

**BREEDING FOR VARIABILITY AND FOLIAR DISEASE RESISTANCE
THROUGH PHYSICAL MUTAGEN IN SUNFLOWER (*Helianthus annuus* L.)**

Thesis submitted in part fulfillment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY in PLANT BREEDING AND GENETICS

to the Tamil Nadu Agricultural University, Coimbatore.

By

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AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE
TAMIL NADU AGRICULTURAL UNIVERSITY
COIMBATORE – 641 003**

2004

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2004

CERTIFICATE

This is to certify that the thesis entitled " **BREEDING FOR VARIABILITY AND FOLIAR DISEASE RESISTANCE THROUGH PHYSICAL MUTAGEN IN SUNFLOWER (*Helianthus annuus* L.)**" submitted in part fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in **PLANT BREEDING AND GENETICS** to the Tamil Nadu Agricultural University, Coimbatore, is a record of bonafide research work carried out by **Mr. S. JAGADEESAN** under my supervision and guidance and that no part of the thesis has been submitted for the award of any degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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ABSTRACT

BREEDING FOR VARIABILITY AND FOLIAR DISEASES RESISTANCE THROUGH PHYSICAL MUTAGEN IN SUNFLOWER

(*Helianthus annuus* L.)

By

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Sunflower (*Helianthus annuus* L.) considered as premium oilseed crop ranks third in area and sixth in production in India. The progress achieved is quite high in terms of area and production but the productivity is lowest, when compared to the world average. This necessitates the development of superior varieties and hybrids with resistance to biotic and abiotic stresses. With this in view, the present investigation was programmed to create genetic variability for the improvement of sunflower with foliar disease resistance through mutation studies. Two promising national check varieties viz., Morden and CO 4 were used in the present investigation. Induced mutagenesis was attempted using gamma rays from Cobalt 60. The LD₅₀ value was determined as 15 kR based on mean performance of germination percentage, shoot length, root length and dry matter production by roll towel method. The treatment doses viz., 5 kR, 10 kR, 15 kR, 20 kR and 25 kR were chosen for both the varieties to conduct the field experiments. The materials were studied through M₁, M₂, M₃ and M₄ generation along with control (Parents). The Characters chosen for study were days to first flower, plant height, head diameter, 100 seed weight, days to maturity, seed yield per plant and oil content.

The M₁ studies revealed a progressive decrease in germination and survival with increase in the dosage of gamma rays. In M₂ generation, increase in the frequency of chlorophyll mutations and viable mutations were observed due to increase in the dosages. Mutagenic effectiveness showed a decreasing trend with increase in dose of mutagen, whereas the mutagenic efficiency showed increasing trend with increase in dose of gamma rays.

Considerable increase in genotypic variance due to mutagenic treatments was observed for plant height, days to maturity and seed yield per plant as compared to other characters. An inconsistent relationship between mutagenic treatments and the deviations in variance was observed. The similar trend was also observed for genetic variance, genotypic coefficient of variability, heritability and genetic advance as percentage of mean for all the characters. A study on measures of dispersion such as skewness and kurtosis indicated that the distribution remained normal in most of the treated populations, though deviation occurred in a few instances.

The superior mutants in M₂ generations of Morden and CO 4 were selected and forwarded to M₃ generation based on seed yield per plant, head diameter and 100 seed weight. The mean expression, genetic variance, genotypic coefficient of variability, heritability and genetic advance as percentage of mean were worked out for M₃ generation. The trend observed for genotypic variance was maintained for heritability also, though genetic advance as percentage of mean showed slight deviations. Based on seed yield per plant, head diameter and 100-seed weight in M₃ generation, the best performed progenies selected and forwarded to M₄ generations. The mean expression, variability, heritability and genetic advance as percentage of mean were studied in M₄ generation also. The similar trend of result was observed as in M₃ generation. The progenies superior over the control were isolated and advanced for further improvement.

The narrow sense heritability (parent – progeny regression) was estimated for M₂ to M₃ and M₃ to M₄ generations. Almost all the characters exhibited moderate to high narrow sense heritability for both the genotypes. The genetic correlation coefficient was worked out in M₂, M₃ and M₄ generations. The days to first flower showed a positive

correlation with seed yield per plant in most of the mutagenic treatments in Morden. In CO 4, the yield contributing characters such as head diameter, 100 seed weight exhibited a positive and significant correlation with seed yield per plant in most of the treatments.

Mutation in doses of gamma rays different treatments could not produce distinct *Alternaria* leaf spot resistant mutants. However, five rust free lines, three stay green trait progenies, two high yielding mutants each from Morden and CO 4 and one dwarf and early mutant from Morden were isolated and forwarded for further exploitation.

CHAPTER 1

INTRODUCTION

Sunflower (*Helianthus annuus* L.) an annual economic oilseed crop of *Asteraceae* family, originated in the South West United States – Mexico. The wild weedy *Helianthus* had spread to Europe during sixteenth century and later to former USSR wherein the crop got domesticated. After the Second World War, the introduction of Russian varieties into Europe and Americas had a decisive impact on the development of sunflower as a commercial oilseed crop. It is the third major edible oil crop in production after soybean and groundnut. It is a rich source of edible oil (40 to 45 per cent) and is considered as good from health point of view due to its high Poly Unsaturated Fatty Acids (PUFA) content which reduce the risk of Coronary disease by regulating the cholesterol content in blood plasma.

Large-scale cultivation of sunflower commenced in India in 1972 with the introduction of open pollinated high yielding Russian varieties like Perodivik (EC 68414) and Armavirski 3497 (EC 68415). Subsequently, an early maturing accession EC 101495 was identified and released as Morden. Since then, sunflower has gained popularity owing to its high yield potential and oil content, short duration and wider adaptability (DOR, 2003). It is being cultivated in 1.30 million hectares in India and 13,300 hectares in Tamil Nadu. The production and productivity are 0.70 million tones, 549 kg per ha and 14,400 tones and 1083 kg per ha, respectively (Damodaran and Hegde, 2002).

Though there is a proportional increase in sunflower cultivation area, the productivity is lower in India among the sunflower growing countries, whereas, France and Italy recorded the highest productivity of 2480 kg per ha. (FAO/EBRD, 1999). Occurrences of wide spread diseases was identified as one of the major constraints for the low productivity levels. Many fungi and bacteria diseases have co-evolved with sunflower, whereas, the major foliar diseases; leaf spot caused by *Alternaria helianthi* (Hansf.), rust caused by *Puccinia helianthi* (Schw) are economically important and appears in all growing seasons and locations in India. The leaf spot disease alone is reported to reduce seed and oil yield by 27 to 80 and 17 to 35 per cent, respectively

(Reddy and Gupta, 1977; Balasubramanyam and Kolte, 1980). The disease can assume serious proportions and causes premature senescence and is eventually responsible for lodging and poor seed filling.

Genetic resistance would be the most economic means of reducing losses in sunflower due to this disease. Breeding for resistance to *Alternaria* leaf spot faces the challenge since the currently available varieties containing only the modest levels of resistance. Furthermore, earlier studies on identification of sources for *Alternaria* resistance were confined to screening of germplasm under natural infection (Velazhahan *et al.*, 1991; Nagaraju *et al.*, 1992). Results of previous studies indicated that significant genetic variation exists in wild sunflowers for the sensitivity to *Alternaria helianthi* (Sujatha *et al.*, 1997), although it is difficult to transfer the resistance to cultivated species.

The other major foliar disease rust caused by *Puccinia helianthi* (Schw) is also a major threat for sunflower growing areas in India. However, the most of the oilseed and confectionery hybrids had good to excellent resistance to the prevailing rust races, but changes in the rust population in the late 1980s have resulted in greater rust severity and occasionally in substantial losses in seed yield and seed quality.

Almost all commercially the grown sunflower varieties and hybrids found susceptible, of which Morden exhibited exorbitant sensitivity to foliar diseases. Further, the genetic variability in the available sunflower germplasm for resistance to these diseases is also limited. Despite intensive research, no resistant lines have been evolved and it is high time to give proper focus and importance to this problem at the earliest.

In this context, mutation breeding has been found to be a potent and handy tool to induce new and additional variability for insect, pest, and diseases resistance, yield and yield component traits. Although, the success rate of mutation is very low, the fact is that experiment with induced mutagenesis is quite successful in many crops. Therefore an attempt to find out the possibility of inducing variability for quantitative traits and foliar

disease resistance in sunflower using the application of physical mutagen (gamma rays) is aimed in this present study.

Objectives

1. To assess the effect of gamma rays on various morphological, physiological and productive characters of two varieties in sunflower,
2. to study the variability generated through mutagenesis for yield, yield contributing components and foliar disease resistance,
3. to isolate economic and foliar disease resistance mutants with increased seed yield,
4. to identify selection indices for yield improvement programme and
5. to access the information from relations through parental offsprings correlation and regression estimates.

CHAPTER II

REVIEW OF LITERATURE

“The knowledge of the laws of mutation would presumably lead to the induction of artificial and intentional mutations and so produce entirely new characters in plants and animals”

- Hugo de Vries

Mutation breeding essentially consists of three phases: generation of genetic variability, selection of useful genotypes and comparative tests to demonstrate the superiority of the selected genotypes. Induced mutations contribute primarily by increasing variability, subsequent selections and testing procedures used in a mutation breeding programme. Induced mutations are an alternative to plant introduction as a source of plant improvement programmes.

Research on induced mutagenesis was extensively studied in cereals like rice, wheat and barley far less research was done in crops belonging to others specially sunflower.

Conventional breeding methods usually require more time when more than one economic character is to be improved in an agronomically desirable genotype. Under such situation, mutation breeding serves as a viable alternative and there are many reports of such improvements in oilseed crops (Ankineedu *et al.*, 1968; Voskoboinik and Soldatove, 1974; Varanceanu and Stoenescu, 1982, Kale *et al.*, 2000; Mathur *et al.*, 2000).

Singh (1986a and 1986b) suggested the following steps for induced mutations in developing high yielding varieties with resistance to diseases.

- i. Exposure / treatment of seed with physical/chemical mutagen of a variety which must be good in all the characters except susceptibility to a disease.
- ii. Selfing of individual M_1 plants and screening of dominant mutations if any.
- iii. Growing M_1 as plant to progenies in M_2 and selection of individual plants under epiphytotic conditions.
- iv. Preliminary yield trial of the selected M_3 progenies along with parental and standard checks.

- v. Multilocation trial of selected superior progenies.

In general, induced mutations provide a potent tool in improvement of oilseed crops especially sunflower (Giriraj *et al.*, 1990; Vranceanu and Iuoras, 1990; Vranceanu *et al.*, 1993).

2.1. Scope of mutation breeding

The concept of inducing mutations and their utilization in plant breeding was first suggested and advanced by Hugo de Vries as early as 1901 by his work on *Oenothera lamarckiana* (Gaul, 1964). Later artificial induction of mutation was demonstrated by Muller (1927) and Stadler (1928) in *Drosophila* and barley, respectively using “X” rays. Similarly, Gager and Blakeslee (1927) and Goodspeed (1929) suggested that X- rays gave a mutation rate many times greater than spontaneous mutation. However, most of the mutations obtained were found to be undesirable. Finally Gustafsson (1947, 1963) and Sigurbjornesson and Mike (1969) reported the usefulness of the induced mutation in crop improvement programmes. This gave an impetus to the breeders turned out to be an effective mutation breeding method in plant breeding programmes. Brunner (1992) while reviewing mutation breeding of the past 50 years observed that more than 1500 mutant cultivars of crop plants with significantly improved attributes have been released world wide in the last thirty years, through irradiation techniques. This indicates that mutation breeding can be successfully used to develop new cultivars of crop plants.

2.2. Choice of mutagens

Although X-rays were first used by Muller (1927), other physical mutagens viz., ultraviolet rays (Altenberg, 1934), beta rays (Ehrenberg *et al.*, 1949), gamma rays (Sparrow and Singleton, 1953) and thermal neutron (Caldecott *et al.*, 1954) have also been used for inducing mutations. Now gamma rays are used more extensively by many workers on account of its effectiveness (Kale *et al.*, 2000).

The mutagenic effect of chemicals like sulphur and nitrogen mustards was reported successfully by Auerbach and Robson (1946) in *Drosophila*. Later, DEMS (Rapport, 1947), EMS (Loveless and Howarth, 1959), nitrosoguanidine (Prasad *et al.*, 1967), bulsulfan (Yamaguchi and Matsubayashi, 1973) and ethidium bromide (Levy and Ashri, 1973) have also been reported to be highly potential mutagenic effects.

The induced mutation was attempted in many agricultural important crops to induce genetic variation. In sunflower crop also many attempts were made and the review of investigations on induced mutagenesis in sunflower is presented herein.

2.3. Sensitivity of genotypes

Different plant genera as well as species, sub species and varieties were known to respond differently to different mutagens. Gregory (1960) suggested that the limiting factor in mutation production and mutagen recovery is the genetic constitution of the experimental organism and not the type of mutation used. Not much report on differential sensitivity of genotypes to mutagenic treatment in sunflower had been demonstrated.

El-keredy and Abd-Alla (1976) studied the sensitivity of nine rice varieties to the effect of gamma rays and reported that IR22 and TKM 6 were most sensitive and resistant respectively. Shepel (1979) examined seeds of two-grain sorghum lines, two fodder sorghum cultivars and hybrids for the sensitivity studies to the chemical mutagens. Field germination and plant survival in the M₁ results indicated that heterotic hybrids were most sensitive to treatment and gave rise to the most useful mutants.

Parihar (1986) observed chromosome aberrations with multiple translocations involving 6th, 8th, 10th and 11th chromosome in the M₁ generations of *Pennisetum americanum* treated with 10-40kR gamma rays. Bijral *et al.*(1989) reported decreased M₁ seed fertility while treating the dry grains of the *Oryza indica* cultivars Tani and IET 2995 with gamma radiation at 10-40kR.

Giriraj *et al.* (1990) reported that the parents (HA 234 and RHA 272) of the hybrid BSH 1 behaved similarly to gamma irradiation and there was not much difference between treatments of the two parents. Both the lines had significant variability for days to flowering, test weight and oil content in M₂ and M₃ generations.

Vranceanu and Iuoras (1990) reported that the sensibility of the two inbred lines namely CG-3663 and CG-3606 differed to gamma radiation in sunflower.

