# EFFECT OF GAMMA IRRADIATION ON FEW IMPORTANT TRAITS OF SELECTED INBREDS OF SUNFLOWER (*Helianthus annuus* L.)

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**JULY, 2011**

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*Thesis submitted to the*
*University of Agricultural Sciences, Raichur*
*in partial fulfillment of the requirement for the*
*Degree of*

**Master of Science (Agriculture)**

**in**

**GENETICS AND PLANT BREEDING**

**By**

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# CERTIFICATE

This is to certify that the thesis entitled **"EFFECT OF GAMMA IRRADIATION ON FEW IMPORTANT TRAITS OF SELECTED INBREDS OF SUNFLOWER (*Helianthus annuus* L.)"** submitted by **Mr. CHETANKUMAR BANAKAR** for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **GENETICS AND PLANT BREEDING** to the University of Agricultural Sciences, Raichur, is a record of research work carried out by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar titles.

**Place: RAICHUR**
**Date: JULY, 2011**

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**4.** _____
**(BASAVE GOUDA)**

*Affectionately Dedicated*
*To*

*Beloved Grand fathers*
*Late Shri. P. N. Banakar,*
*Late Shri. N. V. Tippanagoudar*
*and*
*My Parents, Brothers and Sisters*

## *ACKNOWLEDGEMENT*

***With regards to sweet memories……***

*Any tedious task is made light and smooth by God's grace. At this moment, I would remember 'the almightily god', who has made each impossible work a reality in my life. The fruit of which, I am expressing here.*

*I recall the words of* ***Dr. I. SHANKER GOUD,*** *Associate Director Of Research (ADR) and Principal Scientist and Head (Breeding), AICRP on Sunflower, Main Agricultural Research Station, Raichur, University of Agricultural Sciences, Raichur and Chairman of my Advisory Committee for suggesting need based research, thought provoking discussion, invaluable inspiring guidance, sustained interest, and constructive criticism during the course of investigation.*

*The moral zeal and constant assurance at every count bestowed by members of my advisory committee* ***Dr. R. Lokesha,*** *Professor and Head, Department of Genetics and Plant Breeding, AC, Raichur,* ***Dr. C. R. Konda,*** *Senior Scientist (Breeding), Main Agricultural Research Station, Raichur,* ***Prof. Somasekhar,*** *Scientist (Entomology), Main Agricultural Research Station, Raichur,* ***Dr. Basave Gowda,*** *Seed Officer, Seed Unit, UAS., Raichur for their sensible criticism during the period of my investigation. Their timely suggestions from the beginning of this investigation, valuable counsel and keen interest have helped me to shape this manuscript in the present form.*

*My genuine gratitude to our teacher* ***Dr. Vikas Kulkarni,*** *Scientist (Breeding), MARS, Raichur, and My friends* ***Raghunath, Amasidda, Chari*** *and* ***Umesh*** *for their kind help at time.*

*I avail this opportunity to express my sincere gratitude to the teachers of Department of Genetics and Plant Breeding, Dr. J. R. Diwan, Smt. Suvarna, Dr. Raju Chavan, Dr. B. V. Tembhurne, University of Agricultural Sciences, Raichur for their instantaneous help and valuable suggestions during my tenure of studies.*

*Study in PG was purposeful and meaningful because of ocean of my friends, who legion in number, but more than a small group, to mention a few, Shivaraj, Manju. B, Yallapa, Ganesh, Bharmi, Yallu, Bharat Vinayak[2], Vivek,*

*Amar, Guru, Ragu, Vishrut, Manju (H & DD), Madu, Aravind, Deepa Rehman, Renuka, Vani and Raju. My senior and junior friends Vinod, Rajesh, Kotresh, Boraiah, Sarthi, Kuber, Kumar, Sanjeev Patil Rajendra, Sudarshan, and all my primary, high school, PUC, UG teachers and friends for their boundless love, help, caring in every aspect of my studies. With this company I never felt burden on my studies.*

*On my personal note, it is an immense pleasure to express my sincere gratitude and heartfelt respects to the blessing of my family members my grandmothers,* ***Smt. Kalamma N. T.*** *and* ***Smt Iramma N. B.,*** *father,* ***Mr. Ningappa Banakar****, mother* ***Smt. Kamala Banakar****, my lovely sisters* ***Mamata Rajesh****,* ***Nagarathna Vivek*** *and* ***Poornima****, my beloved brothers* ***Ravikumar*** *and* ***Santoshkumar****, my lovely nephew* ***Akshay,*** *Uncles* ***Smt & Mr Veerabasanagoud, Smt & Mr Gurupadgoud, Smt & Mr Shivangoud*** *and* ***Smt & Mr Jagadeeshgoud*** *and my Uncle and Aunt.*

*I never forget the enormous and timely help by Venkoba, Field Assistants. Nadaf and all farm labours during the course of my research work.*

*I remain ever thankful to the non-teaching staff of Department of Genetics and Plant Breeding, for providing me the necessary materials during my research work.*

***.....any omission in this small manuscript does not mean lack of gratitude***

***RAICHUR***
***JULY, 2011*** **(CHETANKUMAR BANAKAR)**

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# INTRODUCTION

# I. INTRODUCTION

The main objective of plant breeding is to assemble desirable genes in a genotype. To achieve this goal, sufficient variability should be ensured in the genetic material. If a particular desirable allele is not present in the gene pool, or else the variability existing in the genetic material is exhausted, then one of the most important approaches to create new variability is mutation breeding. Stadler's (1928) demonstration that new variations can be induced artificially in plants through induced mutation which was a significant achievement in plant breeding. Artificially induced mutagenesis provides an additional promising approach in generating new alternate forms of an allele to create new variability in a population. Mutation breeding has been used extensively as a valuable supplement to the method of plant breeding in development of better crop cultivars. Seedling studies are used to manipulate the particular dose of gamma irradiation used to enhance the breeding programme.

Induced mutation has been recognized as an important tool for crop improvement and is believed to have sufficient scope in oil seeds as well.

Sunflower *(Helianthus annuus* L.) as a supplemental edible oilseed crop was introduced to India in 1969. However, commercial cultivation on large scale began only in 1972-73 onwards with the introduction of Russian varieties like EC68414 (Peredovik), EC6841S (Armaviriski-3497) and Morden (Cernianka-6S). With the development of array of hybrids and varieties adapted to the varied ecological conditions prevailing in the country sunflower has now established as a potential oilseed crop.

Sunflower (*Helianthus annuus* L.) is an important oil seed crop with wide adaptation due to its wide tolerance to temperature and moisture variations. Although it is an introduced crop to India, in recent years it has become an important oil seed crop of India and cultivated on area of 2.06 m.ha with production of 1.13 m.tons. Karnataka is one of the important state that grows sunflower on total area of 12.3lakh ha. with annual production of 5.20 lakh tones contributes to 57 per cent of acreage and 42 per cent of total production of the country with 549 kg/ha productivity. Sunflower is rich source of edible oil (40-52%). Sunflower oil considered as good for health point of view due to high concentration of PUFA (linoleic acid 55-60% and oleic acid 25-30%) which are known to reduce the risk of coronary diseases.

The main objective of sunflower breeding is to develop productive sunflower hybrids that are stable, high yielding, and resistant to biotic and abiotic stresses. Yield is a complex trait, is controlled by multiple gene effects. Seed yield is variously estimated seed yield per plant, number of seeds per plant (>1,500), volume weight of the 100 ml (45-50 kg/ha), thousand seed mass (>80 g), low hull percentage (20-24%) and high seed oil content (>45). Induced mutations have been applied for the past 40 years to produce mutant cultivars in sunflower by changing plant characteristics for significant increase in plant productivity. Mutagenic treatments, usually on seed, have induced high-oleics, semi-dwarfs and dwarfs, male-sterile plants and other interesting variants such as earliness and seeds with thin hull.

The polygenic system which forms the genetic background for polygenic traits is highly organised system. The different genes of the system are fictionally interlinked in governing the expression of a polygenic trait. Therefore, while inducing mutation in polygenic system the mutagen is administered so that it does not disrupt the balance in the polygenic block. By doing so, useful hidden variability in a polygenic block could be released. From this point of view a mutational event is very important even when it has a smaller effect for specific morphological or physiological characters, because it changes the balance established by natural selection, in the co-adopted gene block and therefore offers new situation for natural or artificial selection (Aastveit, 1977).

Most of the popular hybrids released are very high yielding but they are associated with some of the undesirable traits like tallness, late in flowering and maturity, very large head size which leads to set large sized seeds with small kernels inside, low test weight, low oil content etc. which are all polygenic in nature. The present study aimed at improving such characters without altering genetic background of a genotype and creating variability anew by administering the mutagen in parents of the hybrids.

Mutation breeding has shown promise in creating wide variability for economic quantitative traits *viz.*, days to 50 per cent flowering, plant height, head diameter days to maturity, seed yield per plant and oil content , mutagenesis has been found to be effective in achieving the above objectives in short period (Giriraj *et al.,* 1990). The induced mutations have been found quit effective in generating useful variation for polygenically controlled traits.

In 1976, Soldatov produced a mutant of significant practical importance for sunflower breeding by treating the seed of the cultivar VNIIMK 8931 with a solution of 0.5% dimethyl-sulphate (DMS); $M_3$ lines possessing a high content of oleic acid in oil were obtained. After further breeding, the high-oleic cultivar Pervenetz was developed. The high oleic content of this cultivar has proved to be very stable under varying temperatures and the trait can be easily transferred into other genotypes by normal breeding procedures.

Keeping foregoing points in view, parental lines of four popular hybrids were selected and exposed to gamma irradiation treatments with following objectives.

1. To study the effect of gamma irradiation on quantitative traits of parental lines of four sunflower hybrids
2. To determine $LD_{50}$ of different inbreds of sunflower
3. Evaluation of $M_1$and $M_2$ generations to study variability among traits

# REVIEW OF LITERATURUE

# II. REVIEW OF LITERATURE

Hugo de Vries (1909) for the first time recognised role of mutation in evolution. However method for producing genetic variability artificially was not discovered until late 1920's when Muller (1927) working with Drosophila and Stadler (1928) with Barley and Maize showed that X-ray can induce mutations. After Muller's and Stadler's work, the potential significance of this method as a technique inducing useful mutations in plants was showed by several pioneer workers in mutation field like Nilsson-Ehle (1948), Goodspeed and Uber (1939), Gustafsson (1947, 1954 and 1979), Catcheside (1948), Muller (1955, 1959), Mackey (1956), Gau1 (1958 and 1963), Gregory (1961), Brock (1971), Stubbe (1959), Swaminathan (1969), Sparrow *et al.* (1971). Guidelines for practical mutation breeding methods have been given in manual of Mutation Breeding; IAEA (1977). Studies on mutagenesis are rather scanty in sunflower (Giriraj *et al.*, 1990). This may be either to unexploited genetic variability already existing or may be due to its recent introduction in the Asian and African continents. Hence, in the following paragraphs, literature on other oilseed crops pertaining to present investigations is briefly presented.

## 2.1 SENSITIVITY OF GENOTYPES TO MUTAGENS AND $LD_{50}$

### 2.1.1 Effect on germination and survival

Physical and chemical mutagens have their effect primarily on germinability and have been studied by many workers. Gills and Devinck (1959) found that there was decrease in germination in groundnut with successive increase in dose of gamma rays from 1 to 20 kR.

Reduction in germination and differential response of mutagens to varieties in different crop plants are on record (Shivaraj *et al.,* 1963; Avdhani and Ramana Rao, 1968; Reddy *et al.,* 1977 and Cheah, 1988 in groundnut; Sahai and Dalal, 1970 in safflower; Shakvarnikov *et al.,* 1977 in wheat; Shakvarnikov and Morgan, 1976 in maize; Ilyas and Goud, 1978; Chandrappa, 1980; Deshpande, 1995; Omar *et al*., 1993; Gvozdenovic *et al*., 2009; Soroka and Lyakh, 2009; Jagadeesan *et al*. (2008) in sunflower; Sahu and Kumar, 1978 and Nair and Nair, 1977 in sesame; Belyaeva, 1987 and Bhatnagar *et al.,*1989 in soybean).

The earliest report on the mutagenesis of safflower was given by Beard *et al.* (1957) who studied the effects of X-ray and thermal neutrons and found a strong negative correlation between dosage and effects measured by plant height, survival and pollen fertility.

Gilles and Devinck (1959) made radio-genetical studies in *Arachis hypogea* and reported decreasing trend in the survival rate with increasing dose of gamma rays from 1000 R to 20,000 R on soaked seeds or excised embryos. Seedlings became inviable above 15,000 R. They noticed many vegetative and floral abnormalities in the seedlings in all doses of radiation, 10,000 to 15,000 R being the most effective.

Shivaraj *et al*. (1962) irradiated the seeds of two varieties in groundnut, TMV-2 (bunch type) and TMV-3 (spreading type) with fast neutron doses, 2.5 x 1012, 1 x 1013 and 5 x 1013 and studied the $M_1$ generation and found a decline in germination percentage, growth rate, chlorophyll content of the leaves, leaf size, pollen fertility and number of pods as the dose of neutrons increased.

Shivaraj and Ramanarao (1963) studied the sensitivity of groundnut to fast neutrons and gamma rays. They observed uniform deleterious effects on germination, survival, height and yield of plants in case of fast-neutrons as compared to gamma rays.

Harring *et al*. (1964) studied the sensitivity of castor seeds to treatments with ethyl methane sulphonate and gamma rays. They reported that seedling emergence, plant survival and height increased from 1.5 to 4.6 per cent. Soaking of seeds in water or in EMS increased their sensitivity to radiation. Concentration of one and two per cent EMS had little effect on the characters studied except when seeds were soaked for 16 hours. They found insignificant interaction of these two mutagens for the three characteristics, seedling emergence, plant survival and height.

Rangaswamy (1973) studied the effect of gamma rays and ethyl methane sulfonate on sesame, he treated two varieties KRR-2 and TMN-3 with doses ranging from 50 to 100 kR of gamma rays and 25 to 150 mM of EMS. He reported inhibition in germination at higher doses, reduction in plant survival, reduced plant height on $30^{th}$ day and at maturity, increased pollen sterility and morphological abnormalities in $M_1$ generation.

Sahai and Dalal (1973) reported that germination, survivability, plant height and yield decreased with increase in doses of gamma rays but days to flowering and pollen

sterility increased when two varieties US10 and K11842 of safflower were exposed to different doses of gamma rays at two different moisture levels.

El-Sahhar *et al*. (1983) in soybean indicated that germination per cent and plant survival decreased with increased dose of mutagens in $M_1$ generation. The lethal dose ($LD_{50}$) for germination and survival was 15-20 kR gamma rays and 0.6 to 0.8 per cent EMS respectively.

Mureasan *et al*. (1984) exposed seeds of soybean varieties, B19 and Gigas with dose of 10, 20, 30 and 40 kR and in $M_2$ chlorophyll mutations occurred with frequencies approximately proportional to the dose.

Zakri and Jalani (1988) observed differential genotypic responses when treated with both gamma rays and EMS. Palmetho a variety showed higher survival percentage following either treatment in soybean.

Layrisse *et al*. (1992) tested seven sesame Venezulan cultivars for their gamma rays $LD_{50}$ was 630Gy, and for the more resistant one it was 800Gy. Maloo and Agarwal (1995) assessed the effectiveness of different mutagens *viz.,* EMS, MMS and gamma-rays in inducing variation in Niger. EMS was found effective at 0.25 per cent and gamma rays at 20 kR.

Patil and Bawankar (2000) treated two varieties of *Lathyrus sativus viz.,* Pusa-24 and JRL-115 with 0.1, 0.15 and 0.2 per cent EMS. The effect of various doses was studied on germination, mortality, pollen sterility, pollen size and variability in polygenic characters. The germination percentage, pollen sterility and pollen size decreased in most of the treatment. Mortality percentage increased with increase in the dose of mutagen.

Chavan *et al*. (2000), treated mungbean variety BM4 with 10, 15, 25 kR gamma rays and found that in $M_1$ generation, germination decreased with increased dose of gamma rays. 25 kR showed lowest germination, 10 and 15 kR showed satisfactory germination.

Wakode *et al*. (2000) studied the mutagenic effects of gamma rays (10, 20 and 30 kR) in five cultivars of soybean JS-80-21, JS-335, JS-7105, Monetta and PKV-1. A dose dependent decrease was noticed in most of the characters like root length, shoot length, germination, plant height, plant survival and pollen sterility.

Arslan *et al*. (2001) irradiated gamma rays on EK121 variety belonging to *H. annus* L. with different doses of 10, 20, 30, 40 and 50 kR. Percentage of total abnormalities in the $M_0$, $M_1$ and $M_2$ generations increased parallel to the increasing dose of radiation.

Sharma *et al*. (2005) mutagenised seeds of urd bean cultivars PDU-1 and T-9, with gamma-rays and EMS to determine their mutagen sensitivity, $LD_{50}$, mutagenic effectiveness and efficiency. The increasing doses of gamma rays and EMS decreased germination, plant survival and pollen fertility. $LD_{50}$ values revealed that PDU-1 was more radio and chemo resistant than T-9. The average effectiveness and efficacy (pooled over doses and genotypes) of EMS was 2.0-2.5 and 1.5-2.0 times higher than the gamma rays, respectively. The lower doses of mutagens were more effective and efficient than the higher doses.

### 2.1.2 Effect on pollen fertility

Rai and Jacob (1957) in sesame studied induced mutations in a black seeded variety T-16 by treating with X-ray and reported increase in number of capsules, earliness in flowering, large pollen diameter, high degree of pollen sterility and more productive plants in later generations.

Beard *et al*. (1957) in safflower who studied the effects of X-ray and thermal neutrons and found a strong negative correlation between dosage effects and pollen fertility.

Sahai and Dalal (1973) reported that pollen sterility increased when two varieties US10 and K11842 of safflower were exposed to different doses of gamma rays at two different moisture levels.

Sahu and Kumar (1978) in safflower observed that the effects of EMS increased with concentration, exposure and temperature, reducing germination, seedling height and survival until maturity and pollen fertility in the $M_1$ generation

## 2.2 INDUCED POLYGENIC VARIABILITY

The quantitative characters are governed by many genes with each gene contributing cumulative effect to the total phenotype. Such genes are commonly called as polygenes and the character governed by them show continuous variations. These quantitative traits, controlled by many genes are highly influenced by the environmental

fluctuations and hence any micromutations taking place at few base pairs levels cannot be detected visually. In contrast macromutations that result from mutation in the major genes show striking qualitative characters and are easily detected through visual observation.

The usefulness of micromutations in plant breeding as compared to macromutations, has been emphasized by several workers (Lawrence, 1965; Gaul, 1965 and Scossiroli, 1965), primarily because unlike macromutations, micromutations occurs in higher frequency as they involve simple transition or transversion for individual base pairs. In addition micromutations are less drastic with higher vitality and fertility than macromutations.

### 2.2.1 Sunflower

Lazanyi *et al*. (1961) obtained changes in characters such as plant height, head size, seed size and maturation period in the variety VNIIMK8931 of sunflower treated with sulphonamides or colchicines.

Polygenic variability as affected by seedling irradiation was studied in sunflower by Savin and Stapanko (1968). They irradiated the seedlings with 1 kR gamma rays and observed increase in 1000 seed weight by 19 per cent in the cultivar "Gigant" and by 29 per cent in "Peredovik" and the number of seeds per head reduced.

Cvetkova (1970) irradiated sunflower seeds with 6.5 kR gamma rays. The $M_1$ plants were pollinated with pollen from other $M_1$ plants of the same variety after the pollen was irradiated with 1 kR X-ray. Of the five varieties he studied 2053 IPS and Peredovik gave the highest number of desired mutants and Birimirac 73-4 the lowest. He carried out selections in the $M_2$ generation for large leaf area, short growth period, large seeds and short stem. He found that some families in $M_4$ stabilized in these respects were superior to the standard variety Peredovik. He obtained several mutants with three to five per cent higher kernel oil content.

Surovikin (1973) observed in sunflower that growth period, plant height and oil content in the $M_2$ depend on the mutagen used and on the genotype of the variety.

Chandrappa (1980) exposed the sunflower achenes at various doses of gamma rays, EMS and DES and found increased mean values for yield per plant and oil content and decreased mean for days to flowering and plant height. He also reported that gamma irradiation treatments significantly increased the variance, coefficient of variability,

heritability and genetic advance values with respect to economic traits in $M_2$ generation. Leclercq (1984) reported that gamma ray treatment induced a dwarf sunflower mutant of less than 70 cm, with almost normal duration. In another study, Giriraj *et al*. (1990) induced variability in parental lines of BSH-1 sunflower hybrid for days to flowering, 100-seed weight and oil content. Various doses of gamma radiation *viz.*, 5 kR, 10 kR and EMS treatment at 0.2 per cent, 0.3 per cent significantly increased the variability for days to flowering, test weight in $M_2$ and $M_3$ generations. Early and late flowering mutants isolated. In all mutagenic treatments, the mean test weight shifted in positive direction. They found that EMS was more effective than gamma rays in creating a wider range for test weight and the variability created for important yield components provided scope for selection.

Encheva *et al.* (1993) irradiated zygotic embryos of sunflower with gamma rays and observed changes for days to flowering, plant height, head-diameter and 100-seed weight.

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

Encheva *et al*. (2003) hybridized between Bulgarian fertility restore line R-2574 and mixed pollen from a population of known genetic composition and treatment of immature embryos with gamma radiation or ultra sound a large number of new fertility restorer lines were developed. The combined use of intra linear hybridization with physical mutagenesis or ultra sound and the embryo culture method leads to increased genetic variability in sunflower and to a considerable shortening of the breeding process, producing five generations within a single year.

Gvozdenovic *et al*. (2009) reported that the strategy adopted was to estimate the optimal treatment conditions (doses of mutagens) through relating the extent of damage in seedling progeny to the exposure levels of the initiating propagules to mutagens. Seeds of

15 elite sunflower genotypes commonly used as breeding stocks and grown on commercial scales were treated with a range of mutagens Gamma-rays (γ rays); fast neutrons and with ethyle-methane-sulphonate (EMS) at different treatment doses. The three mutagenic agents affected seedling height, reducing it with increasing dosage. Based on the mutagen damage on seedling height, the 50 per cent and 30 per cent damage indices (D50 and D30, respectively) were estimated for the 15 sunflower genotypes for the three mutagens. The D50 (D30) values for the sunflower lines ranged from 120 to 325Gy (5 to 207Gy) for gamma irradiation; 9 to 21Gy (0.1 to10Gy) for fast neutrons and 0.69 to 1.55 per cent (0.01 to 0.68%) concentration of EMS.

The frequency and spectrum of morphological and physiological mutations obtained in $M_2$ and $M_3$ generations after sunflower immature embryos treatment with ethyl Methanesulphonate (EMS) have been studied by Soroka and Lyakh (2009). Immature 9-10 and 14-15 days old embryos of two genotypes were treated with EMS at the concentration of 0.02 per cent for 16 hours. Thirty-three types of mutation were found, described and classified and reported that Mutation frequency after immature embryo treatment in the $M_2$ generation did not exceed the amount of mutations in $M_3$.

### 2.2.2 Niger, Linseed and Sesame

Goyal and Kumar (1993) recorded 84.4 per cent of variability of total variation in yield from four variables *viz.*, days to maturity, number of branches, number of capitula and seeds per capitulum in the study of regression analysis made on 35 Niger varieties.

Borole and Patil (1997) studied 15 genotypes of Niger for genetic variability and reported low heritability for primary branches, moderate for seed yield per plant and high heritability for remaining characters.

Patil (2000) studied 30 genotypes of Niger and observed that a substantial genetic variability exists for all characters he studied. Significant positive correlation of seed yield with days to maturity and seeds per capitulum was observed. High heritability along with high genetic advance was observed for capitula per plant and plant height.

Nema and Singh (1965) in their study on Niger reported heritability ranging from 95.52 to 30.49 per cent for earliness and grain yield, respectively. Branching, number of heads, number of seeds per head had moderate heritability. Phenotypic selection for head, diameter, 1000 seed weight and oil content was found to be useful because of their higher heritability values.

Rai and Jacob (1957) studied induced mutations in a black seeded variety T-16 of sesame by treating with X-ray and reported increase in number of capsules, earliness in flowering, large pollen diameter, high degree of pollen sterility and more productive plants in later generations. They isolated a white flowered and small seeded mutant in $M_3$ and $M_4$ generations respectively and both were found to have higher oil percentage (52.10%).

Nair (1961) obtained a small seeded mutant (SSM-2) in sesame, with a mean oil content of 55.48 per cent compared with 47.82 per cent in the parent from $M_3$ population of brown seeded variety exposed to X-ray.

Murty (1979) obtained true breeding mutants in sesame with multiloculed capsules, multicapsules and with large capsules and seeds, after exposing N62-32 seeds to gamma rays. Six crosses between $M_4$ mutants including three multilocated mutants, showed increase for seed yield.

Following the treatment with EMS, X-ray at 30 and 60 kR in two varieties of linseed, Sinha *et al.* (1981) produced high yielding $M_2$ plants coupled with high oil content.

Kamala and Sasikala (1985) reported four high yielding mutants developed by gamma irradiation from 'JMV5' and IS103 varieties of sesame, gave 3-30 per cent more yield and 8-13 per cent more oil content.

### 2. 2.3 Castor

Seeds of castor varieties HC-1, HC-2 and a local variety were irradiated with three different levels of gamma radiation from $^{60}CO$ source and found that the number of racemes per plant in the treated population was higher than the control indicating that selection of these plants could lead to the development of high yielding types. Other variations induced, included reduction in the number of spikes and capsules, changes in leaf and stem colour, formation of peak green or white sectors on the leaves, wrinkled lower, varying number of leaf lobes, pink colouration of pedicle and veins, delay in flowering and sterility due to the absence of racemes (Bhatnagar *et al*., 1962).

A classical work on induced mutagenesis in castor was made by Ankineedo and Kulkarni (1965). They studied the effect of radiation on number of fruit locules and found that in $M_2$ generation, the number of tetralocular capsules increased following gamma

irradiation. Ankineedu *et al.* (1968) studied the effect of gamma rays and fast neutrons on seeds of castor variety HC-6 and observed changes in the mutants for number of flowers, capsules, spikes, seed size and yield. RC8 variety gave more number of internodes, higher seed weight and 10-47 per cent more yield than control. A significant positive shift in the mean values for days to flowering and harvest index and negative shift for capsules per raceme were the main features or gamma ray treatment of castor (Athma and Reddy, 1982). Likewise, an increased phenotypic variability for days to flowering, seed yield per plant and harvest index was the main feature of per gamma irradiation of castor (Prasanna and Reddy, 1986). Chauhan *et al*. (1990) irradiated dry seeds of castor cv. Aruna with 100 and 125 kR gamma rays and obtained 3 female $M_2$ mutants *viz.*, $GRFM_l$, $GRFM_2$ and $GRFM_3$ showing higher yield and yield components compared to non-irradiated parent.

