.0389	0.3752	-0.5757	-1.7111	-0.1693	-0.0145	-0.4585	-0.1224	0.4287	0.5286
	0.2 % EMS	-0.3487	-0.7076	0.0108	**-0.6666**	0.3883	0.2075	0.1698	0.2668	0.4073	-0.2480	0.0678	-0.1153	-0.4280	0.2853
	0.3% EMS	-0.0587	-0.0287	0.0160	**-0.0541**	-0.0010	-0.0008	-0.0089	-0.0228	-0.0178	-0.0544	0.0190	-0.0380	0.2339	-0.0127
	0.4% EMS	-0.0125	0.2172	0.0079	**0.2749**	-0.0292	-0.1414	0.0030	-0.2589	-0.1765	0.0002	0.0558	0.0071	-0.0716	-0.0197
	200 Gy+0.1% EMS	0.0466	-0.1634	-0.1352	**-0.6010**	0.3635	0.3456	0.4816	0.4795	0.5127	0.6605	0.1167	0.5072	-0.8938	0.5371
	200 Gy + 0.2% EMS	0.0265	-0.0131	-0.0046	**0.0307**	-0.0164	-0.0058	-0.0036	-0.0244	-0.0109	0.0027	0.0092	-0.0084	0.1422	0.0044
	300 Gy + 0.1% EMS	0.0139	-0.0396	0.2976	**-0.3571**	-0.0286	0.1932	0.0961	-0.0214	-0.2358	0.1278	0.1880	-0.1022	0.3524	-0.1258
	300 Gy +0.2% EMS	-0.1417	0.4233	0.8054	**1.6421**	0.5298	-0.2722	-0.7939	-0.5393	-0.4835	-0.3658	0.5326	0.3978	-0.2333	-0.3831
	Dry control	1.3634	-1.1410	1.7533	**2.3387**	1.0781	2.4867	1.9295	0.2747	-0.4575	-0.7648	1.5453	-1.4456	0.2596	0.6071
	Wet control	-0.2852	0.5099	-0.4259	**-0.7461**	0.6158	0.6016	0.6254	-0.2869	-0.0368	-0.0883	0.1568	0.5454	-0.5829	0.4349

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
No. of Primary branches per plant	100 Gy	3.9927	-4.4915	-37.3330	-24.3267	**39.6095**	32.4560	30.8015	18.4841	27.0148	9.7759	1.2822	-6.3161	0.9949	39.4084
	200 Gy	-0.0434	0.3418	0.3752	-1.2811	**1.9574**	1.7097	1.2228	0.8562	1.2341	0.8377	-0.2179	0.0614	0.5717	1.1190
	300 Gy	0.3622	0.4637	-0.5447	-0.3544	**1.1699**	1.1461	1.1650	0.7144	0.7485	-0.2435	0.1331	0.0017	0.8194	0.9587
	400 Gy	0.1260	-0.0397	0.0713	0.0911	**-0.2044**	-0.0624	0.0519	0.1028	0.0896	-0.0332	0.0439	-0.0107	-0.2696	0.0551
	0.1% EMS	-0.0045	0.0023	0.0101	0.0193	**-0.0229**	-0.0207	-0.0224	0.0250	-0.0043	0.0014	-0.0002	0.0095	0.0989	-0.0023
	0.2 % EMS	-0.1518	0.1401	-0.1106	0.2864	**-0.4916**	-0.5611	-0.4941	-0.2547	-0.3415	-0.3419	0.2484	0.1854	0.9739	-0.4788
	0.3% EMS	-0.2680	-0.4309	-0.0552	-0.0129	**-0.6782**	-0.2975	-0.3473	-0.6597	-0.6023	0.3593	-0.5228	-0.1018	0.5955	-0.4039
	0.4% EMS	-0.7824	-0.1933	0.2405	0.0715	**-0.6737**	-0.6922	-0.7579	-0.0359	0.1071	-0.4087	0.0831	0.0533	0.5902	-0.3976
	200 Gy+0.1% EMS	0.0346	0.0214	0.1254	0.0971	**-0.1606**	-0.1557	-0.1689	-0.1096	-0.1291	-0.1003	-0.0420	-0.0780	0.7909	-0.1270
	200 Gy + 0.2% EMS	-0.0285	0.0568	-0.1895	-0.1255	**0.2354**	0.2187	0.0845	0.0749	0.0567	0.1200	-0.0958	0.0178	0.5155	0.1213
	300 Gy + 0.1% EMS	-0.4650	-2.1469	0.7923	0.4234	**5.2849**	-0.8487	4.6567	-1.5418	-1.3126	5.4089	0.6148	3.7001	0.4941	2.6111
	300 Gy +0.2% EMS	-0.6067	-1.3473	0.1965	-0.5936	**-1.8396**	-1.6888	0.4317	-0.2557	-0.1350	1.0457	-0.7678	0.2506	0.2225	-0.4094
	Dry control	0.8079	-0.8617	-1.3825	-1.0406	**-2.2576**	-1.8735	-0.3432	-1.1365	-0.1575	1.6920	-1.1775	-0.3499	0.0841	-0.1899
	Wet control	0.0842	-0.1439	0.2602	0.2142	**-0.2596**	-0.1312	-0.2077	0.0412	0.0529	0.2389	-0.0911	-0.2184	0.3516	-0.0913

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant(g)	Partial R^2
No. of secondary branches per plant	100 Gy	-60.5907	-53.6747	-54.8279	64.6637	-117.6602	**-143.5930**	-143.3844	33.3573	5.1980	13.7590	78.3273	-14.2018	0.6405	-91.9723
	200 Gy	-0.0029	0.0621	-0.0160	-0.1605	0.2106	**0.2411**	0.1822	0.1115	0.1415	-0.0127	0.0784	0.0102	0.4627	0.1116
	300 Gy	-0.3986	-0.0924	0.7018	0.6174	-1.3166	**-1.3440**	-1.3034	-0.7491	-0.7880	0.4869	0.0240	0.1567	0.7412	-0.9961
	400 Gy	0.0796	0.0657	-0.5720	-0.6523	0.3821	**1.2511**	1.4301	0.3854	0.4882	1.0224	0.0533	0.5379	0.7402	0.9261
	0.1% EMS	-0.0059	-0.0026	0.0001	0.0060	0.0179	**0.0199**	0.0175	-0.0311	0.0040	-0.0079	0.0074	0.0035	0.5873	0.0117
	0.2 % EMS	0.1111	-0.0908	0.3606	-0.1606	0.5887	**0.5158**	0.5101	0.3429	0.3886	0.3863	-0.3933	-0.1532	0.6700	0.3456
	0.3% EMS	0.0497	0.0884	-0.0780	0.0028	0.0874	**0.1993**	0.2270	0.1152	0.1924	-0.1307	0.1365	-0.0354	1.0809	0.2155
	0.4% EMS	1.0167	-0.1144	-0.3235	-0.6226	1.2438	**1.2106**	0.9934	0.1577	0.0169	0.0367	-0.0072	-0.0273	0.4939	0.5979
	200 Gy+0.1% EMS	0.1730	0.0473	0.3783	0.2879	-0.4854	**-0.5006**	-0.4740	-0.2679	-0.3644	-0.2182	-0.0696	-0.1339	0.7894	-0.3952
	200 Gy + 0.2% EMS	-0.0777	0.0848	0.1630	0.0827	-0.4086	**-0.4397**	-0.3532	0.0657	-0.0091	-0.1757	0.1629	-0.0187	0.7394	-0.3252
	300 Gy + 0.1% EMS	-0.5709	0.0064	-0.7543	1.1219	0.3330	**-2.0735**	0.7748	1.5667	1.5626	-0.3684	0.6007	-1.0710	-0.5156	1.0691
	300 Gy +0.2% EMS	0.2663	1.1544	-0.3022	-0.4473	2.4775	**2.6989**	0.8495	1.0456	1.2983	0.1760	1.0952	-0.8273	0.8563	2.3111
	Dry control	-0.0010	0.0060	0.0100	0.0174	0.0136	**0.0164**	0.0146	0.0062	-0.0024	-0.0078	0.0020	0.0011	0.4458	0.0073
	Wet control	-0.1775	0.0593	-0.3352	-0.4449	0.2789	**0.5517**	0.5525	0.2378	0.0921	-0.3868	-0.0348	0.6075	0.8511	0.4695