Yadhava *et al.* (2003) studied the mutation frequency in the M₂ generation ranged from 0.14 to 5.42 per cent and it was highest at 25kR gamma radiation in Kodo millet.

2.4. Studies on induced mutations in sunflower

The investigations so far made on induced mutagenesis in sunflower has been reviewed here.

2.4.1. Mutagenic effects observed in first generation

Vranceanu and Stoenescu (1982) suggested that high-energy radiation proved to be one of the most effective mutagens for sunflower breeding. The best results have been obtained by irradiating plants with 1 to 1.6kR, dry seeds with 5 to 20kR and watery seeds with 3 to 4kR.

Hermilin *et al.* (1987) suggested that the M₁ plants derived from seed irradiation were chimeric for induced mutation. A particular mutation can be present only in a part of the M₁ plant. The chimeric pattern differs strongly with the ontogenetic system of the plant species to decide about the most efficient system of collecting seeds from mutagen treated plants for subsequent mutant screening.

Vranceanu and Iuoras (1993) reported that the plant damage in M₁ was observed as a decrease in germination and a reduction in plant height. They found the effects like leaf flecking, bifurcated and wrinkled leaves, split petioles, dwarfism (less than 50cm) and deviations in branching and head development during plant development. They identified five M₁ sterile plants with atrophied anthers and were crossed with fertile lines. The segregation pattern in M₁ and M₂ indicated that the induced sterility was genetic and monogenic.

Vranceanu *et al* (1993) reported that the plant injury after seed irradiation in M₁ revealed a decreased germination up to 20-30 per cent and the plant height reduction in 200Gy dose of gamma rays. They also observed several deviations as in the leaves, petioles, branching and heads in M₁ generation.

Christov (1994) identified the first sterile plants in M_1 from the cultivar “Progres” during 1983. He also found that the occurrence of sterile plants in M_1 generation was a common phenomenon. Some of the cultivars and lines showed different range of sterile plants in each time of irradiation. He also isolated two new source of cytoplasmic male sterility (CMS) lines developed by gamma rays treatment of ‘Stadion’ (70Gy) and ‘Hemus’ (150Gy) cultivars.

Jambhulkar and Joshua (1999) observed that the plant injuries, like chlorophyll sectors and leaf deformities increased with increasing radiation dose in the M_1 generation. Maximum chlorophyll sectors and leaf deformities like flecking, bifurcation and wrinkling were found with the 200Gy dose of gamma rays. It provided a good index of radiation effect. They also found two plants (0.78%) in 200Gy dose showing a sectorial male sterility in the M_1 generation in which $1/4^{\text{th}}$ sector of the disc had sterile disc florets with smaller ray florets and $3/4^{\text{th}}$ sector with fertile disc florets and normal ray florets. Finally they concluded that this type of chimera affecting male sterility in both ray and disc florets was a common phenomenon in the M_1 generation.

2.4.2. Chlorophyll mutation

Heiner *et al.* (1960) reported that the chemical treatments induced fewer *albina* and more *Xantha* and *Striata* mutants than the gamma irradiation in barley. Sree Ramalu (1969) observed greater proportions of *albina* mutants than *viridis* when treated with physical mutagens but chemical mutagens resulted in the reverse.

Chlorophyll mutations in sunflower could be easily produced by treating seeds with certain concentrations of N-nitroso-N-methylurea (NMH), rifampicin (R) and 2,4-dinitrophenol (DNP) (Beletskii, 1969; Razortileva *et al.* 1995 and Usatov *et al.* 1995).

Fambrini and Pugliesi (1996) studied the chlorophyll mutants in sunflower and reported that pigment deficient mutant in sunflower genetically characterized. This mutant, designed as *Chlorina-apicallis* segregation data from heterozygous progenies indicated that the trait was controlled by one recessive gene.

Jambhulkar and Joshua (1999) observed that in the M₂ generation, the frequency of chlorophyll mutations like *Chimera*, *Xantha* and *Virescent* were increased in the 200Gy dose of gamma rays. It had green leaves in initial stages of plant growth and after 25-30 days, leaf veins of older leaves started yellowing giving the appearance of virus infection leading to leaf yellowing. They also isolated *Xantha*, *Virescent* and a distinct mutant.

Mashkina and Guskov (2001) studied the different pattern of chlorophyll mutants in M₂ and M₃ generation by inducing chlorophyll mutation using N-nitroso-N-methylurea, rifampicin and 2,4-dinitrophenol components which all were inductor of plastid and nuclear mutations.

Fambrini *et al.* (2002) studied the genetic analysis of two monogenic controlled sunflower mutants, designed as *chlorotica* 1 (*chi* 1) and *chlorotica* 2 (*chi* 2). Reciprocal crosses revealed no maternal effect. In both mutants, the leaf content of chlorophyll a (*ch* 1 a), *ch* 1b, β -Carotene, Lutein, Neoxanthin and Violaxanthin were significantly reduced whereas the Zeaxanthin level and the de-epoxidation state were higher with respect to wild type, suggesting that in the mutants the energy absorbed was higher than the capacity of photochemical quenching.

Fambrini *et al.* (2003) reported that a sunflower mutant, designed as *Chlorina* 1 (*ch*1) could be maintained in heterozygote state and the genetic analysis performed on segregating progenies indicated that the trait was controlled by one recessive nuclear gene. Pigment analysis of *ch*1 leaf extracts revealed that the chlorophyll a (*ch*1 a), *ch*1 b, β - carotene, Lutein, Neoxanthin and Violaxanthin contents were significantly reduced in comparison to normal leaves. By contrast, both the Zeaxanthin and de-epoxidation state were higher with respect to wild type.

2.4.3. Macro mutations

Sharma, (1988) reported that the screening process could be started even in M₁ generation when the treated plants with optimum mutagenic damage were identified. Screening

in M₂ generation involved isolation of progeny segregants for macromutations and showing maximum change in mean and variance for economic trait in the normal looking plants.

Vranceanu and Iuoras (1990) observed different types of plant structures such as leaf flecking, split petioles, bifurcated and wrinkled leaves, dwarfism and completely sterile plants. When the sterile plants crossed with fertile inbred lines, the segregation pattern indicated that the induced sterility was genetic and monogenic. They also observed an increased degree of self compatibility in the CG-3606 line. Vranceanu *et al.* (1984) also reported increased degree of self compatibility nature of the different sunflower hybrids.

Vranceanu *et al.* (1993) found that the experiments with branched genotypes did not show plant injury in M₁ generation. The macro mutant plants with chlorophyll deficiency sectors on the leaves or even on the whole leaf, were isolated and these plants presented light yellow flowers accounted 1.1 per cent in M₂ and M₃. The per cent of seed oil content ranged between 25.2 and 42.7. They also found that when the pollen was irradiated with 30 krad dose stimulated gynogenesis. The uniformity of 7 progenies is appreciable as homozygous lines. They also observed a “short petiole” mutant in inbred O-7657, used for reconstruction of plant architecture with the view of increasing plant population per unit area. This trait was controlled by a dominant gene action and this could be easily transferred to different genotypes. Similarly, Vranceanu *et al.* (1988) said that the inheritance of short petiole mutant was controlled by at least two dominant genes with cumulative effect.

Christov, (1994) reported that the male sterility could be induced by physical mutagens in sunflower. He also found three stable male sterile (CMS-Stadion, CMS- Hemus and CMS- Peredovik) mutants by using gamma rays and ultrasound respectively. Leclercq (1971) also reported 100 per cent sterile plants due to physical mutagen.

Kalaijun (1999) identified short leaf petiole mutants viz., M-2006, M-2007, M-2008 in the mutant population with increased tolerance to high plant density (80-150 thousand plants per hectare). He also isolated super early, cold tolerant sunflower mutants (M-1700, M-1925, M-1927) with high density growing conditions with a vegetation

period of 45-75 days. He also observed a unique combination of dwarfness (35-140cm) and large seed size (50-53 % increase).

Jambhulkar and Joshua (1999) extensively studied about the plant injury, chimeric, chlorophyll and morphological mutations in sunflower using gamma rays. They isolated several different type of mutants from M₂ generation viz., three each were for chlorophyll and stem, nine for leaf, eight for capitulum and four for seed coat colour. Yellow leaf florets, stigma emergence and brown patch mutants were found to be novel characteristics in M₂ generation. Among the 4 doses of gamma rays, 200 Gy was the most effective dose for induction of mutation in sunflower.

The induced mutation in sunflower variety “Morden” using gamma rays was studied by Elangovan, (2001). It revealed the presence of an erectophylly leaf mutant from 50Gy treatment from the Morden mutant population.

Jambhulkar, (2002) identified an extreme dwarf mutant from cultivar “Surya” with the height of 11.66 cm. This dwarf mutant flowered in 123 days and matured in 172 days and controlled by single recessive gene fits in 3:1 ratio in M₉ generation.

Fambrini *et al.* (2003) extensively studied the missing flowers (*mf* gene) due to lack of axillary shoots in sunflower. Decapitation experiments and histological analysis indicated that this phenotype was the result of a defect in axillary meristem initiation. Histological analyses showed that in floret primordial of the mutant a clear subdivision in dyads was not established and the primordial progressively bend inside and only large involucre floral bracts were developed. Finally they concluded that the *mf* gene needs an appropriate signal to initiation of axillary meristems during both vegetative and reproductive stage.

2.4.4. Micro mutation

The need of fruitful genetic variability and new sources of useful genes has determined that sunflower breeders and geneticists could utilize the wide range of germplasm resources in their breeding programmes. Mutagenesis had only limited use however the results suggested that its utilization could be a great advantage in improving

sunflower crop (Vranceanu, 1974). The induced mutation breeding in sunflower was first initiated at the Research Institute for Cereals and Industrial crops, Fundulea

(Romania) in 1973, revealed an important increase of variation for all agronomical traits such as seed yield per plant, plant height, head diameter, vegetation period and seed oil content in three varieties Peredovik, VIN11MK and Cerneanka (Vranceanu and Stoenescu, 1982).

The most practical sunflower mutants, obtained in different breeding centers through irradiation or chemical suggested by several sunflower workers as follows,

- i. Early or very early ripening and a short, structural plant,
- ii. Dwarf type with an increased number of leaves, a thin hull and a high oil percentage,
- iii. Very large head with a great number of seeds,
- iv. Thick stem, very resistant to breaking,
- v. Leaves with a greater amount of different chlorophyll components, and with a smooth or very hirsute surface,
- vi. Genetic male sterile plants.

Giriraj *et al.* (1990) reported that the physical and chemical mutagens were employed in parental lines of sunflower hybrid BSH 1. The mutagenic treatments significantly enlarged variability for days to flowering, test weight and oil content in M₂ and M₃ generations. In all mutagenic treatments, the mean test weight shifted into positive direction. The variability generated in the parental lines more in the case of oil content.

Vranceanu *et al.* (1990) investigated that the seed oil content in selected progenies, was over 45.5 – 47.5 per cent in V-2012 and 50-54.2 per cent LC-1004 when comparison with initial inbred lines 34 per cent (V- 2012) and 39 per cent (LC-1004).

Vranceanu and Iuoras(1990) irradiated seeds of two sunflower inbred lines CG-3663 and CG-3606 in the IAEA Laboratory. A decrease in germination and a reduction in plant

height observed in M₁ generation. In M₂ generation considerable variation was observed in three traits namely earliness, plant height and branching. They also observed a increased seed oil content in M₃ progenies viz., 45.5 per cent of CG-3663, 47.5 per cent (12 descendants) and 50-54.2 per cent (21 descendants) of CG-3606.

Seven sunflower mutants had been isolated and advanced based on the performance of certain agronomic characters such as vegetation period 62 to 124 days, plant height (121-213 cm), seed yield (2.39 – 4.45 t/ha) and oil content (48.9 – 53.6 per cent) (Kalaijun, 1999).

The genetically pure seeds of variety “Morden” subjected with 50, 100 and 150 Gy gamma rays to improve yield components in sunflower by Elangovan (2001). He had isolated a erectophylly leaf mutant which showed an almost two fold increase over the parental variety for all investigated characters viz., height, number of leaves, stem diameter, head diameter, 100 seed weight except that of the yield per plant where there was three fold increase.

Vishnuvardhan Reddy *et al.* (2001) treated the filled seeds of the popular variety “Morden” with chemical mutagen of sodium azide (NaN₃) using citric acid- sodium phosphate buffer at pH 3.3. Among the mutant population they have selected 3267 plants in M₂ based on maturity duration, plant height and leaf area index. Finally 1620 plants were isolated based on for seed yield, 100 seed weight and oil content.

2.5. Disease resistance

The use of resistance variety is one of the effective and economic ways of managing crop diseases. Mutation breeding is a potent tool for creating additional variability for biotic and abiotic resistance in crop. Sunflower is invaded by a large number of disease causing pathogens resulting in severe economic losses in yields. Occurrence of wide spread diseases was identified as one of the major constraint for the low productivity levels in India. The *Alternaria* leaf blight (*Alternaria helianthi* (Hansf.) Tubaki and Nishihara, rust (*Puccinia helianthi* (Schw.), downy mildew (*Plasmopara halstedii* (Fart.) Berl. et de Toni), Sclerotinia wilt (*Sclerotinia sclerotium* (Lib) de Bary, Charcoal rot (*Macrophomina phaseolina* (Tasi.) Goid) etc. But, only Alternaria leaf spot,

downy mildew and rust expected to reduce the seed yield up to 90, 80 and 25 per cent respectively. However, in this zone *Alternaria* leaf spot and rust will be the alternate problem in all growing seasons. Hence, the present study was tried to get resistance for these foliar diseases in sunflower.

2.5.1. Reaction of varieties/cultivars/cultures to foliar diseases

The occurrence of diseases in sunflower is partially attributable to a narrow genetic base and a lack of resistant gene in cultivated sunflower. Resistance to *Alternaria* diseases has been found in some species of *Helianthus* like *H. tuberosus*, *H. hirsutus* and *H. resinoses* (Marcelo *et al.*, 1998).

Among the foliar disease of sunflower, leaf spot caused by *Alternaria helianthi* is major problem in all growing seasons and most of locations in India. The disease reported to reduce seed and oil yields by 27 to 80 and 17 – 33 per cent respectively besides leading to germination losses varying 23-32 per cent (Reddy and Gupta, 1977; Balasubramanyam and Kolte, 1980). This caused premature senescence and was eventually responsible for lodging and poor seed filling. Even though several control measures are being adopted, genetic resistance would be the most economic means of reducing loss in sunflower. Hence there is an urgent need for identification of the potential donor with resistance to *Alternaria helianthi* and incorporation of the same into the cultivated sunflower.