### 2.2.4 Rape seed and mustard

Gamma irradiation treatment led to a decrease in the mean values for seed yield per plant and oil content, while the coefficient of variation for many quantitative traits increased, as reported by Ramkumar and Yadav (1988).

Mahla *et al.* (1991a) irradiated the seeds with 80, 100 and 120 kR gamma rays and obtained enhanced yield levels in irradiated populations, but the mean values of siliqua length and seeds per siliqua reduced. An improved variety for seed yield through mutation following induced irradiation was obtained by Rahman and Das (1991).

Bhat *et al*. (2001) used four chemical mutagens, EMS, ethidium bromide (EBr), ethyl nitro urea (ENO) and streptomycin to induce mutations in *brassica juncea*. Agronomically valuable mutants were isolated such as yellow seed.

Landge *et al.,* (2009) induced variability in Westar variety of *Brassica napus* by different doses of Gamma-rays and chemical mutagens EMS and SA and reported that among several morphological mutants, 11 early maturing mutants were identified. The maturity of these mutants ranged from 90-150 days as against 169 days of Westar in Central India.

### 2.2.5 Soybean

Rajput (1987) reported induction of polygenic variability in soybean following irradiation at 10, 15, 20 and 25 kR doses. Changes were seen in $M_2$ generation in mean values for yield components *viz.*, seeds per plant and grain yield per plant. coefficient of

variability for these traits increased which provided scope for selecting high yielding plants. Similarly, high yielding in mutants in $M_2$ showing earliness, determinate growth habit and short stature following different doses of gamma rays and fast neutrons were obtained by Rajput and Sarwar (1989). Increased seed yield in soybean by X-ray irradiation at 25 and 35 kR doses was reported by Khurana and Laxminarayana (1991). They produced high yielding mutants with seed yield of 30g per plant and 26g per plant compared to control with l7 g per plant. They also found that mutants were superior for pods per plant, seeds per pod, 100 seed weight besides early in maturity.

Wang (1991) exposed three genotypes of soybean to eight doses of gamma radiation and obtained changes with respect to plant height, seed weight per plant and 100-seed weight in $M_1$ and $M_2$ generations. He also observed increased coefficient of variation and widened range for the traits in the irradiated population

### 2.2.6 Groundnut

The first extensive study of induced mutagenesis in groundnut was made by Gregory and co-workers using X-ray and they obtained good results (Gregory, 1955, 1956, 1957 and 1960). In the $M_3$ generation Gregory selected large number of vigorous plants and about 10 per cent of these were developed into lines having higher yield levels as compared to control. The released variety NC4x developed from a normal plant was high yielding with good pod and seed quality. He also observed negative relation between mean values and variances for pod yield in irradiated parental populations.

Similar studies on induced mutations in groundnut to create variability for seed characteristics have been reported by several workers (Bilquez and Martin, 1961; Bilquez, 1962; Patil, 1966 and 1971; Patil and Thakare, 1969 and Ashri and Goldin, 1965).

Several improved varieties with various attributes such as large kernels, higher yield and shelling percentage have been isolated following direct selection in X-ray irradiated populations at BARC, Trornbay (Patil, 1966, 1971 and Patil and Thakare, 1969). The varieties TG-1 and TG-3 were developed following X-ray treatment of Spanish improved at 75 kR and 25 kR and selections for kernel weight and number of branches.

Shivaraj *et a1*. (1963) observed reduction of in mean values of various quantitative traits following irradiation of one bunch and one spreading variety with

thermal neutrons. Following gamma irradiation and fast neutrons they observed reduction in height and yield. A dwarf plant in gamma irradiated population particularly at higher doses, was isolated by Sanjeevaiah *et al.* (1967) and found that the yield was reduced by irradiation treatments of higher dosage. Avdhani and Ramana Rao (1968) observed increase in mean values for shelling percentage and test weight following irradiation treatment. In a similar study Martin (1968) observed increased variance in $M_2$ generation with regard to pod size and oil content following irradiation treatments. Higher response to selection was apparent in the population. Gaul (1963 and 1965) and Brock (1971) proposed that the frequencies of micromutations are many times more than macromutations.

These than findings gave impetus to employ physical and chemical mutagens in practical plant breeding programme to induce genetic variability for seed characteristics.

Reddy *et al.* (1977) irradiated groundnut seeds with gamma rays and reported that the mean value in $M_2$ decreased over control for height, branch length and number of nodes, while it increased the variation for these characters. Sinha and Rahman (1979) derived early and mid early maturing mutants from late maturing variety in groundnut by irradiating with gamma rays. In another experiment, Ramanathan (1983) reported that the treated plants gave higher for values genotypic variance, heritability, genetic advance and seed yield in $M_3$ than control. Results of Prasad and Kaul (1984) indicated that compact canopy frame obtained following irradiation increased treatment the yield in Virginia genotypes and also increased variation for pod number, branches and dry weight in Spanish type following the treatments with EMS, NMU and gamma rays. Colchicine induced dwarf mutant was isolated by Tiwari and Khanorkar (1984) that had fewer pods and smaller leaflets than the untreated plants. Pathirana (1985) reported a gamma irradiation induced mutant having higher shelling percentage, larger kernels and more of two-seeded pods than the recommended cultivar. In a similar study, Chandra Mouli *et al.* (1987) isolated mutants in groundnut that gave higher pod yield and increased and the pod and seed size compared to control. The mutants gave a pod of 4083 kg/ha as against 2480 kg/ha pod yield in control.

Dutta *et al.* (1987) irradiated 22 $F_3$ family selections of groundnut with 30 kR gamma rays and showed $F_5$ performance to be improved for pod field, shelling percentage and 100-seed weight over those obtained in the untreated $F_3$ family selections. An increase of 32 to 42 per cent in seed size and 1 to 18 per cent in seed yield per plant over

the parent was reported by Cheah (1988) in groundnut. He also was found that lower irradiation doses led to better performance in terms of pods per plant and pod dry weight over control. Change from spreading to semi compact habit was reported by Singh *et al*. (1988) following the treatment gamma irradiation. They also obtained the mutants that were early and late ones. In another study, Manoharan and Thangvelu (1990) reported a mutant with bold seeds having l00-seed weight ranging from 22.20 to 40.50 compared to 21.20 in control in groundnut following gamma irradiation. Ramani and Jadon (1991) irradiated the seeds with 10, 20, 30, 40 and 50 kR doses and assessed yield components in $M_2$ the generation. They observed reduced plant height, number of leaflets and treated delayed flowering in $M_2$ populations. Moderate to high levels of heritability accompanied by levels of genetic advance were recorded for pod weight per plant, pods per plant and seeds per plant.

## 2.3 MUTATIONS FOR QUALITY CHARACTERISITICS

The economic value of an oilseed crop is determined by its oil content. Mutation breeding has been found to be powerful tool in modifying oil content as well as fatty acid composition.

Qualitative characters are governed by one or few major genes and are relatively less sensitive to environmental fluctuations. Hence any induced change for these qualitative traits can be easily detected by visual observation. The genes controlling these characters linked with polygenic loci can be used as morphological markers in plant breeding. Changes in qualitative characters can be easily induced generating new alleles with the help of mutation and can be used in plant breeding (Ankineedu and Kulkarni, 1967). They observed a mutant with nonshattering behaviour in castor in $M_2$. In another study Ankineedu *et al.* (1968) green stemmed dwarf mutants derived in castor as against brown stemmed tall plants in parent following gamma irradiation.

Soldatov (1971) observed increased genetic variability for oil content in $M_3$ generation in sunflower following treatments with chemical mutagens *viz.,* NMU, NEU and DMS. He isolated plants with 1-2 per cent higher oil content compared to control. Srinivasachar *et al.* (1972) isolated mutants with high iodine value in addition to increase oil content in linseed following gamma irradiation and EMS treatment. In Brassica, Axtell (1979) induced a mutant low erucic acid which enabled cultivation of this species as an edible oilseed crop. Similar results were reported in Brassica by Robbelein and Nitsch (1975).

Vranceanu and Stoenescu (1982) altered the oil composition in sunflower by mutation. They found that irradiation with high energy radiations were effective alter the content. Kubler (1984) also studied possibilities in sunflower of altering the oil content in sunflower by mutagenesis. Following the treatment with EMS and gamma rays he obtained mutants with oil content ranging from 9.1 to 61.9 and 9.4 to 58.8 per cent against 8.7 to 56.5 per cent in control. A successful attempt to isolate zero erucic acid content in Brassica was made by Laakso *et al.* (1986). Similar study was made in Brassica by Rakow *et al.* (1987).

Giriraj *et al*.(1990) treated the sunflower seeds with gamma rays at 5 kR and 10 kR doses and also with EMS separately at 0.20 per cent and 0.30 per cent and observed a widened range and increased variability for oil content. They also noticed a shift in mean value of oil content in positive direction.

Patil *et al.* (1985) treated seeds of soybean with five doses of gamma rays and obtained green and yellow seed coat colour in mutants as against original black coloured, seed coat in the control. In a similar study in sunflower, Coppola (1986) irradiated *Helianthus tuberosus* with 3 kR gamma rays and obtained white coloured tubers in contrast to red coloured tubers in parent. He also observed thin stem with negligible branching character as against thick stem and more branching behaviour in control.

Omar *et al*. (1993) reported the effect of gamma rays and NaCl on growth and cellular contents of soluble carbohydrates, protein and nucleic acids in *Helianthus annuus* L. callus were investigated. Optimal callus initiation was attained in stem segments cultured in MS medium enriched with 0.05 mg/1 2,4-dichloro phenoxyacetic acid (2,4-D) and 0.01 mg/1 N-6 furfurylamino purine (kinetin). adio sensitivity, based on fresh weight changes, was determined following exposure of the calli to different doses of gamma rays. The $LD_{50}$ was calculated and it was equal to 2.8 kR. Inclusion of NaCl in the medium caused a significant reduction in callus fresh weight. In general, the cellular contents of protein, soluble carbohydrates and ribonucleic acid (RNA) were reduced, while deoxyribonucleic acid (DNA) increased at two per cent NaCl level. There is a significant increase in protein, carbohydrates and DNA, while a significant reduction in RNA content was observed. The role of such information in breeding for salt tolerant sunflower following physical mutagenesis in vitro is outlined.

Ya *et al*. (2004) reported that two new inbred lines, T589 (medium β-tocopherol content) and T2100 (high γ-tocopherol content), recently developed in CSIC, Cordoba,

Spain, have been crossed to known tph1 and tph2 mutations which possessed the same phenotypes and which were obtained at VNIIMK, Rasnodar, Russia. Genetic identification of these recessive mutations with TLC profiles showed the new medium β-tocopherol mutation to be allelic to tph1 and the new high γ-tocopherol mutation to be allelic to tph2.

Jagadeesan *et al*. (2008) induced variability in the sunflower varieties Morden and CO 4 (TNAUSUF 7) by a physical mutagen i.e., gamma rays. They observed that the mean expression and variability in quantitative characters increased considerably in the $M_2$ generation and different mutagenic treatments showed an inconsistent relationship with respect to mean and variability. However, considerable increase in variance was observed in traits such as plant height, seed yield per plant and oil content.

Murthy (1988) isolated a tall mutant in $M_2$ following gamma irradiation in sesame with the mutant character controlled by a single recessive gene. Takagi *et al.* (1989) obtained tiny mutant seeds in soybean following X-ray irradiation at 25 kR dose as against large sized seeds in control. Likewise in soybean Bhatnagar *et al.* (1990) isolated mutants with white flowers as against purple in the parent following gamma irradiation at 15-25 kR doses. In addition they obtained mutants with yellow seed coat colour as against black seeded types in the parent.

Chandra Mouli *et al.* (1987) induced high oil content mutants in groundnut following various doses of gamma irradiation. In contrast Ramkumar and Yadava (1988) reported decrease in mean value for oil content in Brassica following gamma irradiation at 100 kR.

Takagi *et al.* (1989) exposed the seeds of soybean to 25 kR X-ray and found that variability for oil content increased markedly in $M_2$ as a result of irradiation. They identified mutants containing 18.4 per cent linolenic acid compared to the 9.4 per cent in parent. Percentages of palmitic, oleic and linolenic acid decreased in mutants. By gamma irradiating the seeds of groundnut at 20 kR Chandra Mouli and Kale (1990) obtained a mutant with lower oil content with 38.6 per cent against 44.56 per cent in control. In a similar study Shpota and Bochkaeva (1990) obtained a mutant with low erucic acid content in rapeseed following irradiation with 50 to 150 kR gamma rays. Takagi *et al.* (1990) obtained a mutant with low linolenic acid content in soybean following X-ray irradiation at 21.4 kR. They observed an inverse relationship between linolenic acid

content and irradiation treatment. In a similar study Bhatnagar *et al*. (1992) observed a greater range and variability for oil content in the mutants than in the parents following gamma irradiation treatment at 15, 20 and 25 kR doses in soybean. However, the mean value for oil content was shifted in a negative direction in the mutants.

## 2.4 CHLOROPHYLL MUTATIONS

In case of induced mutagenesis occurrence of chlorophyll mutations is a common feature of irradiated populations. Chlorophyll mutations are easily detectable and can also occur in substantial frequency. Wide variation exists in chlorophyll mutations from lethal, semilethal types to complete viable types.

Stadler (1928) showed that chlorophyll mutations can be easily induced in diploid plants by ionising radiations. Chlorophyll mutations are often used as a measure of mutation rate and have been used as an indication of effectiveness of the mutagen (Gaul, 1960; Konzak, *et al.*, 1965; Sears, 1972 and Viraktamath, 1975).

Frequency of chlorophyll mutations is expressed in different ways, such as i) On $M_1$ family basis (Gustafsson, 1940), ii) On $M_2$ spike basis (Stadler, 1929) and iii) On $M_3$ plant basis, Gaul (1960) proposed that chlorophyll mutation frequency expressed per 100 $M_2$ seedlings is the best index, as it is proportional the initial mutation rate, individual variations in the progeny and size of the mutated sector. Goud (1967) evaluated the three methods of expressing chlorophyll mutation frequency in wheat and concluded that frequency expressed on primary tiller basis is the best index for tailoring plants. However, expressing the chlorophyll mutation frequency on 100 $M_2$ seedlings appears to be the best index for all types of plants (Sharma and Swaminathan, 1969; Mohan Rao, 1972 and Viraktamath, 1975).

Saroka and Lyakh, 2009, in sunflower reported that mutation frequency after immature seed treatment did not exceed the amount of mutations after mature seed treatment where the maximum frequency amounted to 13.2 per cent. Chlorophyll deficiency mutations averaged a half and more of the visible morphological mutations.

Lyakh *et al.,* 2004, isolated and described chlorophyll mutation in $M_2$ after sunflower mature and immature seed treatment with ethylmethanesulphonate.

In another study in sunflower Hermelin *et al*. (1987) recovered chlorophyll mutants by treating the $F_1$ achenes with 0 to 200Gy gamma rays. Likewise, Ravi and

Monocha (1987) by treating the Lentil seeds with various doses of gamma rays and EMS found that the doses 10 kR gamma rays and 0.2 per cent EMS gave maximum frequency of chlorophyll mutants per 100 $M_2$ plants

In case of castor, Prasanna and Reddy (1986) exposed the plants to gamma rays at the seedling, meiotic and post gametic stages and found that irradiation at the gametic stage gave the highest frequency of chlorophyll mutants. Similarly in Lentil Pratibha and Dubey (1986) induced chlorophyll mutations by separate and simultaneous application of gamma rays and NMU. They found that both the mutagens were equally effective for inducing chlorophyll mutations and reported that $M_2$ chlorophyll included mutants obtained xantha, viridis, alboxantha, virido xantha; striata and tigrima types.

In linseed, Bachyalis (1988) treated dry seeds of two varieties with 1-150 kR gamma rays and observed differential response of the two varieties to induce chlorophyll mutations for given dose. Similarly, Busolo-Bulafu (1988) isolated some chlorophyll mutants in groundnut following irradiation with gamma rays at 20 kR and with fast neutrons separately. In studying the effect of gamma rays, EMS and hydroxylamine on frequency of chlorophyll mutations in lentil Singh *et al*. (1989) found that gamma rays induced higher frequency of chlorophyll mutations than EMS and hydroxylamine. Further they opined that lower gamma ray doses of 5 and 10 kR induced more chloromutations than the higher doses.

In case of soybean, Harb (1990) reported that of four doses of gamma radiation, the 15 kR dose gave the highest frequency of chlorophyll mutants in the $M_2$ generation. Among the chlorophyll mutants he recovered albino, xantha, chlorina and variegata types.

Similarly Mahla *et al.* (1991b) in Brasssica induced chlorophyll mutations following gamma ray and EMS treatments separately. They reported that EMS induced more chlorophyll mutations than did gamma radiation.

Singh *et al*. (2000) studied the effects of gamma rays (10, 20, 30 and 40 kR) and ethyl methane sulphonate (0.01, 0.02, 0.03 and 0.04 M) alone or in combination (10 kR + 0.02 M, 20 kR + 0.02 M, 30 kR + 0.02 M and 40 kR + 0.02 M) on frequency and spectrum of chlorophyll and macromutations in two cultivars, namely, PDU1 and T9 of urd bean have been observed. The combination treatments have yielded the higher frequency and spectrum of chlorophyll mutations whereas the various doses of mutagenic agents have independent response towards macromutations in both the cultivars.

Seed treatment of sesame cv.B67, with EMS, NG, gamma rays, gamma rays + EMS and gamma rays + NG induced five types of chlorophyll mutations and 17 types of viable macro-mutations in $M_2$ (Kharkwal and Jain, 2003) and chlorophyll mutations were highest in only gamma rays treatment than other two combinations.

## 2.5 MUTAGENIC EFFECTIVENESS AND EFFICIENCY OF MUTAGENS AND THEIR DOSES

Success of mutation breading depends on selection of proper mutagens. Mutagenic doses vary considerably in effectiveness and efficiency. Utility of any mutagen in plant breeding depend upon its effectiveness and efficiency. In case of induced mutagenesis the primary importance is to be given to increase the efficiency of induction of desirable hereditary changes.

The concept of effectiveness and efficiency was elucidated by Ehrenberg (1960). Later Konzak *et al.* (1965) revealed clearly those measures such as mutagenic effectiveness and efficiency (gene mutations per unit dose) using $M_l$ injury and mutation frequency in the $M_2$ in case of physical and chemical mutagens. According to them, effectiveness refers to the frequency of mutations induced by the mutagen, whereas, to efficiency refers the ability of mutagen induce to desirable mutations.

Effectiveness is the measure of mutation rate relative to the dose, whereas efficiency relates to mutation rate to the other undesirable biological effects such as gross chromosomal aberrations, physiological and toxic effects that reduce the cell survival and eliminate the mutations (Ehrenberg, 1960; Nilan and Konzak, 1961 and Konzak, 1965).

Rao *et al.* (1971) studied the mutagenic effects of heavy water ($D_2O$) and its combination with EMS in rice. Effects in $M_1$ and $M_2$ generations were more with respect to $D_2O$ and EMS treatment pre-soaked in $D_2O$ than in respective controls. Likewise Goranova and Aleksieva (1986) treated the dry seeds of soybean with various doses of gamma rays and fast neutrons and various concentrations of EMS. They reported highest frequency of mutations, including useful mutations with also respect to gamma rays. In addition they also observed differential response of the soybean varieties regarding effective maximum mutation. In one variety the most effective and efficient gamma ray doses were 7.5 and 10 kR. While in another variety, the highest mutation frequency obtained at the lowest gamma ray dose *viz.*, 2.5 kR.

In another study relating to the stage at which gamma ray treatment be applied to recover maximum mutations Prasanna and Reddy (1986) in castor recorded highest mutagenic effectiveness (mutation frequency per dose) and efficiency (mutation frequency per sterility percentage) for treatment applied at the gametic stage compared to seedling and post gametic stages.

In case of soybean Wang and Yu (1991) exposed three genotypes to eight doses of gamma radiation and reported that the frequency of induced mutations in $M_2$ generation increased with higher doses.

# MATERIALS AND METHODS

# III. MATERIALS AND METHODS

The present investigation was carried out to study the variability induced by gamma irradiation with respect to quantitative characteristics, *viz.*, days to 50 per cent flowering plant height, head diameter, single plant yield and oil content of parental lines of popular sunflower hybrids.

The information on materials used, methods adopted, characters studied both in field and laboratory in different phases of investigation is presented here under.

## 3.1 Location of experimental site

The present field study was carried out at Main Agricultural Research Station, Raichur campus of the University of Agricultural Sciences, Raichur in two seasons. The campus is being geographically situated in the North Eastern Dry Zone (Zone 2) of Karnataka State at $16^{o}$ 12' N latitude and $77^{o}$ 21' E longitude with an altitude of 389.37 meters above mean sea level.$M_1$ studies done in *Kharif* 2010 and evaluation of $M_2$ generation was taken up in *rabi* 2011. The weather data pertaining to the experimental period for the year 2010-11 is given in Appendix-I. The materials used and methods followed during the course of the investigation are presented below.

## 3.2 Materials

The base material for the present study comprised of both the parental (B and R) lines of popular sunflower hybrid RSFH-130 hybrids (CMS-104B and R630), and maintainer lines of RFSH-1hybrid (CMS-103B) and KBSH-44hybrid (CMS-17B). Selfed seeds of the above mentioned lines were obtained from Principal scientist and Head AICRP on sunflower, Main Agricultural Research Station, Raichur. and their salient features are as follow:

| **Characters** | **B and R lines of Sunflower hybrids** | | | |
|---|---|---|---|---|
| | **CMS104B** | **CMS103B** | **CMS17B** | **R630** |
| Days to50 per cent flowering | 60-65 | 60-65 | 60-65 | 59-60 |
| Plant height (cm) | 150-170 | 150-160 | 160-180 | 100-120 |
| Head diameter (cm) | 15-18 | 15-25 | 15-25 | 10-12 |
| Days to maturity | 95-100 | 58-62 | 95-100 | 90-95 |
| Oil content (%) | 38-39 | 40-42 | 34-36 | 38-40 |

**Methods:**

**Irradiation of seeds**

Bold and viable dry seeds of uniform size, weighing 100gm each with 12 per cent moisture were packed in polythene bags separately for each treatment. Seeds were irradiated with 10, 15 and 20kR doses of gamma rays from $^{60}CO$ source at the gamma chamber of Bhabha Atomic Research Centre, Trombay, Mumbai, the seeds were sent to BARC on 13 July 2010 and irradiated seeds were received on 2$^{nd}$ of June 2010. The untreated seeds served as control and is one treatments apart from 10, 15, 20kR doses of gamma rays. One kR is equal to one thousand Roentgen units. Roentgen is a unit to measure the dose of gamma rays treated and is defined as the quantity of radiation whose associated corpuscular emission per 0.001293 gm of air produces in air, ions carrying one esu of electricity per cc of air at NTP.

**$M_l$ generation**

A known number (Table 1) of irradiated seeds of different doses of rays were sown in the field at the Main Agricultural Research Station farm, Raichur on 28-8-2010 as $M_l$ generation. The untreated seeds were also sown simultaneously that served check for $M_l$ generation plants for comparison of characters observed in the field. Seeds were dibbled in the field (one Seed/ hill) in rows following spacing of 60x30cm. Germination count was taken up 30 days of sowing and expressed as per cent. Each $M_1$ plant was selfed during flowering by covering with cloth bag. The plants in $M_1$ generation were harvested separately to constitute $M_2$ plant material.

**$M_2$ generation**

The seeds obtained from each selfed $M_1$ plant were hand dibbled on 28-1-2011 as unreplicated plant to progeny rows (Table 9) to rise $M_2$ generation. The untreated selfed seeds were also sown at the same time in progeny rows that served as control.

Seeds in $M_2$ generation were harvested and bulked treatment wise and advanced to next generation for future studies.

Individual plant observations were recorded in $M_1$ and $M_2$ generations with respect to plant height (cm), days 50 per cent flowering, head diameter (cm), days to maturity, seed yield per plant (g) and Oil content (%) of each plant in $M_1$ and $M_2$ and also for untreated control lines. Likewise, observations were recorded for test weight, seed yield per plant.

### 3.3 Field plot technique

The experiment was laid out in an unreplicated trial. In $M_1$ generation, the irradiated seeds were hand dibbled in rows with respect to each treatment administered. In $M_2$ generation a single row of five meter length with a spacing of 60 cm between lines and 30 cm between plants was adopted to represent a head to progeny line.

All the genotypes and all four treatments were randomised and sown in the field. Full doses of nitrogen, phosphorous and potassium (60:75:60 kg N: P: K/ha) fertilizer was applied 30 days after sowing, recommended plant protection measures were also taken as recommended package of practices. Weather prevailed during crop season is presented in Appendix.

### 3.4 Quantitative and qualitative characters

Individual plant observations were recorded on the following characters on all the plants in $M_1$ and $M_2$ generations as described.

#### 3.4.1 Germination

Number of seeds showing germination was counted on $30^{th}$ in field was calculated by using following formula.

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds sown}} \text{ X } 100$$

Germination was expressed as the per cent of control

#### 3.4.2 Survival

Seedlings survived at maturity were counted. Survival percentage was calculated by using the following formula.

$$\text{Survival (\%)} = \frac{\text{Number of seedlings survived}}{\text{Number of seeds germinated}} \text{ X } 100$$

Survival was expressed as the per cent of control.

#### 3.4.3 Pollen fertility

Ten plants from each treatment were randomly selected to study the pollen fertility in the morning hours of 8 a.m. The pollen grains were stained with one per cent Acetocarmine. Poorly stained pollens were considered as sterile. The counts were taken from microscopic fields. The sterility percentage was calculated as,

$$\text{Pollen ferility (\%)} = \frac{\text{Number of fertile pollen grains}}{\text{Total number of pollen grains}} \text{ X } 100$$

Pollen fertility was expressed in percent of control

### 3.4.4 Days to 50 per cent flowering

This was recorded in terms of number of days taken from the date of sowing to the opening of ray florets in 50 per cent of the plants in each entry.

### 3.4.5 Plant height (cm)

Plant height was measured in centimeters at maturity, as a vertical distance from the ground level to the point of the capitulum attachment.

### 3.4.6 Head diameter (cm)

The diameter of the capitulum in centimeters was recorded at maturity using a plastic scale as distance between two opposite points on the periphery of the capitulum with the line passing through the centre of head.

### 3.4.7 Days to maturity

The data on which the back of the head turns golden yellow is the indication of physiological maturity and then date was recorded and number of days from sowing to maturity was computed.

### 3.4.8 Seed yield per plant (g)

The filled seeds obtained from each head harvested was weighed in grams and recorded.

### 3.4.9 Oil content (%)

Twenty gram filled seeds were taken to analyse oil content (%) using NMR (Nuclear Magnetic Resonance) spectrometer installed at Main Agricultural Research Station, Raichur. and observation on oil content was recorded from $M_2$ generation.

## 3.5 Abnormal plants

### 3.5.1 Chlorophyll mutants

Appearance of chlorophyll mutants in $M_1$ and $M_2$ generations was noted and frequencies were calculated and photographs are also taken.