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
No. of Capsule per Plant	100 Gy	4.3428	32.5526	34.8686	-21.9136	62.5126	80.2719	**80.3886**	-19.7266	-1.4426	-7.3806	-64.0254	13.2916	0.5202	41.815
	200 Gy	0.4773	-0.0130	-0.0272	0.9377	-1.3366	-1.6163	**-2.1397**	0.4837	-0.2057	-0.9299	0.4205	0.7872	0.6157	-1.3174
	300 Gy	0.0566	-0.0460	-0.6608	-0.3821	0.8874	0.8642	**0.8912**	0.6565	0.6447	0.1042	-0.0595	0.0179	0.9371	0.8351
	400 Gy	-0.0181	-0.1779	0.1606	0.4079	0.1374	-0.6189	**-0.5414**	-0.1070	-0.2642	-0.4418	-0.1030	-0.3827	0.9630	-0.5214
	0.1% EMS	-0.0399	0.0943	-0.0791	0.1559	-0.3265	-0.2947	**-0.3339**	0.5585	-0.1038	0.0981	-0.0611	0.1427	0.0467	-0.0156
	0.2 % EMS	0.2173	-0.1273	0.2768	-0.1628	0.6424	0.6321	**0.6392**	0.4363	0.4430	0.3013	-0.4615	-0.1737	0.7151	0.4571
	0.3% EMS	0.0704	0.5724	-0.1898	0.2285	0.7121	1.5831	**1.3903**	1.4235	1.7232	-0.9740	1.2850	-0.3836	1.1081	1.5405
	0.4% EMS	0.5110	0.0440	-0.0242	0.0073	0.7477	0.5453	**0.6646**	0.1408	0.0933	0.3468	-0.2124	-0.0839	0.5136	0.3413
	200 Gy+0.1% EMS	0.5110	0.0440	-0.0242	0.0073	0.7477	0.5453	**0.6646**	0.1408	0.0933	0.3468	0.0882	0.7499	0.8104	0.8475
	200 Gy + 0.2% EMS	-0.0774	0.0072	-0.0039	-0.0616	0.1876	0.4196	**0.5224**	-0.2749	-0.1042	0.3016	-0.3455	0.0596	0.5842	0.3052
	300 Gy + 0.1% EMS	-0.0244	0.2914	-0.1718	0.2285	-0.7480	0.3172	**-0.8489**	0.0632	-0.0546	-0.8518	0.0378	-0.3730	0.3189	-0.2707
	300 Gy +0.2% EMS	0.6174	-0.1011	-0.7173	-0.4863	-0.2361	0.3166	**1.0059**	0.7722	0.9282	-0.7209	-0.8620	-0.3296	0.6795	0.6835
	Dry control	-0.0014	-0.0012	0.0019	0.0062	0.0011	0.0067	**0.0075**	-0.0018	-0.0046	-0.0031	0.0007	0.0075	0.4217	0.0032
	Wet control	0.1849	-0.1063	0.1402	0.2775	-0.2649	-0.3315	**-0.3310**	0.0011	0.1201	0.5197	-0.0796	-0.3460	0.4850	-0.1605

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant(g)	Partial R^2
Diameter of head (cm)	100 Gy	-7.9402	6.0933	45.1139	30.1219	-30.8706	15.3675	16.2332	**-66.1524**	-53.5180	-29.0482	13.7457	-13.2862	0.5793	-38.3229
	200 Gy	0.0369	-0.3651	-0.1838	0.4259	-0.6460	-0.6829	0.3338	**-1.4767**	-1.4600	0.0260	-0.7054	-0.6417	0.6957	-1.0274
	300 Gy	-0.0484	-0.0086	-0.0709	-0.0574	0.0753	0.0688	0.0909	**0.1234**	0.1267	-0.0096	0.0282	-0.0192	0.9144	0.1128
	400 Gy	0.2214	-0.9246	-0.1712	-0.4896	-0.6462	0.3959	0.2539	**1.2852**	1.1682	1.3665	0.1355	-0.3210	0.8166	1.0494
	0.1% EMS	0.1681	-0.1198	-0.0350	0.1227	0.0967	0.1387	0.1479	**-0.0884**	-0.1017	0.0249	0.0073	0.1138	-0.0301	0.0027
	0.2 % EMS	0.0502	-0.0740	0.1251	-0.1679	0.2173	0.2789	0.2863	**0.4195**	0.3856	0.0566	-0.1186	-0.0620	0.5463	0.2292
	0.3% EMS	0.1218	-0.2937	-0.2561	0.3217	0.7413	0.4406	0.7804	**0.7621**	0.6283	-0.0555	0.7033	-0.0587	0.7766	0.5919
	0.4% EMS	-0.2503	0.3553	0.2158	0.6234	-0.0353	-0.0862	-0.1403	**-0.6618**	-0.6490	0.0082	0.1586	-0.0648	0.1904	-0.1260
	200 Gy+0.1% EMS	0.1171	-0.1062	-0.3069	-0.4577	0.3916	0.3069	0.5200	**0.5736**	0.6463	0.5399	-0.0274	0.5534	0.9687	0.5556
	200 Gy + 0.2% EMS	0.0086	0.0450	-0.0377	-0.0566	0.0227	-0.0106	-0.0375	**0.0712**	0.0782	-0.0142	-0.0251	0.0145	0.0909	0.0065
	300 Gy + 0.1% EMS	0.2222	0.4811	0.1447	0.0832	-0.4045	-1.0478	-0.1032	**1.3867**	1.5192	0.4765	-0.8717	-0.0657	0.1546	0.2143
	300 Gy +0.2% EMS	5.6438	-1.9129	-5.2591	-2.4366	1.0313	2.8746	5.6957	**7.4196**	8.1775	-5.4746	-5.6452	-3.6311	0.9137	6.7791
	Dry control	0.3203	2.5580	0.7247	0.3450	1.4787	1.1190	-0.7008	**2.9371**	2.9045	-1.0623	-0.3308	-0.7453	1.0269	3.0162
	Wet control	-0.0261	0.1334	0.0097	-0.1088	0.0449	-0.1220	0.0010	**-0.2830**	-0.2431	-0.3461	-0.0354	0.0341	0.5717	-0.1618

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
No. of seed per Capsule	100 Gy	-7.9839	-26.8403	48.4237	37.1089	-39.8431	2.1147	1.0483	-47.2611	**-58.4185**	-9.8887	21.4413	8.2564	0.5923	-34.6005
	200 Gy	-0.1023	-0.2243	0.0330	-0.0001	0.7401	0.6888	0.1129	1.1606	**1.1739**	-0.5097	1.0902	0.5083	0.6151	0.7220
	300 Gy	-0.7007	-0.1508	-0.6819	-0.9992	0.9863	0.9039	1.1152	1.5838	**1.5416**	-0.1494	0.2388	-0.2002	0.9662	1.4895
	400 Gy	-0.0875	1.0540	0.2156	0.2856	0.5112	-0.4549	-0.5689	-1.0596	**-1.1658**	-1.1479	-0.0917	0.2504	0.8487	-0.9894
	0.1% EMS	-0.0119	-0.0149	0.0086	0.0044	-0.0061	-0.0065	-0.0101	-0.0372	**-0.0324**	-0.0164	-0.0069	0.0097	0.6530	-0.0211
	0.2 % EMS	-0.0053	0.3794	-0.4082	0.5521	-0.6276	-0.6806	-0.6261	-0.8304	**-0.9035**	0.0960	0.0961	-0.0643	0.6895	-0.6229
	0.3% EMS	-0.1110	0.2597	0.1937	-0.1190	-0.3218	-0.3497	-0.4492	-0.2987	**-0.3624**	0.2455	-0.3541	0.1957	0.9581	-0.3472
	0.4% EMS	-0.1636	-0.8333	-0.0704	-0.9637	-0.2386	0.0210	0.2108	1.4721	**1.5012**	-0.0153	-0.5310	0.1109	0.4724	0.7091
	200 Gy+0.1% EMS	-0.0923	0.2359	0.7154	0.7014	-0.6610	-0.5985	-0.7399	-0.9264	**-0.8221**	-0.6065	-0.0241	-0.5440	0.9977	-0.8202
	200 Gy + 0.2% EMS	-0.0631	0.1976	-0.3434	-0.2845	0.1923	0.0165	-0.1592	0.8764	**0.7986**	0.1385	-0.0933	-0.2648	0.1702	0.1359
	300 Gy + 0.1% EMS	-0.2295	-0.4554	-0.1760	-1.1353	0.4270	1.2958	-0.1107	-1.8839	**-1.7195**	0.3980	1.5164	-0.0120	0.4169	-0.7168
	300 Gy +0.2% EMS	-2.2689	0.8650	2.4880	0.7906	-0.1970	-1.2918	-2.4779	-2.9596	**-2.6853**	2.0585	2.1061	1.9450	0.9412	-2.5275
	Dry control	-0.2984	-0.0751	-0.3833	0.4311	-0.1537	0.3266	1.3414	-2.1791	**-2.2036**	0.2828	1.6237	1.0491	0.7241	-1.5955
	Wet control	0.0407	-0.1232	-0.5297	0.0395	-0.1633	0.1337	-0.2905	0.6879	**0.8008**	0.8681	0.0705	0.0845	0.7484	0.5993