By using gamma rays and chemical mutagenesis (ethyl methanesulphonate) Saad (1981) obtained rice mutants with tolerant to *Pyricularia oryzae* in M₂ and M₃ in two seasons.

Chattopadhyay (1999) evaluated different sunflower genotypes and he found that the lines P-2, P-4, P-20, P- 101, P- 115, RES-834-3, GIG-1 x 341, GIG-1 x 342, GIG-1 x 342 – 6, ICAAI TOT-P1 and BLC 25-R-8-23-P4 were highly resistant, while BOL-714, HA 830, NO-491-P2, Morden-787-2-P2 were highly susceptible.

Among the 21 annual and 37 perennial *Helianthus* taxa tested for resistance to *Alternaria helianthi* in the green house in which *H. hirsutus*, *H. rigidus* sub sp

subrhomboideus and *H.tuberosus* were found to be moderately resistant. This resistance is transferable to cultivated sunflower by back cross breeding (Morris *et al.*, 1983; Velazhahan *et al.*, 1991). Nagaraju *et al.* (1992) and Seiler (1992) also reported the presence of *Alternaria* resistance genes in wild sunflower genotypes.

Leite *et al.* (1992) evaluated 28 sunflower genotypes to *Alternaria* leaf spot from which they isolated three genotypes such as Contiflor 3, Contifor 15 and Cargil 9401 showing intermediate level of resistance. Twenty sunflower hybrids and open pollinated varieties were evaluated for their resistance to leaf spot and stem spot caused by *A. helianthi* in the field under epiphytotic condition. Among these only one hybrid Suncross 25-3 was found to be significantly resistant, 5 were moderately susceptible with non significant differences in their reaction and the remaining hybrids were either susceptible or highly susceptible to the disease (Siddique and John, 1996).

Sujatha *et al.* (1997) evaluated 22 wild *Helianthus* species and 8 inter specific hybrids for resistance to *A. helianthi*. Significant resistance was conferred by *H. mollis*, *H. maximiliani*, *H. divericatus*, *H. pauciflorus*, *H. tuberosus* *H. resinosus* and *H. simlans*. According to Ranjan *et al.* (1998), Sungene 90, Predovick and Sunbred 221 were resistant varieties whilst Morden exhibited exorbitant sensitivity to *A. helianthi*.

Marcelo *et al.* (1998) tried to get *alternaria* leaf spot resistance through induced mutation by irradiation with gamma rays. They treated 8000 seeds of the line S4 94 N 208 98V2372 with 15 and 16.5 kR of gamma rays and they isolated some plants having less than 5% diseased leaf area and evaluated the maintenance of this character in the next generation. Jamadar *et al.* (1999) reported that none of the cultivars showed resistant reaction to *Alteranria* leaf spot in sunflower.

Among 110 sunflower genotypes evaluated for leaf blight in natural epiphytotic conditions, three genotypes (HPM-15R, HPM-116 and HPM-140) were resistant, 54 were susceptible, 14 were highly susceptible and the remaining genotypes were moderately susceptible to leaf blight (Amaresh and Nargund, 2000).

Vishnuvardhan Reddy *et al.* (2001) attempted to create resistance to *Alternaria* blight disease through chemical mutagenesis. They obtained a total of 3267 mutant plants and isolated six *Alternaria* tolerant inbreds.

Serene (2002) identified the parents GP 255, GP 324 and TNASUF 6/8 as moderately resistance with high yielding and suggested to use in future breeding programmes for *Alternaria* resistance.

Four independent dominant genes (R1 to R4) control resistance to the four described rust races. All genes controlling resistance to rust have been derived from wild sunflower. The rust resistance has been originally derived from accession 953-88 (Sunrise × Texas wild annual). In India, several sources of resistance have been reported. These include 24 RHA lines, 12 CMS, 20 hybrids, five hybrids, four wild species and 86 open pollinated populations. A number of germplasm accessions showed highly resistant in the national screening projects (DOR, 2003). The widely used cultivars Morden and EC 68414 are susceptible but majority of the hybrids released for cultivation are tolerant or highly resistant. The race flora of the rust pathogen (*P. helianthi*) has not been understood clearly in India. It is, therefore, necessary to understand the genetics of the pathogen monitor the races and programme the resistance breeding accordingly.

Miller, (1992) explained that sunflower rust is a significant disease on in all sunflower grown regions of the world. The R₁ and R₂ gene were derived from MC 69 and MC 29 imparts resistance to the North America Races 1, 2 and 3 races. He also reported that the rust incidence was caused severe yield losses in all over the world.

Inheritance studies of rust resistance to N.A Race 4 indicated that single dominant genes conferred resistance in the lines HA-R1, HA-R2, HA-R3, HA-R4 and HA-R5 (Miller *et al.*, 1988). Yang *et al.* (1989) reported a single gene from the Argentine line, P386, was conferring rust resistance to N.A. races 1, 2, 3 and 4. The gene in P386, was designed Pu6 and was non allelic to the genes of R₁, R₂, R₄ and R₅.

Goulter (1990) investigated the inheritance of resistance in the commercial sunflower hybrid Hysun 33 to Australian rust races 0 and 1. The genetic analysis

indicated that a single dominant gene conferred resistance to both races. The source of this gene was named PhRR3.

Gulya *et al.* (1990) reported that the plants infected by rust prior to bloom suffered a 40 percent yield loss compared to only a 10 percent yield loss when infection was delayed until two weeks after bloom. They also stated that younger plants are more susceptible to rust than plants which have already flowered.

CHAPTER III

MATERIALS AND METHODS

The research work was carried out in Department of oilseeds, Centre for Plant Breeding and Genetics(CPBG), Tamil Nadu Agricultural University, Coimbatore during 2002-2004. The materials used and methods adopted for the various studies are presented in the following topics.

3.1. Materials

3.1.1. Biological material

Two improved cultivars of sunflower Morden and CO 4 (TNAUSUF 7) were selected for the present investigation. Well-dried, viable seeds from genetically pure materials of Morden and CO 4 obtained from the Department of Oilseeds, Tamil Nadu Agricultural University, Coimbatore were used in this study.

Pedigree and other characteristics of the varieties

Sr. No.	Variety	Pedigree	Duration (Days)	Grain yield (Kg/ha)	Special features
1.	Morden	Selection from EC 101495	85	1400	Promising semi dwarf and National Check
2.	CO 4 (TNAUSUF 7)	Derivative of Dwarf x Surya	90	1700	High yielding and National Check

3.1.2. Irradiation

Gamma irradiation was done at the gamma chamber installed at the Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore. Pure and uniform sized seeds selected at random were chosen for irradiation. The seeds were packed in butter paper covers and placed in the gamma cell and exposed to gamma irradiation from the Cobalt 60 (CO⁶⁰) gamma source for the required duration.

3.2. Methods

3.2.1. Fixing up of LD₅₀ Value

Gamma rays (5-50kR) exposed dry seeds of two sunflower varieties, Morden and CO 4 were sown at the rate of 50 seeds per treatment to find out the LD₅₀ value. Seeds were placed in the roll towel with three replications in randomized block design (RBD) with unexposed seeds as control. Observations on germination, root length, shoot length and dry matter production were recorded 15 days after sowing and was expressed as percentage of germinated seedlings to total seeds sown. Based on the final observations, the LD₅₀ Value was arrived at 15kR for both the varieties. Based on the LD₅₀ value the treatments doses viz., 5kR, 10kR, 15kR, 20kR and 25kR were chosen for both the varieties to conduct the field experiments.

3.2.2. Control

For the treatments where irradiation was done the non-irradiated dry seeds served as control. It was included with treatment doses during the field experiments.

3.3. Study of M₁ generation

The seeds subjected to gamma irradiation were sown in the field along with the controls (Parent seeds) in a randomized block design (RBD) with two replication during Rabi, 2002. A total of 100 seeds were sown under each treatment. All the treatments including the control were raised, adopting an uniform spacing of 60cm between rows and 30cm between plants, with scheduled cultural operations. Need based plant protection measures were carried out during the period of crop growth. For all the plants in each treatment in the first generation, the following observations were recorded. All the heads were covered with paper bags before blooming to avoid contamination. All individual plants of M₁ generation were labeled and the seeds were harvested separately and forward to M₂ generation.

3.3.1. Germination on the 15th day

Seedlings emerged up to 15th day after sowing were counted and expressed as percentage of total seeds sown.

3.3.2. Survival on the 30th day

Seedlings survived up to 30th day after sowing were counted and expressed as percentage of total seeds sown.

3.3.3. Days to first flower

The number of days required for first blooming of the individual plants were recorded.

3.3.4. Plant height

The height of the plant from the ground level to the base of the capitulum was measured and expressed in centimeters at the time of harvest.

3.3.5. Head diameter

Diameter of the capitulum at the time of maturity was taken and expressed in centimeters.

3.3.6. Hundred seed weight

One hundred well filled seeds were taken from each plant, weighed and expressed in grams.

3.3.7. Days to maturity

Number of days taken from sowing to physiological maturity were counted and recorded.

3.3.8. Seed yield per plant

At the time of physiological maturity, the seeds collected from single plant were dried, threshed and weighed in grams.

3.3.9. Oil content

Oil content of the seeds was determined with the help of Oxford 4000 Nuclear Magnetic Resonance (NMR) spectrometer available at Department of Biochemistry, Tamil Nadu Agricultural University and expressed in percentage.

3.4. Study of M₂ generation

Seeds obtained from M_1 plants in each treatment were advanced to raise M_2 generation as parent- progeny rows. Each plant was raised in one row of 3m lengths adopting a spacing of 60cm between rows and 30cm between plants during Rabi/Summer, 2002-2003. The standard agronomic practices were followed throughout the period of crop growth. At the time of end of star bud stage all the heads were covered with cloth bags to effect self pollination without any contamination.

3.4.1. Chlorophyll mutation

The M_2 plants at seedlings stage were screened for chlorophyll mutations up to fifteenth day after sowing. Classification of the chlorophyll mutants were done by adopting the method suggested by Gustafasson (1940) and Blixt (1961). Chlorophyll mutation frequency was estimated on M_2 plant basis. The frequency and spectrum chlorophyll mutations for different treatments were studied.

3.4.2. Viable mutation

The viable mutations were observed periodically from the seedling stage to maturity in M_2 generation. The viable and morphological mutants were labeled and harvested separately. The viable mutation frequency was estimated as percentage of mutants to total M_2 plants raised. The viable mutations were described and classified based on the nature of deviations they showed from the normal type.

3.4.3. Study of quantitative characters

All the plants in each treatment were taken for recording the quantitative characters. Morphological deviants and damaged plants were excluded. The normal looking plants were studied for the following quantitative characters in M_2 generation.

1. Days to first flower
2. Plant height (cm)
3. Head diameter (cm)
4. Hundred seed weight (g)
5. Days to maturity
6. Seed yield per plant (g)

7. Oil content (%)

3.4.4. Estimation of mutagenic effectiveness and efficiency

The effectiveness and efficiency of mutagen in inducing chlorophyll and viable mutations were estimated using the formula adopted by Konzak *et al.* (1965) as given below.

$$\text{Mutagenic effectiveness (\%)} = M / kR \times 100$$

$$\text{Mutagenic efficiency (\%)} = M / L \times 100$$

Where,

M – Chlorophyll or viable mutation frequency on M₂ plant basis

kR – Dose of radiation in kilo rad

L – Percentage of lethality *i.e.*, percentage of reduction in survival of seedlings on 30th day.

3.4.5. Evaluation for foliar disease resistance

All the M₂ plants in each treatment were screened for resistance to foliar diseases in field condition during Rabi/Summer, 2002-2003. The disease prevalence was more in all growing seasons. For recording leaf spot disease reaction, all the plants were selected and per cent disease infection of leaves on each line was calculated during the time of harvest and the rating given by Siddique and John (1996) was adopted.

Disease reaction scale

Grade	Amount of disease	Reaction
0	No infection	Immune
1	< 1 % disease	Highly resistant
3	1-5% disease	Resistant
5	5-25% diseases	Moderately resistant
7	25-50% disease	Susceptible
9	>50% disease	Highly susceptible

For recording rust disease reaction, all the plants were subjected to per cent disease infection in leaf *i.e.* the per cent leaf area affected by rust from 0.1 – 40% given by Gulya *et al.* (1990).

3.5. Study of M₃ generation

Selection was imposed in all the treatments of the M₂ generation. The micro mutations and quantitative variable mutants identified in M₂ generations were included in the M₃ generations. Each selected plants were raised as progeny rows of one row of 3m length adopting a spacing of 60cm between rows and 30cm between plants during Kharif, 2003. The progenies were evaluated adopting Augmented Design I. The bulk checks of Morden and CO 4 were replicated once in each block. In each row one plant was selfed using cloth bags and five plants were selected at random and tagged. At the time of maturity, data were recorded.

3.6. Study of M₄ generation

The selection was imposed based on the mean and variance performance of the lines in each treatment for all the characters studied. A total of 152 lines were selected and raised along with checks during Rabi, 2003 –04. Each line was raised in two rows adopting completely randomized block design with two replication. Ten plants were selected at random and tagged for taking observations in each line. The sibbing also imposed in each line using cloth bags. The observations on quantitative traits were recorded same as in the previous generations.

3.3. Statistical Analysis

The mean values recorded for the different treatments were used for statistical analysis. The analysis was done using the WINDOSTAT statistical package, INDOSTAT Services Ltd., Hyderabad and AGRISTAT statistical package, Coimbatore.

Statistical analysis for M₁ and M₄ generations

The mean values recorded for the different characters were subjected to statistical analysis. Analysis of variance, estimation of standard error and critical difference were

worked out individually for all the characters by adopting the method suggested by Panse and Sukhatme (1967). The ANOVA table was constructed as follows.

ANOVA for Randomized Block Design

Source	d.f.	SS	MSS	Expectation
Replications (r)	r-1	RSS		--
Treatments (t)	t-1	TrSS	GMS	$\sigma^2e + r\sigma^2t$
Error (e)	(r-1) (t-1)	ESS	EMS	σ^2e
Total	rt-1	TSS		

Test of significance was carried out by referring to the 'F' table given by Snedecor and Cochran (1967).