### 3.5.2 Abnormal lethal plants

Appearance of abnormal plants with respect to leaf shape stems shape. Head abnormalities were noted and photographs were taken whenever required. Frequencies of lethal plants in $M_2$ population were calculated and used to calculate mutagenic efficiency.

## 3.6 Estimation of mutagenic effectiveness and mutagenic efficiency

Mutagenic effectiveness is defined as a measure of frequency of mutations induced by unit dose of mutagen. While mutagenic efficiency gives an idea of mutations in relation to undesirable effects like lethality, injury and sterility. The formulae given by Konzac *et al.* (1965) were used to calculate both mutagenic effectiveness and efficiency.

$$\text{Mutagenic effectiveness} = \frac{M}{kR}$$

$$\text{Mutagenic efficiency} = \frac{M}{L} \quad \text{or} \quad \frac{M}{I}$$

Where,

M = Frequency expressed as percentage of chlorophyll mutations in $M_2$ generation, estimated on $M_2$ plant basis.

kR = Gamma ray dose in kilo Roentgen unit

L = Per cent lethality or survival reduction in $M_1$

I = Per cent seedling injury or height reduction in $M_1$

## 3.7 Statistical Analysis

### 3.7.1 Mean, range and variance

The mean, range and variance of each population on all the characters were calculated. The shift in the mean values of the treated population was compared to control population.

### 3.7.2 Determination of $LD_{50}$

LD50 values were determined based on germination, survival and pollen fertility in above mentioned genotypes used in this study by following Probit analysis (Sharma, 1998).

### 3.7.3 Estimation of phenotypic variance ($V_P$)

The standard deviation values obtained for observations recorded with respect to each of the characters were squared and expressed as phenotypic variance, as proposed by Falconer (1986).

$$\text{Phenotypic Variance } (V_P) = \frac{\sum X^2 - \frac{(\sum X)^2}{n}}{n-1}$$

Where,

X = Observations recorded for $M_1$ and $M_2$

Vp = Phenotypic variance

### 3.7.4 Estimation of genotypic variance ($V_G$)

The environmental variance values were deducted from respective phenotypic variance values to get genotypic variance for each character, as proposed by Falconer (1986).

$$V_G = V_P - V_E$$

Where,

$V_G$ = Genotypic variance

$V_P$ = Phenotypic variance

$V_E$ = Environmental variance

### 3.7.5 Estimation of environmental variance ($V_E$)

The standard deviation values were calculated based on observations recorded on plant in control. These values were squared and expressed as environmental variance as given by Falconer (1986).

### 3.7.6 Estimation of heritability (H) in broad sense

Heritability estimates of all characters were calculated based on phenotypic and genotypic variance values as proposed by Hanson *et al.* (1956).

$$\text{Broad sense heritability (H)} = \frac{V_G}{V_P} \text{X}100$$

Where,

H = Broad sense heritability

$V_G$ = Genotypic variance

$V_P$ = Phenotypic variance

### 3.7.7 Estimation of genetic advance (GA)

Genetic advance estimates of all characters were calculated based on phenotypic standard deviation, intensity of selection and heritability values as proposed by Johnson *et al.* (1955).

Genetic advance (GA) = H. i. $\sqrt{V_P}$

Where,

H = Broad sense heritability

i = Selection intensity which takes the value of 2.063 at 5 % level of significance

$V_P$ = Phenotypic variance

### 3.7.8 Estimation of phenotypic coefficient of variation (PCV)

Phenotypic coefficient of variance is calculated based on phenotypic variance and mean values for each of the character observed as proposed by Burton (1951).

$$PCV = \frac{\sqrt{V_P}}{\overline{X}} X100$$

Where,

PCV = Phenotypic coefficient of variation

$\overline{X}$ = Mean

$\sqrt{V_P}$ = Phenotypic standard deviation

### 3.7.9 Estimation of genotypic coefficient of variation (GCV)

It is calculated based on genotypic standard deviation and mean of the character, as proposed by Burton (1951).

$$GCV = \frac{\sqrt{V_G}}{\overline{X}} X\ 100$$

Where,

GCV = Genotypic coefficient of variation

$\overline{X}$ = Mean

$\sqrt{V_G}$ = Genotypic standard deviation

### 3.7.10 Estimation of standard error of estimates

To compute standard error of estimates with respect to different characters studied, standard deviation values and number of individual plant observations were considered.

$$SE = \sqrt{\frac{V_P}{n}}$$

Where,

SE = Standard error of mean

n = Number of individual plant observations recorded

$\sqrt{V_G}$ = Standard deviation value

# EXPERIMENTAL RESULTS

# IV. EXPERIMENTAL RESULTS

The observations collected on $M_1$ and $M_2$ generations were classified, tabulated and statistically analysed. The results of the present investigation are presented under the following headings.

## 4.1 $M_1$ GENERATION

Effect of gamma irradiation doses on germination, survival, quantitative characters and presence of any abnormalities like chlorophyll mutants were studied in $M_1$ generation.

### 4.1.1 Germination

The data on germination expressed both in actual percentage and percent of control is presented in Table 1.

Irradiation reduced the germination in all the doses and in all the genotypes studied as against unirradiated controls. Germination was much lower at 20 kR in all the genotypes. No clear differential response of genotypes to irradiation with respect to germination was observed in all the genotypes studied. Maximum germination was recorded in CMS-104B at 10 kR (72.4%) and CMS-103B recorded minimum germination at 20 kR (1.5%). CMS-103B and R630 genotypes shown insignificant differences in reduction of germination at 10 kR (45.9% and 47.0% respectively) and 15 kR (42.7% and 47.5%respectively). CMS-17B appears to be the most radiosensitive, followed by R630.

### 4.1.2 Survival

The data on survival of plants recorded at 40 days after sowing and expressed as both actual percentage and percent control is given in Table 1.

Generally reduction in survival was noticed at all the irradiation doses in genotypes with the increase in dosage as against controls. In case of CMS-103B lowest survival was noticed in 20 kR dose (34.65%) and highest survival was noticed in CMS-17B genotype at 10 kR (89.29) among all the treated material. In case of CMS-103B same amount of reduction was observed at 10 kR (70.09%) and 15 kR (70.18%) and survival was decreased in 20 kR (34.65%) as compared to control (89.66%). In case of R-630 there was decrease in survival at all doses as against

**Table 1. Effect of gamma rays on germination, survival and pollen fertility in $M_1$ generation**

| Genotypes | Dose (kR) | No. of seeds sown | Per cent germination | | $LD_{50}$ | No. of survival plants | Per cent survival | | $LD_{50}$ | Per cent pollen fertility | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Actual | % over control | | | Actual | % over control | | Actual | % over control |
| **CMS-104B** | 0 | 100 | 90.0 | 100.00 | 18.41 | 89 | 98.89 | 100.00 | 17.22 | 98.00 | 100.00 |
| | 10 | 1900 | 72.4 | 80.41 | | 1110 | 80.73 | 81.63 | | 90.32 | 92.16 |
| | 15 | 2014 | 56.1 | 62.34 | | 895 | 79.20 | 80.09 | | 91.75 | 93.62 |
| | 20 | 2089 | 32.3 | 35.90 | | 319 | 47.26 | 47.79 | | 90.39 | 92.23 |
| **CMS-103B** | 0 | 100 | 87.0 | 100.00 | 12.14 | 87 | 100.00 | 100.00 | 8.50 | 99.20 | 100.00 |
| | 10 | 2205 | 45.9 | 52.81 | | 710 | 70.09 | 70.09 | | 85.44 | 86.12 |
| | 15 | 2200 | 42.7 | 49.06 | | 659 | 70.18 | 70.18 | | 88.23 | 88.94 |
| | 20 | 2355 | 26.8 | 30.85 | | 219 | 34.65 | 34.65 | | 87.17 | 87.87 |
| **CMS-17B** | 0 | 100 | 89.0 | 100.00 | 3.60 | 88 | 98.88 | 100.00 | 3.90 | 94.50 | 100.00 |
| | 10 | 325 | 8.6 | 9.68 | | 104 | 89.29 | 90.30 | | 83.46 | 88.31 |
| | 15 | 338 | 2.4 | 2.66 | | 38 | 87.50 | 88.49 | | 84.94 | 89.88 |
| | 20 | 337 | 1.5 | 1.67 | | 12 | 60.00 | 60.68 | | 85.58 | 90.56 |
| **R630** | 0 | 100 | 88.0 | 100.00 | 17.30 | 86 | 97.73 | 100.00 | 4.36 | 98.35 | 100.00 |
| | 10 | 3106 | 47.0 | 53.42 | | 1190 | 81.51 | 83.40 | | 81.72 | 83.09 |
| | 15 | 3140 | 47.5 | 54.03 | | 1274 | 85.33 | 87.31 | | 83.91 | 85.31 |
| | 20 | 3440 | 41.6 | 47.24 | | 1208 | 84.48 | 86.44 | | 79.12 | 80.44 |

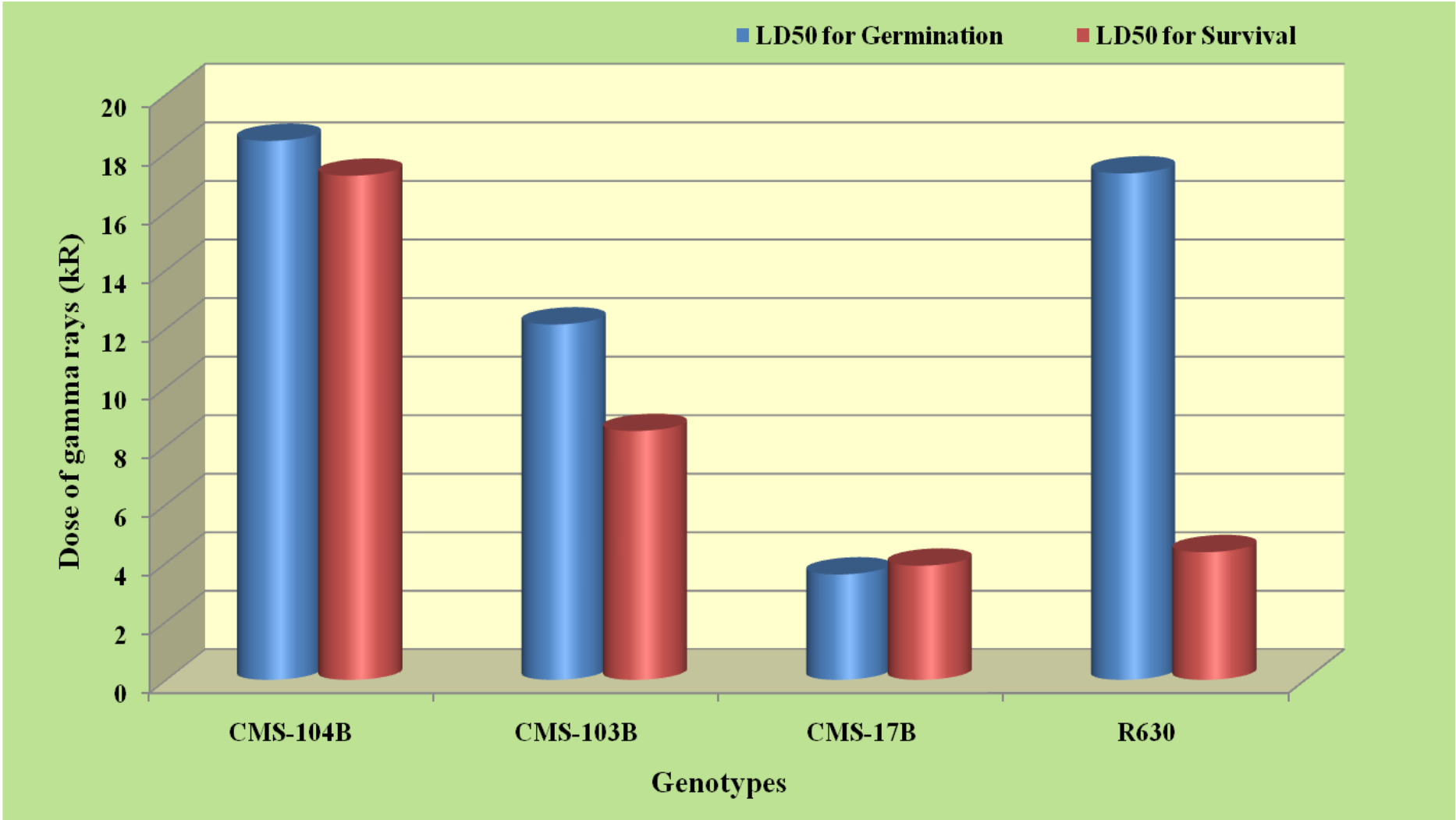



**Fig. 1. $LD_{50}$ values of gamma rays for germination and survival under field condition in $M_1$ generation**

control (87.50%), but among treatments more survival was observed at higher doses of 15 kR (85.33%) and 20 kR (84.48%) as compared to survival at lower dose 10 kR (81.51%).

### 4.1.3 Pollen fertility

Fertility of pollen grains, at different doses in the four genotypes is expressed in actual percent as well as percent of control and is given in Table 1.

Fertility of the pollen grains invariably reduced at all the doses, but the magnitude of reduction in fertility at different doses was not markedly different. No definite relationship was observed between the dose given and the reduction in fertility. Though no clear cut genotypic differences was observed, R630 appears to be the most radiosensitive from the data on pollen fertility.

### 4.1.4 $LD_{50}$ for germination and survival

The $LD_{50}$ values for germination and survival were obtained based on probit analysis and presented in Table 1and Fig. 1. The $LD_{50}$ for seed germination was found to be 18.41 kR for CMS-104B, 12.14 kR for CMS-103B likewise 3.6 kR and 17.30 for CMS-17B and R630 respectively.

The $LD_{50}$ value for survival in CMS-104B was 17.22 kR, for CMS-103B it was 8.50 kR similarly 3.9 kR and 4.36 kR for CMS-17B and R630 respectively. It indicates that CMS-17B was most sensitive to radiation followed by R630.

### 4.1.5 Quantitative characters

Effect of irradiation on quantitative characters were measured in terms of parameters such a range, mean, variance, coefficient of variability, genetic variability, genotypic coefficient of variation, phenotypic coefficient of variation, heritability and genetic advance.

A decrease in mean values and increase in range, variance, coefficient of variability, genetic variability, and genotypic coefficient of variability, heritability and genetic advance estimates was observed in most of the quantitative traits following irradiation treatment. Except for that, the various estimates calculated did not follow any trend what so ever. Nevertheless a general behaviour and trend of these parameters has been presented in the following paragraphs.

#### 4.1.5.1 Days to 50 per cent flowering

Data on days to 50 per cent flowering are presented in Table 2.

In all the irradiated genotypes early flowering was observed. For instance with respect to CMS-104B genotype, the days to 50% flowering were 60, 62 and 62 days at 10,15 and 20 kR respectively as against 65 days in control. In case of 10, 15 and 20 kR of CMS-103B genotype observed days to 50 per cent flowering were 50, 52 and 53 days respectively as against 55 days in control. CMS-17B genotype took 52 days in 10 kR, 54 days in 15 kR and 55 days in 20 kR as against control which was recorded 56 days. In case of R630 genotype as compared to control (54 days) there was reduced number of days to 50% flowering in 10 (49 days),15 (50 days) and 20 kR (52 days) doses.

#### 4.1.5.2 Plant height

Data on plant height are presented in Table 3 and Fig. 2.

In CMS-104B genotype, an increase in range values in positive and negative directions was observed in irradiated treatments compared to control. At 10, 15 and 20 kR treatments the range widened to 28 to 125, 22 to 135 and 20 to 130 respectively as against a narrow range of 85 to 145 observed in control. Similarly enlarged range for plant height was noticed in CMS-103B genotype as result of gamma irradiation. At 10, 15 and 20 kR treatments values ranged from 55 to 102, 28 to 94 and 18 to 88 respectively as against 78 to 105 in control. In CMS-17B genotype also widened range was noticed in treatments as compared to control (62 to 100). At 10 kR range was 28 to 105, at 15 kR range was 44 to 90 and at 20 kR a range of 38 to 86 was observed. Similar trend of enlarged range for plant height was noticed in R630 genotype. As compared to control (52 to 98) treatments showed 20 to 100, 25 to 82 and 28 to 85 range at 10, 15 and 20 kR.

The mean for a character as affected by the irradiation doses showed lower values in all the four genotypes studied as compared to control. With respect to CMS-104B genotype, the mean value for a trait decreased gradually as increase in dose, highest mean value was recorded at 10 kR (92.25) followed by 15 kR (85.43) and then 20 kR (78.71) as against control (125.14). A similar trend of dose dependent decrease in mean values at 10 kR (72.04), 15 kR (68.61) and 20 kR (54.88) as against the control (95.85) was observed in case of CMS-103B genotype. In case of CMS-17B genotype, highest mean values for the character observed at 15 kR (71.17) followed by 10 kR (68.00) and 20 kR (49.00) as

**Table 2. Days to 50 per cent flowering in $M_1$ generation**

| Genotypes | Dose (kR) | | | |
|---|---|---|---|---|
| | **0** | **10** | **15** | **20** |
| **CMS-104B** | 65 | 60 | 62 | 62 |
| **CMS-103B** | 55 | 50 | 52 | 53 |
| **CMS-17B** | 56 | 52 | 54 | 55 |
| **R630** | 54 | 49 | 50 | 52 |

compared to control (88.36). In R630 genotype, there was a reduction in mean values for character as compared to control (85.38), but the mean value was highest at 20 kR (68.86) followed by 10 kR (65.00) then in 15 kR (55.20).

Variance for the trait increased as increase in dosage of gamma rays in all the four genotypes studied. With respect to CMS-104B genotype, increased variance was noticed from lower dose of 10 kR (363.19) to 15 kR (443.68) and then to 20 kR (482.26) compared to control (256.00). In case of CMS-103B genotypes, variance for a character increased in comparison with control, 10 kR was recorded the value 171.26 and 15 and 20 kR recorded 238.88 and 198.24 respectively. With regard to CMS-17B which followed same trend as in CMS-103B genotype, values for variance of a trait increased from controlled value which was recorded 222.55, in case of treatments variance value was highest at 10 kR (437.00) followed by 20 kR (247.00) and then at 15 kR (229.37). In case of R630 genotype, variance value for a plant height was 251.42 (10 kR), 234.42 (15 kR) and 369.14 (20 kR) as against 158.80 in control.

As in case of variance, the coefficient of variability estimate also showed similar behaviour of increased value from lower dose of 10 kR (20.66) to 15 kR (24.66) and then to 20 kR (27.90) as against control (12.79) in CMS-104B genotype. In case of CMS-103B genotype, the coefficient of variability values at 10, 15 and 20 kR were 18.17, 22.53 and 25.66 respectively as against 13.43 in case of control. In 10, 15 and 20 kR of CMS-17B genotype coefficient of variability values were 30.74, 21.28 and 32.07 respectively in comparison with 16.88 in control. There was an increased trend of values for a character was noticed in R630 genotypes and highest value was at 20 kR (27.90) followed by 15 kR (27.74) then at 10 kR (24.39) as against control (14.76).

Higher magnitude of genetic variability was recorded at 20 kR (226.26) followed by 15 kR (187.68) and in 10 kR (107.19) treatments in CMS-104Bgenotype. Similar trend was observed in CMS-103B genotype with 5.68 at 10 kR, 73.38 at 15 kR and 32.66 at 20 kR treatments. In case of CMS-17B highest genetic variability recorded was 214.45 (10 kR) followed by 24.45 (20 kR) and then 6.82 (10 kR). Values for a character in R630 genotypes were 92.62 at 10 kR, 75.62 at 15 kR and 210.34 at 20 kR doses.

In CMS-104B genotype, estimate of heritability for plant height increased with increase in radiation dose. 10 kR recorded 29.51 per cent of heritability 15 and 20 kR recorded 42.30 and 46.92 per cent of heritability. In CMS-103B genotype, dose 10 kR

**Table 3. Mean, range, variance, heritability, genetic advance and coefficient of variability for plant height in $M_1$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 85-145 | 125.14 | 1.60 | 256.00 | 12.79 | - | - | 256.0 | - | - | - | - | 12.79 |
| | 10 | 28-125 | 92.25 | 0.89 | 363.19 | 20.66 | 363.19 | 107.19 | - | 29.51 | 11.60 | 20.66 | 11.22 | - |
| | 15 | 22-135 | 85.43 | 1.28 | 443.68 | 24.66 | 443.68 | 187.68 | - | 42.30 | 18.38 | 24.66 | 16.04 | - |
| | 20 | 20-130 | 78.71 | 1.83 | 482.26 | 27.90 | 482.26 | 226.26 | - | 46.92 | 21.26 | 27.90 | 19.11 | - |
| **CMS-103B** | 0 | 78-105 | 95.85 | 1.29 | 165.58 | 13.43 | 165.58 | - | 165.58 | - | - | | - | 13.43 |
| | 10 | 55-102 | 72.04 | 1.39 | 171.26 | 18.17 | 171.26 | 5.68 | - | 3.32 | 0.90 | 18.17 | 3.31 | - |
| | 15 | 28-94 | 68.61 | 2.05 | 238.88 | 22.53 | 238.88 | 73.30 | - | 30.69 | 9.78 | 22.53 | 12.48 | - |
| | 20 | 18-88 | 54.88 | 1.88 | 198.24 | 25.66 | 198.24 | 32.66 | - | 16.47 | 4.78 | 25.66 | 10.41 | - |
| **CMS-17B** | 0 | 62-100 | 88.36 | 4.31 | 222.55 | 16.88 | 222.55 | - | 222.55 | - | - | | - | 16.88 |
| | 10 | 28-105 | 68.00 | 6.30 | 437.00 | 30.74 | 437.00 | 214.45 | - | 49.07 | 21.16 | 30.74 | 21.54 | - |
| | 15 | 44-90 | 71.17 | 6.18 | 229.37 | 21.28 | 229.37 | 6.82 | - | 2.97 | 0.93 | 21.28 | 3.67 | - |
| | 20 | 38-86 | 49.00 | 9.07 | 247.00 | 32.07 | 247.00 | 24.45 | - | 9.90 | 3.21 | 32.07 | 10.09 | - |
| **R630** | 0 | 52-98 | 85.38 | 1.26 | 158.80 | 14.76 | 158.80 | - | 158.80 | - | - | | - | 14.76 |
| | 10 | 20-100 | 65.00 | 1.33 | 251.42 | 24.39 | 251.42 | 92.62 | - | 36.84 | 12.05 | 24.39 | 14.81 | - |
| | 15 | 25-82 | 55.20 | 2.42 | 234.42 | 27.74 | 234.42 | 75.62 | - | 32.26 | 10.19 | 27.74 | 15.75 | - |
| | 20 | 28-85 | 68.86 | 7.26 | 369.14 | 27.90 | 369.14 | 210.34 | - | 56.98 | 22.59 | 27.90 | 21.06 | - |

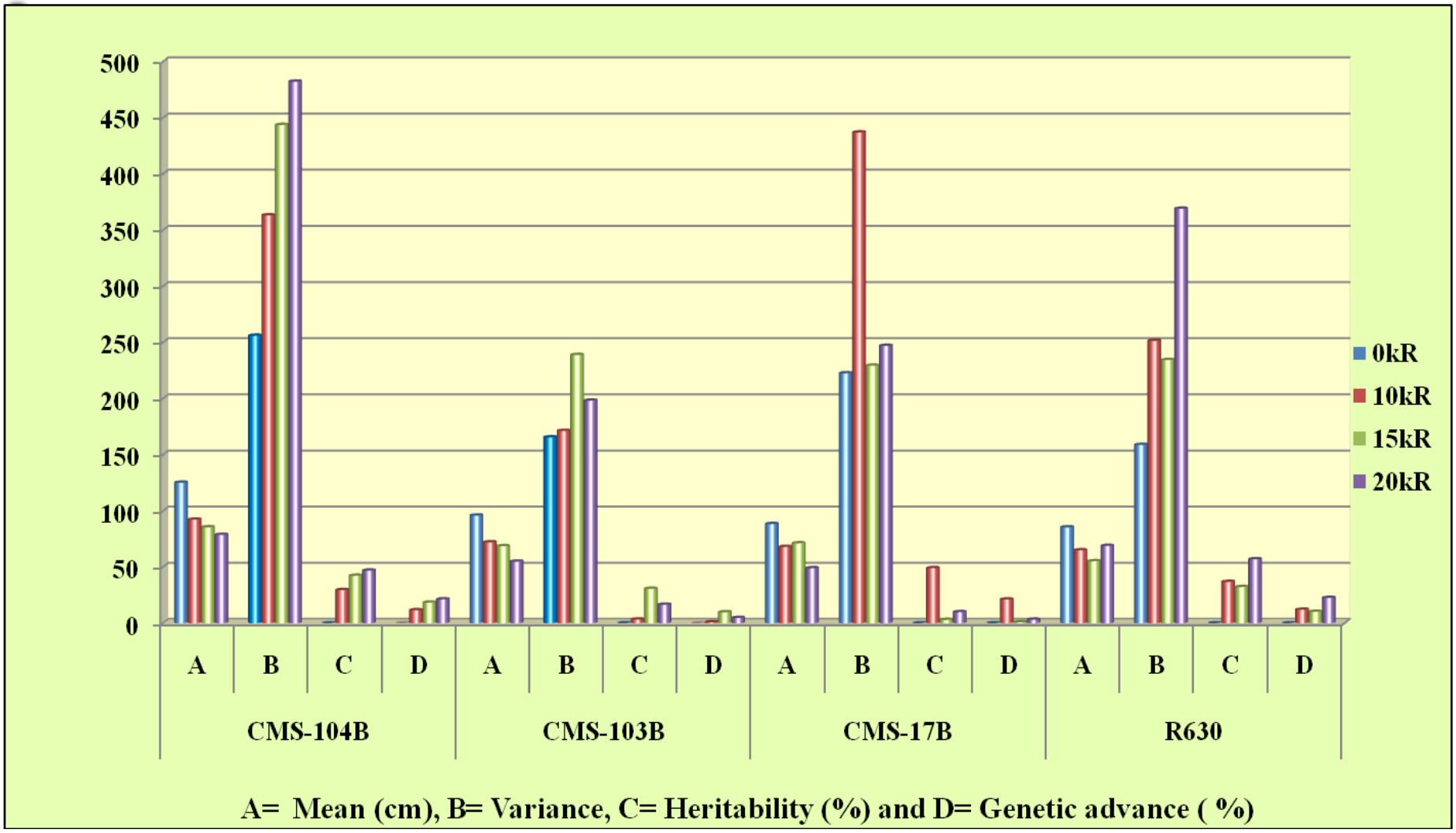



**Fig. 2. Mean, variance, heritability and genetic advance for plant height in $M_1$ generation**

recorded the lowest heritability of 3.32 per cent followed by 16.47 at 20 kR and 30.69 per cent was observed in 15 kR dose. In case of CMS-17B heritability for a trait was highest at 10 kR (49.07) followed by 20 kR (9.90) and lowest was recorded in 15 kR (2.97). Heritability for a plant height in R630 genotype was 36.84, 32.26 and 56.98 per cent observed at 10, 15 and 20 kR treatments.