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
100 seed weight (g)	100 Gy	-28.7224	-12.9829	-14.9534	-16.0341	20.2854	-7.8756	-7.5461	36.0911	13.9129	**82.1913**	-12.0370	40.8198	0.3453	28.3843
	200 Gy	-0.0033	-0.0213	0.0072	-0.0459	0.0328	-0.0040	0.0333	-0.0013	-0.0332	**0.0765**	0.0037	-0.0464	0.6452	0.0494
	300 Gy	0.0290	0.1740	-0.0272	0.1909	-0.1452	-0.2526	0.0816	-0.0543	-0.0676	**0.6973**	0.0161	0.1790	0.1869	0.1303
	400 Gy	-0.0058	-0.0075	-0.0190	-0.0197	0.0039	0.0198	0.0197	0.0257	0.0238	**0.0242**	-0.0028	0.0083	1.0556	0.0255
	0.1% EMS	0.4575	0.3393	-0.3281	-0.0071	-0.0356	-0.2402	-0.1764	-0.1689	0.3032	**0.6004**	0.1943	-0.2943	0.1614	0.0969
	0.2 % EMS	-0.0129	-0.2265	-0.1206	-0.1141	-0.2134	-0.2297	-0.1446	-0.0414	0.0326	**-0.3068**	0.2039	0.0509	0.4071	-0.1249
	0.3% EMS	-0.0433	0.0052	-0.0553	-0.1257	0.0663	0.0820	0.0877	0.0091	0.0848	**-0.1251**	0.0241	-0.0945	-0.4451	0.0557
	0.4% EMS	-0.0042	-0.0140	0.0015	0.0000	-0.0119	-0.0006	-0.0102	0.0002	0.0002	**-0.0196**	-0.0069	0.0114	0.1499	-0.0029
	200 Gy+0.1% EMS	0.0823	-0.0497	0.0168	-0.1989	0.1131	0.0789	0.1038	0.1703	0.1335	**0.1810**	-0.0600	0.2036	0.8504	0.1539
	200 Gy + 0.2% EMS	-0.0278	-0.0039	0.0223	0.0075	0.0431	0.0338	0.0488	-0.0168	0.0147	**0.0846**	-0.0389	-0.0384	0.5303	0.0448
	300 Gy + 0.1% EMS	0.0052	0.1092	-0.0914	-0.6472	1.8506	0.3212	1.8143	0.6214	-0.4185	**1.8081**	0.9430	0.5525	0.5193	0.9390
	300 Gy +0.2% EMS	-0.2594	0.4155	-0.6265	0.1916	0.4890	-0.0561	0.6166	0.6348	0.6595	**-0.8603**	-0.2343	-0.6268	-0.7135	0.6139
	Dry control	-0.5282	-0.1133	0.2828	0.2070	0.4743	0.2998	0.2586	0.2289	0.0812	**-0.6329**	0.8872	-0.0380	-0.0853	0.0540
	Wet control	0.1481	-0.1253	-0.0468	0.0092	-0.0715	-0.0545	-0.1219	0.0950	0.0842	**0.0777**	-0.0633	-0.1881	0.8581	0.0666

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Hull content (%)	100 Gy	2.2620	-2.0186	0.0659	0.8080	0.0846	-1.4261	-2.0822	-0.5432	-0.9596	-0.3829	**2.6144**	-0.8824	-0.5528	-1.4452
	200 Gy	-0.0249	0.0515	0.1057	0.0033	-0.0177	0.0517	-0.0313	0.0760	0.1477	0.0077	**0.1591**	0.1088	0.6489	0.1032
	300 Gy	-0.0891	0.5479	0.0400	-0.2513	0.1547	-0.0243	-0.0908	0.3105	0.2105	0.0313	**1.3593**	-0.6979	0.0461	0.0626
	400 Gy	0.2237	-0.3196	0.0683	0.1825	-0.1425	0.0283	0.1263	0.0700	0.0522	-0.0780	**0.6638**	-0.0886	0.2968	0.1970
	0.1% EMS	-0.3769	-0.0222	0.0091	-0.1878	0.0043	0.1882	0.0925	0.7013	0.1072	0.1634	**0.5051**	-0.0621	-0.1170	-0.0591
	0.2 % EMS	-0.1782	0.1261	-0.0962	-0.0563	-0.2798	-0.4221	-0.3997	-0.1565	-0.0589	-0.3680	**0.5537**	-0.0741	-0.3362	-0.1862
	0.3% EMS	-0.0209	-0.0232	0.0340	0.0415	-0.0911	-0.0809	-0.1092	-0.1090	-0.1154	0.0227	**-0.1182**	0.0476	0.7327	-0.0866
	0.4% EMS	0.0290	0.0665	0.1720	0.0361	-0.0220	-0.0011	-0.0569	-0.0427	-0.0630	0.0630	**0.1781**	0.0099	0.0556	0.0099
	200 Gy+0.1% EMS	0.0213	-0.0124	0.0037	-0.0242	0.0326	0.0174	0.0105	-0.0060	0.0037	-0.0414	**0.1248**	0.0460	-0.1821	-0.0227
	200 Gy + 0.2% EMS	0.0098	0.0054	-0.0072	-0.0052	0.0071	0.0065	0.0116	0.0062	0.0020	0.0080	**-0.0175**	0.0065	-0.1747	0.0031
	300 Gy + 0.1% EMS	-0.5297	-0.1642	0.5625	0.5080	-0.1122	0.2795	0.0430	0.6064	0.8508	-0.5032	**-0.9647**	0.1282	-0.1171	0.1130
	300 Gy +0.2% EMS	2.5569	-2.6867	-5.1096	-1.5040	-1.9355	-1.8818	3.9739	3.5283	3.6371	-1.2627	**-4.6374**	0.4701	-0.4281	1.9853
	Dry control	-0.0117	0.0044	0.0220	0.0313	0.0247	0.0057	0.0041	-0.0053	-0.0349	-0.0664	**0.0473**	-0.0060	-0.5360	-0.0254
	Wet control	0.0389	-0.0094	0.0504	-0.0184	0.0307	-0.0055	0.0211	0.0109	0.0077	-0.0715	**0.0876**	0.0099	-0.0691	-0.0061

Continue

Character	Treatment	Plant height (Cm)	Days to rosette (Days)	Days to 50% flowering (Days)	Days to maturity (Days)	Primary Branches per plant	Secondary branches per plant	No. Of capsule /plant	Diameter of head (cm)	No. of seed / capsule	100 seed weight	Hull content (%)	Oil content (%)	Grain yield per plant (g)	Partial R^2
Oil content (%)	100 Gy	31.7563	25.5988	0.2790	22.5768	7.4147	-4.5989	-7.6883	-9.3390	6.5718	-23.0936	15.6949	**-46.4993**	0.3379	-15.7125
	200 Gy	0.0602	-0.1739	-0.1314	-0.5815	-0.0493	-0.0665	0.5780	-0.6828	-0.6803	0.9523	-1.0751	**-1.5712**	-0.0685	0.1076
	300 Gy	0.0608	-0.0806	-0.0998	0.0126	0.0002	-0.0185	0.0032	-0.0247	-0.0206	0.0408	-0.0816	**0.1589**	-0.0186	-0.0030
	400 Gy	0.0460	-0.0564	0.0302	0.0457	-0.0095	-0.0781	-0.1284	0.0454	0.0390	-0.0621	0.0242	**-0.1817**	0.1756	-0.0319
	0.1% EMS	0.0105	0.0861	-0.0348	0.0313	0.1310	-0.0556	0.1346	0.4053	0.0939	0.1544	0.0388	**-0.3150**	-0.2193	0.0691
	0.2 % EMS	0.3559	-0.2285	0.3242	-0.0942	0.2053	0.1617	0.1479	0.0805	-0.0387	0.0903	0.0728	**-0.5445**	-0.5664	0.3084
	0.3% EMS	-0.0064	-0.0033	-0.0004	-0.0078	-0.0017	0.0020	0.0031	0.0009	0.0060	-0.0084	0.0045	**-0.0111**	-0.1779	0.0020
	0.4% EMS	-0.0306	-0.0101	-0.0615	-0.0079	0.0243	0.0069	0.0388	-0.0301	-0.0227	0.1783	-0.0170	**-0.3073**	-0.3010	0.0925
	200 Gy+0.1% EMS	0.1945	-0.3544	-0.0156	-0.4606	0.2652	0.1460	0.3913	0.5265	0.3611	0.6139	0.2013	**0.5457**	0.7618	0.4158
	200 Gy + 0.2% EMS	0.1396	0.0131	0.0102	0.0634	-0.0174	-0.0098	-0.0263	-0.0468	0.0764	0.1047	0.0853	**-0.2304**	-0.3602	0.0830
	300 Gy + 0.1% EMS	1.5456	0.3846	0.3624	-0.6499	-1.5903	-1.1732	-0.9982	0.1076	-0.0158	-0.6941	0.3019	**-2.2715**	0.8783	-1.9951
	300 Gy +0.2% EMS	0.1346	-0.4499	0.4166	0.2029	-0.1141	-0.2568	-0.2745	-0.4100	-0.6068	0.6103	-0.0849	**0.8377**	-0.2409	-0.2018
	Dry control	0.6887	-0.4709	0.0686	0.5800	-0.1454	-0.0623	-0.9274	0.2381	0.4467	-0.0563	0.1184	**-0.9383**	0.1261	-0.1183
	Wet control	-0.0451	0.0506	-0.0188	-0.0417	0.0480	0.0629	0.0597	-0.0069	0.0060	-0.1382	0.0065	**0.0571**	0.5991	0.0342

11) Hull content

The genotypic path coefficients indicated high negative direct effect of hull content on seed yield per plant was recorded at all mutagenic treatments except 0.3% EMS, 200 Gy + 0.2% and 300 Gy + 0.2% EMS dose of combination treatments. The hull contenthas an indirect effecton seed yield per plant due todays to 50% flowering, days to maturity, primary branches per plantand diameter of head.Hull content had a negative connection and a negative direct effect on seed yield per plant in present study. This suggests that decreasing the hull content can increase seed yield. The findings are consistent with the results of Jawanjal *et. al.* (2006) in Safflower, Gopal *et. al.* (2014) in Safflower, Cerrotta *et. al.* (2020) in Safflower and Rathod *et. al.* (2021) in Safflower.

12) Oil content

The genotypic path coefficients showed high positive direct influence of oil content on seed yield per plant was recorded at 300 Gy, 200 Gy + 0.1% EMS and 300 Gy + 0.2% dose of combination treatments. The indirect effect of oil content on seed yield per plant through number of primary branches per plant, number of secondary branches per plant, number of capsule per plant and 100 seed. In the present study, oil content demonstrated positive correlation and positive direct effect on seed yield per plant. This reveals that improving seed yield can be accomplished by increasing oil content. The findings are consistent with the results of Sreenivasa *et. al.* (2011) in Safflower, Khalili *et. al.* (2013) in Safflower, Shivani *et. al.* (2011) in Safflower, Topal *et. al.* (2010) in safflower and Bhakre *et.al*. (2015) in Safflower.