Statistical analysis for M₂, M₃ and M₄ generation

Genotypic and phenotypic variances, genotypic and phenotypic co-efficient of variability, heritability and genetic advance were worked out for different characters.

The phenotypic variance (PV) was calculated from the each treatment in the M₂ population. The environmental variance (EV) was estimated from the control raised along with the treatments. Genotypic variance (GV) was calculated by subtracting the environmental variance from phenotypic variance.

Genotypic variance (GV) = Phenotypic variance (PV) – Environmental variance (EV).

Genotypic and phenotypic coefficients of variation

Genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were calculated by using the formulae as suggested by Burton (1952).

$$\text{GCV} = \frac{\sqrt{\text{Genotypic variance}}}{\text{Mean}} \times 100$$

$$\text{PCV} = \frac{\sqrt{\text{Phenotypic variance}}}{\text{Mean}} \times 100$$

The PCV and GCV were classified as per Sivasubramanian and Madhava Menon (1973).

Less than 10%	= Low
10 – 20 %	= Moderate
More than 20%	= High

Heritability (h^2)

Heritability in broad sense was calculated following the method advocated by Lush (1940) and expressed in percentage.

$$\text{Heritability percent} = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} \times 100$$

The heritability per cent was categorized as suggested by Robinson *et al.* (1949).

0 – 30 %	- Low
31 – 60 %	- Moderate
Above 60%	- High

Genetic advance (GA)

Genetic advance was estimated by the method formulated by Johnson *et al.* (1955).

$$\text{Genetic advance} = k \times h^2 \times p^h$$

Where

h^2 – heritability in broad sense

p^h – phenotypic standard deviation

k – selection differential (at 5% selection intensity) (*i.e.*) 2.06 (Falconer, 1960)

Genetic advance (GA) was also expressed as percentage of mean.

$$\text{GA as per cent of mean} = \frac{\text{Genetic advance}}{\text{Grand mean}} \times 100$$

The genetic advance as per cent of mean was categorized as suggested by Johnson *et al.* (1955).

Less than 10%	- Low
10 – 20 %	- Moderate
More than 20%	- High

Skewness and kurtosis

These were calculated using the frequency distribution (Kapur, 1981) for all the characters studied.

$$\beta_1 = \text{Skewness}$$

If, $\beta_1 > 0$, then positively skewed
 $\beta_1 < 0$, then negatively skewed
 $\beta_1 = 0$, then symmetric distribution

$$\beta_2 = \text{Kurtosis}$$

If, $\beta_2 > 1$, then leptokurtic
 $\beta_2 < 1$, then platykurtic
 $\beta_2 = 1$, then mesokurtic

$$\beta_1 = \frac{\mu_3}{\mu_2^{3/2}}$$

$$\beta_2 = \frac{\mu_4}{\mu_2^2}$$

where,

$$\mu_2^2 = \frac{1}{N} \sum f_i (X_i - \bar{X})^2$$

$$\mu_3^2 = \frac{1}{N} \sum f_i (X_i - \bar{X})^3$$

$$\mu_4^2 = \frac{1}{N} \sum f_i (X_i - \bar{X})^4$$

where,

$\bar{X}_i$ is the individual observation

$\bar{X}$ is the mean of the character under observation and

N is the number of observations

Statistical analysis for M₃ generation

The mean values recorded for the different characters were subjected to statistical analysis. Analysis of variance, estimation of standard error and critical difference were worked out individually for all the characters by adopting the Augmented Design I propounded by Federer (1956). The ANOVA table was constructed as follows.

ANOVA for Augmented Design I

Source	d.f.	SS	MSS
Among entries(e)	e-1	eSS	
Among checks (c)	c-1	cSS	cMS
Among varieties (v)	v-1	vSS	vMS
c Vs v	1	cvSS	cvMS
Error	c (b-1)	ESS	EMS
Total	N-1	TSS	

Test of significance was carried out by referring to the 'F' table given by Snedecor and Cochran (1967). Standard Error of mean difference was calculated as follows,

$$SE_{d1} (\text{between checks}) = \frac{\sqrt{2EMS}}{B}$$

$$SE_{d2} (\text{between varieties}) = \sqrt{2EMS}$$

$$SE_{d3} \text{ (between a check and a variety) } = \sqrt{EMS(1+1/b)}$$

$$CD_1 - CD_3 = SE_d \times t \text{ (5\% or 1\% of error d.f.)}$$

Where as “b”- total number of replication by checks

Correlation Co-efficient

Genotypic correlation coefficients were worked out as per the method suggested by Goulden (1959) to find out the relationship between yield and its components in the M₃ population. The variance and co-variance values were utilized to calculate the correlation coefficients by applying the following formula

$$r_{xy} = \frac{\text{Cov}(x, y)}{\sqrt{V(x) V(y)}}$$

where,

$$\begin{aligned} r_{xy} &= \text{Correlation coefficient between character x and y} \\ \text{Cov}(x, y) &= \text{Covariance between characters x and y} \\ V(x) &= \text{Variance of character x and} \\ V(y) &= \text{Variance of character y} \end{aligned}$$

The significance of correlation co-efficients was tested with reference to the 't' table given by Snedecor and Cochran (1967) at (n-2)degrees of freedom.

Parent progeny regression

The estimate of parent progeny regression between the M₂, M₃ and M₄ were worked out. Heritability was computed by using parent progeny regression method as suggested by Cahaner and Hillet (1980). The genetic portion of the variance in a population was estimated by a regression of the progeny means on parental values (Panse, 1940). The M₃ regression was worked out with reference to standardized variable to eliminate the seasonal effect (Falconer, 1960).

The heritability was calculated as a method given by Mahmud and Kramer (1951).

$$\text{Heritability (h}^2\text{m)} = X / Y \times b_{xy} \times 100$$

$$x = \text{mean of parent (M}_2\text{) / (M}_3\text{)}$$

$y = \text{mean of progeny } (M_3) / (M_4)$

$b_{xy} = \text{regression of X on Y}$

CHAPTER IV

EXPERIMENTAL RESULTS

The experimental results obtained from the present investigation are presented in this chapter.

4.1. Mutation studies

4.1.1. LD₅₀ determination under laboratory conditions

Observations on germination percentage, shoot length, root length and dry matter production were recorded and studied in laboratory conditions (Table 1). Differences due to mutagenic treatments were significant for all the characters studied.

4.1.1.1. Germination percentage

A general reduction in germination percentage was noticed due to mutagenic treatments. The gamma dose had more effect on Morden than CO 4 in reducing germination. There was a considerable reduction in germination from 84.00 to 4.00 per cent and 88.00 to 10.67 per cent as the dosage increased from 5 kR to 50 kR in Morden and CO 4, respectively.

4.1.1.2. Shoot length

There was a reduction in shoot length from 16.73 to 6.54 cm and 16.54 to 5.23 cm in Morden and CO 4, respectively.

4.1.1.3. Root length

The rate of reduction in root length due to increased dose of gamma irradiation was the highest 12.56 cm and 13.5 cm in 5 kR and the lowest 3.25 cm and 2.35 cm in 50 kR in both Morden and CO 4, respectively.

4.1.1.4. Dry matter production

The similar trend was noticed in dry matter production also which ranged from 10.56 to 42.15g for Morden and 15.64 to 42.15g for CO 4.

Based on over all observations, LD₅₀ for gamma rays was arrived at 15 kR for both Morden and CO 4. The treatment doses viz., 5 kR, 10 kR, 15 kR, 20 kR and 25 kR were chosen for both the varieties to conduct the field experiment.

4.1.2. Study of M₁ generation (Plate 1)

4.1.2.1. Effect of gamma rays

Differences due to mutagenic treatments were significant for germination and survival studied in M₁ generation (Table 2).

4.1.2.1.1. Germination on the 15th day

In general reduction in germination percentage with increasing dosage of gamma rays was noticed for both Morden and CO 4. Reduction in germination percentage was higher in case of Morden than CO 4 (Table 2). The lowest germination percentage of 25.00 and 37.00 were recorded at 25 kR in Morden and CO 4, respectively. Whereas, 15 kR showed 55.00 per cent and 57.50 per cent germination for Morden and CO 4, respectively.

4.1.2.1.2. Survival on the 30th day

A similar trend as in germination was observed for survival also (Table 2). The survival percentage was higher in CO 4 than Morden for all the treatments. While, a significant reduction was observed (79.67 per cent) at 5 kR of Morden when compared to control. However, the 15 kR recorded 51.50 per cent and 52.50 per cent survival for Morden and CO 4, respectively.

4.1.2.2. Mean performance

The mean performance of quantitative characters in M₁ generations of Morden and CO 4 are given in the tables 3 and 4, respectively.

4.1.2.2.1. Days to first flower

In Morden, the minimum (51.94) and maximum (53.03) values for days to first flower were recorded in 5 kR and 15 kR treatments respectively. All the treatments except 15 kR registered lower mean values than the control. In CO 4, minimum and maximum value for days to first flower was recorded as 56.31 days and 57.12 days at

15 kR and 10 kR respectively. All the treatments recorded lower mean values than the control except 10 kR.

4.1.2.2.2. Plant height

In Morden, the minimum plant height was 47.36 cm and maximum was 61.66 cm at 25 kR and 5 kR, respectively. The similar trend was also observed in CO 4 whereas, the maximum and minimum value was 115.39 cm and 76.32 cm at 5 kR and 25 kR, respectively. All the treatments recorded lower plant height over the control for both the varieties.

4.1.2.2.3. Head diameter

The mean head diameter showed a slight increase than the control in Morden at 15 kR. The maximum and minimum head diameter recorded at 15 kR (8.90 cm) and 25 kR (6.94 cm). In CO 4, the head diameter ranged from 7.53 (25 kR) to 11.91cm (10 kR). In both the varieties, all the treatments recorded significantly lower mean values than the control except 15 kR in Morden.

4.1.2.2.4. 100 Seed weight

In Morden, the hundred seed weight ranged from 3.29 (15 kR) to 4.10 g (10 kR). In CO 4, 100 seed weight ranged from 3.75 (20 kR) to 4.69g (10 kR). Varied pattern of 100 seed weight was recorded for all the treatments when compared to control of both the varieties.

4.1.2.2.5. Days to maturity

In Morden, the days to maturity had minimum and maximum value of 81.94 and 83.03 at 5 kR and 15 kR respectively. All the treatments had lower mean values than the control except 15 kR which had same value of control. In CO 4, the days to maturity ranged from 86.31 (15 kR) to 87.12 (10 kR). Significantly lower mean values than the control were recorded in all the treatments except 10 kR.

4.1.2.2.6. Seed yield per plant

In Morden, the seed yield per plant ranged from 6.01 (25 kR) to 6.71 g (20 kR) and all the treatments recorded significantly lower seed yield per plant than the control.

In CO 4, the seed yield per plant had minimum and maximum value of 10.94g (15 kR) and 16.02g (25 kR), respectively. The seed yield per plant was lower in Morden for all the treatments when compared with CO 4.

4.1.2.2.7. Oil content

In Morden, the oil content recorded minimum and maximum value of 25.88 per cent and 32.15 per cent at 25 kR and 20 kR, respectively. In CO 4, the oil content ranged from 29.42 (20 kR) to 35.02 per cent (25 kR). Significantly lower mean values than the control were recorded in 20 kR and 10 kR.

4.1.3. Study of M₂ generation (Plate 1)

4.1.3.1. Studies on chlorophyll and viable mutations

Observations were recorded on the frequency and spectrum of chlorophyll and viable mutations. The frequency was estimated on M₂ population basis. The changes in the spectrum due to different mutagenic treatments in Morden and CO 4 are presented in the tables 5 and 6.

4.1.3.1.1. Chlorophyll mutations

The frequency and spectrum of chlorophyll mutations are presented in table 5.

The frequency for chlorophyll mutations on M₂ plant basis ranged from 0.98 to 2.49 per cent in Morden and from 0.76 to 2.15 per cent in CO 4. In both varieties. There was an increase in the frequency of chlorophyll mutations as the dose increased. The dose 25 kR was found to induce more chlorophyll mutations than single treatments. Among the treatments, the least number of chlorophyll mutations was induced at 5 kR and 15 kR in Morden and CO 4, respectively.

The chlorophyll mutations were classified into four types, *albina*, *xantha*, *viridis* and *striata*. The *albina* predominated in 10 kR in Morden and 25 kR in CO 4, respectively. However, no *striata* was observed in both the varieties.

4.1.3.1.2. Viable mutants

The frequency and spectrum of viable mutations are presented in table 6.

The frequency of viable mutations on M₂ plant basis was increased as the dosage of gamma irradiation increased for both the varieties. CO 4 produced more viable mutations than Morden. However, Morden registered high magnitude of viable mutations at 25 kR. The magnitude of increase with the increasing dose of gamma rays in Morden was from 1.00 to 2.88 per cent and in CO 4 from 1.24 to 2.49 per cent.

In Morden, the viable mutations were maximum (2.88%) and minimum (1.00%) at 25 kR and 5 kR, respectively. Similarly, in CO 4, the spectrum of viable mutations were ranged from 1.24 (10 kR) to 2.49 per cent (25 kR).

The spectrum of viable mutations and the details of different plant characters were classified according to plant height, growth habit, leaf modifications, seed colours and sterile plants. Mutation in plant height and leaf modification were present in all the mutagenic treatments of Morden and CO 4. While seed colours and sterile were also observed in most of the treatment in both the varieties. However, growth habit was marginally less.

Some of the viable mutations of interest realized were those dwarf, fork, seed colour and leaf modifications in overall M₂ populations (Plates 9 to 11a).

4.1.3.2. Mutagenic effectiveness and efficiency

The mutagenic effectiveness and efficiency based on lethality on M₂ plant basis for chlorophyll and viable mutations are presented in table 7.

4.1.3.2.1. Mutagenic effectiveness

The mutagenic effectiveness of gamma dose showed a decrease with increase in dose for both chlorophyll and viable mutations in the two genotypes except for 20 kR in Morden and 25 kR in CO 4, where, a slight increase was observed. The effectiveness of the mutagens was more for viable mutations than chlorophyll mutations. The mutation effectiveness recorded higher for all the treatments in Morden when compared with CO 4.