As the trend observed in variance, coefficient of variability and heritability same trend for genetic advance was associated with respective genotypes. In case of CMS-104B genetic advance values were 11.60, 18.38 and 21.26 at 10, 15 and 20 kR respectively. There was lowest genetic advance in case of CMS-103B genotype was observed at 10 kR (0.90) followed by at 20 kR (4.78) and then at 15 kR (9.78). CMS-17B recorded highest genetic advance for a plant height in lower dose of 10 kR (21.16) followed by higher dose of 20 kR (3.21) and lowest was at 15 kR (15.93) doses. In contrary to this R630 showed highest value at 20 kR (22.59) followed by at 10 kR (12.05) and lowest was observed in 15 kR (10.19) treatments.

Genotypic coefficient of variability for a trait increased from 10 kR (11.22) to 15 kR (16.04) then to 20 kR (19.11) in CMS-104B genotype. In 10, 15 and 20 kR doses in CMS-103B were recorded the values 3.31, 12.48 and 10.41 respectively. CMS-17B genotype recorded highest value in 10 kR (21.54) followed by 20 kR (10.09) then least in 15 kR (3.67). The values 14.81, 15.75 and 21.06 were observed in 10, 15 and 20 kR doses in R630 genotype.

**4.1.4.3 Head diameter**

The data on head diameter are presented in Table 4.

In genotype CMS-104B irradiated treatments showed enlarged range for a character, for instance in 10, 15 and 20 kR treatments, the values observed were 6 to 18, 8 to 20 and four to 15 respectively as against 10 to 18 in control. In CMS-103B genotype the irradiation had a drastic effect in widening the range at all the doses with the values ranging from 3 to 15 in 10 kR and 2 to 15 in 15 and 20 kR doses as against a narrow range of eight to 17 in control. In case of CMS-17B 10, 15 and 20 kR treatments recorded 3 to 15, 5 to 18 and 2 to 16 respectively compared to 10 to 19 in control. R630 genotypes recorded 3 to 10 at 10 kR, 2 to 12 at 15 kR and 5 to 14 at 2 kR as against 9 to 13 in control.

The mean value of a character was also affected by irradiation treatments in all the four genotypes studied. In case of CMS-104B decrease in mean value for head diameter as increase in dose of gamma rays was observed. In 10, 15 and 20 kR doses values were 12.40, 11.88 and 11.45 respectively as against 15.45 in control. 10, 15 and 20 kR treatments of CMS-103B genotype, recorded decreased mean values of 11.31, 11.47 and 10.75 respectively compared to control which was recorded 14.47. Gamma ray had an effect on head diameter of CMS-17B genotype by decreasing the mean values at higher doses, for instance 10 and 15 kR recorded 11.18 and 10.66 and at 20 kR mean value was reduced to 8.13 as against 14.42 in control. Similar trend was also seen in case of R630 genotype, which was recorded 8.31, 7.13 and 7.02 at 10, 15 and 20 kR doses in comparison with 9.01 in control.

In focus of variability for head diameter in all the four genotypes studied was increased in accordance with the increased dosage of gamma ray. For instance CMS-104B was recorded 10.75 (10 kR), 12.35 (15 kR) and 14.00 (20 kR) as against 6.76 in control. In case of CMS-103B genotype highest variability for a trait was observed in 20 kR (13.17) followed by 15 kR (10.15) and then in 10 kR (7.40) as against control (6.68). CMS-17B also showed the same trend by recording 10.65 (10 kR), 10.88 (15 kR) and 12.04 (20 kR) in comparison with 9.17 in case of control. Genotype R630 was also evident for dose dependent increased variance for a character. In case of 10, 15 and 20 kR doses values were 8.82, 11.91 and 12.57 respectively compared to 5.00 observed in control.

Coefficient of variability for trait followed the same trend as variance in all the four genotypes studied as the result of gamma irradiation in case of CMS-104B genotypes highest coefficient of variability value was observed at higher dose of 20 kR (32.68) followed by 15 kR (29.58) and then at 10 kR (26.44) treatments as against control (16.83). In CMS-103B genotype also highest was 33.76 (20 kR) followed by 27.77 (15 kR) and 24.05 (10 kR) compared to 17.86 in control. In case of CMS-17B lowest coefficient of variability was observed in lower dose of 10 kR (29.19) followed by 15 kR (29.19) and in 20 kR (30.94) treatments as against in control (21.01). A similar kind of behaviour was showed by R630 genotype by recording highest coefficient of variability at 20 kR (50.51) followed by 15 kR (48.40) then lowest in 10 kR (35.74) treatments compared to control (24.82).

**Table 4. Mean, range, variance, heritability, genetic advance and coefficient of variability for head diameter in $M_1$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 10 – 18 | 15.45 | 0.26 | 6.76 | 16.83 | - | - | 6.76 | - | - | - | - | 16.83 |
| | 10 | 6 – 18 | 12.40 | 0.15 | 10.75 | 26.44 | 10.75 | 3.99 | - | 37.12 | 2.51 | 26.44 | 16.11 | - |
| | 15 | 8 - 20 | 11.88 | 0.21 | 12.35 | 29.58 | 12.35 | 5.59 | - | 45.24 | 3.28 | 29.58 | 19.89 | - |
| | 20 | 4 - 15 | 11.45 | 0.22 | 14.00 | 32.68 | 14.00 | 7.24 | - | 51.71 | 3.99 | 32.68 | 23.50 | - |
| **CMS-103B** | 0 | 8 - 17 | 14.47 | 0.26 | 6.68 | 17.86 | - | - | 6.68 | - | - | - | - | 17.86 |
| | 10 | 3-15 | 11.31 | 0.29 | 7.40 | 24.05 | 7.40 | 0.72 | - | 9.73 | 0.55 | 24.05 | 7.50 | - |
| | 15 | 2 - 15 | 11.47 | 0.42 | 10.15 | 27.77 | 10.15 | 3.47 | - | 34.17 | 2.25 | 27.77 | 16.23 | - |
| | 20 | 2 - 15 | 10.75 | 0.49 | 13.17 | 33.76 | 13.17 | 6.49 | - | 49.29 | 3.69 | 33.76 | 23.70 | - |
| **CMS-17B** | 0 | 10 - 19 | 14.42 | 0.87 | 9.17 | 21.01 | - | - | 9.17 | - | - | - | - | 21.01 |
| | 10 | 3 - 15 | 11.18 | 1.06 | 10.65 | 29.19 | 10.65 | 1.48 | - | 13.90 | 0.94 | 29.19 | 10.88 | - |
| | 15 | 5 - 18 | 10.66 | 1.33 | 10.88 | 30.94 | 10.88 | 1.71 | - | 15.72 | 1.07 | 30.94 | 12.27 | - |
| | 20 | 2 - 16 | 8.13 | 1.84 | 12.04 | 42.68 | 12.04 | 2.87 | - | 23.84 | 1.71 | 42.68 | 20.84 | - |
| **R630** | 0 | 9- 13 | 9.01 | 0.13 | 5.00 | 24.82 | - | - | 5.00 | - | - | - | - | 24.82 |
| | 10 | 3 -10 | 8.31 | 0.11 | 8.82 | 35.74 | 8.82 | 3.82 | - | 43.31 | 2.66 | 35.74 | 23.53 | - |
| | 15 | 2 - 12 | 7.13 | 0.22 | 11.91 | 48.40 | 11.91 | 6.91 | - | 58.01 | 6.11 | 4.13 | 36.86 | - |
| | 20 | 5 - 14 | 7.02 | 0.61 | 12.57 | 50.51 | 12.57 | 7.57 | - | 60.23 | 6.33 | 4.41 | 39.20 | - |

Among the different doses of radiation applied, the dose 20 kR (7.24, 6.49, 2.87 and 7.57) was very effective to create more genetic variability followed by 15 kR (5.59, 3.47, 1.71 and 6.91) and then 10 kR (3.99, 0.72, 1.48 and 3.82) treatments in CMS-104B, CMS-103B, CMS-17B and R630 genotypes.

With regard to heritability estimate highest value was recorded in 20 kR (51.71) followed by 15 kR (45.24) and then in 10 kR (37.12) dose, in case of CMS-104B genotype. Heritability for a character in CMS-103B genotype, increased from 9.73 to 34.17 and then to 49.29 at 10, 15 and 20 kR doses respectively. A similar kind of behaviour exhibited by CMS-17B genotype by increased heritability values as increased dose from 10 kR (13.90), 15 kR (15.72) to 20 kR (23.84). Genotype R630 recorded highest value at 20 kR (60.23) followed by 15 kR (58.01) and then in 10 kR (43.31).

In CMS-104B genotype, genetic advance estimates at 10, 15 and 20 kR doses were 2.51, 3.28 and 3.99 respectively and in case of CMS-103B genotype genetic advance values 0.55, 2.25 and 3.69 were observed at 10, 15 and 20 kR treatments. Genetic advance for a character in CMS-17B increased in association with increased dose of gamma rays from 10 kR (0.94) to 15 kR (1.07) then to 20 kR (1.71). In case of R630 genotype gamma rays had an effect of increased values from lower dose 10 kR (2.66) but values at 15 and 20 kR (4.13 and 4.41) did not differ much.

Genotypic coefficient of variability values for a character in CMS-104B genotype, were 16.11 (10 kR), 19.89 (15 kR) and 23.50 (20 kR). CMS-103B recorded 7.50, 16.23 and 23.70 at 10, 15 and 20 kR doses respectively. Highest values for genotypic coefficient of variability in CMS-17B was recorded at 20 kR (20.84) followed by 15 kR (12.27) and then to 10 kR (10.88). In case of 10, 15 and 20 kR doses recorded 23.53, 36.86 and 39.20 respectively in R630 genotype.

**4.1.4.4 Days to maturity**

Data on days to maturity are presented in Table 5.

Gamma rays had an effect on widening the range of values for a character in all the four genotypes studied. Genotype CMS-104B recorded 88 to 120, 89 to 120 and 88 to 122 in 10, 15 and 20 kR doses respectively as against the narrow range of 90 to 117 observed in control. In case of CMS-103B observed range in 10, 15 and 20 kR doses were 88 to 120, 86 to 119 and 82 to 117 respectively compared to 91 to 118 in control. In CMS-17B genotype, control recorded narrow range of 90 to 120 as compare to widen

range at gamma irradiated treatments of 10 kR (83 to 118), 15 kR (82 to 120) and at 20 kR (84 to 117). Similar widen range values in gamma irradiated treatments of 10 kR (89 to 116), 15 kR (84 to 116) and 20 kR (89 to 118) as against a narrow range of 92 to 112 in control of R630 genotypes.

Generally gamma irradiation shifted the mean values for the character in negative direction as against control in all the genotypes studied. In case of CMS-104B mean values were 100.72, 95.19 and 94.49 at 10, 15 and 20 kR respectively as against 103.77 in control. Similarly CMS-103B recorded highest mean values at 10 kR (91.54) but did not differ much in case of 15 and 20 kR (90.26 and 90.02) compared to control (92.44). In CMS-17B mean values were 98.27 (10 kR), 94.00 (15 kR) and 92.33 (20 kR) as against control (103.25). In case of R630 genotype gamma radiation shifted mean values towards positive direction in 10 kR (97.54) and 15 kR (96.10) but in case of 20 kR (94.08) mean value shifted in negative direction compared to mean value in control (95.39).

Variance for a character in CMS-104B genotype was 52.72, 58.58 and 77.12 at 10, 15 and 20 kR doses as against 50.18 in control. CMS-103B genotype recorded increased variance values from 10 kR (86.95) to 15 kR (93.48) and then to 20 kR (96.48) compared to control (51.14). In case of CMS-17B genotype 20 kR (54.33) was recorded highest value of variance followed by 15 kR (37.60) then in 10 kR (23.42) as against control (21.30). The variance value for days to maturity in R630 genotype were 26.30, 29.63 and 42.00 at 10, 15 and 20 kR treatments respectively as against 23.15 under unirradiated control.

Coefficient of variability was increased from lower dose of 10 kR (7.21) to 15 kR (8.04) and then to 20 kR (9.29) in irradiated treatments of CMS-104B compared to control (6.83) of same genotype. The values 7.74, 10.19, 10.71 and 10.91 were recorded in control, 10, 15 and 20 kR treatments of CMS-103B genotype. Similarly increased coefficient of variability in accordance with increased dose was observed in CMS-17B genotype, in 10 kR coefficient of variability was 4.95, 6.52 and 7.98 at 10, 15 and 20 kR doses respectively as against 4.47 in control. R630 genotype recorded 5.26 (10 kR), 5.66 (15 kR) and 6.89 (20 kR) as against 5.04 in control.

Estimated of genetic variability for a days to maturity were 2.54 (10 kR), 8.40 (15 kR) and 26.94 (20 kR) in CMS-104B genotype. In case of CMS-103B genotype highest genetic variability was recorded in higher dose of 20 kR (45.01) followed by

**Table 5. Mean, range, variance, heritability, genetic advance and coefficient of variability for days to maturity in $M_1$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 90-117 | 103.77 | 0.71 | 50.18 | 6.83 | - | - | 50.18 | - | - | - | - | 6.83 |
| | 10 | 88-120 | 100.72 | 0.34 | 52.72 | 7.21 | 52.72 | 2.54 | - | 4.82 | 0.72 | 7.21 | 1.58 | - |
| | 15 | 89-120 | 95.19 | 0.43 | 58.58 | 8.04 | 50.58 | 8.40 | - | 14.34 | 2.26 | 8.04 | 3.04 | - |
| | 20 | 88-122 | 94.49 | 0.73 | 77.12 | 9.29 | 77.12 | 26.94 | - | 34.93 | 6.33 | 9.29 | 5.49 | - |
| **CMS-103B** | 0 | 91-118 | 92.44 | 0.72 | 51.14 | 7.74 | - | - | 51.14 | - | - | - | - | 7.74 |
| | 10 | 88-120 | 91.54 | 0.81 | 86.95 | 10.19 | 86.95 | 6.54 | - | 11.29 | 1.77 | 8.32 | 2.79 | - |
| | 15 | 86-119 | 90.26 | 1.28 | 93.48 | 10.71 | 93.48 | 42.07 | - | 45.01 | 8.98 | 10.71 | 7.19 | - |
| | 20 | 82-117 | 90.02 | 2.14 | 96.48 | 10.91 | 96.48 | 31.01 | - | 46.65 | 9.45 | 10.91 | 7.45 | - |
| **CMS-17B** | 0 | 90-120 | 103.25 | 1.33 | 21.30 | 4.47 | - | - | 21.30 | - | - | - | - | 4.47 |
| | 10 | 83-118 | 98.27 | 1.46 | 23.42 | 4.92 | 23.42 | 2.12 | - | 9.05 | 0.90 | 4.92 | 1.48 | - |
| | 15 | 82-120 | 94.00 | 3.36 | 37.60 | 6.52 | 37.60 | 16.30 | - | 43.35 | 5.48 | 6.52 | 4.30 | - |
| | 20 | 84-117 | 92.33 | 4.25 | 54.33 | 7.98 | 54.33 | 33.03 | - | 60.80 | 9.24 | 7.98 | 6.22 | - |
| **R630** | 0 | 92-112 | 95.39 | 0.48 | 23.15 | 5.04 | - | - | 23.15 | - | - | - | - | 5.04 |
| | 10 | 89-116 | 97.54 | 0.58 | 26.30 | 5.26 | 26.30 | 3.15 | - | 11.98 | 1.27 | 5.26 | 1.82 | - |
| | 15 | 84-116 | 96.10 | 0.86 | 29.63 | 5.66 | 29.63 | 6.48 | - | 21.87 | 2.46 | 5.66 | 2.65 | - |
| | 20 | 89-118 | 94.08 | 1.27 | 42.00 | 6.89 | 42.00 | 18.85 | - | 44.88 | 6.00 | 6.89 | 4.61 | - |

15 kR (42.07) and lowest in 10 kR (35.54). Increased genetic variability for a trait as increased in dose was also observed in CMS-17B, which was recorded lowest value in 10 kR (2.12) followed by 15 kR (16.30) and highest was at 20 kR (33.03). Same trend was followed by R630 genotype and which was recorded 3.15, 6.48 and 18.85 at 10, 15 and 20 kR doses respectively.

Heritability estimates for days to maturity in case of CMS-104B were 4.82 per cent (10 kR), 14.34 per cent (15 kR) and 34.93 per cent (20 kR). In CMS-103B genotype, increased heritability was observed from 10 kR (11.29 %) to 15 kR (45.01%) and then to 20 kR (46.65 %). In 10, 15 and 20 kR treatments of CMS-17B recorded 9.05, 43.35 and 60.80 per cent for heritability of days to maturity. Similar increased trend was observed in 10 kR (11.98 %), 15 kR (21.87 %) and 20 kR (44.88%) doses in R630 genotype.

A similar kind of behaviour of dose dependant increase in genetic advance was observed in all the four genotypes studied. For instance CMS-104B had a value 0.72, 2.26 and 6.33 in 10, 15 and 20 kR doses respectively. In case of CMS-103B genotype, genetic advance values were 1.77 (10 kR), 8.98 (15 kR) and 9.45 (20 kR) in irradiated treatments. Highest value observed in case of CMS-17B was in 20 kR (9.24) followed by 15 kR (5.48) and lowest was in 10 kR (0.90). Likewise 1.27 (10 kR), 2.46 (15 kR) and 6.00 (20 kR) values were observed in treatments of R630 genotypes.

Genotypic coefficient of variability values in CMS-104B were 1.58, 3.04 and 5.49 at 10, 15 and 20 kR doses of gamma rays. In CMS-103Bgenotype lowest value was recorded in 10 kR (2.79) followed by 15 kR (7.19) and highest value was in 20 kR (7.45) treatments. In 10, 15 and 20 kR treatments of CMS-17B values were 1.48, 4.30 and 6.22 respectively. In case of R630 genotype, values were 1.82 (10 kR), 2.65 (15 kR) and 4.61 (20 kR).

**4.1.4.5 Seed yield per plant**

Data on seed yield per plant are presented in Table 6

Estimates of range for character enlarged in irradiated CMS-104B genotype compare to untreated control. In 10, 15 and 20 kR doses values ranged from 4.12 to 18.80, 4.68 to 26.00 and 5.00 to 22.40 as against narrow range of 12.40 to 26.63 in control. CMS-103B genotype, showed enlarged range for a trait in 10 kR (4.50 to 20.90), 15 kR (6.00 to 25.40) and 20 kR (7.20 to 19.90) than in control (9.46 to 21.50). In

CMS-17B values were 4.02 to 20.10 (10 kR), 3.08 to 19.60 (15 kR) and 2.48 to 23.40 (20 kR) in irradiated treatments than in control (12.80 to 22.30). Similarly R630 genotype also had widened range for seed yield per plant in 10 kR (5.80 to 15.50), 15 kR (4.20 to 13.80) and 20 kR (2.00 to 11.80) treatments than in control which was recorded a narrow range of 8.00 to 14.12.

Generally decrease in mean value for trait as increase in dosage of gamma rays treatments than in control of all the four genotypes studied, in contrast CMS-104B genotype recorded highest mean value at 20 kR (14.12) and values in 10 and 15 kR (13.74 and 13.58) did not differ significantly as against 18.12 observed in control. In CMS-103B genotype, values were 12.74, 10.49 and 8.36 at 10, 15 and 20 kR doses as against 17.80 in control. In case of CMS-17B mean values for a trait were 10.92, 9.83 and 9.01 in 10, 15 and 20 kR treatments respectively. Treatments 10, 15 and 20 kR of R630 genotype, recorded 9.80, 8.60 and 9.14 respectively compared to control (12.75).

Variance was decreased in 20 kR (4.74) and increased in 10 and 15 kR doses (5.75 and 7.72) in comparison with control (3.54). Variance was decreased as decrease in dosage of gamma rays in case of CMS-103B genotype, 10 kR of this genotype recorded 3.52. 15 and 20 kR recorded 4.65 and 4.91 as against 2.65 in control. In case of CMS-17B value at 10 kR was 2.64 and values at 15 and 20 kR were 2.90 and 3.14 respectively as against 2.39 in control. R630 genotype recorded highest values at 20 kR (3.90) followed by 15 kR (1.85) and lowest in 10 kR (1.15) as against 1.08 in control.

Estimate of coefficient of variability in 10, 15 and 20 kR treatments were 17.46, 20.47 and 15.42 as against 10.38 in control of CMS-104B genotype. In case of CMS-103B genotype values were 26.51 (20 kR), 20.56 (15 kR) and 14.72 (10 kR) compared to 9.15 (control). In case of CMS-17B genotype highest coefficient of variability was at 20 kR (19.67) followed by 15 kR (17.32) and then 10 kR (14.88) compared to control which was recorded 9.07. Values in 10, 15 and 20 kR treatments of R630 genotype were 10.94, 15.82 and 21.61 respectively as against 8.15 in control.

Genetic variability in CMS-104B was highest at 15 kR (4.18) followed by 10 kR (2.21) and at 20 kR (1.20). In case of CMS-103B genotype values were 0.87 (10 kR), 2.00 (15 kR) and 2.26 (20 kR). In 10, 15 and 20 kR treatments of CMS-17B recorded values of 0.25, 0.51 and 0.75 respectively. R630 genotype recorded highest genetic variability in case of 20 kR (2.82), then 15 kR (0.77) and lowest in 10 kR (0.07).

**Table 6. Mean, range, variance, heritability, genetic advance and coefficient of variability for seed yield per plant in $M_1$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 12.40 - 26.63 | 18.12 | 0.19 | 3.54 | 10.38 | - | - | 3.54 | - | - | - | - | 10.38 |
| | 10 | 4.12 - 18.80 | 13.74 | 0.24 | 5.75 | 17.46 | 5.75 | 2.21 | - | 38.47 | 1.90 | 17.46 | 10.83 | - |
| | 15 | 4.68 - 26.00 | 13.58 | 0.28 | 7.72 | 20.47 | 7.72 | 4.18 | - | 54.17 | 3.11 | 20.47 | 15.06 | - |
| | 20 | 5.00 - 22.40 | 14.12 | 0.22 | 4.74 | 15.42 | 4.74 | 1.20 | - | 25.28 | 1.14 | 15.42 | 7.75 | - |
| **CMS-103B** | 0 | 9.46 - 21.50 | 17.80 | 0.16 | 2.65 | 9.15 | - | - | 2.65 | - | - | - | - | 9.15 |
| | 10 | 4.50 - 20.90 | 12.74 | 0.19 | 3.52 | 14.72 | 3.52 | 0.87 | - | 24.65 | 0.95 | 14.72 | 7.31 | - |
| | 15 | 6.00 - 25.40 | 10.49 | 0.22 | 4.65 | 20.56 | 4.65 | 2.00 | - | 43.01 | 1.91 | 20.56 | 13.48 | - |
| | 20 | 7.20 -19.90 | 8.36 | 0.22 | 4.91 | 26.51 | 4.91 | 2.26 | - | 46.03 | 2.10 | 26.51 | 17.98 | - |
| **CMS-17B** | 0 | 12.80 -22.30 | 17.04 | 0.15 | 2.39 | 9.07 | - | - | 2.39 | - | - | - | - | 9.07 |
| | 10 | 4.02 -20.10 | 10.92 | 0.16 | 2.64 | 14.88 | 2.64 | 0.25 | - | 9.47 | 0.32 | 14.88 | 4.58 | - |
| | 15 | 3.08 -19.60 | 9.83 | 0.17 | 2.90 | 17.32 | 2.90 | 0.51 | - | 17.59 | 0.62 | 17.32 | 7.26 | - |
| | 20 | 2.48 -23.40 | 9.01 | 0.18 | 3.14 | 19.67 | 3.14 | 0.75 | - | 23.89 | 0.87 | 19.67 | 9.61 | - |
| **R630** | 0 | 8.00 -14.12 | 12.75 | 0.10 | 1.08 | 8.15 | - | - | 1.08 | - | - | - | - | 8.15 |
| | 10 | 5.8 0-15.50 | 9.80 | 0.11 | 1.15 | 10.94 | 1.15 | 0.07 | - | 6.09 | 0.13 | 10.94 | 2.70 | - |
| | 15 | 4.20- 13.80 | 8.60 | 0.14 | 1.85 | 15.82 | 1.85 | 0.77 | - | 41.62 | 1.17 | 15.82 | 10.20 | - |
| | 20 | 2.00 -11.80 | 9.14 | 0.20 | 3.90 | 21.61 | 3.90 | 2.82 | - | 72.31 | 2.95 | 21.61 | 18.37 | - |

In all the four genotypes studied heritability values increased with increase in dose of gamma rays, in contrast to this CMS-104B genotype recorded highest value in 15 kR (54.17) followed by 10 kR (38.47) then in 20 kR (25.58). Treatment 20 kR (46.03) showed highest heritability value than in 15 kR (43.01) and 10 kR (24.65) treatments of CMS-103B genotype. Values 9.47, 17.59 and 23.89 were observed in 10, 15 and 20 kR treatments of CMS-17B genotype. R630 genotype showed highest values at 20 kR (72.31) and 15 kR (41.62) and lowest in 10 kR (6.09).

The highest genetic advance value observed was 3.11 in 15 kR of CMS-104B genotype, 10 and 20 kR showed 1.90 and 1.14 respectively. CMS-103B showed the values 0.95 (10 kR), 1.91 (15 kR) and 2.10 (20 kR). In case of CMS-17B values were 0.32, 0.62 and 0.87 at 10, 15 and 20 kR doses respectively. In case of R630 genotype 20 kR recorded highest genetic advance value of 2.95 followed by 1.71 in 15 kR and 0.13 in 10 kR.

As in case of most of the estimates of CMS-104B genotype, the highest genotypic coefficient of variability was in 15 kR (15.06) followed by 10 kR (10.83) then in 20 kR (7.75). CMS-103B genotype showed 7.31, 13.48 and 17.98 at 10, 15 and 20 kR respectively. The observed values of genotypic coefficient of variability for a trait in CMS-17B genotype were 4.58 (10 kR), 7.26 (15 kR) and 9.61 (20 kR). R630 genotype recorded highest value at 20 kR (18.37) followed by 15 kR (10.20) and 10 kR (2.70) treatments.

## 4.2 Gamma rays induced abnormalities

### 4.2.1 Chlorophyll abnormalities in $M_1$ and $M_2$ generations

Frequency of chlorophyll abnormalities both in $M_1$ and $M_2$ generations are presented in Table 7.

Most of the chlorophyll abnormalities were observed at seedling stage some of them were manifested in later stages of plant growth. Abnormalities observed in later stages were restricted in majority of the cases to one or two leaves (Plate 1) but some of the seedlings were completely greenish yellow are greenish white (Plate 2). The abnormalities encountered could not be classified defiantly in to different types. Most of the abnormalities were in the form of white and light green streaks, white light green and yellow patches and various mosaic patterns of all sorts. In few cases only half of the

leaves was completely white or very light green, the remaining half being of perfectly green in colour. In few cases chlorophyll deficient condition was noticed in bracts also (Plate 2).