4.2.7Isolation of desirable mutants in M_2 generation

Different mutagens, such as gamma rays, ethyl methane sulphonate and their combination generated various types of micro and macro mutations, which were obtained during M_2 generation after emergence and are presented in Table 39.

Various types of mutants were isolated from the mutagenic population in the M_2 generation, including dwarf, highly branched, large size capitula, bold seeded, high seed weight, early bolting, early flowering, early maturity, high oil content, high oleic acid, low linoleic acid and high seed yield per plant mutants. A total of 125 mutants were isolated from the M_2 generation and confirmed in the M_3 generation.

Eight dwarf mutants were isolated from the mutagenic population in M_2 generation, including T_2-7-12 (53 cm), T_3-10-20 (55 cm), T_4-8-12 (57 cm), T_6-5-16 (56 cm), T_8-3-2 (54 cm), T_{11}-8-13 (55 cm), T_{13}-2-9 (56 cm) and T_{13}-2-13 (58 cm) over control (69 cm). Rampure *et. al.* (2017) in Safflower, Julia *et. al.* (2018) in Indian mustard, Pavadai *et. al.* (2009) in Soybean, Cvejic *et. al.*(2011) in Sunflower, and Lande *et. al.* (2018) in Soybean previously explored similar mutants.

In the M_2 generation, eight highly branched mutants were isolated from the mutagenic population, including T_2-4-10 (47), T_2-3-5 (45), T_4-6-3 (42), T_7-9-11 (41), T_7-9-16 (40), T_8-5-5 (39), T_{10}-12-15 (44) and T_{10}-3-3 (42) over control (32). Similar types of mutant were identified previously by Rampure *et. al.* (2017) in Safflower, Lande *et. al.* (2018) in Soybean, Ravichandran and Jayakumar (2015) in Sesame and Cvejic *et. al.* (2011) in Sunflower.

In the M_2 generation, four large size capitula mutants were recovered from the mutagenic population, namely T_2-3-5 (3.8 cm), T_7-9-16 (3.7 cm), T_8-5-5 (3.8 cm), and T_{10}-12-15 (3.9 cm) over control (3.3 cm). Rampure *et. al.* (2017) reported similar mutants in Safflower and Singh and Singh (2018) found them in Sesame.

Eight bold seeded mutants *viz.*, T_2-8-13 (SW-5.82 mm, SL-10.92 mm) , T_2-4-10 (SW-5.75 mm, SL-10.84 mm), T_7-5-8 (SW-5.66 mm, SL-10.12 mm), T_4-5-14 (SW-5.92 mm, SL-10.94 mm), T_9-3-6 (SW-5.76 mm, SL-10.68 mm), T_{10}-3-3 (SW-5.93 mm, SL-10.86 mm), T_{10}-6-10 (SW-5.72 mm, SL-10.82 mm) and T_{12}-2-13 (SW-5.69 mm, SL-10.75 mm) over control (SW-3.92 mm, SL-8.96 mm) were isolated from mutagenic population in M_2 generation.Rampure *et. al.* (2017) reported similar mutants in safflower and Julia *et. al.* (2018) identified them in Indian mustard.

Six high test weight mutants were recovered from the mutagenic population in M_2 generation, namely T_2-8-13 (7.5 gm), T_6-4-6 (7.2 gm), T4-5-14 (9 gm), T_{10}-3-3 (7.9 gm), T_{10}-6-10 (8.3 gm) and T_{12}-2-13 (7.8 gm) over control (5.7 gm). Similar kinds of mutant were identified earlier by Rampure *et. al.* (2017) in Safflower, Channaoui *et. al.*(2019) in Rapeseed and Lande *et. al.* (2018) in Soybean.

In the M_2 generation, four early bolting mutants were isolated from the mutagenic population *viz.,* T_2-7-12 (35 days), T_3-10-20 (36 days), T_8-3-2 (36 days) and T11-8-13 (37 days) over control (43 days). Rampure et al. (2017) identified a similar type of mutation in Safflower.

Three early flowering mutants *viz.,* T_2-7-12 (62 days), T_{10}-6-18 (63 days) and T11-8-13 (64 days), were separated from the mutagenic population in M2 generation over control (78 days). Similar types of mutant were observed earlier by Rampure *et. al.* (2017) in Safflower, Cvejic *et. al.* (2011) in Sunflower, Channaoui *et. al.* (2019) in Rapeseed, Lande *et. al.* (2018) in Soybean, Singh and Singh (2018) in Sesame and Ahire *et. al.* (2005) in Soybean.

Three early maturity mutants were recovered from the mutagenic population in M2 generation, namely T_2-7-12 (107 days), T_{10}-6-18 (108 days), and T_{11}-8-13 (110 days) over control (124 days). Rampure *et. al.* (2017) in Safflower, Ahire *et. al.* (2005) in Soybean and Ahmed *et. al.* (2012) in Safflower had previously found similar sorts of mutant.

In the M_2 generation, four high oil content mutants were isolated from the mutagenic population *viz.,* T_2-2-3 (34.20 %), T_8-5-5 (32.50 %), T_9-3-6 (33.17 %) and T_{10}-3-3 (32.2 %) over control (29.54 %). Similar types of mutant were found earlier by Rampure *et. al.* (2017) in Safflower, Cvejic *et. al.* (2011) in Sunflower and Seeba *et. al.* (2003) in Sesame.

Four high oleic acid mutants *viz.,* T_2-12-13(18.26%), T_8-2-4 (18.04%), T_9-3-6 (18.20%) and T_{10}-9-10 (18.38%) over control (15.25%) were isolated from mutagenic population in M_2 generation. Similar types of mutant were observed earlier by Rampure *et. al.* (2017) in Safflower and Khadeer and Anwar (1991) in Safflower.

Three low linoleic acid mutants *viz.,* T_2-12-13 (72.17%),T_9-11-16 (70.62%) and T_{10}-9-10 (70.44%) over control (78.87%) were isolated from mutagenic population in M_2 generation. Similar types of mutant were observed earlier by Rampure *et. al.* (2017) in Safflower and Khadeer and Anwar (1991) in Safflower.

Similarly, fourteen high seed yield mutants *viz.,* T_2-7-12 (52.86 gm), T_{10}-6-18(51.53 gm), T_2-8-13 (52.36gm), T_{11}-8-13(48.13 gm), T_2-2-3(50.78 gm),T_8-5-5 (47.44 gm), T_9-3-6 (47.24),T_{10}-3-3(50.94 gm), T_{10}-9-10(49.64 gm), T_2-12-13 (50.27 gm), T_4-5-14(48.89 gm), T_6-4-6 (48.92 gm), T_{10}-6-10 (48.16 gm) and T_{12}-2-13(46.29 gm) over control (39.78 gm) were isolated from mutagenic population in M_2 generation. Similar types of mutant were observed earlier by Rampure *et. al.* (2017) in

Safflower, Khadeerand Anwar (1991) in Safflower, Ahire *et. al.* (2005) in Soybean and Ahmed *et. al.* (2012) in Safflower.

Table 4.39: Isolation of desirable mutants in M_2 generation

Sr. No.	Desirable characters	Control	Mutants
1	Dwarf mutant	69 cm	T_2-7-12 (53 cm), T_3-10-20 (55 cm), T_4-8-12 (57 cm), T_6-5-16 (56 cm), T_8-3-2 (54 cm), T_{11}-8-13 (55 cm), T_{13}-2-9 (56 cm), T_{13}-2-13 (58 cm).
2	Highly branched	32	T_2-4-10 (47), T_2-3-5 (45), T_4-6-3 (42),T_7-9-11 (41),T_7-9-16 (40), T_8-5-5(39), T_{10}-12-15 (44), T_{10}-3-3 (42).
3	Large size capitula	3.3 cm	T_2-3-5 (3.8 cm), T_7-9-16 (3.7 cm), T8-5-5 (3.8 cm), T_{10}-12-15 (3.9 cm).
4	Bold seeded	SW-3.92 mm SL-8.96 mm	T_2-8-13 (SW-5.82 mm, SL-10.92 mm), T_2-7-12 (SW-5.75 mm, SL-10.84 mm),T_7-5-8(SW-5.66 mm, SL-10.12 mm), T_4-5-14(SW-5.92 mm, SL-10.94 mm), T_9-3-6 (SW-5.76 mm, SL-10.68 mm), T_{10}-3-3(SW-5.93 mm, SL-10.86 mm), T_{10}-6-18 (SW-5.72 mm, SL-10.82 mm), T_{12}-2-13(SW-5.69 mm, SL-10.75 mm).
5	High test weight	5.7gm	T_2-8-13(7.5 gm), T_6-4-6 (7.2 gm), T_4-5-14 (9 gm) , T_{10}-3-3(7.9 gm), T_{10}-6-10 (8.3 gm),T_{12}-2-13 (7.8 gm)
6	Early bolting	43 days	T_2-7-12 (35 days), T_{10}-6-18 (36 days), T_8-3-2 (36 days), T_{11}-8-13 (37 days).
7	Early flowering	78 days	T_2-7-12 (62 days), T_{10}-6-18 (63 days), T_{11}-8-13(64 days).
8	Early maturing	124 days	T_2-7-12 (107 days), T_{10}-6-18 (108 days), T_{11}-8-13 (110 days)
9	High oil content	29.54%	T_2-2-3 (34.20%), T_8-5-5 (32.50 %), T_9-3-6(33.17%), T_{10}-3-3 (32.2%)
10	High oleic acid	15.25 %	T_2-12-13(18.26%), T_8-2-4(18.04%), T_9-3-6 (18.20%), T_{10}-9-10 (18.38%)
11	Low linoleic acid	76.87%	T_2-12-13 (72.17%), T_9-11-16 (70.62%),T_{10}-9-10 (70.44%)
12	High seed yield per plant	39.78 gm	T_2-7-12 (52.86 gm), T_{10}-6-18(51.53 gm), T_2-8-13 (52.36gm), T_{11}-8-13(48.13 gm), T_2-2-3(50.78 gm) T_8-5-5 (47.44 gm), T_9-3-6 (47.24),T_{10}-3-3(50.94 gm) T_{10}-9-10(49.64 gm), T_2-12-13(50.27 gm), T_4-5-14(48.89 gm), T_6-4-6 (48.92 gm), T_{10}-6-10 (48.16 gm), T_{12}-2-13(46.29 gm).