4.1.3.2.2. Mutagenic efficiency

The efficiency of the mutagen to induce chlorophyll mutations decreased with increase in dose of gamma rays in Morden (from 39.84 to 9.10%) and CO 4 (from 40.64 to 5.07 %). The lower efficiency of 5.07 per cent was observed at 15 kR, whereas, the highest efficiency was observed 40.64 per cent at 25 kR in CO 4.

The similar trend was observed in the efficiency of viable mutation in all the doses of gamma rays. The highest and lowest frequency of viable mutations was observed at 25 kR (46.08 %) and 5 kR (9.28 %) in Morden. In CO 4, the efficiency was ranged from 6.63 (10 kR) to 47.33 per cent (25 kR).

The maximum mutagenic efficiency for chlorophyll mutation as well as viable mutations was observed at 25 kR in both the cultivars/ varieties.

4.1.3.3. Studies on quantitative character

The data of mean, genotypic variance, heritability, genetic advance as percentage of mean and measures of dispersion for seven quantitative characters are presented in tables 8 to 14.

4.1.3.3.1. Days to first flower

The range, mean, variance, coefficient of variability, heritability, genetic advance as percentage of mean and measures of dispersion for the days to first flower are presented in table 8.

In Morden, the days to first flower was ranged from 50.43 (5 kR) to 54.34 days (20 kR). The mean values of all the treatments were lower than the control except for 20 kR. The maximum values of genotypic variances (8.96), genotypic coefficient of variability (5.51%), heritability (56.45%) and genetic advance as percentage of mean (15.78%) were recorded in the progenies of 20 kR.

In CO 4, the trait days to first flower recorded minimum and maximum days of 53.10 and 54.02 at 5 kR and 20 kR, respectively. The maximum value of genotypic variances (7.63), genotypic coefficient of variability (5.11%), heritability (45.99%) and genetic advance as percentage of mean (7.15%) were recorded in the progenies of 20 kR.

The minimum values of genotypic variance (3.71), genotypic coefficient of variability (3.62%), heritability (29.25%) and genetic advantage as percentage of mean (4.03%) were recorded in the progenies of 15 kR.

The studies on the measures of dispersion such as skewness and kurtosis showed that the distribution remained normal in most of the treatments. The skewness was significant at 10 kR and 20 kR in Morden and positive and significant skewness was observed at 20 kR in CO 4. Significant kurtosis was observed at 15 kR in Morden and 5 kR and 20 kR in CO 4.

4.1.3.3.2. Plant height

The range, mean, variance, coefficient of variability, heritability, genetic advance as percentage of mean and measures of dispersion for the plant height are presented in table 9.

In Morden, the plant height ranged from 98.40 to 142.29 cm recorded in the progenies of 10 kR and 20 kR, respectively. The mean values were higher than the control whereas, the progenies of 5 and 10 kR had lower mean values. The maximum values of genotypic variance (496.55), genotypic coefficient of variability (20.13%), heritability (56.52%) and genetic advance as percentage of mean (11.07) were recorded in the progenies of 15 kR.

The minimum values for genotypic variance (68.31), genotypic coefficient of variability (8.40%), heritability (15.17%), and genetic advance as percentage of mean (0.03%) were recorded in the progenies of 10 kR in CO 4. The plant height, registered the minimum and maximum value of 153.10 cm and 177.46 cm, respectively. The mean values of all the five treatments were lower than the control.

In CO 4, the maximum values of genotypic variance (480.93), genotypic coefficient of variability (14.32%), heritability (58.42%) and genetic advance as percentage of mean (22.55%) were recorded at 10 kR. The minimum values of genotypic variance (137.63%), genotypic coefficient of variability (6.69%), heritability (28.68%) and genetic advance as percentage of mean (7.38%) were recorded in the progenies of 5 kR.

For plant height most of the treatments showed positive skewness for all the treatments, whereas, 5 kR in CO 4 registered negative skewness. The maximum positive skewness was registered in 15 kR followed by 25 kR in Morden. Significant kurtosis was observed at 15 kR and 10 kR in Morden and 5 kR in CO 4.

4.1.3.3.3. Head diameter

The range, mean, variance, coefficient of variability, heritability, genetic advance as percentage of mean and measures of dispersion for the head diameter are presented in table 10.

In Morden, the head diameter had minimum value of 8.86 cm and maximum value of 10.35 cm in the progenies of 20 kR and 15 kR, respectively. The maximum values of genotypic variance (5.99), genotypic coefficient of variability (25.74%), heritability (52.89%), and genetic advance as percentage of mean (34.23%) were recorded in the progenies of 15 kR. Whereas, the minimum values of genotypic variance (4.33), genotypic coefficient of variability (22.76%), heritability (44.80%) and genetic advance as percentage of mean (31.01%) were recorded in the progenies of 20 kR.

In CO 4, the head diameter ranged from 8.60 (15 kR) to 10.57 cm (5 kR). The mean value of head diameter was lower than the control. The maximum values of genotypic variance (4.69), genotypic coefficient of variability (24.47%), heritability (44.36%) and genetic advance as percentage of mean (28.09%) were recorded in the progenies of 5 kR, whereas, 25 kR recorded on par with the 5 kR.

In Morden, the distribution showed positive skewness and kurtosis for 10 kR and 15 kR. The skewness and kurtosis were significant positive at 5 kR, and 15 kR respectively in CO 4.

4.1.3.3.4. 100 seed weight

The range, mean, variance, coefficient of variability, heritability, genetic advance as percentage of mean and measures of dispersion for 100 seed weight are presented in table 11.

The 100 seed weight ranged from 3.68 (20 kR) to 4.36 g (10 kR) in Morden. The mean values of all the treatments were higher than the control. The maximum values of genetic variance (2.02), genotypic coefficient of variability (37.62%), heritability (70.31%) and genetic advance as percentage of mean (67.97%) were recorded in the progenies of 5 kR. Whereas, the minimum values of genetic variance (1.05), genotypic coefficient of variability (25.79%), heritability (55.29%) and genetic advance as percentage of mean (57.10%) were recorded in the progenies of 15 kR.

In CO 4, the 100 seed weight had minimum and maximum values of 4.40 and 4.87g, which were recorded in the progenies of 10 kR and 25 kR respectively. The maximum values of genotypic variance (2.18), genotypic coefficient of variability (30.35%), heritability (61.24%) and genetic advance as percentage of mean (48.92%) were recorded in the progenies of 25 kR, whereas, the minimum values of genotypic variance (0.61), genotypic coefficient of variability (16.39%), heritability (30.72%) and genetic advance as percentage of mean (18.71%) were recorded in the progenies of 5 kR.

The distribution showed positive skewness in many of the treatments for 100 seed weight. Positive skewness was observed at 25 kR, 20 kR and 5 kR in Morden. In CO 4, 15 kR showed maximum (0.90) positive and significant skewness followed by 5 kR. Significant positive kurtosis was observed at 25 kR in Morden. However, one of the treatments showed significant kurtosis in case of CO 4.

4.1.3.3.5. Days to maturity

The range, mean, variance, coefficient of variability, heritability, genetic advance as percentage of mean and measures of dispersion for the days to maturity are presented in table 12.

The days to maturity had lowest and highest mean values of 81.44 days and 82.75 days recorded in the progenies of 10 kR and 15 kR, respectively in Morden. The mean values of all the treatments were higher than the control, except in 10 kR. The maximum values of genetic variance (8.11), genotypic coefficient of variability (3.50%), heritability (53.23%) and genetic advance as percentage of mean (8.15%) were recorded in the progenies of 10 kR.

Whereas, the minimum values of genetic variance (1.81), genotypic coefficient of variability (1.63%), heritability (20.26%) recorded at 25 kR and also minimum genetic advance as percentage of mean (4.60%) were recorded in 5 kR.

In CO 4, the days to maturity ranged from 86.76 to 87.57 days recorded in progenies of 20 kR and 15 kR, respectively. The mean values of all the treatments were lower than control, except in 15 kR and 25 kR where it was slightly higher. The maximum values of genetic variance (4.50), genotypic coefficient of variability (2.44%), heritability (50.09%) and genetic advance as percentage of mean (3.56%) were recorded in the progenies of 5 kR. However, the minimum values were recorded at 25 kR for genetic variance (2.86), genotypic coefficient of variability (1.93%), heritability (38.98%) and genetic advance as percentage of mean (2.49%).

In Morden, the distribution was positively and significant skewed only at 5 kR dose. Most of the treatments showed positive skewness for Morden except at 5 kR and 15 kR, whereas, all the treatments showed negative kurtosis.

4.1.3.3.6. Seed yield per plant

The range, mean, variance, coefficient of variability, heritability, genetic advance as percentage of mean and measures of dispersion for the seed yield per plant are presented in table 13.

The seed yield per plant was lowest in 25 kR (5.64g) and highest in 15 kR (12.36g) for Morden. The mean values of all the treatments were higher than the control, except in 25 kR. The maximum values of genetic variance (26.97), genotypic coefficient of variability (49.22%), heritability (47.21%) and genetic advance as percentage of mean (29.94%) were recorded in the progenies of 20 kR. Similarly in minimum values of genetic variance (10.74), genotypic coefficient of variability (30.56%), heritability (26.26%) and genetic advance as percentage of mean (12.27) were recorded in the progenies of 5 kR.

In CO 4, the lowest and highest value of seed yield per plant was 7.40 to 3.19 g recorded in the progenies of 15 kR and 5 kR, respectively. The mean values of all the treatments were lower than the control, except in 5 kR. The maximum values of genetic

variance (48.34), genotypic coefficient of variability (52.69%), heritability (61.28%) and genetic advance as percentage of mean (48.34%) were recorded in the progenies of 5 kR. Whereas, the minimum values of genetic variance (5.10), genotypic coefficient of variability (27.72%), heritability (14.31%) and genetic advance as percentage of mean (21.60%) were recorded in the progenies of 10 kR.

There was a positive skewness and kurtosis in distribution for all the treatments in both the two genotypes. The skewness and kurtosis showed a highly significant and positive distribution for seed yield per plant in all the treatments of both the varieties.

4.1.3.3.7. Oil content

The range, mean, variance, coefficient of variability, heritability, genetic advance as percentage of mean and measures of dispersion for the oil content are presented in table 14.

In Morden, the oil content ranged from 25.56 to 34.16 per cent recorded in the progenies of 25 kR and 20 kR, respectively. The mean values of all the treatments were higher than the control, except for 25 kR. The maximum values of genetic variance (43.44), genotypic coefficient of variability (19.30%), heritability (63.21%) and genetic advance as percentage of mean (22.28%) were recorded in the progenies of 20 kR. The minimum values of genetic variance (7.57), genotypic coefficient of variability (9.50%), heritability (23.04%) and genetic advance as percentage of mean (8.82%) were recorded in the progenies of 15 kR.

In CO 4, the oil content was lowest (32.02%) at 15 kR and highest (35.90%) at 25 kR. The mean values of all the treatments were higher than the control. The maximum values of genetic variance (26.30), genotypic coefficient of variability (15.69%), heritability (50.77%) and genetic advance as percentage of mean (23.02%) were recorded in the progenies of 10 kR. The minimum values of genetic variance (1.34), genotypic coefficient of variability (3.61%), heritability (4.98%), and genetic advance as percentage of mean (1.66%) were recorded in the progenies of 15 kR.

Most of the treatments were negatively skewed in both the varieties except 5 kR in Morden and 15 kR and 25 kR in CO 4. Kurtosis was significant at 15 kR and 10 kR in Morden and CO 4, respectively.

4.1.4. Study of M₃ generations

All the M₂ treatments were carried forward to M₃ generations (plate 3) and seven quantitative characters were studied. The results are presented characterwise.

4.1.4.1. Analysis of variance

The results of pooled analysis of variance for varieties in M_3 generation are presented in table 15 for Morden and table 16 for CO 4, respectively.

In the analysis of variance M_3 generation, for Morden and CO 4 was similar for all seven characters studied. The variance for treatments and test entries were highly significant for all the characters studied except oil content in both the genotypes.

The analysis of variance for all the individual treatments in M_3 generation are presented in tables 17 to 21 for Morden and 22 to 26 for CO 4.

In Morden, all the variances due to entries/checks/varieties and (checks Vs varieties) were highly significant ($P < .01$) for days to flower, plant height, head diameter, 100 seed weight and days to maturity at all treatment doses studied, it was non significant for 100 seed weight. Seed yield per plant showed non significant differences among the checks and test entries whereas it showed significant difference among the treatments and check Vs test entries for all the gamma doses studied. However, none of the gamma doses showed the significant among the oil content in the Morden progenies.

In CO 4, almost similar trend was noticed as Morden. All the variances among the treatments and test entries showed highly significant over the days to first flower, plant height, head diameter, days to maturity for all the treatments. Where as 100 seed weight, seed yield per plant showed non significant differences among the test entries for all the treatments studied. However, none of the treatments showed significant differences for oil content in CO 4.

4.1.4.2. Mean expression and genetic parameters for quantitative traits in M_3 generations

The range, mean expression and genetic parameters, such as genotypic, phenotypic variance, genotypic coefficient of variability, phenotypic coefficient of variability, heritability in broad sense, genetic advance and genetic advance as percentage of mean for the seven quantitative characters in the M_3 generation are presented characterwise in the tables 27 to 33.

4.1.4.2.1. Days to first flower

In Morden, the minimum and maximum value of days to first flower was 50.03 and 53.86 recorded at 5 kR and 20 kR, respectively (Table 27). The mean values of all the irradiation doses were higher than the control. The maximum values of genetic variance (7.20), genotypic coefficient of variability (37.94%), heritability (61.19%) and genetic advance as percentage of mean (8.64%) were recorded in the progenies of 5 kR. The minimum values of genetic variance (1.67), genotypic coefficient of variability (17.83%), heritability (26.74%) and genetic advance as percentage of mean (2.62%) were recorded in the progenies of 25 kR progenies.

In CO 4, the days to first flower ranged from 54.31 to 56.72 recorded in the progenies of 10 kR and 20 kR, doses respectively. The mean values of all the irradiation doses were lower than the control, except in 20 kR and 25 kR. The maximum values of genetic variance (4.12), genotypic coefficient of variability (27.20%), heritability (56.73%) and genetic advance as percentage of mean (5.65%) were recorded in the progenies of 15 kR. The minimum values of genetic variance (1.24), genotypic coefficient of variability (15.12%), heritability (28.29%), and genetic advance as percentage of mean (2.25%) were recorded in the progenies of 10 kR.