In general, frequency of chlorophyll mutations increased with the increase in dose in case of both $M_1$ and $M_2$ generations. In $M_1$ generation the maximum chlorophyll mutation was observed in 15 kR (28.04 %) of CMS-104B genotype and minimum was at 20 kR treatment of CMS-17B genotype where no plants showed chlorophyll mutations. In case of CMS-104B genotype highest abnormal plants observed at 15 kR (28.04 %) rather than in 20 kR (15.36 %). In $M_2$ generation maximum frequency was observed in 20 kR (7.20%) of CMS-104B genotype and minimum in 10 kR of CMS-17B genotype (1.16%). Effect of gamma irradiation in induction of overall chlorophyll abnormalities was more in case of $M_1$ generation (12.94) than in $M_2$ generation (4.31%).

### 4.2.2 Mutagenic effectiveness and efficiency of gamma rays based on chlorophyll mutations

Data on mutagenic effectiveness and efficiency are presented in Table 8. Effectiveness of gamma rays based on the mutations induced was in general directly proportional to the dose applied in all the four genotypes studied. In case of CMS-104B genotype, the dose 15 kR was very effective in inducing mutations (0.45) followed by 20 kR (0.42) and in 10 kR (0.36) in CMS-103B genotype mutagenic effectiveness was highest at 20 kR (0.19) followed by 15 kR (0.17) and 10 kR (0.15). Highest effectiveness values in CMS-17B genotype was 0.14 (20 kR), 0.14 (15 kR) and 0.12 (10 kR). Similar trend of increased effectiveness at higher doses was showed by R630 genotype also, where it recorded lowest value at 10 kR (0.10) followed by 15 kR (0.13) and 20 kR (0.16) treatments.

Efficiency of gamma rays also appears to be increased with dosage. However no significant differences were noticed among doses with respect to efficiency. In CMS-104B genotype, mutagenic efficiency values observed at 10, 15 and 20 kR doses were 0.14, 0.59 and 0.16 respectively. In CMS-103B genotype efficiency values were 0.12 (10 kR), 0.19 (15 kR) and 0.23 (20 kR). In case of CMS-17B genotype highest value was recorded at 20 kR (0.36) followed by 15 kR (0.24) and 10 kR (0.09). In R630 genotype 0.11, 0.14 and 0.18 were the efficiency values observed at 10, 15 and 20 kR doses respectively.

**Table 7. Frequency of chlorophyll abnormalities in $M_1$ and $M_2$ generations**

| Genotypes | Dose (kR) | Number of plants in $M_1$ | | Frequency (%) in $M_1$ | Over all Frequency of genotype | Number of plants in $M_2$ | | Frequency (%) in $M_2$ | Over all Frequency of genotype |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | Abnormal | | | Total | Abnormal | | |
| **CMS-104B** | 0 | 86 | 0 | 0.00 | 18.28 | 100 | 0 | 0 | 5.33 |
| | 10 | 1110 | 125 | 11.26 | | 18120 | 761 | 4.20 | |
| | 15 | 895 | 251 | 28.04 | | 9926 | 675 | 6.80 | |
| | 20 | 319 | 49 | 15.36 | | 4090 | 294 | 7.20 | |
| **CMS-103B** | 0 | 78 | 0 | 0.00 | 9.50 | 100 | 0 | 0 | 2.09 |
| | 10 | 710 | 62 | 8.73 | | 4233 | 63 | 1.50 | |
| | 15 | 659 | 44 | 6.67 | | 4178 | 104 | 2.50 | |
| | 20 | 219 | 45 | 20.54 | | 548 | 21 | 3.80 | |
| **CMS-17B** | 0 | 66 | 0 | 0.00 | 8.5 | 100 | 0 | 0 | 2.00 |
| | 10 | 25 | 2 | 8.00 | | 394 | 5 | 1.16 | |
| | 15 | 7 | 1 | 14.20 | | 514 | 11 | 2.14 | |
| | 20 | 3 | 0 | 0.00 | | 238 | 7 | 2.80 | |
| **R630** | 0 | 77 | 0 | 0.00 | 12.5 | 100 | 0 | 0 | 2.20 |
| | 10 | 1190 | 117 | 9.80 | | 1164 | 19 | 1.60 | |
| | 15 | 1274 | 155 | 12.20 | | 1542 | 31 | 2.00 | |
| | 20 | 1208 | 187 | 15.50 | | 1542 | 31 | 3.20 | |

Over all frequency of chlorophyll abnormalities in $M_1 = \frac{1038}{8019} \times 100 = 12.94\%$

Over all frequency of chlorophyll abnormalities on $M_2$ plant basis = $\frac{2022}{46867} \times 100 = 4.31\%$

A. CMS-104B at 10 kR ($M_1$ generation)

B. R 630 at 20 kR ($M_1$ generation)

C. CMS-17B at 20 kR ($M_1$ generation)

D. CMS-103B at 15 kR ($M_1$ generation)

**Plate 1. Chlorophyll abnormalities in $M_1$ and $M_2$ generations**

a

**A. Seedling showing chlorophyll deficiency in CMS-17B at 15kR**

**B. Chlorophyll deficiency in bracts of CMS-104B at 10kR**

**Plate 2. Chlorophyll Abnormalities recovered in $M_1$ generation**

**Table 8. Mutagenic effectiveness and efficiency of different doses of gamma rays**

| Genotypes | Dose (kR) | Mutagenic effectiveness | Mutagenic efficiency |
|---|---|---|---|
| **CMS104B** | 0 | - | - |
| | 10 | 0.36 | 0.14 |
| | 15 | 0.45 | 0.59 |
| | 20 | 0.42 | 0.16 |
| **CMS103B** | 0 | - | - |
| | 10 | 0.15 | 0.12 |
| | 15 | 0.17 | 0.19 |
| | 20 | 0.19 | 0.23 |
| **CMS17B** | 0 | - | - |
| | 10 | 0.12 | 0.09 |
| | 15 | 0.14 | 0.24 |
| | 20 | 0.14 | 0.36 |
| **R630** | 0 | - | - |
| | 10 | 0.10 | 0.11 |
| | 15 | 0.13 | 0.14 |
| | 20 | 0.16 | 0.18 |

### 4.2.3 Abnormal seedlings

Mutants with abnormalities for leaf morphology and leaf characteristics were recovered in both $M_1$ and $M_2$ generations and are presented in Plate 3.

Most of the morphological abnormalities were observed at seedling stage. Changes with respect to leaf shape were noticed in mutants.

### 4.2.4 Stem and branching abnormalities

The appearance of branching type in non branching CMS-104B, CMS-103B and CMS-17B genotypes were observed in both $M_1$ and $M_2$ generations and these are presented in Plate 4. In some of the cases gamma ray had an effect by inducing abnormalities in morphology of stems (Plate 5).

### 4.2.5 Head and floral abnormalities

Some of the abnormal forms of heads like twin heads and malformed heads are noticed in both $M_1$ and $M_2$ generations. Some abnormal flowers with no disc florets and very small and lathery ray florets were observed in both $M_1$ and $M_2$ generations and are presented in Plate 6.

## 4.3 $M_2$ GENERATION

Effect of gamma irradiation doses on germination, survival, quantitative characters and presence of any abnormalities like chlorophyll mutants were studied in $M_1$ generation.

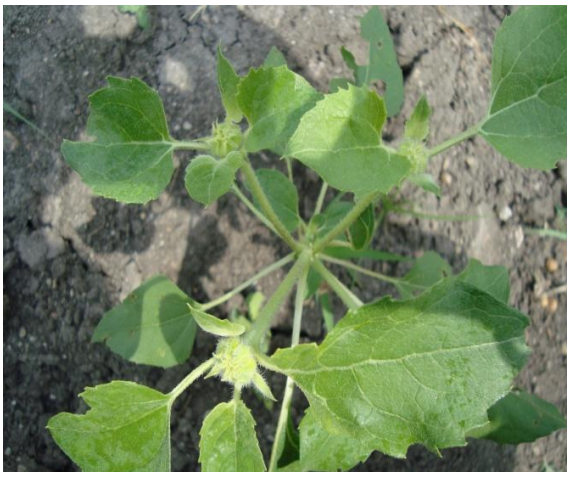
### 4.3.1 Survival

Data on survival (Table 9) of plants in $M_2$ generation recorded at the time of maturity and expressed in percentage. Reduction in survival was noticed in all the four genotypes studied at all the doses of gamma rays. CMS-104B genotype recorded highest survival per cent in 20 kR (72.18) followed by 15 kR (63.54) and then 10 kR (46.32) as against control (88.00). Per cent survival of plants observed at 10, 15 and 20 kR doses in CMS-103B genotype were 68.35, 53.54 and 48.32 as compared to 86.00 per cent in case of unirradiated population. In CMS-17B genotype, increase in dosage caused the deleterious effect on survival and which was recorded lowest survival per cent at 20 kR (38.33) followed by 15 kR (41.45) and highest in 10 kR (47.07) compared to control (80.00). Similarly dose dependent decrease in survival was noticed in R630 genotype,

**Table 9. Percentage of surviving plants in $M_2$ generation**

| Genotypes | Dose (kR) | Number of families | Plant population | | |
|---|---|---|---|---|---|
| | | | Expected | Observed | Survival (%) |
| **CMS-104B** | 0 | 04 | 100 | 88.00 | 88.00 |
| | 10 | 365 | 25104 | 18120 | 72.18 |
| | 15 | 274 | 15622 | 9926 | 63.54 |
| | 20 | 144 | 8830 | 4090 | 46.32 |
| **CMS-103B** | 0 | 04 | 100 | 86.00 | 86.00 |
| | 10 | 89 | 6193 | 4233 | 68.35 |
| | 15 | 57 | 7804 | 4178 | 53.54 |
| | 20 | 18 | 1134 | 548 | 48.32 |
| **CMS-17B** | 0 | 04 | 100 | 80.00 | 80.00 |
| | 10 | 12 | 837 | 394 | 47.07 |
| | 15 | 18 | 1240 | 514 | 41.45 |
| | 20 | 06 | 620 | 238 | 38.33 |
| **R630** | 0 | 04 | 100 | 81.00 | 81.00 |
| | 10 | 25 | 1760 | 1164 | 66.11 |
| | 15 | 41 | 2895 | 1542 | 53.25 |
| | 20 | 07 | 2099 | 980 | 46.67 |

**A. CMS-103B at 20 kR ($M_1$ generation)**



**B. R 630 at 10kR ($M_2$ generation)**

**D. CMS-17B at 20kR ($M_2$ generation)**

**C. CMS-104B at 15kR ($M_2$ generation)**

**Plate 3. Leaf morphological abnormalities observed in $M_1$ and $M_2$ generations**

**A. Split branching in CMS-104B at 10kR in $M_1$ generation.**

**B. Rudimentary branching in CMS-103B at 20kR in $M_2$ generation**

**Plate 4. Branching abnormalities in $M_1$ and $M_2$ generations**

**A. Twisted stem near the head in CMS-104B at 15kR in $M_1$ generation**

**B. Malformed stem in CMS-103B at 10kR in $M_2$ generation**

**Plate 5. Stem abnormalities recovered in $M_1$ and $M_2$ generations**

**A. A flower with malformed disc florets and few feathery ray florets in CMS-104B at 10 kR in $M_1$ generation**

**B. A malformed capitulum without ray florets in CMS-104B at 10 kR in $M_2$ generation**

**C. A flower with very small ray florets in CMS-103B at 15 kR in $M_2$ generation**

**Plate 6. Floral and head abnormalities in $M_1$ and $M_2$ generations**

which was recorded 66.11 (10 kR), 53.25 (15 kR) and 46.67 (20 kR) per cent as against 81.00 per cent in control.

### 4.3.2 Quantitative characters

The estimates such as range, mean, variance, coefficient of variability, genetic variation, heritability, genetic advance and genotypic coefficient of variability were calculated in $M_2$ generation to know the effect of gamma irradiation doses on quantitative character.

#### 4.3.2.1 Days to 50 per cent flowering

The data on effect of gamma irradiation on days to 50 per cent flowering in $M_2$ are presented in Table 10.

In $M_2$ generation, several early flowering types were observed following gamma irradiation treatments. The observed range values at 10, 15 and 20 kR doses in CMS-104B genotype were 48 to 79, 51 to 76 and 45 to 73 as against the value of 54 to 67 days in control. A similar widening of the range was observed in CMS-103B genotype at 10 kR (42 to 58), 15 kR (42 to 59) and 20 kR (42 to 59) as against a narrow range of 48 to 58 days observed in control. CMS-17B genotype recorded 46 to 62 (10 kR), 47 to 62 (15 kR) and 44 to 63 (20 kR) compared to 52 to 60 in control. Likewise 54 to 69, 50 to 68 and 46 to 68 were observed in R630 genotype at 10, 15 and 20 kR respectively as against a narrow range of 57 to 65 in control.

The mean value of character was reduced in $M_2$ generation in all the four genotypes studied. In CMS-104B genotype mean values were 58.33, 57.42 and 60.37 at 10, 15 and 20 kR doses respectively when compared to 60.50 in case of control. CMS-103B genotype highest mean value was at 20 kR (51.98) followed by 15 kR (51.77) and in 10 kR (50.23) as against 54.00 in control. CMS-17B genotype 15 kR was more effective in reducing the number of days to 50 per cent flowering by recording 52.67 days followed by 10 kR which was recorded 53.96 and 20 kR recorded 54.46 days for 0 per cent flowering in comparison with 55.50 days in control. R630genotype recorded more number of days for 50 per cent flowering in case of 10 kR (60.88) than in control (59.50) and 15 and 20 kR were recorded 57.92 and 58.17 respectively.

Irradiation treatments increased the variability for days to 50 per cent flowering in all the four genotypes studied. With respect to CMS-104B genotype the variance values

**Table 10. Mean, range, variance, heritability, genetic advance and coefficient of variability for days to 50 per cent flowering in $M_2$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 54-67 | 60.50 | 2.72 | 29.67 | 9.00 | - | - | 29.67 | - | - | - | - | 9.00 |
| | 10 | 48-79 | 58.33 | 0.67 | 33.36 | 9.90 | 33.36 | 3.69 | - | 11.06 | 1.32 | 9.90 | 3.29 | - |
| | 15 | 51-76 | 57.42 | 0.58 | 37.83 | 10.71 | 37.83 | 8.16 | - | 21.57 | 2.74 | 10.71 | 4.97 | - |
| | 20 | 45-73 | 60.37 | 0.62 | 44.93 | 11.10 | 44.93 | 15.26 | - | 33.96 | 4.70 | 11.10 | 6.47 | - |
| **CMS-103B** | 0 | 48-58 | 54.00 | 2.16 | 18.67 | 8.00 | - | - | 18.67 | - | - | - | - | 8.00 |
| | 10 | 42-58 | 50.23 | 0.50 | 24.87 | 9.93 | 24.87 | 6.20 | - | 24.93 | 2.56 | 9.93 | 4.96 | - |
| | 15 | 42-59 | 51.77 | 0.50 | 25.49 | 9.75 | 25.49 | 6.82 | - | 26.76 | 2.79 | 9.75 | 5.04 | - |
| | 20 | 42-59 | 51.98 | 0.54 | 28.85 | 10.33 | 28.85 | 10.18 | - | 35.29 | 3.91 | 10.33 | 6.14 | - |
| **CMS-17B** | 0 | 52-60 | 55.50 | 1.71 | 11.67 | 6.16 | - | - | 11.67 | - | - | - | - | 6.16 |
| | 10 | 46-62 | 53.96 | 0.46 | 21.55 | 8.60 | 21.55 | 9.88 | - | 45.85 | 4.39 | 8.60 | 5.83 | - |
| | 15 | 47-62 | 52.67 | 0.97 | 28.46 | 10.13 | 28.46 | 16.79 | - | 59.00 | 6.49 | 10.13 | 7.78 | - |
| | 20 | 44-63 | 54.46 | 1.04 | 32.41 | 10.45 | 32.41 | 20.74 | - | 63.99 | 7.52 | 10.45 | 8.36 | - |
| **R630** | 0 | 57-65 | 59.50 | 1.85 | 13.67 | 6.21 | - | - | 13.67 | - | - | - | - | 6.21 |
| | 10 | 54-69 | 60.88 | 0.40 | 16.21 | 6.60 | 16.21 | 2.54 | - | 15.67 | 1.30 | 6.61 | 2.62 | - |
| | 15 | 50-68 | 57.92 | 0.41 | 17.00 | 7.12 | 17.00 | 3.33 | - | 19.59 | 1.67 | 7.12 | 3.15 | - |
| | 20 | 46-68 | 58.17 | 1.17 | 31.51 | 9.65 | 31.51 | 17.84 | - | 56.62 | 6.56 | 9.65 | 7.26 | - |

increased at higher dose of 20 kR (44.93) followed by 15 kR (37.83) and then at 10 kR (33.36) doses as compared to less variance observed in control (29.67). Likewise 20 kR of CMS-103B genotype recorded highest variance value (28.85), 15 kR (25.49) and 10 kR (24.87) as against 18.67 days in control. CMS-17B genotype was recorded lowest variance was 21.55 (10 kR) followed by 28.46 (15 kR) and then highest was 32.41 (20 kR) as against 11.67 in control. A similar kind of behaviour was showed by R630 genotype by recording highest at 20 kR (31.51) followed by 15 kR (17.00) and then at 10 kR (16.21) against 13.67 in control.

An increase in magnitude of coefficient of variability was highest at 20 kR (11.10) followed by 15 kR (10.71) and at 10 kR (9.90) as against control (9.00) of CMS-104B genotype. In CMS-103B genotype 20 kR (10.33) was the effective dose for increased coefficient of variability followed by 10 kR (9.93) and then at 15 kR (9.75) as compared to control which was recorded 9.93 coefficient of variability for a trait. Gamma irradiation had a influence on CMS-17B genotype by increasing the coefficient of variability at higher dose of 20 kR (10.45) and 15 kR (10.13) than in lower dose of 10 kR (8.60) as against a least value of coefficient of variability in control (6.16). Similarly R630 genotype recorded 9.65, 7.12 and 6.60 at 20, 15 and 10 kR respectively compared to 6.21 in control.

In CMS-104B genotype, the dose 20 kR (15.26) was very effective in increasing the magnitude of genetic variability than 15 kR (8.16) and 10 kR (3.69). CMS-103B genotype also recorded highest values 10.18 in 20 kR followed by 6.82 in 15 kR and 6.20 in 10 kR. In case of CMS-17B genotype lowest genetic variability value in 10 kR (9.88) followed by 15 kR (16.79) and highest was recorded in 20 kR (20.74). Gamma rays had a very much effect in increasing the genetic variability value at higher dose of 20 kR (17.84) but did not differentiated between 10 and 15 kR by recording 2.54 and 3.33.

With respect to heritability estimates the values for a trait increased consistently as increase in dosage in all the four genotype studied. CMS-104B genotype showed a high heritability value at 20 kR (33.96) followed by 15 kR (21.57) then in 10 kR (11.06). CMS-103B genotype recorded 24.93, 26.76 and 35.29 heritability values in 10, 15 and 20 kR doses respectively. In CMS-17B genotype lowest heritability value was recorded at 10 kR (45.85) followed by 15 kR (59.00) and highest value at 20 kR (63. 99). In case of 10, 15 and 20 kR doses of R630 genotype recorded the values 15.67, 19.59 and 56.62 respectively.

Highest genetic advance values were recorded at 20 kR (4.70, 3.91, 7.52 and 6.56) dose of CMS-104B, CMS-103B, CMS-17B and R630 genotypes, followed by 15 kR (2.74, 2.79, 6.49 and 1.67) and then in 10 kR (1.32, 2.56, 4.39 and 1.30).

Genetic coefficient of variability in case of CMS-104B genotype was 3.29, 4.97 and 6.47 in 10, 15 and 20 kR doses respectively. In case of CMS-103B genotype highest value was at 20 kR (6.14) followed by 15 kR (5.04) and at 10 kR (4.96). Similarly CMS-17B genotype recorded values 5.83 (10 kR), 7.78 (15 kR) and 8.36 (20 kR). In 10, 15 and 20 kR doses of R630 genotype value recorded were 2.62, 3.15 and 7.26 respectively.

**4.3.2.2 Plant height**

The effect of gamma irradiation on plant height based on estimates such as range, mean, variance, coefficient of variability, genetic variation heritability, genetic advance and genotypic coefficient of variation is presented in Table 11 and Fig. 3.

In CMS-104B genotype, an increase in range values were observed in irradiated treatments compared to control. At 10, 15 and 20 kR treatments the range widened to 48 to 135, 58 to 150 and 70 to 150 respectively as against a narrow range of 88 to 156 observed in control. Similarly enlarged range for plant height was noticed in CMS-103B genotype as result of gamma irradiation. At 10, 15 and 20 kR treatments values ranged from 60 to 141, 40 to 122 and 43 to 126 respectively as against 72 to 120 in control. In CMS-17B genotype also widened range was noticed in treatments as compared to control (87 to 125). At 10 kR range was 63 to 115, at 15 kR range was 70 to 120 and at 20 kR a range of 58 to 125 was observed. Similar trend of enlarged range for plant height was noticed in R630 genotype, as compared to control (53 to 115) and treatments showed 55 to 110, 63 to 118 and 65 to 120 ranges at 10, 15 and 20 kR respectively.

The mean for a character as affected by the irradiation doses showed higher values in all the four genotypes studied as compared to control. With respect to CMS-104B genotype, the mean value for a trait increased gradually as increase in dose, highest mean value was recorded at 20 kR (130.46) followed by 15 kR (129.23) and then 10 kR (120.54) as against control (117.17). A similar trend of dose dependent increase in mean values at 10 kR (99.84), 15 kR (102.00) and 20 kR (100.00) as against the control (95.16) was also observed in case of CMS-103B genotype. In case of CMS-17B genotype, highest mean values for the character observed at 20 kR (114.45) followed by 15 kR

**Table 11. Mean, range, variance, heritability, genetic advance and coefficient of variability for plant height in $M_2$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 88-156 | 117.17 | 1.95 | 378.71 | 16.61 | - | - | 378.71 | - | - | - | - | 16.61 |
| | 10 | 48-135 | 120.54 | 2.11 | 443.41 | 17.47 | 443.41 | 64.70 | - | 14.59 | 6.34 | 17.47 | 6.67 | - |
| | 15 | 58-150 | 129.23 | 2.32 | 538.72 | 17.96 | 538.72 | 160.01 | - | 29.70 | 14.22 | 17.96 | 9.79 | - |
| | 20 | 70-150 | 130.46 | 2.36 | 557.43 | 18.10 | 557.43 | 178.72 | - | 32.06 | 15.62 | 18.10 | 10.25 | - |
| **CMS-103B** | 0 | 72-120 | 95.16 | 1.03 | 106.68 | 10.85 | - | - | 106.68 | - | - | - | - | 10.85 |
| | 10 | 60-141 | 99.84 | 1.07 | 115.33 | 10.76 | 115.33 | 8.65 | - | 7.50 | 1.66 | 10.76 | 2.95 | - |
| | 15 | 40-122 | 102.00 | 1.12 | 126.47 | 11.03 | 126.47 | 19.79 | - | 15.65 | 3.63 | 11.03 | 4.36 | - |
| | 20 | 43-126 | 100.00 | 1.13 | 127.65 | 11.30 | 127.65 | 20.97 | - | 16.43 | 3.83 | 11.30 | 4.58 | - |
| **CMS-17B** | 0 | 87-125 | 102.69 | 0.99 | 97.02 | 9.59 | - | - | 97.02 | - | - | - | - | 9.59 |
| | 10 | 63-115 | 109.36 | 1.12 | 124.72 | 10.21 | 124.72 | 27.70 | - | 22.21 | 5.12 | 10.21 | 4.81 | - |
| | 15 | 70-120 | 110.20 | 1.83 | 140.32 | 10.75 | 140.32 | 43.30 | - | 30.86 | 7.54 | 10.75 | 5.79 | - |
| | 20 | 58-125 | 114.45 | 2.06 | 159.01 | 11.02 | 159.01 | 61.99 | - | 38.98 | 10.14 | 11.02 | 6.88 | - |
| **R630** | 0 | 53-115 | 98.05 | 1.14 | 125.94 | 11.45 | - | - | 125.94 | - | - | - | - | 11.45 |
| | 10 | 55-110 | 103.88 | 1.23 | 150.75 | 11.82 | 150.75 | 24.81 | - | 16.45 | 4.16 | 11.82 | 4.79 | - |
| | 15 | 63-118 | 108.85 | 1.42 | 200.00 | 12.99 | 200.00 | 74.06 | - | 37.03 | 10.80 | 12.99 | 7.90 | - |
| | 20 | 65-120 | 114.23 | 2.98 | 230.00 | 13.28 | 230.00 | 104.06 | - | 45.24 | 14.15 | 13.28 | 8.93 | - |

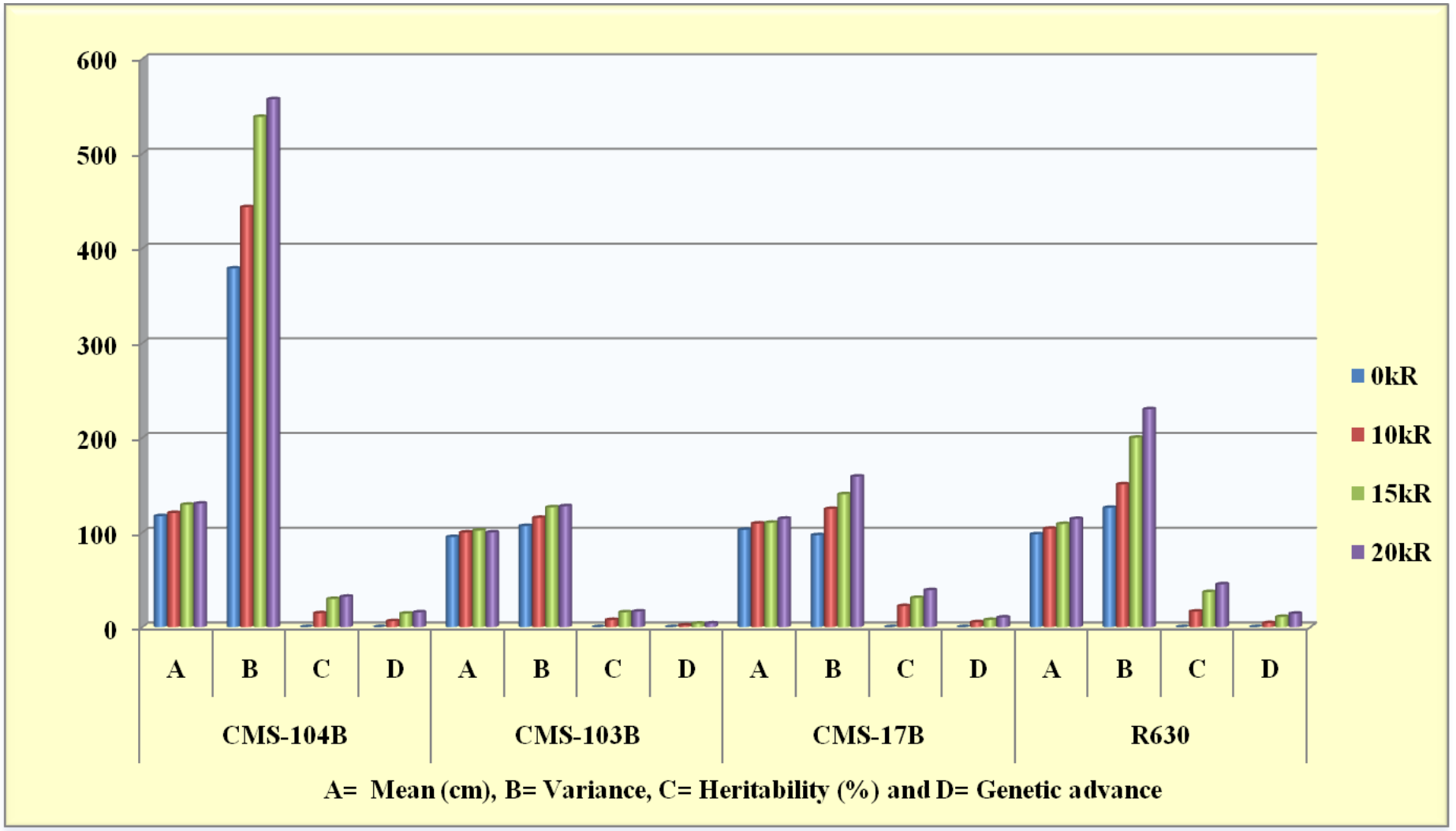



**Fig. 3. Mean, variance, heritability and genetic advance for plant height in $M_2$ generation**

(110.20) and 10 kR (103.96) as compared to control (102.69). In R630 genotype, there was a increase in mean values for character as compared to control (98.05) and the mean value was highest at 20 kR (114.23) followed by 15 kR (108.85) then in 10 kR (103.88).