Where, T_1- 100 Gy, T_2- 200 Gy, T_3- 300 Gy, T_4-400 Gy, T_5-500 Gy, T_6- 0.1% EMS, T_7-0.2% EMS, T_8-0.3% EMS, T_9-0.4% EMS, T_{10}- 200 Gy+ 0.1% EMS, T_{11}-200 Gy +0.2% EMS, T_{12}- 300 Gy +0.1% EMS and T_{13}- 300 Gy+0.2% EMS mutagenic treatments.

4.2.7.1 High seed yield along with earliness mutants

Three earliness mutants *viz.,* T2-7-12, T10-6-18, and T11-8-13, were identified from the mutagenic population with high seed yields of 52.86 (g), 51.53 (g) and 48.13 (g) and earliness of 107 days, 108 days, and 110 days respectively over control (39.78 (g), 124 days). These finding are broad agreement with the findings of Ahmed*et. al.* (2012) in Safflower and Rampure *et. al.*(2017) in Safflower.

Table 4.40 High seed yield along with earliness mutants

Mutants	Seed yield per plant (gm)	Days to maturity (days)	Others yield contributing characters
T_2-7-12	52.86	107	DB (35 days), DFF (62days), PBP (19), SBP (41), NCP (40), NSC (34), 100 Seed weight (7.2 g), OC (29.76%)
T_{10}-6-18	51.53	108	DB (36 days), DFF (63 days) , PBP (17), SBP(42), NCP (41),NSC (32), 100 Seed weight (6.8 g), OC(30.12%)
T_{11}-8-13	48.13	110	DB (37 days), DFF (64 days), PBP (16), SBP (36), NCP (35), NSC (31), 100 Seed weight (6.5 g), OC (29.89%)
Control	39.78	124	DB (43 days), DFF (79 days), PBP (9), SBP (27), NCP (26), NSC (30), 100 Seed weight (5.7g), OC (29.54%)

Where, DB- days to bolting, DFF- days to 50% flowering, PBP- Number of primary branches per plant, SBP-Number of secondary branches per plant, NCP-Number of capsule per plant, NSC- Number of seeds per capsule and OC- oil content. And T_2-200 Gy, T_{10}-200 Gy+ 0.1% EMS and T_{11}- 200 Gy+ 0.2% EMS treatment.

4.2.7.2 High seed yield along with high oil content

Three high oil content mutants *viz.,* T2-2-3, T8-5-5, and T9-3-6, were developed from mutagenic population with high seed yields of 50.78 (g), 47.44 (g) and 47.24 (g) and high oil content of 34.20 %, 32.50 % and 33.17 %

correspondingly over control (39.78 (g), 29.54 %). These results are similar to those of Khadeer and Anwar (1991) in Safflower and Ragab *et. al.* (2008) in Safflower.

Table 4.41 High seed yield along with high oil content

Mutants	Seed yield per plant (gm)	Oil content (%)	Other yield contributing characters
T_2-2-3	50.78	34.20	PBP (16), SBP (35), NCP (34), NSC (37), DH (3.6 cm), 100 Seed weight (6.6 g), OA (15.67%), LA (77.24%)
T_8-5-5	47.44	32.50	PBP (14), SBP (39), NCP (32), NSC (36), DH (3.8 cm), 100 Seed weight (6.2 g), OA (16.04%), LA (76.04%)
T_9-3-6	47.24	33.17	PBP (14), SBP (33), NCP (32), NSC (39), DH (3.5 cm), 100 Seed weight (6.3 g), OA (18.20%), LA (72.61%)
Control	39.78	29.54	PBP (9), SBP (27), NCP (26), NSC (30), DH (3.3 cm) 100 Seed weight (5.7g), OA (15.25 %), LA (76.87%)

Where, PBP- Number of primary branches per plant, SBP-Number of secondary branches per plant, NCP- Number of capsule per plant, NSC- Number of seeds per capsule, DH- Diameter of head, OA- oleic acid and LA- Linoleic acid. And T_2-200 Gy, T_8- 0.3% EMS and T_9- 0.4% EMS treatment.

4.2.7.3 High seed yield along with high oleic acid

In M_2 generation, two high oleic acid mutants *viz.*, T_2-12-13, T_{10}-9-10 and T_9-3-6were identified from the mutagenic population, with high seed yields of 50.27 (g), 49.64 (g) and 47.24(g) and high oleic acid of 18.26 %, 18.38 % and 18.20% respectively over control (39.78 (g), 15.25 %). These finding are broad agreement with the findings of Khadeer and Anwar (1991) in Safflower and Rampure *et. al.* (2015) in Safflower.

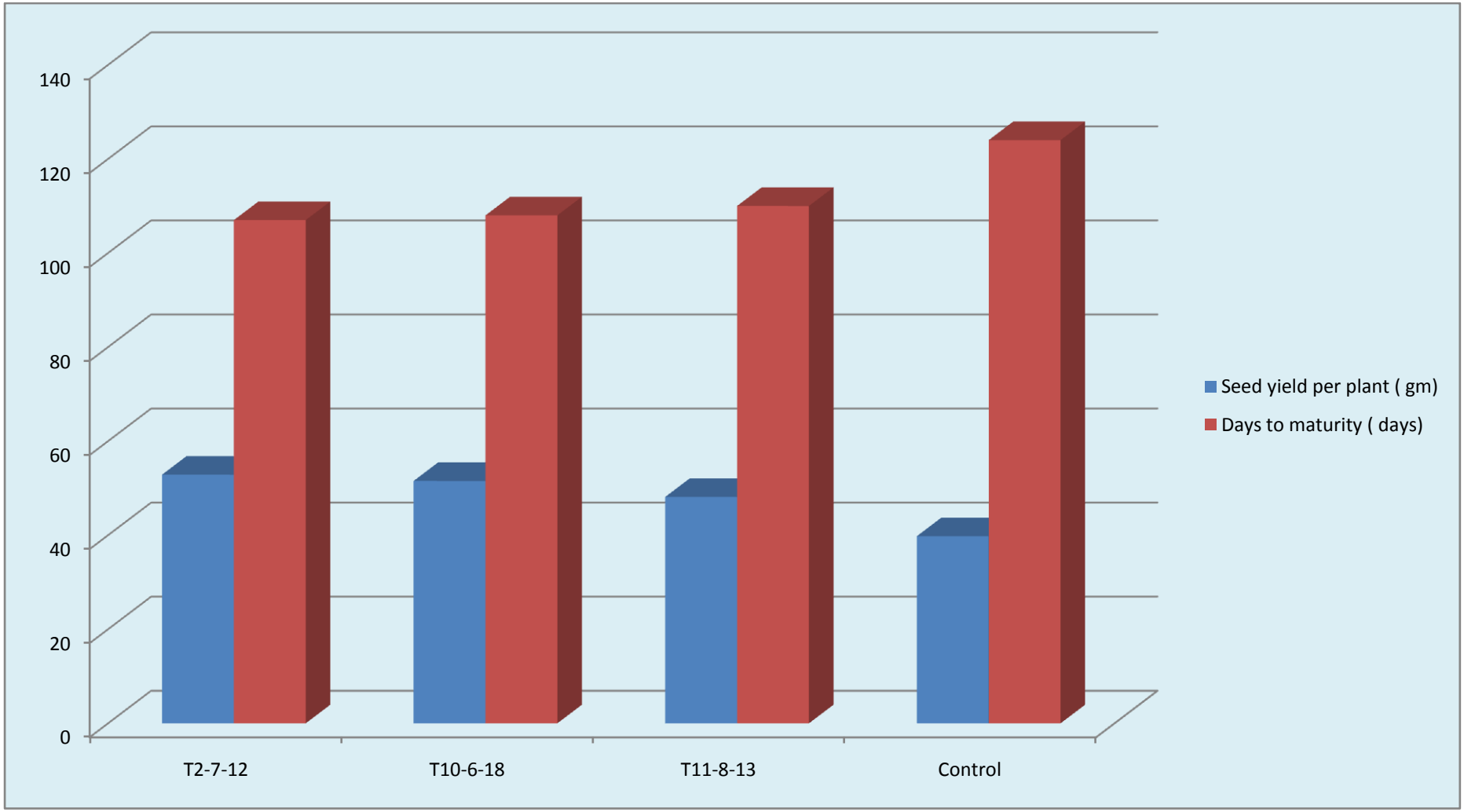


Figure 4.4: High seed yield per plant along with earliness mutants in M_2 generation