4.1.4.2.2. Plant height

In Morden, the plant height had lowest and highest value of 80.28 and 103.23 cm recorded in progenies of 25 kR and 10 kR, respectively (Table 28). The progeny mean values of all the treatments were higher than the control except at 10 kR. The maximum values of genetic variance (533.75), genotypic coefficient of variability (254.09%), heritability (60.39%) and genetic advance as percentage of mean (44.73%) were recorded in the progenies of 25 kR. The minimum values of genetic variance (73.51), genotypic coefficient of variability (86.92%), heritability (17.35%) and genetic advance as percentage of mean (7.56%) were recorded in the progenies of 20 kR.

In CO 4, the minimum and maximum value of plant height was 111.31 and 119.44 cm recorded in the progenies of 10 kR and 5 kR, respectively. The mean values of 5 kR, 20 kR and 25 kR were higher than the control. The maximum values of genetic

variance (245.25), genotypic coefficient of variability (143.30%), heritability (46.09%) and genetic advance as percentage of mean (18.34%) were recorded in the progenies of 5 kR and minimum values of genotypic variance(63.57), genotypic coefficient of variability (74.33%), heritability (18.14%) and genetic advance as percentage of mean (6.08%) were recorded in the progenies of 15 kR.

4.1.4.2.3. Head diameter

In Morden, the head diameter ranged from 10.27 (25 kR) to 11.68 cm (5 kR). The mean values of 5 kR, 10 kR, 15 kR and 25 kR were higher than the control (Table 29). The maximum values of genetic variance (9.21), genotypic coefficient of variability (88.77%), heritability (75.70%) and genetic advance as percentage of mean (46.55%) were recorded in the progenies of 5 kR. The minimum values of genetic variance (0.69), genotypic coefficient of variability (25.99%), heritability (19.02%) and genetic advance as percentage of mean (7.29%) were recorded in the progenies of 25 kR.

In CO 4, the lowest and highest head diameter were 11.00 cm and 12.34 cm recorded in the progenies of 15 kR and 5 kR respectively. The mean values of irradiation doses were higher than the control. The maximum values of genotypic variance (33.97), genotypic coefficient of variability (166.40%), heritability (92.35%) and genetic advance as percentage of mean (94.05%) were recorded in the progenies of 10 kR.

4.1.4.2.4. 100 seed weight

In Morden, the 100 seed weight ranged from 3.72 (10 kR) to 4.68 g (20 kR). The mean values of all the irradiation doses were higher than the control except 10 kR (Table 30). The maximum values of genetic variance (0.82), genotypic coefficient of variability (43.63%), heritability (35.07%) and genetic advance as percentage of mean (25.96%) were recorded in the progenies of 25 kR. The minimum values of genetic variance (0.28), genotypic coefficient of variability (27.10%), heritability (15.59%) and genetic advance as percentage of mean (11.27%) were recorded in the progenies of 5 kR.

In CO 4, the minimum and maximum value of 100 seed weight was 3.13 and 4.70 g recorded at 25 kR and 15 kR, respectively. The mean values of all the treatments were

higher than the control. The maximum values of genetic variance (0.66), genotypic coefficient of variability (38.45%), heritability (85.51%) and genetic advance as percentage of mean (34.78%) were recorded in the progenies of 20 kR. Whereas the minimum values of genetic variance (0.26), genotypic coefficient of variability (29.07%), heritability (70.41%) and genetic advance as percentage of mean (28.40%) were recorded in the progenies of 25 kR.

4.1.4.2.5. Days to maturity

In Morden, the days to maturity had minimum and maximum value of 80.03 and 84.04 recorded in the progenies of 5 kR and 15 kR, respectively. The mean values of all the treatments were higher than the control, except in 5 kR. The maximum values of genetic variance (6.44), genotypic coefficient of variability (28.37%), heritability (54.71%) and genetic advance as percentage of mean (4.83%) were recorded in the progenies of 5 kR. The minimum values of genetic variance (0.90), genotypic coefficient of variability (10.47%), heritability (14.50%) and genetic advance as percentage of mean (0.90%) were recorded in the progenies of 25 kR (Table 31).

In CO 4, the days to maturity ranged from 85.31 to 86.83 days recorded in the progenies of 10 kR and 25 kR, respectively. The mean values of all the treatments were higher than the control except 5 kR and 10 kR doses. The maximum values of genetic variance (3.79), genotypic coefficient of variability (21.00%), heritability (54.67%) and genetic advance as percentage of mean (3.45%) were recorded in the progenies of 5 kR. The minimum values of genetic variance (1.24), genotypic coefficient of variability (12.06%), heritability (28.29%) and genetic advance as percentage of mean (1.43%) were recorded in the progenies of 10 kR.

4.1.4.2.6. Seed yield per plant

In Morden, the seed yield per plant had minimum and maximum mean value of 9.70 and 12.47 g recorded in the progenies of 10 kR and 20 kR, respectively (Table 31). The mean values of all the irradiation doses were higher than the control. The maximum values of genetic variance (19.68), genotypic coefficient of variability (125.65%), heritability (57.47%) and genetic advance as percentage of mean (55.57%) were recorded

in the progenies of 20 kR. The minimum values of genetic variance (5.40%), and heritability (27.05%) in the progenies of 10 kR whereas the minimum value of genotypic coefficient of variability (71.02%) and genetic advance as percentage of mean (23.14%) were recorded in the progenies of 5 kR.

In CO 4, the seed yield per plant ranged from 12.82 (20 kR) to 15.09 g (10 kR). The mean values of all the irradiation doses were higher than the control except 15 kR (Table 32). The maximum values of genetic variance (28.66), genotypic coefficient of variability (137.79%), heritability (53.80%) and genetic advance as percentage of mean (53.59%) were recorded in the progenies of 10 kR. The minimum values of genetic variance (5.66) were noticed in 20 kR progenies and low genotypic coefficient of variability (62.50%) and genetic advance as percentage of mean (14.57%) were recorded in the progenies of 5 kR, whereas, low heritability (18.69%) were recorded in the progenies of 20 kR.

4.1.4.2.7. Oil content

In Morden, the oil content ranged from 28.56 (25 kR) to 31.17 per cent (5 kR). The progenies of 5 kR, 15 kR and 20 kR recorded higher mean value than the control. The maximum values of genetic variance (10.30), genotypic coefficient of variability (32.54%) and genetic advance as percentage of mean (12.56%) were recorded in the progenies of 20 kR. The minimum values of genetic variance (4.01), genotypic coefficient of variability (35.87%), heritability (15.80%) and genetic advance as percentage of mean (5.26%) were recorded in the progenies of 5 kR progenies.

In CO 4, the oil content minimum and maximum value of 31.61 and 32.33 per cent recorded in the progenies of 5 kR and 20 kR, respectively. The mean values of 20 kR and 10 kR were higher than the control. The maximum values of genetic variance (12.00), genotypic coefficient of variability (61.40%), heritability (46.78%) and genetic advance as percentage of mean (15.33%) were recorded in the progenies of 15 kR families. The minimum values of genetic variance (7.88), genotypic coefficient of variability (49.85%), heritability (36.60%) and genetic advance as percentage of mean (11.03%) were recorded in the progenies of 25 kR progenies.

4.1.5. Study of M₄ Generation

From the M₃ generation, all the treatments were carried forward to the M₄ generation (Plate 4). Seven quantitative characters were studied and the results are presented characterwise.

4.1.5.1. Analysis of variance

The results of analysis of variance for M₄ generation of all the five gamma dose treatments are presented in table 34.

The analysis of variance was worked out for each treatment for each character for between treatments for all the seven quantitative characters studied in both the genotypes.

(i) Within treatment comparison

In Morden, the significant progeny variance was noticed in plant height, head diameter and seed yield per plant for most of the treatments. The gamma doses 15 kR progenies showed significant differences for the characters days to first flower and days to maturity. Whereas as 20 kR progenies exhibit significant difference for the character oil content. However non significant progeny difference observed in all the treatments. None of the treatment showed significant differences for 100 seed weight and oil content except in 15 kR treatment.

In CO 4, plant height showed significant progeny variance observed at 5 kR, 10 kR and 15 kR. The significant differences also observed for days to flower at 25 kR. The gamma doses 5 kR and 20 kR exhibited significant progeny variances for the character seed yield per plant whereas 10 kR, 15 kR and 25 kR progenies exhibited significant differences for the character days to maturity. But, none of the treatments exhibited significant differences for the characters, 100 seed weight and oil content.

(ii) Between treatment comparison

Significant differences were noticed for the characters days to flower, plant height, 100 seed weight, days to maturity, seed yield per plant and oil content. However head diameter showed non significant difference between the treatments of both the varieties.

4.1.5.2. Mean expression and genetic parameters for quantitative traits in M₄ generation

The mean expression and genetic parameters such as genotypic coefficient of variability, phenotypic coefficient of variability, heritability in broad sense and genetic advance as percentage of mean for the seven quantitative characters in the M₄ generation are presented characterwise in the tables 35 to 41.

4.1.5.2.1. Days to first flower

The maximum and minimum mean values were recorded at 25 kR (54.63) and 15 kR (50.38), respectively in Morden. The mean values of all the treatment doses were higher than the control (Table 35). The maximum genotypic coefficient of variability (27.86%), heritability (93.01%) and genetic advance as percentage of mean (55.35%) were recorded in the progenies of 5 kR. The minimum values of genotypic coefficient of variability (1.26%) was observed in the progenies of 20 kR, whereas 20 kR also had minimum values of heritability (2.50%) and genetic advance as percentage of mean (0.41%).

In CO 4, the lowest and highest mean values were ranged from 51.29 to 52.44 days recorded in the progenies of 20 kR and 25 kR, respectively. The maximum values of genotypic coefficient of variability (19.65%), heritability (90.46%) and genetic advance as percentage of mean (38.50%) were observed at 25 kR progenies. Whereas, the minimum values of genotypic coefficient of variability (3.09%), heritability (38.47%) and genetic advance as percentage of mean (3.95%) were recorded in the progenies of 5 kR.

4.1.5.2.2. Plant height

In Morden, the plant height ranged from 84.09 (5 kR) to 123.29 cm (20 kR). The mean values of all the treatment doses were higher than the control except 5 kR (Table 36). The maximum values of genotypic coefficient of variability (218.94%), heritability (93.72%) and genetic advance as percentage of mean (436.61%) were recorded in the progenies of 25 kR. The minimum values of genotypic coefficient of variability (26.04%) and genetic advance as percentage of mean (49.15%) were recorded in the progenies of 20 kR. Whereas, lower values of heritability (78.08%) was observed at 5 kR progenies.

In CO 4, the lowest and highest plant height were 121.98 cm and 142.93 cm recorded in the progenies of 25 kR and 20 kR, respectively. The mean values of the treatment doses are higher than the control except at 25 kR. The maximum values of genotypic coefficient of variability (60.55%) and genetic advance as percentage of mean (106.80%) were recorded in the progenies of 25 kR. The minimum values of genotypic coefficient of variability (11.84%) and genetic advance as percentage of mean (20.81%) were recorded in 5 kR and 20 kR progenies, respectively.

4.1.5.2.3. Head diameter

In Morden, the head diameter ranged from 11.21 (20 kR) to 13.48 cm (10 kR). The mean values of all the irradiation doses were higher than the control except 20 kR (Table 37). The maximum values of genotypic coefficient of variability (149.24%) and genetic advance as percentage of mean (211.77%) were recorded in the progenies of 25 kR, whereas, 10 kR progenies recorded high heritability (89.94%). The minimum values of genotypic coefficient of variability (19.58%) and genetic advance as percentage of mean (35.58%) were observed in the progenies of 5 kR whereas low heritability (47.42%) was observed at 25 kR progenies.

In CO 4, the head diameter had minimum and maximum value of 11.00 cm and 12.33 cm recorded in the progenies of 20 kR and 10 kR, respectively. The mean values of the irradiation doses were higher than the control. The maximum values of genotypic coefficient of variability (34.93%) and genetic advance as percentage of mean (47.29%) were observed in the progenies of 15 kR, whereas, high heritability (75.69%) was recorded at 5 kR progenies. The minimum values of genotypic coefficient of variability (8.21%), heritability (27.79%) and genetic advance as percentage of mean (8.92%) were recorded in the progenies of 10 kR.

4.1.5.2.4. 100 seed weight

In Morden, the 100 seed weight ranged from 4.46 to 4.63 g recorded in the progenies of 15 kR and 25 kR, respectively (Table 38). The mean values of 10 kR and 25 kR were higher than the control. The maximum values of genotypic coefficient of variability (61.84%), heritability (88.90%) and genetic advance as percentage of mean

(91.72%) were registered in the progenies of 25 kR. The minimum values of genotypic coefficient of variability (7.07%), heritability (4.88%) and genetic advance as percentage of mean (3.22%) were recorded in the progenies of 10 kR.

In CO 4, the lowest and highest 100 grain weight was 4.02 and 4.71 g recorded in the progenies of 25 kR and 20 kR, respectively. None of the irradiation doses over values were higher than control. The maximum values of genotypic coefficient of variability (28.21%) and genetic advance as percentage of mean (33.05%) were recorded in the progenies of 15 kR, whereas, high heritability (41.19%) was exhibited by 10 kR progenies. The minimum values of genotypic coefficient of variability (3.42%) recorded in the progenies of 5 kR where as low heritability (1.04%) and genetic advance as percentage of mean (1.29%) recorded in the 25 kR progenies.

4.1.5.2.5. Days to maturity

In Morden, the days to maturity ranged from 79.73 (15 kR) to 84.63 (25 kR). The mean values of all the treatments doses were higher than the control (Table 39). The maximum high values of genotypic coefficient of variability (15.82%), heritability (73.69%) and genetic advance as percentage of mean (27.97%) were recorded in the progenies of 15 kR. The low values of genotypic coefficient of variability (0.52%), heritability (0.49%) and genetic advance as percentage of mean (0.07%) were recorded in the progenies of 10 kR.

The minimum and maximum values of days to maturity was 81.22 and 82.75 days recorded in the progenies of 20 kR and 15 kR, respectively. The mean values of all the five irradiated doses were lower than the control except 15 kR progenies. The maximum values of genotypic coefficient of variability (11.69%), heritability (86.05%) and genetic advance as percentage of mean (22.33%) were exhibited in the progenies of 25 kR. The minimum values of genotypic coefficient of variability (1.96%), heritability (38.47%) and genetic advance as percentage of mean (2.50%) were observed in the progenies of 5 kR.