Variance for the trait increased as increase in dosage of gamma rays in all the four genotypes studied. With respect to CMS-104B genotype, increased variance was noticed from lower dose of 10 kR (443.41) to 15 kR (538.72) and then to 20 kR (557.43) compared to control (378.71). In case of CMS-103B genotypes, variance for a character increased in comparison with control, 10 kR was recorded the value 115.33 and 15 and 20 kR recorded 126.47 and 127.65 respectively. With regard to CMS-17B which followed same trend as in other genotypes, values of variance for a trait increased from controlled value which was recorded 97.07. In case of treatments variance value was highest at 20 kR (159.01) followed by 15 kR (140.32) and then at 10 kR (124.72). In case of R630 genotypes variance value for a plant height were 150.75 (10 kR), 200.00 (15 kR) and 230.00 (20 kR) as against 125.94 in control.

As in case of variance, the coefficient of variability estimate also showed similar behaviour of increased value from lower dose of 10 kR (17.47) to 15 kR (17.96) and then to 20 kR (18.10) compared to control (16.61) in CMS-104B genotypes. In case of CMS-103B genotype, the coefficient of variability values at 10, 15 and 20 kR were 10.76, 11.03 and 11.30 respectively as against 10.83 in case of control. In 10, 15 and 20 kR of CMS-17B genotype coefficient of variability were 10.21, 10.75 and 11.02 respectively in comparison with 9.59 in control. There was increased trend of values for a character was noticed in R630 genotypes and highest value was at 20 kR (13.28) followed by 15 kR (12.99) then at 10 kR (11.82) as against control (11.45).

Higher magnitude of genetic variability was recorded at 20 kR (178.72) followed by 15 kR (160.01) and in 10 kR (64.70) treatments in CMS-104B. Similar trend was observed in CMS-103B genotype with 8.65 at 10 kR, 19.79 at 15 kR and 20.97 at 20 kR treatments. In case of CMS-17B highest genetic of variability recorded was 61.99 (20 kR) followed by 43.30 (15 kR) and then 27.70 (10 kR). Values for a character in R630 genotypes were 24.81 at 10 kR, 74.06 at 15 kR and 104.06 at 20 kR doses.

In CMS-104B genotype, estimate of heritability for plant height increased with increase in radiation dose. 10 kR recorded 14.59 per cent of heritability 15 and 20 kR

recorded 29.70 and 32.06 per cent of heritability. In CMS-103B genotype, dose 10 kR recorded the lowest heritability of 7.50 per cent followed by 15.65 at 15 kR and 16.43 per cent was observed in 20 kR dose. In case of CMS-17B heritability for a trait was highest at 200 kR (38.98) followed by 15 kR (930.86) and lowest was recorded in 10 kR (22.21). Heritability for a plant height in R630 genotype was 16.45, 37.03 and 45.24 per cent observed at 10, 15 and 20 kR treatments.

As the trend observed in variance, coefficient of variability and heritability same trend for genetic advance was associated with respective genotypes. In case of CMS-104B genetic advance values were 6.34, 14.22 and 15.62 at 10, 15 and 20 kR respectively. There was lowest genetic advance in case of CMS-103B genotype was observed at 10 kR (1.66) followed by at 15 kR (3.63) and then at 20 kR (3.83). CMS-17B recorded highest genetic advance for a plant height in higher dose of 20 kR (10.14) followed by 15 kR (7.54) and lowest was at 10 kR (5.12) doses. In similar to this R630 showed highest value at 20 kR (14.15) followed by at 15 kR (10.80) and lowest was observed in 10 kR (4.61) treatments.

Genotypic coefficient of variability for a trait increased from 10 kR (6.67) to 15 kR (9.79) then to 20 kR (10.25) in CMS-104B genotype. 10, 15 and 20 kR doses in CMS-103B were recorded the values 2.95, 4.36 and 4.58 respectively. CMS-17B genotype recorded highest value in 20 kR (6.88) followed by 15 kR (5.97) then least in 10 kR (4.81). The values 4.79, 7.91 and 8.31 were observed in 10, 15 and 20 kR doses in R630 genotype.

**4.3.2.3 Head diameter**

The data on head diameter are presented in Table 12.

In genotype CMS-104B irradiated treatments showed enlarged range for a character, for instance in 10, 15 and 20 kR treatments, the values observed were 7 to 21, 6 to 21 and 4 to 19 respectively as against 8 to 20 in control. In CMS-103B genotype the irradiation had a drastic effect in widening the range at all the doses with the values ranging from 4 to 16 in 10 kR and 5 to 20 in 15 kR and 4 to 21 in 20 kR doses as against a narrow range of 9 to 19 in control. In case of CMS-17B 10, 15 and 20 kR treatments recorded three to 15, five to 18 and two to 16 respectively compared to 10 to 19 in control. R630 genotypes recorded three to 10 at 10 kR, two to 12 at 15 kR and five to 14 at 2 kR as against nine to 13 in control.

**Table 12. Mean, range, variance, heritability, genetic advance and coefficient of variability for head diameter in $M_2$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 8-20 | 18.43 | 0.32 | 10.53 | 23.95 | - | - | 10.53 | - | - | - | - | 17.61 |
| | 10 | 7-21 | 14.09 | 0.34 | 11.60 | 28.17 | 11.60 | 1.07 | - | 9.22 | 2.21 | 25.74 | 7.82 | - |
| | 15 | 6-21 | 12.77 | 0.36 | 12.95 | 28.18 | 12.95 | 2.42 | - | 18.69 | 4.99 | 28.18 | 12.18 | - |
| | 20 | 4-19 | 13.23 | 0.39 | 14.99 | 34.47 | 14.99 | 4.46 | - | 29.75 | 9.20 | 27.48 | 14.99 | - |
| **CMS-103B** | 0 | 9-20 | 11.8 | 0.26 | 6.53 | 21.65 | - | - | 6.53 | - | - | - | - | 21.66 |
| | 10 | 4-16 | 10.54 | 0.27 | 7.14 | 25.26 | 7.14 | 0.61 | - | 8.54 | 1.26 | 25.35 | 7.41 | - |
| | 15 | 5-20 | 10.41 | 0.30 | 9.25 | 29.23 | 9.25 | 2.72 | - | 29.41 | 5.61 | 29.22 | 15.84 | - |
| | 20 | 4-21 | 10.53 | 0.26 | 6.96 | 25.05 | 6.96 | 0.43 | - | 6.18 | 0.89 | 25.05 | 6.23 | - |
| **CMS-17B** | 0 | 9-19 | 11.77 | 0.24 | 5.61 | 20.13 | - | - | 5.61 | - | - | - | - | 20.12 |
| | 10 | 4-18 | 9.31 | 0.25 | 6.18 | 26.67 | 6.18 | 0.57 | - | 9.22 | 1.18 | 26.70 | 8.11 | - |
| | 15 | 6-18 | 8.77 | 0.45 | 5.94 | 28.21 | 5.94 | 0.33 | - | 5.56 | 0.68 | 27.79 | 6.55 | - |
| | 20 | 4-20 | 6.24 | 0.53 | 8.45 | 46.58 | 8.45 | 2.84 | - | 33.61 | 5.86 | 46.58 | 27.01 | - |
| **R630** | 0 | 8-18 | 9.28 | 0.24 | 5.92 | 26.22 | - | - | 5.92 | - | - | - | - | 26.22 |
| | 10 | 4-19 | 7.25 | 0.26 | 7.03 | 36.57 | 7.03 | 1.11 | - | 15.79 | 2.29 | 36.57 | 14.53 | - |
| | 15 | 3-16 | 8.34 | 0.27 | 7.84 | 33.57 | 7.84 | 1.92 | - | 24.49 | 3.96 | 33.57 | 16.61 | - |
| | 20 | 4-17 | 6.58 | 0.59 | 8.00 | 42.99 | 8.00 | 2.08 | - | 26.00 | 4.29 | 42.99 | 21.92 | - |

The mean value of a character was also affected by irradiation treatments in all the four genotypes studied. In case of CMS-104B decrease in mean value for head diameter as increase in dose of gamma rays was observed. In 10, 15 and 20 kR values were 14.09, 12.77 and 13.23 respectively as against 18.43 in control. 10, 15 and 20 kR treatments of CMS-103B genotype, recorded decreased mean values of 10.54 10.41 and 10.53 respectively compared to control which was recorded 11.18. Gamma ray had an effect on head diameter of CMS-17B genotype by decreasing the mean values at higher doses, for instance 10 and 15 kR recorded 9.31 and 8.77 and at 20 kR mean value was reduced to 6.24 as against 11.77 in control. Similar trend was also seen in case of R630 genotype, which was recorded 7.25, 8.34, and 6.58 at 10, 15 and 20 kR doses in comparison with 9.28 in control.

In focus of variability for head diameter in all the four genotypes studied was increased in accordance with the increased dosage of gamma ray. For instance CMS-104B was recorded 11.60 (10 kR), 12.95 (15 kR) and 14.99 (20 kR) as against 10.53 in control. In case of CMS-103B genotype highest variability for a trait was observed in 15 kR (9.25) followed by 10 kR (6.96) and then in 20 kR (7.14) as against control (6.53). CMS-17B genotype showed the values 6.18 (10 kR), 5.94 (15 kR) and 8.45 (20 kR) in comparison with 5.61 in case of control. Genotype R630 was also evident for dose dependent increased variance for a character. In case of 10, 15 and 20 kR values were 7.03, 7.84 and 8.00 respectively compared to 5.92 observed in control.

Coefficient of variability for trait followed the same trend as variance in all the four genotypes studied as the result of gamma irradiation in case of CMS-104B genotypes highest coefficient of variability value was observed at higher dose of 20 kR (34.47) followed by 15 kR (28.18) and at 10 kR (28.17) treatments as against control (23.95). In CMS-103B genotype also highest was 29.23 (15 kR) followed by 25.26 (10 kR) and 25.05 (15 kR) compared to 21.65 in control. In case of CMS-17B lowest coefficient of variability was observed in lower dose of 10 kR (26.67) followed by 15 kR (28.21) and in 20 kR (46.58) treatments as against in control (20.13). A similar kind of behaviour was showed by R630 genotype by recording highest coefficient of variability at 20 kR (42.99) followed by 15 kR (33.57) then lowest in 10 kR (36.57) treatments compared to control (26.22).

Among the different doses of radiation applied, the dose 20 kR (4.46) was very effective to create more genetic variability followed by 15 kR (2.42) and then 10 kR

(1.07) treatments in CMS-104B. In case of CMS-103B genotype, highest value was at 15 kR (2.72) followed by 10 kR (0.61) and then in 20 kR (0.43).

With regard to heritability estimate highest value was recorded in 20 kR (29.75) followed by 15 kR (18.65) and then in 10 kR (9.22) dose, in case of CMS-104B genotype. Heritability for a character in CMS-103B genotype, were 8.54, 29.41 and 6.18 at 10, 15 and 20 kR doses respectively a similar kind of behaviour exhibited by CMS-17B genotype by increased heritability values at 20 kR (33.61), followed by 10 kR (9.22) and at 15 kR (33.61). Genotype R630 recorded highest value at 20 kR (26.00) followed by 15 kR (24.49) and then in 10 kR (15.79).

In CMS-104B genotype, genetic advance estimates at 10, 15 and 20 kR doses were 2.21, 4.99 and 9.20 respectively and in case of CMS-103B genotype genetic advance values 1.26, 5.61 and 0.89 were observed at 10, 15 and 20 kR treatments. Genetic advance for a character in CMS-17B were 1.18 (10 kR), 0.68 (15 kR) and 1.18 (20 kR). In case of R630 genotype gamma rays had an effect of increased values from lower dose 10 kR (2.29) to 15 (3.96) and 20 kR (4.29) treatments.

Genotypic coefficient of variability values for a character in CMS-104B genotype, were 7.82 (10 kR), 12.18 (15 kR) and 14.99 (20 kR). CMS-103B recorded 7.41, 15.84 and 6.23 at 10, 15 and 20 kR doses respectively. Highest values for genotypic coefficient of variability in CMS-17B was recorded at 20 kR (27.01) followed by 10 kR (8.11) and then to 15 kR (6.55). In case of 10, 15 and 20 kR doses recorded 14.53, 16.61 and 21.92 respectively in R630 genotype

**4.3.2.4 Days to maturity**

Data on days to maturity are presented in Table 13.

Gamma rays had an effect on widening the range of values for a character in all the four genotypes studied. Genotype CMS-104B recorded 73 to 115, 89 to 115 and 87 to 116 in 10, 15 and 20 kR doses respectively as against the narrow range of 90 to 109 observed in control. In case of CMS-103B observed range in 10, 15 and 20 kR doses were 86 to 98, 84 to 104 and 84 to 109 respectively compared to 91 to 97 in control. In CMS-17B genotype, control recorded narrow range of 90 to 112 as compare to widen range at gamma irradiated treatments 10 kR (88 to 115), 15 kR (88 to 114) and at 20 kR (83 to 116). Similar widen range values observed in gamma irradiated treatments of

**Table 13. Mean, range, variance, heritability, genetic advance and coefficient of variability for days to maturity in $M_2$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 90-109 | 101.29 | 0.43 | 18.61 | 4.26 | - | - | 18.61 | - | - | - | - | 4.26 |
| | 10 | 73-115 | 103.35 | 0.79 | 63.20 | 7.69 | 63.20 | 44.59 | - | 70.55 | 11.57 | 7.69 | 6.46 | - |
| | 15 | 89-115 | 105.52 | 0.82 | 66.76 | 7.74 | 66.76 | 48.15 | - | 72.12 | 12.16 | 7.74 | 6.58 | - |
| | 20 | 87-116 | 108.25 | 0.72 | 68.25 | 7.63 | 68.25 | 49.64 | - | 72.73 | 12.40 | 7.63 | 6.51 | - |
| **CMS-103B** | 0 | 91-97 | 92.34 | 0.30 | 9.26 | 3.29 | - | - | 9.26 | - | - | - | - | 3.30 |
| | 10 | 86-98 | 94.06 | 0.34 | 11.35 | 3.70 | 11.35 | 2.09 | - | 18.41 | 1.28 | 3.58 | 1.54 | - |
| | 15 | 84-104 | 97.41 | 0.42 | 17.76 | 4.66 | 17.76 | 8.50 | - | 47.86 | 4.16 | 4.33 | 2.99 | - |
| | 20 | 84-109 | 96.25 | 0.44 | 19.74 | 4.98 | 19.74 | 10.48 | - | 53.09 | 4.87 | 4.62 | 3.36 | - |
| **CMS-17B** | 0 | 90-112 | 100.81 | 0.61 | 37.20 | 5.98 | - | - | 37.20 | - | - | - | - | 6.05 |
| | 10 | 88-115 | 103.49 | 0.67 | 44.54 | 6.58 | 44.54 | 7.34 | - | 16.48 | 2.27 | 6.45 | 2.62 | - |
| | 15 | 88-114 | 105.12 | 1.35 | 54.67 | 7.38 | 54.67 | 17.47 | - | 31.96 | 4.87 | 7.03 | 3.98 | - |
| | 20 | 83-116 | 106.45 | 1.44 | 62.00 | 7.40 | 62.00 | 24.80 | - | 40.00 | 6.50 | 7.40 | 4.68 | - |
| **R630** | 0 | 89-96 | 91.29 | 0.32 | 10.23 | 3.50 | - | - | 10.23 | - | - | - | - | 3.50 |
| | 10 | 84-100 | 92.92 | 0.36 | 12.68 | 3.92 | 12.68 | 2.45 | - | 19.32 | 1.42 | 3.83 | 1.68 | - |
| | 15 | 84-101 | 89.72 | 0.42 | 17.54 | 4.67 | 17.54 | 7.31 | - | 41.68 | 3.60 | 4.67 | 3.01 | - |
| | 20 | 82-98 | 94.61 | 0.89 | 18.34 | 4.62 | 18.34 | 8.11 | - | 44.22 | 3.91 | 4.53 | 3.01 | - |

10 kR (84 to 100), 15 kR (84 to 101) and 20 kR (82 to 98) as against a narrow range of 89 to 96 in control of R630 genotypes.

Generally gamma irradiation shifted the mean values for the character in positive direction as against control in all the genotypes studied. In case of CMS-104B mean values were 103.35, 105.52 and 108.25 at 10, 15 and 20 kR respectively as against 101.29 in control. Similarly CMS-103B recorded highest mean value at 15 kR (94.06) followed by 20 kR (96.25) and at 10 kR (92.34) compared to control (92.34). In CMS-17B mean values were 100.81 (10 kR), 103.49 (15 kR) and 105.12 (20 kR) as against control (100.81). In case of R630 genotype gamma radiation shifted mean values towards positive direction in 10 kR (92.92) and 20 kR (94.61) but in case of 15 kR (89.72) mean value shifted in negative direction compared to mean value in control (91.29).

Variance for a character in CMS-104B genotype was 63.20, 66.76 and 68.25 at 10, 15 and 20 kR doses as against 18.66 in control. CMS-103B genotype recorded increased variance values from 10 kR (11.35) to 15 kR (17.76) and then to 20 kR (19.74) compared to control (9.26). In case of CMS-17B genotype 20 kR (62.00) was recorded highest value of variance followed by 15 kR (54.67) then in 10 kR (44.54) as against control (37.20). The variance value for days to maturity in R630 genotype were 12.68, 17.54 and 18.34 at 10, 15 and 20 kR treatments respectively as against 10.23 under unirradiated control.

Coefficient of variability values were 7.69 (10 kR), 7.74 (15 kR) and 7.63 (20 kR) in irradiated treatments of CMS-104B compared to 4.26 in control of same genotype. 3.29, 3.70, 4.66 and 4.98 values were recorded in control, 10, 15 and 20 kR treatments of CMS-103B genotype. Similarly increased coefficient of variability in accordance with increased dose was observed in CMS-17B genotype, in 10 kR coefficient of variability was 6.58, 7.38 and 7.40 at 10, 15 and 20 kR doses respectively as against 5.98 in control. R630 genotype recorded 3.92 (10 kR), 4.67 (15 kR) and 4.62 (20 kR) as against 3.50 in control.

Estimated of genetic variability for a days to maturity were 44.59 (10 kR), 48.15 (15 kR) and 49.64 (20 kR) in CMS-104B genotype. In case of CMS-103B genotype highest genetic variability was recorded in higher dose 20 kR (10.48) followed by 15 kR (8.50) and lowest in 10 kR (2.09). Increased genetic variability for a trait as increase in dose was also observed in CMS-17B, which was recorded lowest value in 10 kR (7.34) followed by 15 kR (17.47) and highest was at 20 kR (24.80). Same trend was followed by

R630 genotype and which was recorded 2.45, 7.31 and 8.11at 10, 15 and 20 kR doses respectively.

Heritability estimates for days to maturity in case of CMS-104B were 70.55 per cent (10 kR), 72.12 per cent (15 kR) and 72.73 per cent (20 kR). In CMS-103B genotype, increased heritability was observed from 10 kR (18.41%), 15 kR (47.86%) and 20 kR (53.09 %). In 10, 15 and 20 kR treatments of CMS-17B recorded 16.48, 31.96 and 40.00 per cent for heritability of days to maturity. Similar increased trend was observed in 10 kR (19.32 %), 15 kR (41.68%) and 20 kR (44.22%) doses in R630 genotype.

CMS-104B genotype had a genetic advance value 11.57, 12.16 and 12.40 in 10, 15 and 20 kR doses respectively. In case of CMS-103B genotype, genetic advance values were 1.28 (10 kR), 4.16 (15 kR) and 4.87 (20 kR) in irradiated treatments. Highest value observed in case of CMS-17B was in 20 kR (6.50) followed by 15 kR (4.87) and lowest was in 10 kR (2.27). Likewise 1.42 (10 kR), 3.60 (15 kR) and 3.91 (20 kR) values were observed in treatments of R630 genotypes.

Genotypic coefficient of variability values in CMS-104B were 6.54, 6.58 and 6.51 at 10, 15 and 20 kR doses of gamma rays. In CMS-103Bgenotype lowest value was recorded in 10 kR (1.54) followed by 15 kR (2.99) and highest value was in 20 kR (3.36) treatments. In 10, 15 and 20 kR treatments of CMS-17B values were 2.62, 3.98 and 4.68 respectively. In case of R630 genotype, values were 1.68 (10 kR), 3.01 (15 kR) and 3.01 (20 kR).

**4.3.2.5 Seed yield per plant**

Data on seed yield per plant are presented in Table 14.

Estimates of range for character enlarged in irradiated CMS-104B genotype compare to untreated control. In 10, 15 and 20 kR doses values ranged from 5.40 to 25.60, 4.58 to 23.99 and 2.4 to 24.99 as against narrow range of 10.58 to 28.00 in control. CMS-103B genotype, showed enlarged range for a trait in 10 kR (4.00 to 26.00), 15 kR (5.00 to 20.00) and 20 kR (4.00 to 21.00) than in control (9.00 to 24.00). In CMS-17B values were 4.00 to 19.00 (10 kR), 3.20 to 20.40 (15 kR) and 2.48 5.63 to 23.45 (20 kR) in irradiated treatments than in control (8.00 to 25.00). Similarly R630 genotype also had widened range for seed yield per plant in 10 kR (4.12 to 22.00), 15 kR (6.70 to 22.35) and 20 kR (1.70 to 18.70) treatments than in control which was recorded a narrow range of 9.32 to 20.40.

**Table 14. Mean, range, variance, heritability, genetic advance and coefficient of variability for seed yield per plant in $M_2$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 10.50-28.00 | 26.30 | 0.41 | 16.84 | 15.60 | - | - | 16.84 | - | - | - | - | 15.60 |
| | 10 | 5.40-25.60 | 20.67 | 0.42 | 17.66 | 20.33 | 17.66 | 0.82 | - | 4.64 | 0.40 | 20.33 | 4.38 | - |
| | 15 | 4.58-23.99 | 20.20 | 0.48 | 22.99 | 23.74 | 22.99 | 6.15 | - | 26.75 | 2.65 | 23.74 | 12.28 | - |
| | 20 | 2.40-24.90 | 19.43 | 0.50 | 24.51 | 25.48 | 24.51 | 7.67 | - | 31.29 | 3.20 | 25.48 | 14.25 | - |
| **CMS-103B** | 0 | 9.00-24.00 | 19.80 | 0.26 | 6.53 | 12.91 | - | - | 6.53 | - | - | - | - | 12.91 |
| | 10 | 4.00-26.00 | 16.43 | 0.27 | 7.14 | 16.26 | 7.14 | 0.61 | - | 8.54 | 0.47 | 16.26 | 4.75 | - |
| | 15 | 5.00-20.00 | 12.41 | 0.30 | 9.25 | 24.51 | 9.25 | 2.72 | - | 29.41 | 1.85 | 24.51 | 13.29 | - |
| | 20 | 4.00-21.00 | 10.53 | 0.33 | 10.96 | 31.44 | 10.96 | 4.43 | - | 40.42 | 2.76 | 31.49 | 19.99 | - |
| **CMS-17B** | 0 | 8.00-25.00 | 21.77 | 0.33 | 10.80 | 15.10 | - | - | 10.80 | - | - | - | - | 15.10 |
| | 10 | 4.00-19.00 | 18.83 | 0.35 | 12.57 | 18.83 | 12.57 | 1.77 | - | 14.08 | 1.03 | 18.83 | 7.07 | - |
| | 15 | 3.20-20.40 | 15.37 | 0.37 | 13.97 | 24.32 | 13.97 | 3.17 | - | 22.69 | 1.75 | 24.32 | 11.58 | - |
| | 20 | 5.63-23.45 | 13.45 | 0.39 | 15.43 | 29.21 | 15.43 | 4.63 | - | 30.01 | 2.43 | 29.21 | 16.00 | - |
| **R630** | 0 | 9.32-20.40 | 16.15 | 0.26 | 6.64 | 15.96 | - | - | 6.64 | - | - | - | - | 15.96 |
| | 10 | 4.12-22.00 | 15.57 | 0.28 | 8.12 | 18.30 | 8.12 | 1.48 | - | 18.23 | 1.07 | 18.30 | 7.81 | - |
| | 15 | 6.70-22.35 | 15.82 | 0.32 | 10.47 | 20.45 | 10.47 | 3.83 | - | 36.58 | 2.44 | 20.45 | 12.37 | - |
| | 20 | 1.70-18.70 | 14.12 | 0.40 | 16.39 | 28.67 | 16.39 | 9.75 | - | 59.49 | 4.97 | 28.67 | 22.11 | - |

Generally decrease in mean value for trait as increase in dosage of gamma rays treatments than in control of all the four genotypes studied, for instance CMS-104B genotype recorded lowest mean value at 20 kR (19.43) and values in 10 and 15 kR (20.67 and 20.20) did not differ significantly as against 26.30 observed in control. In CMS-103B genotype, values were 16.43, 12.41 and 10.53 at 10, 15 and 20 kR doses as against 19.80 in control. In case of CMS-17B values were 18.83(10 kR), 15.37 (15 kR) and 13.45(20 kR) as against 21.77in control. 10, 15 and 20 kR treatments of R630 genotype, recorded 15.57, 15.82 and 14.12 respectively compared to control (16.15).