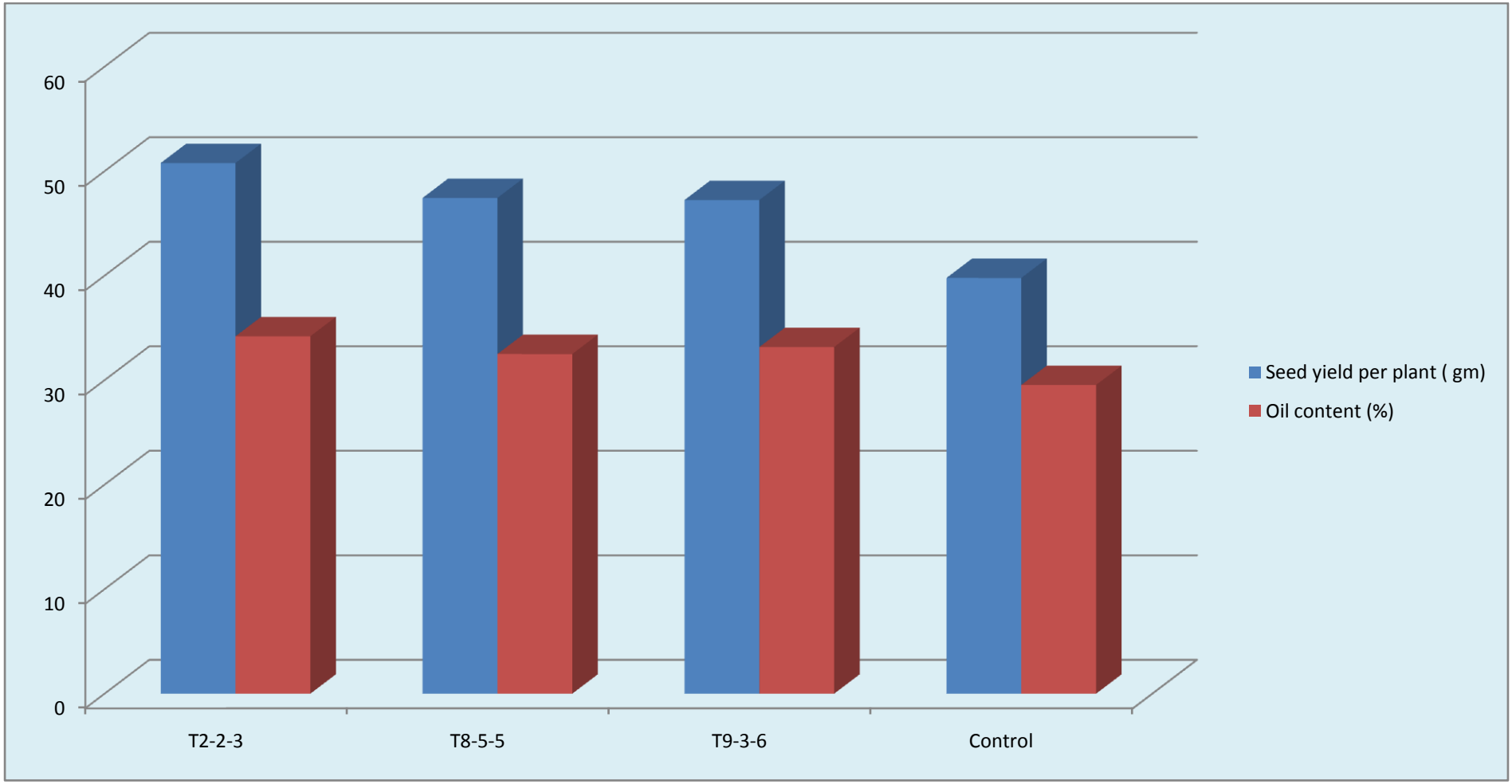


Figure 4.5: High seed yield per plant along with high oil content mutants in M_2 generation.

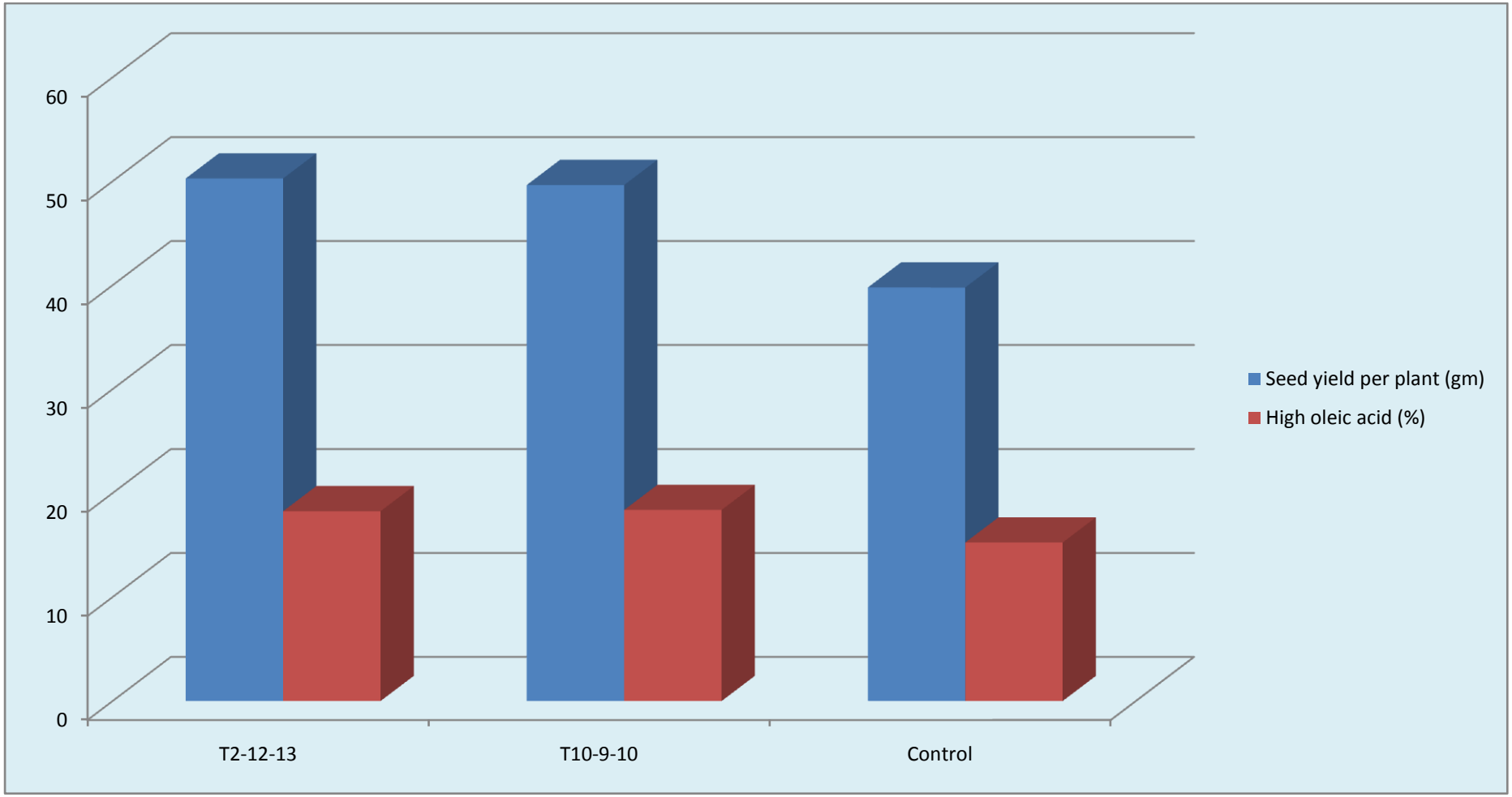


Figure 4.6: High Seed yield per plant along with high oleic acid content mutants in M_2 generation.

Table 4.42 High seed yield along with high oleic acid

Mutants	Seed yield per plant (gm)	High oleic acid (%)	Other yield contributing characters
T_2-12-13	50.27	18.26	PBP (15), SBP (35), NCP (35), NSC (38), DH (3.4 cm) 100 Seed weight (7.0 g), OC (30.08 %), LA (72.17%)
T_{10}-9-10	49.64	18.38	PBP (16), SBP (33), NCP (32), NSC (39), DH (3.4 cm) 100 Seed weight (6.7g), OC (30.23%), LA (70.44%)
T_9-3-6	47.24	18.20	PBP (11), SBP (31), NCP (30), NSC (35), DH (3.5 cm) 100 Seed weight (6.4g), OC (33.17%), LA (74.55%)
Control	39.78	15.25	PBP (9), SBP (27), NCP (29), NSC (30), DH (3.3 cm) 100 Seed weight (5.7g), OC (29.54 %), LA (76.87%)

Where, PBP- Number of primary branches per plant, SBP-Number of secondary branches per plant, NCP- Number of capsule per plant, NSC- Number of seeds per capsule, DH- Diameter of head, OC- oil content and LA- Linoleic acid. And T_2-200 Gy, T_9- 0.4% EMS and T_{10}- 200 Gy + 0.1% EMS treatment.

5.2.8 Future line of work

1. Induced mutations are important for enhancing genetic variability in economically important traits. As a result, mutant breeding approaches should be utilized to fine-tune the popular variety for one or two flaws.
2. Earliness and other desirable character mutants were isolated in M_2 generation and are grown in M_3 generation for confirmation.
3. In the majority of mutant populations originating from comprehensive studies of complex quantitative features, it is frequently identified that the mutants have a wide range of agroclimatic adaptation. This can be proven by calculating the per se performance of these mutants in a variety of environmentsfor their stability and superiority.