4.1.5.2.6. Seed yield per plant

In Morden, the seed yield per plant had minimum and maximum value of 16.45 and 21.30 g recorded in the progenies of 5 kR and 10 kR, respectively. The mean values of all the irradiation doses were higher than the control. The maximum and minimum values of genotypic coefficient of variability (469.38% and 54.80%), and genetic advance as percentage of mean (880.08 and 105.73%) were recorded in the progenies of 25 kR and 5 kR, respectively. The high and low heritability (87.73 and 73.29%) was recorded in the progenies of 5 kR and 15 kR, respectively (Table 40).

In CO 4, the seed yield per plant ranged from 14.40 (15 kR) to 19.41 g (5 kR). The mean values of 5 kR and 10 kR doses were higher than the control. The maximum values of genotypic coefficient of variability (76.12%), heritability (84.51%) and genetic advance as percentage of mean (144.16%) were exhibited in the progenies of 20 kR. The minimum values of genotypic coefficient of variability (23.90%) was observed in the progenies of 5 kR, whereas, low heritability (13.90%) and genetic advance as percentage of mean (33.13%) were observed in the progenies of 25 kR progenies.

4.1.5.2.7. Oil content

Table 41 shows the mean and variability various treatment for oil content in M₄ generation for Morden and CO 4. The maximum and minimum mean values of oil content (30.34 % and 34.32 %) recorded in the progenies of 5 kR and 25 kR, respectively in Morden. The treatment doses 25 kR and 20 kR were higher than the control. The higher values of genotypic coefficient of variability (73.10%), heritability (73.20%) and genetic advance as percentage of mean (128.76%) were exhibited in the progenies of 25 kR. The lower values of genotypic coefficient of variability (3.52%), heritability (7.60%) and genetic advance as percentage of mean (2.00%) were recorded in the progenies of 5 kR.

The higher and lower values of oil content were from 29.79 and 31.75 per cent in the progenies of 10 kR and 20 kR, respectively in CO 4. The mean values of all the irradiation doses were higher than the control except 10 kR. The maximum values of genotypic coefficient of variability (15.30%), and genetic advance as percentage of mean (14.55%) were recorded in the progenies of 15 kR, whereas, high heritability (37.73%) was observed at 10 kR progenies. The minimum values of genotypic coefficient of

variability (5.18%), heritability (11.73%) and genetic advance as percentage of mean (3.65%) were noticed in the progenies of 20 kR.

4.1.6. Estimation of heritability by parent progeny regression method

The heritability values of M_2 to M_3 generation and M_3 to M_4 generation of Morden and CO 4 estimated by parent progeny regression method are presented in the tables 42 and 43, respectively.

4.1.6.1. Heritability by parent progeny regression in M_3 generation

The narrow sense heritability values estimated by parent- progeny regression of M_2 to M_3 generation are presented in the table 42.

4.1.6.1.1. Morden

The narrow sense heritability values for the M_2 to M_3 generation estimated by parent progeny regression are presented in the table 42. The heritability estimates were higher for days to first flower (66.70%), head diameter (63.50%), and plant height (56.80%) in 5 kR. In the progenies of 10 kR, the heritability estimate, were high for plant height (58.60%), 100 seed weight (56.80%) and days to first flower (37.20%). The heritability estimates were high in the case of plant height (54.80%) and seed yield per plant (54.00%) in the progenies of 15 kR. Days to first flower (39.50%) and 100 seed weight (44.30%) had high heritability for the progenies of 20 kR. The heritability estimates were higher in the progenies of 25 kR for days to maturity (32.40%) and seed yield per plant (25.60%).

4.1.6.1.2. CO 4

The heritability estimates were higher for seed yield per plant (64.50%) and days to first flower in the progenies of 5 kR. In the progenies of 10 kR, the heritability estimates were high for head diameter (51.60%) and days to maturity (46.90%). High heritability estimates were noticed for plant height (54.00%) and days to first flower in the progenies of 15 kR. In the progenies of 20 kR, the heritability estimates were higher for the characters seed yield per plant (36.50%) and days to first flower (35.60%). The heritability was higher for the characters head diameter (32.50%) and days to first flower (28.00) in the progenies of 25 kR.

4.1.6.2. Heritability by parent progeny regression in M₄ generation

The heritability values by parent progeny regression for M₃ to M₄ generations are presented in the table 43.

4.1.6.2.1. Morden

The heritability estimates were high in the progenies of 5 kR for days to maturity (82.00%), and head diameter (68.40%). The progenies of 10 kR had higher heritability estimates for 100 seed weight (68.20%), followed by seed yield per plant (64.50%). The characters 100 seed weight (75.30%) and head diameter (70.20%) were recorded high heritability in the progenies of 15 kR. High heritability estimates were noticed for days to first flower (66.00%) and seed yield per plant (64.80%) in the progenies of 20 kR. Whereas the high heritability was noticed for 100 seed weight (55.40%) and days to first flower (55.30%) in the progenies of 25 kR.

4.1.6.2.2. CO 4

The high heritability estimates were noticed in the progenies of 5 kR for the characters seed yield per plant (64.30%) and plant height (60.10%). The heritability estimates were high for oil content (73.30%) and 100 seed weight (67.50%) in the progenies of 10 kR. In the progenies of 15 kR, the heritability values was higher for plant height (64.60%) and head diameter (64.50%). High heritability estimates were noticed for days to maturity (53.30%) and plant height (47.50%) in the progenies of 20 kR. The characters plant height (57.40) and days to maturity (42.60%) exhibited high heritability estimates in the progenies of 25 kR.

4.1.7. Correlation studies in M₂, M₃ and M₄ generations

The genetic correlation coefficient between different traits of M₂, M₃ and M₄ generations are presented irradiation dose wise in the tables 44 to 48.

4.1.7.1. Progenies of 5 kR

The genetic correlation coefficient between yield and yield attributing traits of both the varieties are presented in the table 44.

4.1.7.1.1. Morden

Seed yield per plant recorded positive and significant genetic correlation with head diameter (0.371) and 100 seed weight (0.339) in M_2 generation. In M_3 generation, the traits plant height (0.276) exhibited significant positive association with seed yield per plant, whereas days to first flower (-0.415) and days to maturity (-0.415) exhibited negative association with seed yield per plant. The positive and significant association was observed in the traits of plant height (0.473) and head diameter (0.535) with seed yield per plant in M_4 generation.

4.1.7.1.2. CO 4

A significantly negative association was observed between days to maturity (-0.152) with seed yield per plant in M_2 generation. The positively significant correlation was exhibited by 100 seed weight (0.266) with the seed yield per plant in M_3 generation. In M_4 generation, the traits plant height (0.632) and head diameter (0.781) recorded a significantly positive relationship with seed yield per plant.

4.1.7.2. Progenies of 10 kR

The genetic correlation coefficients between yield and yield attributing traits of both the varieties are presented in the table 45.

4.1.7.2.1. Morden

Seed yield per plant exhibited a significantly positive relationship with days to first flower (0.302) and 100 seed weight (0.389) in M_2 generation. In M_3 generation, head diameter (0.481) was recorded a significantly positive genetic correlation with seed yield per plant. The traits plant height (0.514) and head diameter (0.736) exhibited significantly positive association with seed yield per plant in M_4 generation. A significantly positive association was also observed between oil content and seed yield per plant in M_2 generation.

4.1.7.2.2. CO 4

Plant height exhibited a significantly positive correlation with seed yield per plant in M_4 generation. None of the traits exhibited positive and significant correlation with seed yield per plant in M_2 and M_3 generation. The inter correlation among yield

components were observed between head diameter (0.434) and 100 seed weight. The plant height (0.564) also exhibited a significantly positive association with head diameter when inter correlations among yield components were considered.

4.1.7.3. Progenies of 15 kR

The genetic correlation coefficients between yield and yield attributing traits of both the varieties are presented in the table 46.

4.1.7.3.1. Morden

The trait 100 seed weight (0.321) had a significantly positive relationship with the seed yield per plant in M₂ generation. Whereas, none of the yield components characters exhibited significantly positive correlation with seed yield per plant in M₃ generation. The yield contributing characters such as plant height (0.449) and head diameter (0.701) exhibited a significantly positive association with seed yield per plant in M₄ generation.

4.1.7.3.2. CO 4

None of the traits exhibited significantly positive association with seed yield per plant in M₂ and M₃ generations. However, a significantly positive relationship was observed in the traits plant height (0.516) and head diameter (0.790) with seed yield per plant in M₄ generation. When the intercorrelation among characters were considered, days to first flower showed significant and positive correlation with days to maturity in M₃ (0.984) and M₄ (0.966) generation.

4.1.7.4. Progenies of 20 kR

The genetic correlation coefficients between yield and yield attributing traits of both the varieties for 20 kR are presented in the table 47.

4.1.7.4.1. Morden

The significantly positive association was noticed in plant height (0.605) with seed yield per plant in M₂ generation. Seed yield per plant also exhibited significant and positive correlation with head diameter (0.638) in M₃ generation. Similarly, head diameter (0.308) and days to maturity (0.295) exhibited significantly positive relationship

with seed yield per plant in M₄ generation. In M₂ generation, oil content recorded a positive and significant relationship (0.492) with seed yield per plant.

4.1.7.4.2. CO 4

In M₂ generation, the traits days to first flower (0.250), plant height (0.279) and head diameter (0.308) were recorded significant and positive genetic correlation with seed yield per plant. The significantly positive correlation (0.389) was observed between 100 seed weight and seed yield per plant in M₃ generation, whereas a significant and positive association was observed between head diameter (0.633) with seed yield per plant when the intercorrelation was concerned. Further, also plant height and exhibited a positive and significant correlation with head diameter in M₂ (0.642) and M₃ (0.405) generations.

4.1.7.5. Progenies of 25 kR

The genetic correlation coefficients between yield and yield attributing traits of both the varieties are presented in the table 48.

4.1.7.5.1. Morden

The traits head diameter (0.500) and 100 seed weight (0.730) exhibited significant and positive correlation with seed yield per plant in M₂ generation. Whereas, no significantly positive correlation was observed between any traits with seed yield per plant in M₃ generation. In M₄ generation, significant and positive relationship (0.509) was observed between 100 seed weight and seed yield per plant. The oil content exhibited a significant association with seed yield per plant in M₃ generation.

4.1.7.5.2. CO 4

None of the character exhibited positive and significant association with seed yield per plant in M₂ and M₄ generations. However, a significant and positive genetic correlation observed between plant height (0.755) and seed yield per plant. The intercorrelation relationship showed that the trait plant height had significant and positive relationship with head diameter in M₂ (0.642) and M₄ (0.503). Days to first flower also exhibited a significantly positive correlation with days to maturity in M₃ (0.882) and M₄ (0.856) generations.

4.1.8. Foliar disease resistance

The foliar disease expression was observed in all M₂, M₃ and M₄ generations based on the scale for both *Alternaria* leaf spot and rust under field conditions. But no resistance progeny was observed for *Alternaria* leaf spot disease. Families of the mutated progenies did not show any clear cut for resistance for *Alternaria* leaf spot, however, in M₂ generation three progeny rows in CO 4 at 15 kR have been identified with regards to stay green trait *i.e.*, the crop with stand greenish until harvest. In M₃ generation, five plants of a single progeny row have been identified for resistance to rust diseases in CO 4 at 20 kR. These plants did not show any disease impact due to rust even though the season was affected by severe rust outbreak. These isolated stay green trait plants and rust resistant lines were forwarded to M₄ generation. The stay green trait and rust resistance nature were confirmed in field condition.

CHAPTER V

DISCUSSION

Vegetable oils and fats constitute an important component of human diet, ranking third after cereal and animal products. Oil forms the basic cooking medium for majority of dishes, especially of Indian cuisine and enhances the taste of these preparations. The per capita recommended oils and fats is 30 g per day but their availability in India is despairingly below this level. This underlines the need for a concerted effort to enhance the oil production.

Sunflower (*Helianthus annuus* L.) is one of the important oil seed crops in India after groundnut and rapeseed mustard. Production of sunflower in India had increased six fold from 1970 to 1990 due to the introduction of high yielding varieties and hybrids. Presently, the area under cultivation has crossed 1.30 million hectares with a production of 0.70 million tonnes (Damodaran and Hegde, 2002). Even though the progress achieved is quite high in terms of area and production, the productivity (549 kg per ha) seems to be the lowest in the world.

The major objective of sunflower breeding is to increase the quantity and quality of seed and oil. This necessitates the development of high yielding varieties and hybrids, which intum relies on the availability of suitable genetic resources. Enhancement of the genetic potential of the crop in order to maximize economic gain per unit of input remains as the most possible means of increasing the production. For improving the genetic potential of a crop, creation of variation is the foremost requirement. Hybridization and induced mutation are the viable techniques to create genetic variation in crop improvement. Mutation breeding is resorted to achieve rapid genetic changes in the targeted material for crop improvement. Nevertheless, serious work by many scientists has resulted in improved techniques for the application of induced mutations in plant breeding, so that, it can be regarded as an important indispensable tool. As a result of this progress in understanding the role of induced mutations in breeding and at the mutation process a number of crop varieties have been commercially released through induced mutations in different crop plants.. Many crop varieties released through induced mutagenesis are still in popular at many areas.

Though high yielding varieties/hybrids could be developed, the biotic and abiotic stresses are considered as limiting factors to attain high productivity. Among biotic stresses, foliar diseases are important as the crop loss is about 80 per cent. Hence, the criteria for the selection and creation of superior variety/hybrid should also include the resistance to foliar diseases.

Keeping the above points in view, the present study was undertaken to create genetic variability for the improvement of sunflower seed yield through mutation breeding. The results obtained from various generations through mutation are discussed hereunder.

5.1. Mutation studies

The dry seeds were treated with gamma rays and sown at the rate of 50 seeds per treatment with three replication in Randomized Block Design in roll towel method under laboratory. The observations on germination percentage, shoot length, root length and dry matter production were recorded at 15 days after sowing. Based on the observations, the LD₅₀ for gamma rays was arrived at 15 kR for both Morden and CO 4. Accordingly the treatment doses viz., 5 kR, 10 kR, 15 kR, 20 kR and 25 kR were chosen for the conduct the further field experiment.