Variance for a trait was increased from 10 kR (17.66) to15 and 20 kR doses (22.99 and 24.51) in comparison with control (16.84). Variance decreased as decrease in dosage of gamma rays in CMS-103B genotype, 10 kR of this genotype recorded 7.14, 15 and 20 kR recorded 9.25 and 10.96 as against 6.53 in control. In case of CMS-17B value at 10 kR was 12.57 and values at 15 and 20 kR were 13.97 and 15.43 respectively as against 10.80 in control. R630 genotype recorded highest values at 20 kR (16.39) followed by 15 kR (10.47) and lowest in 10 kR (8.12) as against 6.64 in control.

Estimated of coefficient of variability in 10, 15 and 20 kR treatments were 20.33, 23.74 and 25.48 as against 15.60 in control of CMS-104B genotype. In case of CMS-103B genotype values were 16.26 (10 kR), 24.51 (15 kR) and 31.44 (20 kR) compared to 12.91 (control). In case of CMS-17B genotype highest coefficient of variability was at 20 kR (29.21) followed by 15 kR (24.32) and then 10 kR (18.83) compared to control which was recorded 15.10. Values in 10, 15 and 20 kR treatments of R630 genotype were 18.30, 20.45 and 28.67 respectively as against 15.96 in control.

Genetic variability in CMS-104B was highest at 20kR (7.67) followed by 15kR (6.15) and least at 10 kR (0.82). In case of CMS-103B genotype values were 0.61 (10 kR), 2.72 (15 kR), and 4.43 (20 kR). In 10, 15 and 20kR treatments of CMS-17B recorded values of 1.77, 3.17 and 4.63 respectively. R630 genotype recorded highest genetic variability in case of 20 kR (9.75), then 15kR (3.83) and lowest in 10 kR (1.48).

In all the four genotypes studied heritability values were increased with increase in dose of gamma rays .CMS-104B genotype recorded highest value in 20 kR (31.29) followed by 15 kR (26.75) then 10 kR (4.64). 20 kR (40.42) showed highest heritability value than in 15 kR (29.41) and 10 kR (8.54) treatments of CMS-103B genotype. 14.08, 22.69 and 31.01 values were observed in 10, 15 and 20 kR treatments of CMS-17B

genotype. R630 genotype showed highest values at 20 kR (59.49) and 15 kR (36.58) and lowest in 10 kR (18.23). The value 3.20 was the highest genetic advance value observed in 20 kR of CMS-104B genotype, 10 and 15 kR showed 0.40 and 2.65 respectively. CMS-103B showed the values 0.47 (10 kR), 1.85 (15 kR) and 2.76 (20 kR). In case of CMS-17B values were 1.03, 1.75 and 2.43 at 10, 15 and 20 kR respectively. In case of R630 genotype 20 kR recorded highest genetic advance value of 4.97 followed by 2.44 in 15 kR and 1.07 in 10 kR.

As in case of most of the estimates of CMS-104B genotype, the highest genotypic coefficient of variability was in 20 kR (14.25) followed by 15 kR (12.28) then in 20 kR (4.38). CMS-103B genotype showed 4.75, 13.29 and 19.99 at 10, 15 and 20 kR respectively. The observed values of genotypic coefficient of variability for a trait in CMS-17B genotype were 7.07 (10 kR), 11.58 (15 kR) and 16.00 (20 kR). R630 genotype recorded highest value at 20 kR (22.11) followed by 15 kR (12.37) and 10 kR (7.81) treatments.

**4.3.2.6 Oil content (%)**

Data on oil content are presented in Table 15 and Fig. 4.

In general radiation treatments are enlarged the range values in all the four genotypes studied in $M_2$ generation. In CMS-104B genotype, an increase in range values were observed in irradiated treatments compared to control. At 10, 15 and 20 kR treatments the range widened to 29.15 to 43.50, 25.30 to 44.20 and 30.20 to 44.20 respectively as against a narrow range of 35.90 to 42.40 observed in control. Similarly enlarged range for oil content was noticed in CMS-103B genotype as result of gamma irradiation. At 10, 15 and 20 kR treatments values ranged from 30.60 to 44.40, 25.60 to 30.20 and 25.50 to 44.20 respectively as against 32.40 to 41.00 in control. In CMS-17B genotype also widened range was noticed in treatments as compared to control (28.90 to 32.20). At 10 kR range was 24.70 to 39.40, at 15 kR range was 37.20 to 40.60 and at 20 kR a range of 34.50 to 41.70 was observed. Similar trend of enlarged range for plant height was noticed in R630 genotype, as compared to control (36.50 to 40.00) and treatments showed 30.10 to 39.30, 21.90 to 39.39 and 28.70 to 38.50 ranges at 10, 15 and 20 kR respectively.

The mean for a character as affected by the irradiation doses generally showed higher values in all the four genotypes studied as compared to control. With respect to

**Table 15. Mean, range, variance, heritability, genetic advance and coefficient of variability for oil content in $M_2$ generation**

| Genotypes | Dose (kR) | Range | Mean | S.E | Variance | C.V | $V_P$ | $V_G$ | $V_E$ | H% | GA | PCV | GCV | ECV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CMS-104B** | 0 | 35.90-42.40 | 36.59 | 0.32 | 2.42 | 4.25 | - | - | 2.42 | - | - | - | - | 4.25 |
| | 10 | 29.15-43.50 | 42.01 | 0.29 | 4.44 | 5.01 | 4.44 | 2.02 | - | 45.44 | 1.97 | 5.01 | 3.38 | - |
| | 15 | 25.30-44.20 | 41.47 | 0.44 | 6.14 | 5.98 | 6.14 | 3.72 | - | 60.59 | 3.10 | 5.98 | 4.65 | - |
| | 20 | 30.20-44.20 | 41.09 | 0.37 | 8.84 | 7.24 | 8.84 | 6.42 | - | 72.62 | 4.45 | 7.24 | 6.17 | - |
| **CMS-103B** | 0 | 32.40-41.00 | 36.45 | 0.23 | 1.02 | 2.77 | - | - | 1.02 | - | - | - | - | 2.77 |
| | 10 | 30.60-44.40 | 38.05 | 0.26 | 2.80 | 4.40 | 2.80 | 1.78 | - | 63.57 | 2.19 | 4.40 | 3.51 | - |
| | 15 | 25.60-30.20 | 28.09 | 0.38 | 1.46 | 4.30 | 1.46 | 0.44 | - | 30.18 | 0.75 | 4.30 | 2.36 | - |
| | 20 | 25.50-44.20 | 37.25 | 0.61 | 8.45 | 7.80 | 8.45 | 7.43 | - | 87.93 | 5.27 | 7.80 | 7.32 | - |
| **CMS-17B** | 0 | 28.90-32.20 | 30.74 | 0.22 | 0.94 | 3.15 | - | - | 0.94 | - | - | - | - | 3.15 |
| | 10 | 24.70-39.40 | 31.85 | 0.24 | 1.11 | 3.31 | 1.11 | 0.17 | - | 15.32 | 0.33 | 3.31 | 1.29 | - |
| | 15 | 37.20-40.60 | 38.80 | 0.45 | 2.63 | 4.18 | 2.63 | 1.69 | - | 64.26 | 2.15 | 4.18 | 3.35 | - |
| | 20 | 34.50-41.70 | 39.66 | 0.58 | 4.68 | 5.46 | 4.68 | 3.74 | - | 79.92 | 3.57 | 5.46 | 4.88 | - |
| **R630** | 0 | 31.50-40.00 | 38.35 | 0.39 | 3.08 | 4.58 | - | - | 3.08 | | - | - | - | 4.58 |
| | 10 | 30.10-39.30 | 38.83 | 0.59 | 6.20 | 6.41 | 6.20 | 3.12 | - | 50.30 | 2.58 | 6.41 | 4.55 | - |
| | 15 | 21.90-39.30 | 33.03 | 0.60 | 6.38 | 7.65 | 6.38 | 3.30 | - | 51.72 | 2.70 | 7.65 | 5.50 | - |
| | 20 | 28.70-38.50 | 30.60 | 0.61 | 8.86 | 9.73 | 8.86 | 5.78 | - | 65.24 | 4.01 | 9.73 | 7.86 | - |

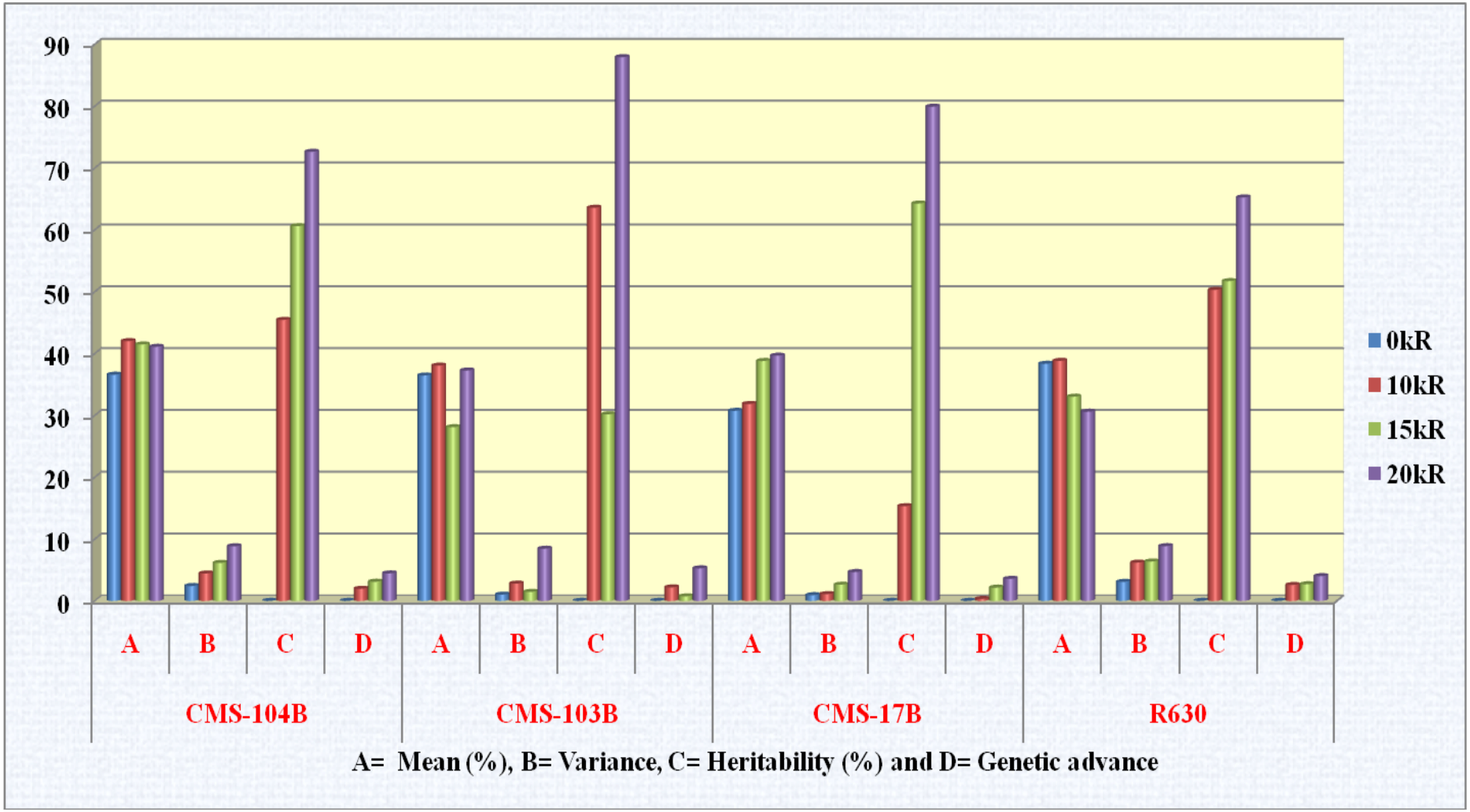



**Fig. 4. Mean, variance, heritability and genetic advance for oil content in $M_2$ generation**

CMS-104B genotype, the mean value for a trait increased gradually as increase in dose, highest mean value was recorded at 10 kR (42.01) followed by 15 kR (41.47) and then 20 kR (41.09) as against control (36.59). CMS-103B showed both positive shifts in 10 and 20 kR (38.05and 37.25) and negative shift in the mean value for trait in 15 kR (28.09) irradiated treatments compared to control (36.45). In case of CMS-17B genotype, highest mean values for the character observed at 20 kR (39.66) followed by 15 kR (38.80) and 10 kR (31.85) as against control (30.74). In R630 genotype, gamma ray had an effects in tilting mean values for character towards negative shift at 15 and 20 kR (33.03 and 30.60) but values did not differ much in case of 10 kR and the control (38.35 and 38.83).

Variance for the trait increased as increase in dosage of gamma rays in all the four genotypes studied. With respect to CMS-104B genotype, increased variance was noticed from lower dose of 10 kR (4.44) to 15 kR (6.14) and then to 20 kR (8.84) compared to control (2.42). In case of CMS-103B genotypes, variance for a character increased in comparison with control (2.77). 10 kR was recorded the value 4.40 and 15 and 20 kR recorded 4.30 and 7.80 respectively. With regard to CMS-17B which followed same trend as in case of other genotypes. Values of variance for a trait increased from controlled value which was recorded 0.94, in case of treatments variance value was highest at 20 kR (4.68) followed by 15 kR (2.63) and then at 10 kR (1.11). In case of R630 genotypes variance value for an oil content were 6.20 (10 kR), 6.38 (15 kR) and 8.86 (20 kR) as against 3.08 in control.

As in case of variance, the coefficient of variability estimate also showed similar behaviour of increased value from lower dose of 10 kR (5.01) to 15 kR (5.98) and then to 20 kR (7.23) as against control (4.25) in CMS-104B genotypes. In case of CMS-103B genotype, the coefficient of variability values at 10, 15 and 20 kR were 4.40, 4.30 and 7.80 respectively as against 2.77 in case of control. In 10, 15 and 20 kR doses of CMS-17B genotype coefficient of variability were 3.31, 4.18 and 5.46 respectively in comparison with 3.15 in control. There was increased trend of values for a character was noticed in R630 genotypes and highest value was at 20 kR (9.73) followed by 15 kR (7.65) then at 10 kR (6.41) as against control (4.58).

Higher magnitude of genetic variability was recorded at 20 kR (6.42) followed by 15 kR (3.72) and in 10 kR (2.02) treatments in CMS-104B. Similar trend was observed in CMS-103B genotype with 1.78 at 10 kR, 0.44 at 15 kR and 7.43 at 20 kR treatments. In

case of CMS-17B highest genetic of variability recorded was 3.74 (20 kR) followed by 1.69 (15 kR) and then 0.17 (10 kR). Values for a character in R630 genotypes were 3.12 at 10 kR, 3.30 at 15 kR and 5.78 at 20 kR doses.

In CMS-104B genotype, estimate of heritability for oil content increased with increase in radiation dose. 10 kR recorded 45.44 per cent of heritability 15 and 20 kR recorded 60.59 and 72.62 per cent of heritability. In CMS-103B genotype, dose 15 kR recorded the lowest heritability of 30.18 per cent followed by 63.57 at 10 kR and 87.93 per cent was observed in 20 kR dose. In case of CMS-17B heritability for a trait was highest at 20 kR (79.92) followed by 15 kR (64.26) and lowest was recorded in 10 kR (15.32). Heritability for oil content in R630 genotype was 50.30, 51.72 and 65.24 per cent observed at 10, 15 and 20 kR treatments.

As the trend observed in variance, coefficient of variability and heritability same trend for genetic advance was associated with respective genotypes. In case of CMS-104B genetic advance values were 1.97, 3.10 and 4.45 at 10, 15 and 20 kR respectively. There was lowest genetic advance in case of CMS-103B genotype was observed at 15 kR (0.75) followed by at 10 kR (2.19) and then at 20 kR (5.27). CMS-17B recorded highest genetic advance for a oil content in higher dose of 20 kR (3.57) followed by 15 kR (2.15) and lowest was at 10 kR (0.33) doses. In similar to this R630 showed highest value at 20 kR (4.01) followed by at 15 kR (2.70) and lowest was observed in 10 kR (2.58) treatments.

Genotypic coefficient of variability for a trait increased from 10 kR (3.38) to 15 kR (4.65) then to 20 kR (6.17) in CMS-104B genotype. 10, 15 and 20 kR doses in CMS-103B were recorded the values 3.51, 2.36 and 7.32 respectively. CMS-17B genotype recorded highest value in 20 kR (4.88) followed by 15 kR (3.35) then least in 10 kR (1.29). The values 4.55, 5.50 and 7.86 were observed in 10, 15 and 20 kR doses in R630 genotype.

# DISCUSSION

# V. DISCUSSION

Mutation breeding has been found to be an efficient method in-supplementing conventional breeding methods (Brock, 1971). A number of varieties have been released in various crop plants using different mutagens. Physical mutagens like gamma-rays, effective in creating variability in quantitative and qualitative traits through gene and chromosomal mutations and hence are extensively used in many crop plants (Stadler, 1928a and 1928b).

Muller (1927) in fruit fly Stadler (1928a, 1928b) in maize and barley demonstrated the mutagenic potentiality of X-rays. Immediately, it's Nilsson, Ehle grasped the idea and initiated a fully fledged mutation breeding programme. Gregory (1955) added a new dimension to mutation breeding by hypothesising the occurrence of polygenic mutations and their potentialities in improving polygenic traits. He demonstrated that selection of morphologically similar to control plants from irradiated population could result in isolation of high yielding genotypes. Gregory also postulated that these plants may be carrying large number of small and individually inconsequential, heritable changes which would provide sufficient genetic variability for practicing effective selection. Subsequent to Gregory's investigation lot of efforts have been impounded to this area and the potentialities of mutagenic agents in inducing mutations in polygenic system has been documented by several workers (Rawlings *et al.,* 1958; Williams and Hanway, 1961; Scossiroli *et al.,* 1966 and Sarker and Sharma, 1988).

The studies on polygenic mutations have revealed that they occur in fairly higher frequency as a large number of loci are involved in governing a polygenic system and that they have better survival chance because of less lethal effects (Gaul, 1964). Owing to these two properties, polygenic mutations are expected to generate sufficient genetic variability that can be exploited through selection. These observations also have over-ruled the feeling that polygenic mutations with their smaller magnitude of effects cannot be detected in the population because the polygenic traits are extremely sensitive to environmental factors.

## 5.1 CHOICES OF THE MUTAGEN AND DOSE

Undoubtedly gamma rays have proved to be the most efficient and effective physical mutagen in different crops species either individually or in combination with chemical mutagens. Radiations were known to produce more of chromosomal aberrations

such as deletions and translocations, in contrast, chemical mutagens are likely to produce more of gene or point mutations (Ehrenberg *et al*., 1961; Abrams and Frey, 1964; Amano and Smith, 1965 and Amano, 1968). Swaminathan *et al*. (1962) inferred that randomness in the action of radiations make them capable of inducing variation in most genetically controlled properties.

The radiosensitivity of an organism (plant) to a mutagen is not only dependent on the type of mutagen employed, but also an a number of other factors such as dose, genotypic constitution (Blixt, 1968), chromatin content (Sharma and Chatterji, 1962), physiological status (Ilivea-Staneva, 1971), conditions before, during and after treatments (Brock, 1965) and seed moisture content ( Lal and Richaria, 1981).

In general, the genotypic variance induced by a mutagen is known to show a linear relation with dose. Such linearity is more seen when low to medium doses are administered (Daly, 1960; Brock and Latter, 1961 and Lawrence, 1965). Such linearity seems to diminish with higher doses and it is likely that variances decrease at such a dose levels (Brock and Latter, 1961 and Kao *et al.*, 1960). Such behaviour is attributed to an association between lethal and mutational events at higher doses (Scossiroli, 1965).

Gustafsson (1947) stated the most useful dosage of irradiation is that which produces the maximum genetic effect whilst still giving sufficient field material. The doses that cause gross chromosomal changes are useful in inducing polygenic mutations (Griffith and Johnston, 1962).

The polygenic system which forms the genetic background for polygenic traits is highly organised system. The different genes of the system are fictionally interlinked in governing the expression of a polygenic trait. Hence, its seems likely that genes of a polygenic system might be kept together in a linkage block which has been termed as co-adopted block (Mather's terminology) in order to prevent frequent disruption through recombination. Therefore, while inducing mutation in polygenic system only low to medium doses of the mutagen is administered so that it does not disrupt the balance in the polygenic block. By doing so, useful hidden variability in a polygenic block could be released. From this point of view a mutational event is very important even when it has a smaller effect for specific morphological or physiological characters, because it changes the balance established by natural selection, in the co-adopted gene block and therefore offers new situation for natural or artificial selection (Aastveit, 1977).

Lethal doses of different mutagens in respect of particular biological parameters are known to be comparable. In the present study $LD_{50}$ value for seed germination and seedling survival was taken as criteria to fix the doses to carry material to field conditions.

## 5.2 SELECTION OF GENOTYPES FOR IRRADIATION

Mutation breeding can also be used in cases where a variety has to be improved for only one character with rest of the traits unchanged. Mutation breeding approach in sunflower holds promise to improve seed characteristics as revealed by the work of Giriraj *et al.* (1990).

In the present study, seeds of three maintainer lines and one restorer line *viz.*, CMS-104B, CMS-103B, CMS-17B and R630 were subjected to different doses of gamma rays with an objective to create variability for quantitative traits and to know the mutagenic effect on plant characteristics. Further, the study also aimed at effectiveness and efficiency of different gamma ray doses based on chlorophyl1 mutations and lethality in $M_1$ and $M_2$ generations respectively (Konzak *et al*., 1965).

The CMS-104B line has a very high plant height. It has desirable features with respect to head diameter, seed yield per plant and high oil content. So it can be promising female line used to develop sunflower hybrids. Induced mutagenesis has been utilized in this line to isolate mutants with shorter plant height to ensure good hand pollination during crossing work and non lodging during seed set and early maturing types in hybrid seed production programme. Another maintainer CMS-103B line has shorter plant height, early maturing, and very large head diameter which results in very big seeds with small kernel. In this case mutation was applied to isolate the mutants with medium head size and high seed yield per plant. CMS-17B has a medium plant height, medium maturity and brown seed colour so the mutation was applied for isolating the mutants with black seed colour. Restorer line R630 has a branching behaviour to ensure abundant pollen supply throughout the crossing period during hybrid seed production. Generally branching restorer lines has low *per se* yield. Hence for improvement in the above trait and to study comparative effects of gamma rays on male lines and female lines mutagen was applied.

The results obtained based on evaluation of the four genotypes in $M_1$ and $M_2$ generations are discussed character wise in the following paragraphs.

## 5.3 GERMINATION

For evaluating the effects of mutagenic treatments, criteria of germination and survival have been widely used (Gustafsson, 1947 and Gaul, 1958). In the present study a dose dependent reduction in germination following increase in radiation dosage was observed in all the four genotypes studied in $M_1$ generation. Among the different doses administered, *viz.*, 10, 15 and 20 kR, the highest dose of 20 kR proved to be highly detrimental in all the four genotypes. CMS-17B genotype (1.67) a drastic reduction in germination percentage was observed at 20 kR dose compared to CMS-104B (35.90), CMS-103B (30.85) and R630 (47.24) at same 20 kR dose. Similar reports made by earlier workers (Cheah, 1988; Singh *et al*., 1988 and Ramani and Jadon, 1991 in groundnut; Sahai and Dalal, 1973 in safflower; Nair and Nair 1977 and Sahu and Kumar, 1978; Lokesha, 1990 in rice bean; Ilyas and Goud, 1978 in sunflower).

Many causes for reduced germination in irradiated population of $M_1$ and $M_2$ generations have been indicated. The main causes for reduced germination and survival following irradiation are:

1. Cell death due to lethal effect of mutagens (Bacq and Alenxander, 1961). Here lysosomes are broken resulting in destruction of internal cell orgenelles.

2. Irradiation treatment cause ionisation of water molecules and produce free radicals *viz.*, $H^+$, $OH^-$ and $H_3O^+$ which interact with the genetic material and other cell orgenells and causes chromosomal aberrations (Sparrow and Woodwell, 1962 and Srivastava, 1973).

3. Enzyme release hypothesis (Bacq and Alenxander, 1961). Normally during germination there is hydrolysis of starch and other stored products in the nourishing tissue endosperm, being triggered by enzymes released from the embryo. So reduced germination following seed irradiation will results from the effect of irradiation on the enzymes that are involved in the process of germination. As a result, growth of embryo is inhibited.

4. Physiological causes such as disturbance in hormones (Skoog, 1935; Gordon, 1955; Sparrow and Woodwell, 1962), effects on the auxin levels ( Skoog, 1935; Gaur snd Notani, 1960 and Woodstock and Comb, 1965) which control synthesis of enzyme specific RNA in translocation of enzymes required for germination.

5. Reduced activities of ATP's and inorganic Phosphates, Amylase, Ribonulease and Three-nucleotidase (Srivastava, 1973), Peroxidase and Isocitric hydrogenase (Sydorenko, 1962) which intern leads to reduction in germination.
6. Inhibition of mitosis (Sparrow and Evans, 1961).

Hence, all the possible causes cited above are essentially associated with one another in the developmental process, one leading to another in biochemical path way and ultimately results in the failure of the seed to germinate following gamma irradiation at various doses.

## 5.4 SURVIVAL

In the irradiated population of $M_1$ and $M_2$ generation, not all the seedlings survive till maturity. Many plants die in the vegetative phase itself, before flowering and setting seeds. The surviving plants till maturity gives indication that they are relatively tolerant to lethal irradiation of gamma rays.

The death of the seedling before maturity is mainly due to stoppage of mitosis (Catcheside, 1948 and Cercek *et al*., 1971), effect on respiratory enzymes (Sydorenko, 1962), diplontic selection and chlorophyll mutations, where chlorophyll is lacking (Konzak *et al.*,1965; Goud, 1967 and Hermelin *et al.*, 1987).

In the present study also, a gradual decrease in survival of plants till maturity with consequent increase in dosage was observed in $M_1$ and $M_2$ generation of all the four genotypes studied. These lethal plants were weak, stunted in appearance with very few, small abnormal leaves (Plate 3). It seems that some of the vital genes for survival, *viz.*, genes coding for chlorophyll synthesis, chlorophyll binding proteins or genes for Rubisco enzyme have mutated in such plants and enzymes produced by mutated genes are non functional resulting in cessation of the important biochemical reaction and there by whole metabolic processes of the plant will be impaired leading to premature death of the seedlings (Sparrow and Woodwell, 1982).

Similar studies on differential response of genotypes to mutagens are on record (Sahai and Dalal, 1973 in safflower; Ilyas and Goud, 1978 in sunflower and Cheah, 1988 in groundnut).

## 5.5 POLLEN FERTILITY

Reduction in the fertility of pollen grains from irradiated population is one of the parameters to assess the radio-sensitivity and mutagenic effectiveness and efficiency. The

abnormalities in the pollen grains/eggs assume special significance, since pollens/eggs are carriers of the deviations (mutations) induced to subsequent generations. Pollen grains/ eggs form the bridge between the generations.