4. In order to use PBNS-12 mutants in breeding trials, further confirmation of earliness and other desirable traits in advanced generations is required.
5. Complementation tests can be used to work out the genetics and inheritance pattern of early and high oil content mutants, which can then be used in cross breeding programs.
6. By developing mapping populations involving varied mutants and higher yielding homozygous genotypes, these mutants can be significant genetic resources for molecular investigations.

CHAPTER-V

SUMMARY AND CONCLUSIONS

CHAPTER-V

SUMMARY AND CONCLUSIONS

In the present investigation an attempt was made to create desirable variability through mutagens to improve seed yield and its components characters in safflower. The present investigation entitled "Genetic improvement of safflower (*Carthamus tinctorius* L.) through induced mutation" was undertaken to estimate variability, heritability, correlation and path analysis in safflower crop and also was aimed at elucidating information mainly on the sensitivity of safflower variety PBNS-12 to gamma irradiation, EMS treatments and their combination, the nature of induced mutations in general and polygenic mutations in particular and the effect of mutagens on character association in mutant populations, Screening of the mutant populations was also carried out to identify the desirable mutants for both qualitative and quantitative traits including earliness and high oleic acid. In order to induce desirable variability, the experimental material used for this study consisted of a well adapted and popular variety of safflower (*Carthamus tinctorius* L.), PBNS-12 (Parbhani Kusum) for mutagenic treatments. The seeds of PBNS-12 were exposed to irradiation and chemical treatments and were used to evaluate in M_1 and subsequent M_2 generation at All India coordinated research project on safflower, Vasantrao Naik Maratwada Krishi Vidyapeeth, Parbhani during *Rabi* 2019-20 (M_1 generation) and *Rabi* 2020-21 (M_2 generation) respectively.

The pure, dry and well filled seeds of variety PBNS-12 were treated with five doses of gamma rays *viz.,* 100 Gy, 200 Gy, 300 Gy, 400 Gy and 500 Gy, four EMS *viz.,* 0.1%EMS, 0.2%EMS, 0.3%EMS and 0.4%EMS and their combinations treatments. Seed emergence, plant survival and pollen fertility were all reduced in dose-dependent ways in the M_1 generation, according to the observations on mutagenesis effects. When comparing gamma irradiated populations to EMS and their combination treatments, the mutagen damage measure for emergence and plant survival was more pronounced in gamma irradiated populations. In the case of gamma ray treatments, the LD_{50} dose was 299.5 Gy, while in the case of EMS treatments, it was 0.2536 percent. The LD_{50} dose of gamma rays radiation between 250 to 350 Gy and 0.2 to 0.3 % EMS concentrations were proven to be appropriate for mutagenic treatments applied to the safflower variety PBNS-12.

Chlorophyll mutation frequency in the safflower variety PBNS-12, was expressed on M_2 seedling basis. The frequency of chlorophyll mutation (0.11%) was recorded in 0.3% EMS concentration treatment. The spectrum of chlorophyll mutations comprised albina, xantha, viridis, xanthaviridis, chlorina. In the M_2 generation, a single xantha type chlorophyll mutant was detected at 0.3 % EMS concentration.

Lower or intermediate doses were shown to be more effective and efficient than higher doses in both the mutagens and their combination treatments, while gamma rays were found to be more effective and efficient than EMS and combination treatments.

Across all mutagenic populations, the M_2 seedling-based assessment of viable mutation frequency showed a dose-dependent rise in mutation frequency. The frequency of viable mutations was higher in combination treatments than in gamma rays and EMS concentration treatments. The combined mutagenic treatments produced a larger spectrum of viable mutations in the safflower variety PBNS-12 than gamma rays and EMS mutagenic treatments alone.

Mutagenic treatments resulted in a broad range of viable mutations with both academic and practical significance. The spectrum of viable mutations revealed that mutagenic treatments with gamma rays, EMS and their combination resulted in alterations affecting plant habit, leaf morphology, seed and oil properties. Bold seeded varieties with high oil content may be especially helpful.

In general, wide range of variation was observed for most of the traits in M_2 generation. However, there was significant reduction in the mean for plant height (in some M_2 generation populations); days to rosette (200 Gy and 200 Gy + 0.1% EMS dose of combination treatments) , days to bolting (200 Gy and 200 Gy + 0.1% EMS dose of combination treatments), days to 50% flowering (in 200 Gy and 200 Gy + 0.1% EMS dose of combination treatments in M_2 generation); days to maturity (200 Gy and 200 Gy + 0.1% EMS dose of combination treatments), hull content (200 Gy and 0.4% EMS concentration treatments), Linoleic acid (0.4% EMS and 200 Gy + 0.1% EMS dose of combination treatments) and seed yield (in some M_2 generation population). Significant increase in the mean for number of primary branches per plant (200 Gy and 200 Gy + 0.1% EMS dose of combination treatments); number of

secondary branches per plant (200 Gy and 200 Gy + 0.1% EMS dose of combination treatments); number of capsule per plant (200 Gy and 200 Gy + 0.1% EMS dose of combination treatments), diameter of head (200 Gy and 200 Gy + 0.1% EMS dose of combination treatments), number of seeds per capsule(200 Gy and 200 Gy + 0.1% EMS dose of combination treatments), 100 seed weight (200 Gy and 200 Gy + 0.1% EMS dose of combination treatments), Seed length (in some M_2 generation population); Seed width (in some population of M_2 generation); oil content (200 Gy, 0.3% EMS and 0.4% EMS concentration treatments); oleic acid content (200 Gy, 0.4% EMS and 200 Gy + 0.1% EMS dose of combination treatments) and seed yield (in some M_2 generation populations).

Although there was no change in mean of some populations for various quantitative characters, variability increased considerably with almost all the treatments compared to control. Induced variability indicated that significant improvement can be achieved by proper selection techniques.

Analysis of variance in M_2 generation indicated highly significant differences between populations.

Studies on effect of mutagens on character associations indicated that mutagens were responsible for enhancing, reducing or altering some of the correlations compared to control populations in all the genotypes and thus provides an opportunity to improve yield by selection for those characters which have shown enhanced correlations with yield *viz*., number of seeds per capsule, number of primary branches per plant, number of capsule per plant, 100 seed weight in safflower.

The effect of mutagens on path coefficient indicated that mutagens were also responsible for changing the direct and indirect effects of components traits on yield compared to control populations. It also revealed that number of primary branches per plant exerted maximum direct effects as well as indirect effects on seed yield in most of the populations thus indicating numbers of primary branches per plant, number of secondary branches per plant, number of capsule per plant, 100 seed weight as the most important yield contributing traits in safflower.

From the present investigation, 125 putative mutants were identified as relatively better performers with respect to yield and yield related characters,

earliness, oil content and high oleic acid content. It is suggested to grown in M_3 generation for confirming their potentiality.

Conclusions

1. Combination mutagenic treatments were shown to produce higher variability than irradiated and chemically treated populations in the current study.

2. The majority of characters had high PCV, GCV, Heritability and Genetic Advance, indicating that genetic factors govern most of the characters and that they are extremely sensitive to the environment.

3. Correlation studies revealed a significant and positive relationship between plant height, number of primary branches per plant, number of secondary branches per plant, number of capsules per plant and 100 seed weight with seed yield per plant in all populations treated with 200 Gy gamma rays, 0.2% EMS, 200 Gy +0.1 % EMS and 300 Gy+0.1 % EMS combination treatment.

4. Path analysis revealed high positive direct effect of plant height, numbers of primary branches per plant , number of secondary branches per plant , number of capsule per plant , 100 seed weight with seed yield per plant in 200 Gy gamma rays , 200 Gy +0.1%EMS, 300 Gy+0.2%EMS and 0.2 % EMS for all the populations.

5. The putative mutants *viz;* T_2-7-12, T_{10}-6-18 and T_{10}-6-18 were identified as high seed yielders along with earliness.

6. The putative mutants *viz;* T_2-2-3 and T_{10}-9-10 were identified as high seed yielders with high oil content.

7. The putative mutants *viz;* T_2-12-13, T_8-5-5 and T_9-3-6 were identified as high seed yielders possessing high oleic acid.