Reduction was observed in fertility of the pollen grains from irradiated population, as has been reported earlier in many studies (Johanson, 1936 in sunflower).

But there was no linear relationship between the dose administered and reduction in fertility. Similar irregularity in the linear trend was observed by Anderson *et al.* (1949) and Beard *et al.* (1957). A possible explanation may be that at higher doses, the drastic change induced is unable to pass through diplontic sieve (Gaul, 1961 and Swaminathan *et al.*, 1962). Hence at higher doses, high sterility of pollen grains was not noticed.

The causes for radiation induced sterility is mainly,

1. The structural changes induced in the chromosomes which lead to the formation of bridges at the division and genetic imbalance after divisions.
2. Physical changes in the chromosomes affecting the differentiation of the chromatids, coiling cycle of the chromosomes and chromosomal movement (Brewbaker and Emery, 1967).
3. Indirect effects such as physiological reactions (Johanson, 1936) and
4. Changes in cytoplasmic constituents ( Malinoveski *et al.*, 1973)

## 5.6 LETHAL DOSE-50 ($LD_{50}$)

Germination on $30^{th}$ day and survival of seedlings at maturity was generally taken for the estimation of Lethal Dose-50. Based on Probit Anlysis, Based on lethality of the seedlings in all genotypes under different treatments it is evident that CMS-17B genotype is more radiosensitive during germination and survival (3.60 and 3.90) followed by R630 (17.30 and 4.36), CMS-103B (12.14 and 8.50) and CMS-104B (18.41 and 17.22) respectively. This differential response of genotypes to gamma rays is in contrary to results obtained by Premajyoti (2006); she reported $LD_{50}$ in case of gamma ray was between 30 to 33 kR and 0.5 to 0.7 in case of EMS irrespective of two genotypes of Niger.

The higher $LD_{50}$ observed may be attributed to the following reasons. It is more likely that UV-rays incidence is higher at higher elevations. The evolution of

wild forms has occurred only in the hilly areas there is a possibility that natural selection must have played an important role in evolution of wild form which can resist more radiation attack. Cultivation of sunflower was confined to temperate countries like America and Russia; the land races primitive cultivars which might have undergone unconscious selection by tribal people have helped in acquiring such radio resistance character. Unlike other crops sunflower is found to be resistant to morphological mutations.

## 5.7 CHLOROPHYLL ABNORMALITIES

Increase in frequency of chlorophyll abnormalities with increases in dosage was observed in $M_1$ and $M_2$ generations of all the four genotypes this observation is in support of earlier studies by Hermelin and Daskalov (1987) in sunflower, Busolo-Bulafo (1988) in groundnut and Harb (1990) in soybean.

The frequency of chlorophyll abnormalities indicates, CMS-104B genotype as the radio sensitive genotype since the overall frequency of abnormalities in was highest in both $M_1$ (18.28) and $M_2$ (5.33) generations.

Chlorophyll abnormalities observed in a $M_1$ and $M_2$ generations are due to somatic mutations (Sparrow and Woodwell, 1962).These usually results due to periclinal chimeras or plastid mutations. Hence, these chlorophyll Abnormalities do not breed true in subsequent generations as there is irregular distribution of the cytoplasmic organelles like plastids, to daughter cells (Goud, 1967).

In the present study, most of the chlorophyll mutants were observed at seedling stage and were not distinct to assign definite categories *viz.,* xantha, viridis, chlorina and albino types as suggested by Gustafsson (1940). Most of the abnormalities observed were in the form of white and light green streaks; white, light green and yellow patches and various mosaic patterns (Plates 1 and 2).

In a similar study in sunflower, Chandrappa (1980) irradiated the achenes with various doses of gamma rays and he also reported that the spectrum of chlorophyll mutations induced in $M_2$ was very narrow.

## 5.8 MUTAGENIC EFFECTIVENESS AND EFFICIENCY

The mutagenic effect of a mutagen, which is an index for the appropriate choice, can be evaluated in terms of “mutagenic effectiveness and efficiency” (Konzak *et al*.,

1965). Mutagenic effectiveness is a measure of the frequency of mutations induced by a unit dose of mutagen. Mutagenic efficiency refers to the proportion of mutation in relation to other associated undesirable biological effects such as gross chromosomal aberrations, lethality and sterility, induced by the mutagen in question.

In the present study, effectiveness and efficiency of different gamma irradiation doses, *viz.,* 10 kR, 15 kR and 20 kR, were measured to assess the effect of these doses on different plant characters in all the genotypes. In a similar experiment Konzak *et al.* (1965) studied the effectiveness efficiency of radiations for inducing changes in various in plant characters. They proposed that mutagenic effectiveness gives the mutation rate per unit dose of the mutagens, while mutagenic efficiency is ratio of the mutation rate to undesirable changes like lethality, injury and sterility. They also opined that efficiency of a mutagenic agent depends on the reaction of the plant to the mutagen and the degree of physiological damage, chromosomal aberrations and sterility caused by the mutagen.

A dose dependent increase in mutagenic effectiveness and efficiency was noticed in the present study. The highest dose of 20 kR was found to be the most effective dose inducing maximum number of mutations in all the genotypes except CMS-104B in which effectiveness was more in 15 kR (Table 8). These results are in conformity with the earlier reports of Goranova and Aleksieva (1986) and Wang and Yu (1991).

The gamma ray doses were more effective in case of CMS-104B compared to other three genotypes studied, in inducing physiological damage, seedling injury, and chlorophyll abnormalities lethality. Particularly the higher dose of 20 kR was effective in all the genotypes in inducing seedling injuries and lethality. The possible reason may be that, genetic background of the material under study could play an important role in determining the effectiveness and efficiency of the mutagen (Richharia, 1981). Similar type of differential response among the genotypes to induce mutations was by noticed by Goranova and Aleksieva (1986) in soybean.

## 5.9 EFFECT ON QUANTITATIVE CHARACTERS

The reduction in mean values in most of the quantitative characters *viz.,* days to 50 per cent flowering, plant height, head diameter, seed yield per plant and a general widening of range, increase in variance, coefficient of variation observed in $M_1$ and $M_2$

generations of the present study is in agreement with earlier studies made by Gregory (1957), Reddy *et al.* (1977), Ramani and Jadon (1991) in groundnut; Atma and Reddy (1982) in castor; Giriraj *et al.* (1990) and Echenova *et al.* (1993) in sunflower; Kamala (1990) in sesame and Wang and Yu (1991) in soybean. The observation that there is also general increase in the genetic variation, genotypic coefficient of variability, heritability and genetic advance estimates in most of the quantitative traits studied are in agreement with earlier studies (Ramanathan, 1983 in groundnut and Mahla *et al.*, 1991b in mustard)

### 5.9.1 Days to 50 per cent flowering

In the present study early as well as late flowering mutants were observed. Early flowering mutants obtained in the $M_2$ generation of all the maintainer lines and one restorer line studied may be used to ensure synchrony with the early flowering male lines and female lines respectively in a hybrid seed production programme and there by helps to derive short duration hybrids. In cases where, female line is late in flowering, synchronous flowering of restorer R630 genotype could be achieved by increasing the duration of flowering in male parent**.** Late flowering mutants of one male line and three female lines obtained in the present study following various irradiation doses could be used in combination with late flowering female lines and male lines respectively in order to develop hybrids of longer duration. Hence both the early and late flowering mutants obtained in the present study would be helps to synthesis new hybrid combinations of different maturity groups. Similar kind of findings of altering the flowering duration following irradiation treatments have been reported by Athma and Reddy (1982) in castor, Singh *et al.* (1988) in groundnut, Giriraj *et al.* (1990) and Encheva *et al.* (1993) in sunflower.

In the present study in all the genotypes of $M_2$ generation the mean values for days to 50 per cent was decreased as compared to control and lowest was observed at 10 kR than the 15 and 20 kR. Likewise in all the genotypes of $M_2$ population, compared to 15 and 20 kR doses maximum number of early and late flowering plants were observed at 10 kR dose. Therefore lower dose of 10 kR was the most effective dose in recovering the desirable types (early and late mutants) with respect to flowering. From this observation it is clear that even though mean days 50 percent flowering time of the irradiated population did not alter appreciably as compared to untreated genotypes (Table 10), the widened range and enlarged variance offered scope for selecting either early or late flowering mutants in all four genotypes.

Compared to lower doses the higher doses of 20 kR was most effective in increasing the genetic variance, heritability, genetic advance and genotypic coefficient of variability for the traits in $M_1$ and $M_2$ generations of all the genotypes studied. These observations are in contradictory to the observations reported by Prasanna and Reddy (1986) in castor; Sharma and Sharma (1987) in groundnut; Deshapande (1995) in sunflower, where lower dose was most effective in increasing the variability, heritability and genetic advance for days to flowering.

### 5.9.2 Plant height

In the present study based on mean values observed (Tables 3, 11), the plants in $M_1$ generation raised from the seeds irradiated with various doses of gamma rays, have reduced the heights and irradiated plants in $M_2$ generation have increased the height compared to the untreated control population in all the genotypes. Similar results of drastic reduction in reduced plant height have been obtained in earlier studies by Leclercq (1984), Encheva *et al*. (1993) Deshapande (1995) in sunflower and Lokesha (1990) in rice bean.

In contrast to above findings, the mean value increased in irradiated populations of all the four genotypes in $M_2$ generation as against values in control.

As in case of days to 50 per cent flowering, irradiation treatments significantly increased the variance and coefficient of variability for the trait in all the genotypes. Increased variance and coefficient of variability for the trait following irradiation treatment has also been observed by Reddy *et al.* (1977) and Wang and Yu (1991).

Among the different irradiation doses the highest dose of 20 kR was most optimum dose in increasing the genetic variance, heritability, genetic advance and genotypic coefficient of variability for the trait in all the genotypes studied. Similar trend was reported by Jagadeesan *et al.* (2008). Contrary to this, Deshpande (1995) reported lower dose was effective in increasing the genetic variance, heritability, genetic advance and genotypic coefficient of variability for the trait.

### 5.9.3 Head diameter

In all the genotypes studied reduction in mean values of head diameter in the irradiated population was observed in all the doses in $M_1$ generation (Table 4). The results were in confirmation with findings of Mahla *et al.* (1991a) and Encheva *et al.* (1993).

Contrary to these results, Reddy (1986) observed increase in capsule length in sesame following various gamma radiation doses.

The negative relationship between radiation dose and mean value for head diameter was apparent in CMS-104B genotype ($M_1$ generation) and in CMS-103B genotype (both $M_1$and $M_2$). Similar to days to 50 per cent flowering and plant height, the range variance and coefficient of variability estimates were of higher value in treated populations compared to control (Tables 4 and 12). These results are in accordance with observations obtained by Jagadeesan *et al.* (2008) in sunflower and Lokesha (1990) in pod length of rice bean. Likewise the genetic variability, genotypic coefficient of variation heritability and genetic advance estimates showed higher magnitude at higher dose of 20 kR compared to 15 kR and 10 kR treatments.

CMS-17B and R630 genotypes were found to be more sensitive to gamma rays than other two genotypes with respect to reduction in head diameter. This could be attributed to differential response of mutagens to genotypes for the same trait.

In all the genotypes studied, a general reduction in the mean value of head diameter was apparent with increase in dosage. The possible reason for reduction in head diameter may be due to its close association with reduction in plant height, as a result of hormonal and biochemical changes (Sparrow *et al.*, 1971).

### 5.9.4 Days to maturity

All most all the genotypes showed the negative shift in means indicating the earliness as compared to control in $M_1$ generation but in case of R630 lateness in 10 and 15 kR( 97.54 and 96.10) and earliness in the higher dose of 20 kR (94.08) as compared to control. Exactly opposite to results obtained in $M_1$, irradiated populations in $M_2$ showed lateness in maturity compared to control of all the genotypes. Such a shift in positive direction is contrary to the generalised views where a negative shift is usually expected. However the mean of the treated population showing the significant increase over control has been reported by Khan (1983, 1984 and 1987) in mung bean.

In the present study early as well as late maturing mutants were observed. Early maturing mutants obtained in the $M_2$ generations of all the maintainer lines and one restorer line studied may be used for hybridization with early maturing male lines and female lines respectively in a hybrid seed production programme and there by helps to derive short duration hybrids. Late maturing mutants of one male line and three female

lines obtained in the present study following various irradiation doses could be used in combination with late maturing female lines and male lines respectively in order to develop hybrids of longer duration. Hence both the early and late maturing mutants obtained in the present study would be helps to synthesis new hybrid combinations of different maturity groups.

In the present study in all the genotypes of $M_2$ generation the mean values for days to maturity was increased as compared to control except in 15 kR (89.72) dose in R630 genotype where mean value decreased than in control (91.29). Lowest mean values were observed at 10 kR than the 15 and highest at 20 kR except in CMS-103B which showed maximum of 5 days delayed in maturity at 15 kR compared to two days and four days delay in maturity against control (Table 13). Generally in all the genotypes of $M_2$ population, maximum number of early maturing and late maturing plants were observed at 20 kR dose. Therefore higher dose of 20 kR were the most effective dose in recovering the desirable types (early and late mutants) with respect to maturity. From this observation it is clear that even though mean days to maturity time of the irradiated population did not alter appreciably as compared to untreated genotypes (Table 13), the widened range and enlarged variance offered scope for selecting either early or late maturing mutants in all four genotypes.

Compared to lower doses the higher doses of 20 kR was most effective in increasing the genetic variance, heritability, genetic advance and genotypic coefficient of variability for the traits in $M_1$ and $M_2$ generations of all the genotypes studied. These observations were in contradictory to the observations reported by Jgadeesan *et al*. (2008) in sunflower, where lower dose was most effective in increasing the variability, heritability and genetic advance for days to maturity.

### 5.9.5 Seed yield per plant

In present study, with regard to $M_1$ and $M_2$ generations, a range was observed in both negative and positive direction in all the genotypes studied. In general, gradual decrease in mean value of seed yield per plant with increase in dosage was noticed in all the genotypes. Such a decrease in mean value of trait following a irradiation treatment has also been stated by earlier workers (Gregory, 1955).

Like many other mutation breeding experiments (Gregory, 1960; Hassan *et al*., 1984; Prassanna and Reddy, 1986; Ramkumar and Yadav, 1988 and Kamala, 1990), in

the present investigation also, the change in the mean values in mutagen treated populations of $M_1$ and $M_2$ generations was followed by increase in variance and coefficient of variability values. The released variability would enable efficient selection of mutants with high seed yield per plant at early stage of $M_2$ generation (Brock, 1971).

Following gamma irradiation treatments increase in genetic variability and genotypic coefficient of variation was noticed in $M_1$ and $M_2$ generations of all the genotypes studied, at higher irradiation dose of 20 kR followed by 15 kR and 10 kR treatments.

Although this genetic coefficient of variation is useful to compare the extent of genetic variability in the different population and traits, it is not possible to determine, the heritable portion of variation of a given trait (Malha *et al*, 1991a). Broad sense heritability for the trait therefore was computed to determine the induced genetic effects which may be passed on to the next generations and based on heritability values; the amount of genetic advance for the trait was calculated.

After investigation of the effect of various gamma ray doses on seed yield per plant in $M_1$ and $M_2$ generations of all the genotypes, the high estimates of heritability were found at higher dose of 20 kR compared to lower doses of 15 and 10 kR. The same trend could be traced with respect to genetic advance estimate (Tables 6 and 14).

### 5.9.6 Oil content

Oil content is the most important economic trait in sunflower. Increase in oil content of the all the four genotypes used in present study, is necessary in order to incorporate the improved trait in the reconstituted hybrid. Earlier, Giriraj *et al.* (1990) in sunflower had used various doses of gamma rays and EMS to improve the oil content in parental lines of BSH-1 hybrid and reported wide range and increased variability for oil content. They also noticed a shift in mean oil content in positive direction.

In the present study also, compared to control, a general widening of range in both positive and negative directions in $M_2$ generations of all the four genotypes studied can be perceived from Table 15. Kubler (1984) also studied the use of induced mutagenesis in altering the oil content in sunflower. Following the treatment with EMS and gamma rays he obtained mutants with oil content ranging from 9.1 to 61.9 and 9.4 to 58.8 per cent against 8.7 to 56.5 in control.

In $M_2$ generation of CMS-104B mean value increased 10 kR (42.01) followed by 15 and 20 kR (41.47 and 41.09) doses compared to control (39.65). In CMS-17B compared to control (30.74) mean values in treated population increased as in increase in dosage from 10 kR (31.85) followed by 15 kR (38.80) and then in 20 kR (39.66). In case of CMS-103B highest mean value observed at 10 kR (38.05) followed by 20 kR (37.25) but in 15 kR (28.09) dose the mean value decreased drastically compared to control (36.45).Results obtained in these genotypes were in accordance with the observations made by Jagadeesan *et al*. (2008). Likewise, Vranceanu and Stoenescu (1982) treated the sunflower seeds with various doses of gamma radiations and found that irradiation with high energy radiations were effective to increase the oil content. Similarly in another study, Chandramouli *et al*. (1987) induced high oil content mutants in groundnut following various doses of gamma irradiation. In contrary to general increase in mean value for oil content in treated population compared to control, R630 genotype the mean value for trait was decreased in higher doses of 15 kR (33.60) and 20 kR (30.60) compared to control (38.35) but value in treatment 10 kR (38.83) was all most on par with the control. This decrease in irradiated populations of R630 genotype compared to other three genotypes studied may be attributed to differential response of genotype to gamma rays treatment for the trait. This result was on support of decrease in mean value for oil content following various irradiation treatments reported by Rakow *et al.* (1987); Ramakumar and Yadava (1988) in Brassica; Chandramouli and Kale (1990) in groundnut.

As in case of previous traits *viz.,* days to 50 per cent flowering, plant height, head diameter, days to maturity and seed yield per plant, with respect to oil content also, increase in variability and coefficient of variation values at 10 kR, 15 kR and 20 kR treatments compared to control (Table 15) Soldatov (1971) and Jagdeesan *et al*. (2008) also observed increased genetic variability for oil content in sunflower following induced mutagenesis. In a similar study Bhatnagar *et al*. (1992) in soybean observed agreater variability for oil content in mutants than in the parents following gamma irradiation treatment at 15, 20 and 25 kR doses.

In all the genotypes, highest values of heritability for the trait was observed at 20 kR dose followed by 15 kR and then in 10 kR doses. Genetic advance values of higher magnitude were observed at higher dose of 20 kR compared to lower doses. These results were in accordance with observations of Jagadeesan *et al.* (2008).

Higher heritability, greater genetic advance values at 20 kR in all the genotypes, provides scope for selecting mutants with high oil content in $M_2$ generation.

**FUTURE LINE OF WORK:**

The main objectives of the present study envisaged the widening variability for days to 50 per cent flowering, plant height, head diameter, days to maturity, seed yield per plant and oil content in four parental lines.

The foregoing results have clearly established the utility of mutation breeding in achieving the above objectives. Several workers have also reported variation for fatty acid composition in derived mutant lines. The derived mutant lines in the present study needs to be analysed for variation in fatty acid composition particularly with respect to oleic and linoleic acid and also molecular characterisation of these derived mutants is needed.

The mutants derived in the study should be assessed for their performance in maintainer lines, CMS-104B, CMS-103B and CMS-17B and fertility restoration in R630 genotype for identifying high yield potential female and male lines. The superior lines for *per se* seed yield and oil content should be utilized in heterosis breeding programme for developing high yield potential single cross hybrids.

The derived mutants in all the three maintainers and restorer have to be confirmed for fertility maintenance and restoration respectively and also assess the seed yield potential and oil content of newly synthesised single cross hybrids in comparison with original lines.

The derived mutant lines should also be identified for developing early, normal and late maturing hybrids.

# SUMMARY AND CONCLUSIONS

# VI. SUMMARY AND CONCLUSIONS

The study on induced mutagenesis present in four parental lines of sunflower was taken up to create variability for various quantitative traits. The CMS-104B line has a very high plant height. It has desirable features with respect to head diameter, seed yield per plant and high oil content. So it can be promising female line used to develop sunflower hybrids. Induced mutagenesis has been utilized in this line with gamma rays at 10, 15 and 20 kR doses to isolate mutants with shorter plant height to ensure good hand pollination during crossing work and non lodging during seed set and early maturing types in hybrid seed production programme. Another maintainer CMS-103B line has shorter plant height, early maturing, and very large head diameter which results in very big seeds with small kernel. In this case mutation was applied in same doses of gamma ray to isolate the mutants with large head size and high seed yield per plant. CMS-17B has a medium plant height, medium maturity and brown seed colour so the mutation at the doses of 10, 15 and 20 kR doses was applied for isolating the mutants with black seed colour. Restorer line R630 has a branching behaviour to ensure abundant pollen supply throughout the crossing period during hybrid seed production. Generally branching restorer lines has low *per se* yield. Hence for improvement in the above trait and to study comparative effects of gamma rays on male lines and female lines mutagen (10, 15 and 20 kR doses) was applied.

The following are the salient findings of the present study.

1. The study in $M_1$ and $M_2$ generations revealed that in all the genotypes, there was a dose dependent decrease in germination and survival. The dose 20 kR was found to be more deleterious in reducing the germination and survival.

2. Gamma irradiations induced the chlorophyll mutations and most of them were manifested both in seedling and later stages. The mutation observed in $M_1$ and $M_2$ generations were in the form of white, light green and yellow streaks and patches. In general frequency of chlorophyll mutations increased with increase in dose, in all the genotypes, with the highest frequency at 20 kR dose. Genotypic differences were observed with respect to frequency of chlorophyll mutations. Highest frequency of chlorophyll mutation was observed in CMS-104B followed by R630, CMS-103B and then CMS-17B.

3. Effectiveness of gamma rays on mutations induced was in general, directly proportional to the dose applied. Maximum effectiveness was observed at 20kR dose in all the genotypes. Efficiency of gamma rays appeared to be increase with the dosage. However, significant differences were not noticed in doses with respect to effectiveness and efficiency.

4. The range widened in positive and negative directions for most of the characters studied, *viz.,* days to 50 per cent flowering, plant height, head diameter, days to maturity, seed yield per plant and oil content. Hence effective selection can be practiced in $M_2$ generations for desirable types, for future studies. Higher dose of 20kR was most effective in enlarging the range of variability for all the characters.

5. There was general decrease in mean values with increase in dose, in $M_1$ and $M_2$ generations of all the four genotypes for days to 50 percent flowering, head diameter, days to maturity, seed yield per plant. In $M_2$ generation of all the genotypes irradiation treatments increased the plant height and oil content. But in case of R630 genotype, per cent oil content was decreased in irradiated population than in unirradiated controls.

6. In $M_1$ and $M_2$ generations of all the genotypes, wide variability and coefficient of variability were expressed for all the characters studied. In general 20 kR treatment was more effective in enlarging variability in most of the characters.

7. With respect to oil content, gamma irradiation treatments widened the range and increased the mean, variability, coefficient of variation, heritability and genetic advance values as compared to control. Mean values for oil content increased in irradiated populations of all the genotypes studied except R630, where mean values decreased in irradiated population than in control and this may be attributed to differential response of a genotype to mutagen for the character.

8. Among the different gamma irradiation doses, *viz.*, 10, 15 and 20 kR, the highest dose of 20 kR was most efficient dose, in increasing the genetic variability, heritability, genetic advance and genotypic coefficient of variation for all the economic traits studied in all the four genotypes.

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# VII. REFERENCES


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* Originals not seen

# APPENDIX

# APPENDIX - I

**Meteorological data from June 2010 to February 2011 at Main Agricultural Research Station, Raichur**

| Month and date | Standard week | Temperature ($^{o}$C) | | Relative humidity (%) | | Rainfall (mm) |
|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Morning | Evening | |
| June 2010 | 23 | 40.2 | 21.0 | 67 | 31 | 0.0 |
| | 24 | 33.7 | 23.5 | 86 | 57 | 83.0 |
| | 25 | 33.7 | 20.6 | 87 | 54 | 1.0 |
| | 26 | 34.3 | 22.2 | 82 | 47 | 0.0 |
| July 2010 | 27 | 32.2 | 20.8 | 89 | 66 | 89.0 |
| | 28 | 33.1 | 21.9 | 86 | 56 | 16.0 |
| | 29 | 32.2 | 20.3 | 86 | 68 | 81.0 |
| | 30 | 32.6 | 18.5 | 90 | 72 | 61.0 |
| | 31 | 32.3 | 17.8 | 92 | 59 | 18.0 |
| August 2010 | 32 | 33.0 | 17.2 | 87 | 54 | 0.0 |
| | 33 | 31.8 | 16.8 | 93 | 66 | 37.1 |
| | 34 | 31.5 | 16.9 | 95 | 66 | 85.0 |
| | 35 | 30.1 | 16.7 | 91 | 70 | 12.0 |
| September 2010 | 36 | 29.7 | 16.5 | 91 | 72 | 53.0 |
| | 37 | 31.4 | 16.5 | 88 | 65 | 70.0 |
| | 38 | 30.9 | 17.4 | 90 | 65 | 10.0 |
| | 39 | 32.0 | 17.5 | 90 | 67 | 28.0 |
| October 2010 | 40 | 33.0 | 20.3 | 87 | 62 | 0.0 |
| | 41 | 32.8 | 19.1 | 89 | 51 | 18 |
| | 42 | 31.0 | 20.3 | 91 | 69 | 18.4 |
| | 43 | 31.6 | 18.6 | 92 | 60 | 4.2 |
| | 44 | 29.7 | 18.3 | 92 | 68 | 9.8 |
| November 2010 | 45 | 30.9 | 19.6 | 93 | 59 | 2.4 |
| | 46 | 31.7 | 19.3 | 94 | 63 | 4.8 |
| | 47 | 31.9 | 18.5 | 91 | 48 | 0.0 |
| | 48 | 31.4 | 15.8 | 92 | 44 | 0.0 |
| December 2010 | 49 | 29.2 | 15.6 | 91 | 49 | 3.0 |
| | 50 | 30.4 | 14.9 | 85 | 41 | 0.8 |
| | 51 | 29.4 | 9.0 | 83 | 24 | 0.0 |
| | 52 | 30.3 | 12.9 | 92 | 44 | 0.0 |
| January 2011 | 1 | 30.6 | 13.9 | 92 | 60 | 0.0 |
| | 2 | 30.6 | 9.0 | 95 | 53 | 0.0 |
| | 3 | 33.3 | 11.5 | 95 | 33 | 0.0 |
| | 4 | 32.1 | 12.9 | 89 | 36 | 0.0 |
| | 5 | 32.7 | 13.7 | 86 | 26 | 0.0 |
| February 2011 | 6 | 32.5 | 12.5 | 77 | 15 | 0.0 |
| | 7 | 33.0 | 14.4 | 81 | 20 | 0.0 |
| | 8 | 33.4 | 18.3 | 80 | 38 | 0.0 |
| | 9 | 29.6 | 16.3 | 70 | 25 | 0.0 |