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APPENDIX

APPENDIX-I

Weekly average meteorological data during field experiment for the year 2019-20 at Parbhani

WK	Period	RF	Temperature oC		Humidity (%)		EVP (mm)	BSS (Hrs.)	WS (Kmph)
			Max	Min	RH1	RH2			
1	1-7 Jan.	0.0	30.4	7.9	75	19	4.2	9.2	2.5
2	8-14 Jan.	0.0	29.5	9.5	76	28	4.4	8.6	2.8
3	15-21 Jan.	0.0	31.0	11.0	77	25	4.4	8.4	2.7
4	22-28 Jan.	0.0	30.1	13.8	75	37	4.8	6.5	4.4
5	29-4 Feb.	0.0	29.4	10.7	76	22	5.2	8.9	4.4
6	5-11 Feb.	0.0	30.8	9.8	73	20	5.5	9.2	4.3
7	12-18 Feb.	0.0	33.7	13.1	73	21	6.0	8.7	4.6
8	19-25 Feb.	0.0	36.4	16.2	70	19	6.9	9.4	3.9
9	26-4 Mar	0.0	29.9	12.5	55	15	6.8	8.4	4.1
10	5-11 Mar.	0.0	35.5	14.9	65	15	7.8	9.6	3.9
11	12-18 Mar.	0.0	38.1	18.8	63	15	9.5	9.2	4.3
12	19-25 Mar.	0.0	38.8	18.9	52	19	10.5	9.3	4.0
13	26-1 Apr.	0.0	41.1	19.9	51	16	11.4	9.3	3.9
14	2-8 Apr.	0.0	40.9	21.3	40	12	12.1	8.6	4.6
15	9-15 Apr.	1.6	42.0	22.2	38	9	11.8	9.6	4.5
16	16-22 Apr.	0.0	39.3	21.4	40	14	9.4	9.3	4.4
17	23-29 Apr.	0.0	43.9	24.5	36	8	13.6	9.3	5.1
18	30-6 May	0.0	41.6	24.2	39	11	13.3	9.8	6.1
19	7-13 May	0.0	41.8	26.1	35	14	13.6	9.7	6.4
20	14-20 May	0.0	42.4	24.8	41	12	13.3	10.3	5.3
21	21-27 May	0.0	44.1	27.1	38	14	14.1	10.3	5.4
22	28-3 Jun.	0.0	43.9	28.7	36	14	14.6	8.6	5.9
23	4-10 Jun.	33.7	40.9	24.8	76	24	8.5	5.9	6.8
24	11-17 Jun.	0.0	39.3	25.2	62	30	10.4	9.8	7.9
25	18-24 Jun.	10.5	35.3	24.7	69	48	8.6	6.4	7.3
26	25-1 Jul.	46.9	33.2	22.7	85	59	4.9	4.8	5.6
27	2-8 Jul.	10.6	33.2	23.1	76	58	5.1	2.7	8.3
28	9-15 Jul.	34.2	33.5	22.6	83	49	5.5	6.7	7.0
29	16-22 Jul.	11.2	34.2	22.9	79	46	6.6	7.7	5.8
30	23-29 Jul.	64.3	30.6	22.6	81	62	4.5	4.1	6.3
31	30-5 Aug.	85.4	28.1	21.8	92	85	2.1	1.2	6.6

Contd…

WK	Period	RF	Temperature oC		Humidity (%)		EVP (mm)	BSS (Hrs.)	WS (Kmph)
			Max	Min	RH1	RH2			
32	6-12 Aug.	62.2	30.5	22.0	89	65	4.0	3.5	6.2
33	13-19 Aug.	9.7	32.3	21.5	80	57	4.6	5.4	4.6
34	20-26 Aug.	1.2	32.2	22.0	80	56	5.6	6.5	6.0
35	27-2 Sept.	78.0	31.2	21.5	88	59	4.6	5.6	4.7
36	3-9 Sept.	13.2	30.1	21.6	83	70	2.9	2.0	4.7
37	10-16 Sept.	86.4	30.0	21.2	88	68	2.8	4.7	5.4
38	17-23 Sept.	118.8	30.9	21.9	94	67	2.3	5.1	3.5
39	24-30 Sept.	35.6	31.3	21.1	92	62	3.7	6.5	3.3
40	1-7 Oct.	21.2	31.4	20.5	88	60	3.8	7.3	2.8
41	8-14 Oct.	5.1	31.5	20.1	87	53	4.1	7.0	2.7
42	15-21 Oct.	121.4	30.1	18.6	82	55	3.5	5.9	4.1
43	22-28 Oct.	100.0	29.7	20.6	82	63	2.4	4.3	3.6
44	29-04 Nov.	13.0	30.4	20.7	84	62	3.2	6.9	3.8
45	5-11 Nov.	0.0	31.4	18.4	89	48	3.4	8.6	1.6
46	12-18 Nov.	0.0	30.0	14.7	77	45	3.7	8.3	2.7
47	19-25 Nov.	0.0	30.0	13.2	81	44	3.4	8.5	2.1
48	26-02 Dec.	0.0	30.1	15.4	80	46	3.8	7.9	2.6
49	3-9 Dec.	0.0	28.9	14.8	76.3	46.4	4.2	7.4	3.5
50	10-16 Dec	0.0	30.0	15.6	86.4	44.3	3.6	7.1	2.5
51	17-23 Dec	0.0	28.3	14.9	88.3	44.6	3.3	6.1	2.9
52	24-30 Dec	1.4	26.2	15.2	81.1	49.0	2.7	3.0	4.1

APPENDIX-II

Weekly average meteorological data during field experiment for the year 2020-21 at Parbhani

WK	Period	RF	Temperature oC		Humidity (%)		EVP (mm)	BSS (Hrs.)	WS (Kmph)
			Max	Min	RH1	RH2			
1	1-7 Jan.	3.40	27.00	14.99	83	52	2.66	5.67	4.07
2	8-14 Jan.	0.00	27.99	12.87	78	43	3.31	6.86	3.37
3	15-21 Jan.	0.00	29.03	13.94	78	42	3.24	7.84	3.40
4	22-28 Jan.	0.00	31.20	13.79	81	33	4.11	8.89	3.10
5	29-4 Feb.	1.30	28.87	13.73	77	40	4.30	8.09	5.16
6	5-11 Feb.	0.00	28.57	16.51	75	50	3.54	5.56	5.11
7	12-18 Feb.	0.00	31.54	13.06	78	31	4.97	8.81	3.63
8	19-25 Feb.	0.00	33.59	14.34	78	24	7.00	9.54	3.70
9	26-4 Mar	0.00	32.96	12.25	66	24	6.08	8.04	3.25
10	5-11 Mar.	9.00	32.93	15.94	75	30	7.66	8.87	4.17
11	12-18 Mar.	2.80	34.30	17.77	67	27	7.31	9.24	4.10
12	19-25 Mar.	8.80	35.33	16.84	71	23	6.97	9.16	3.67
13	26-1 Apr.	36.80	37.14	20.53	74	25	7.50	9.07	5.46
14	2-8 Apr.	0.00	37.67	20.56	70	25	3.80	9.74	3.80
15	9-15 Apr.	0.00	39.13	20.04	61	18	3.76	9.76	3.76
16	16-22 Apr.	0.00	40.43	23.44	54	17	9.31	9.60	3.89
17	23-29 Apr.	0.00	40.40	21.73	55	19	9.70	10.73	4.54
18	30-6 May	0.00	41.37	22.93	51	18	10.57	10.13	4.16
19	7-13 May	0.00	40.83	24.86	46	17	12.77	10.14	4.97
20	14-20 May	13.00	40.39	24.86	62	24	9.27	6.96	5.03
21	21-27 May	0.00	43.73	24.61	48	15	12.69	10.33	5.37
22	28-3 Jun.	13.60	38.79	25.71	56	31	12.30	9.63	6.50
23	4-10 Jun.	5.00	36.06	23.30	71	36	8.84	8.19	7.63
24	11-17 Jun.	148.00	31.99	23.39	85	64	3.57	4.11	4.99
25	18-24 Jun.	9.20	33.07	23.71	84	61	3.74	3.49	5.54
26	25-1 Jul.	23.70	34.53	23.97	87	54	5.19	7.23	4.09
27	2-8 Jul.	63.00	32.46	23.43	85	68	4.10	4.81	4.71
28	9-15 Jul.	103.40	32.54	23.00	84	61	3.73	6.50	4.14
29	16-22 Jul.	31.40	31.14	22.86	85	72	3.81	4.81	3.47
30	23-29 Jul.	30.10	31.37	22.87	84	64	3.97	6.40	2.97
31	30-5 Aug.	36.10	31.93	23.11	80	67	4.10	6.40	2.81

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WK	Period	RF	Temperature oC		Humidity (%)		EVP (mm)	BSS (Hrs.)	WS (Kmph)
			Max	Min	RH1	RH2			
32	6-12 Aug.	29.20	30.60	22.51	86	68	3.70	3.94	4.26
33	13-19 Aug.	42.50	27.83	22.03	94	82	1.46	0.40	3.99
34	20-26 Aug.	28.80	30.20	21.71	92	70	2.11	3.57	3.44
35	27-2 Sept.	24.20	31.13	21.63	91	64	3.29	5.87	3.59
36	3-9 Sept.	19.80	33.56	22.11	86	54	4.91	8.09	2.80
37	10-16 Sept.	53.20	31.80	22.23	91	64	3.67	5.83	3.14
38	17-23 Sept.	198.20	31.16	22.27	95	75	2.00	2.71	3.07
39	24-30 Sept.	47.20	30.40	22.07	90	64	3.21	3.96	3.13
40	1-7 Oct.	17.00	33.37	21.00	90	49	4.91	7.47	3.89
41	8-14 Oct.	85.60	31.33	21.74	89	66	3.39	4.64	2.63
42	15-21 Oct.	8.00	31.53	21.94	77	51	3.54	5.67	4.17
43	22-28 Oct.	6.40	32.00	20.70	90	47	3.73	6.14	2.53
44	29-04 Nov.	0.00	32.46	15.59	100	36	4.84	9.16	1.86
45	5-11 Nov.	0.00	31.00	10.94	85	22	5.31	9.20	2.80
46	12-18 Nov.	0.00	31.97	14.84	84	35	4.76	9.26	3.06
47	19-25 Nov.	0.00	32.20	17.19	83	43	4.17	8.24	2.51
48	26-02 Dec.	0.00	29.71	15.16	80	41	4.67	6.64	4.80
49	3-9 Dec.	0.00	31.03	9.19	87	27	4.77	9.31	2.86
50	10-16 Dec	0.00	30.34	14.81	83	35	4.09	7.19	2.77
51	17-23 Dec	0.00	28.76	10.17	89	36	3.99	7.93	2.90
52	24-30 Dec	0.00	32.73	10.81	98	38	4.44	9.31	2.79

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