5.1.1. LD₅₀ determination

The effect of gamma rays for the determination of LD₅₀ value were studied in terms of germination percentage, shoot length, root length and dry matter production. The germination percentage as well as expression of other traits in Morden and CO 4 were reduced when the dosage of gamma rays was increased. This was in conformity with the results obtained by Soni *et al.* (1983) in sorghum and El-Keredy and Abd-Alla (1976) in rice. Skoog (1935) reported that the reduction in germination percentage due to mutagen was by inhibition of auxin synthesis. Gunckel and Sparrow (1961) revealed that germination reduction due to mutagen was due to inhibition of mitosis and chromosomal damage.

Reduction in germination, root length, shoot length and dry matter production has been reported by several workers in various crops (Sjodin, 1962; Hussain and Disouki, 1976; Sharma and Sharma, 1986 and Rao, 1988).

Based on the characters studied the LD₅₀ value was obtained at 15 kR. The same level of dosage was confirmed by several workers in sunflower in case of gamma rays (Giriraj *et al.*, 1990; Vranceanu *et al.*, 1993; Christov, 1994; Jambhulkar and Joshua, 1999; Elangovan, 2001).

5.2. M₁ generation

5.2.1. Studies on germination and survival percentage

The M₁ effects can be measured quantitatively by estimating lethality, injury and sterility (Jana, 1964 and Gaul, 1970). Physical and chemical mutagens induce physiological damages, chromosome mutations and factor mutations in the biological material as observed by Gaul (1970) in M₁ generation. In the present study, the biological effects of the mutagenic treatments were determined from the observations made on germination and survival percentages.

Progressive decrease in germination with increase in the dose of gamma rays was observed in the present study. The reduction was more pronounced at higher doses of gamma rays. The increasing doses of mutagen causing a progressive increase in the biological damage measured in terms of reduction in germination and plant survival in M₁ generation has been reported in some leguminous crops also (Sjodin, 1962; Gregory, 1968; Nerkar, 1976) and other oilseeds crops like groundnut using chemical mutagen (Mathur *et al.* 1997 and 1998).

The similar dose dependent relationship in reducing germination has been observed in the irradiated material of sunflower by earlier workers (Vranceanu and Iuoras, 1990; Marcelo *et al.* 1998; Jumbhulkar and Joshua, 1999).

The survival also decreased with increase in the doses of gamma rays in both the varieties. Shepel (1979) reported the similar results in sorghum. Such inverse relation

between doses and survival is due to non availability of essential gene products or through the occurrence of certain antagonists (Pathak and Patel 1988 and Mehetre *et al.* 1995).

In the present study, reduction in survival to less than 50 per cent was obtained at the higher doses of 20 kR and 25 kR. In a similar manner reports are available in barley (Doll and Sandfaer, 1969), groundnut (Ramanathan, 1979 and 1983), cowpea (Thirugnana Kumar, 1986) and sesame (Prabhakar, 1985) causing greater reduction in survival.

5.2.2. Morphological traits

In the M_1 generation, the genotypes showed both inhibitory and stimulatory effects for various characters in the present study. A general reduction in their mean values for most of the characters was noticed at higher doses.

Stimulatory effect was observed at lower doses of the mutagen for characters, days to first flower and 100 seed weight in both the varieties. The characters, days to first flower, head diameter, days to maturity and seed yield per plant showed positive shift from the control to 15 kR doses. The increase in mean values of quantitative characters may be attributed stimulatory effect of the mutagen. Such a stimulatory effect has been reported in a wide variety of crop plants (Davis, 1979). Stimulatory effect for various characters has been reported by Jones (1965), Prabhakara Rao (1965), Dahiya (1973), Louis and Sundaram (1973), Palanisamy (1975), Rao and Rao (1982), Sathiyamoorthy (1983) and Thirugnana Kumar (1986) in various crops.

Considerable decrease has also been noticed for many traits. Pronounced inhibitory effects were noticed at higher doses of treatments in most of the cases. Such inhibitory effects in quantitative characters have been reported in groundnut (Habib *et al.*, 1979 Dorairaj, 1979 and Mathur *et al.*, 2000) and sesame (Rajan, 1969 and Prabakar, 1985). Decrease in plant height was noticed due to mutagenesis resulting in a stunted growth. Reduction in M_1 generation may be due to several reasons: physiological disturbance coupled with cytological changes (Gunckel, 1957 and 1965), structural changes involving translocations, inversions and deletions (Caldecott *et al.*, 1954),

suppression of enzyme pattern (Endo, 1967), failure of normal physiological mechanisms (Quastler and Baer, 1950), production of diffusible growth retarding substances (Mackey, 1951), delay in the onset of first mitosis (Natarajan, 1958) and inhibition of DNA synthesis (Mikaelson, 1968).

5.3. M₂ generation

5.3.1. Studies on chlorophyll and viable mutations

5.3.1.1. Chlorophyll mutations

In the present study, an increase in the number of chlorophyll mutations were observed with an increase in the dose of single treatments. However, in general, the frequency of chlorophyll mutants was low (Plate 8). It may be perhaps due to the fact that oilseed crops in general are resistant to induced chlorophyll mutations (Rajan, 1969). Earlier reports of Ashri and Levy (1974) also indicated such a low magnitude of occurrence of chlorophyll mutations in groundnut (Mathur *et al.* 2000). The low frequency has also been attributed to the buffering effect in polyploids as reported in wheat (Mackey, 1954 and 1961) and barley (Natarajan, 1958). The occurrence of chlorophyll mutations in low frequency might be due to the elimination of gametes carrying mutations or due to zygote inviability as observed in sesame (Prabhakar, 1985).

Higher doses have brought about increased chlorophyll mutation frequency when compared to lower doses in the present study. Similar increased mutation frequency due to combination treatments was also reported in groundnut (Ramanathan, 1979), peas (Mehandjiev, 1969) and Frenchbean (Margittu, 1973). Contradictory results have also been reported in crops like barley (Fauret, 1963) and rice (Hasengawa and Inove, 1983).

The spectrum of chlorophyll mutations obtained in the present study include *albina*, *xantha*, *viridis* and *striata* (Plate 8). Jambhulkar and Joshua (1999) reported the occurrence of chimera, *xantha* and *virescent* and it increased in the 200 Gy dose of gamma rays. Hermilin *et al.* (1987), Vranceanu *et al.* (1993) and Mashkina and Guskov (2001) reported the occurrences of different chimerism and chlorophyll mutations in sunflower. Fambrini *et al.* (2003) reported that one recessive nuclear gene controlling *Chlorina 1* (*Ch1*) mutant in sunflower.

The spectrum of mutation varied with genotypes. In the present study *albina* and *xantha* occurred in high frequency in Morden and CO 4 at 20 kR and 25 kR gamma doses.

5.3.1.2. Viable mutations

In the present study, increase in the dose of gamma increased the number of viable mutations in both the varieties. Viable mutants included plant height, growth habit, leaf modification, seed colour and sterile plants. (Plates 5,6,7,9,10 and 15-17).

In sunflower, different types of viable mutants were identified by various workers for brown, black and white colour seeds (Jambhulkar and Joshua, 1999), sterile plants (Vrancernu and Iuoras, 1990), super early, dwarf and short petiole mutants (Kalaijun, 1999) and dwarf mutant (Jambhulkar, 2002).

Variations in plant height types, leaf modifications and sterile plants were observed almost in all the treatments in CO 4 and Morden (Plates 5-17). Plant height types and leaf modifications variations were occurred in high frequency than other type of viable mutations. Such mutants can effectively be used for genetic studies.

5.3.1.3. Mutagenic effectiveness and efficiency

Mutagenic effectiveness and efficiency for different characters are worked out for both chlorophyll and viable mutations as suggested by Konzak *et al.* (1965). Mutagenic effectiveness can be considered as a measure of gene mutation in relation to the dose and mutagenic efficiency, as an estimate of mutation rate in relation to the dose and mutagenic efficiency and as an estimate of mutation rate in relation to other biological effects induced such as lethality.

The effectiveness for chlorophyll and viable mutations were higher in case of lower doses. Both Morden and CO 4 responded similarly for mutation effectiveness of chlorophyll and viable mutations.

The effectiveness was higher for chlorophyll (19.6%) and viable mutations (20.01%), respectively at 5 kR in Morden. Whereas in CO 4, the effectiveness was found to be more at 5 kR for chlorophyll (15.4%) and viable (28.6%) mutations.

The lower doses were more efficient for both chlorophyll and viable mutations, though it decreased as the intensity of the doses increased. This might be due to the negative synergism of the mutagen. Khan (1983) and Thirugnana Kumar (1986) also observed such a higher dose of gamma increased and the efficiency of the mutagen decreased. Konzak *et al.* (1965) stated that the greater efficiency of the mutagen at lower dose was due to the fact that biological damage increased at a faster rate with the increase in dose.

5.3.1.4. Studies on quantitative characters

5.3.1.4.1. Mean and variance

It is well established that variability in quantitative characters can be increased considerably by treating the biological material with mutagens. As a consequence of peculiarity of phenotypic manifestation of quantitative characters, the only method available to detect the induction of new variability coming from mutagenic treatment is that given by mean and variance comparisons (Scossiroli, 1977). Though more reliable result can be obtained from the study of quantitative characters in advanced generations than in M_2 (Aastveit, 1968 and Scossiroli, 1977). Hence, it would be a worthwhile effort to study the shift in the mean value, induced variability and its components in the present study. The shift in mean values and the nature and extend of variability induced for different quantitative characters are discussed below.

In general, different mutagenic treatments showed an inconsistent relationship between the mutagen and the mean expression for various traits studied. However, the effect of mutagen was more drastic in M_1 and less in M_2 , indicating the fact that through subsequent generations, the nuclear damages had started repairing (Imam, 1979).

In M_2 generation, there was an increase in the mean values in most of the treatments for characters such as plant height, head diameter, 100 seed weight, days to

maturity, seed yield per plant and oil content in Morden. Such a shift towards positive direction is contrary to the generalized view where a negative shift is usually expected. However, the mean of the treated population showing a significant increase over control has been reported by Khan (1983, 1984 and 1988) in mungbean for characters such as 100 seed weight and number of pods and pod weight. Days to first flower, plant height, head diameter and seed yield per plant showed a negative shift in the mean value in CO 4.

Such decrease in mean values due to mutagenic treatments have been reported in groundnut (Gregory, 1968; Sivasubramaniam, 1978, Ramanathan, 1983 and Mathur *et al.* 2000), soybean (Rawlings *et al.*, 1958), lablab (Rathinasamy, 1975), cowpea (Palanisamy, 1975), blackgram (Soundarapandian, 1978 and Kundu and Singh, 1981) and redgram (Nadarajan *et al.*, 1983).

The genetic changes in quantitative characters were realized by increased genotypic variance in M₂ generation. The most dependable measure of micromutations is the genotypic variance which showed extended value for the characters studied in the present investigation. Considerable increase in variance was observed in characters such as plant height, seed yield per plant and oil content.

The increase in genetic variance varied widely depending upon the variety, trait and the mutagenic dose. Such increase in variance as a result of mutagenic treatments were reported by Gregory, (1955), Sivasubramaniam (1978) and Ramanathan (1983). There was an increase in induced variance due to an increase in dose of the mutagen employed in both the genotypes, Morden and CO 4 for days to first flower, plant height and seed yield per plant. However the present studies revealed that the linear relationship between dose and genotypic variance was not maintained for all the characters in the genotypes studied. Similarly the magnitude of increase in variance also differed for different traits and was inconsistent with varying doses of the mutagen in one and the same genotype. The traits such as plant height, head diameter, seed yield per plant and oil content should the maximum variance for the treatments in both the varieties.

Gregory (1955) reported that radiation could be used as a potent source of inducing variability in groundnut. Increasing genetic variability for yield and other quantitative characters has been reported by Giriraj *et al.* (1990) in sunflower. Increased variability due to mutagenic treatments was reported in other oilseed crops like soybean (Rawlings *et al.*, 1958 and He, 1982), Sesame (Arzumanova and Pravikovakaya 1972) and *Brassica juncea* (Sanghavan and Yadava, 1975) and groundnut (Mathur *et al.* 2000) and also they recorded increased variance for plant height and seed yield per plant.

In the present study, variability induced was low for characters such as days to first flower, days to maturity and oil content. The low variance may be due to restricted heterozygosity in the mutated genes governing these traits in M₂ generation which may produce greater variability in later generation.

5.3.1.4.2. Heritability and genetic advance

The trend observed for genotypic variance was maintained for heritability also. However, genetic variance as percentage of mean showed slight deviations. High heritability and genetic advance was observed for 100 seed weight. However, the moderate heritability and genetic advance was observed for all the other characters studied, except for 100 seed weight.

Heritability and genetic advance as percentage of mean were maximum at 20 kR and 5 kR in the genotypes Morden and CO 4, respectively for seed yield per plant. For oil content, the high heritability and genetic advance was observed in 20 kR and 10 kR for Morden and CO 4, respectively. The increased heritability and genetic advance in the treated populations in the present study is also in conformity with results obtained in other oilseeds crops like sesame (Chavan and Chopde, 1982), mustard (Labana *et al.*, 1980) and groundnut (Mathur *et al.* 2000). The mutants isolated with increased mean values, high heritability and genetic advance may be useful for utilizing in crop improvement programmes.

5.3.1.4.3. Skewness and Kurtosis

Skewness describes the degree of departure of a distribution from symmetry and kurtosis characterizes the peakedness of a distribution. In a frequency distribution of a segregating generation skewness could result when *first* certain combinations of genes are lethal, *second* there is incomplete linkage of certain genes controlling the trait, *third* presence of epistasis, *fourth* non additive genetic effects (dominance or over dominance), *fifth* presence of genotype x environment interaction and *sixth* one gene has a very much larger effect than others.

Skewness helps us to draw the conclusion about the gene action for a particular trait. The positive skewness indicated the presence of complementary epistasis gene action for the trait and the gain is slower with mild selection and gain is faster with intensive selection. The negative skewness indicated the presence of duplicate epistasis gene action and the gain is faster with mild selection and rapid with intense selection (Snape and Riggs, 1975).

Kurtosis will occur if either a few genes are controlling to the phenotypic distribution or there are inequalities in the additive genetic effects at different loci. Traits for which data showing leptokurtic distribution are usually those under control of relatively few segregating genes, whereas, data showing a platykurtic distribution usually represent characters that are controlled by many genes. The positive values of kurtosis indicated leptokurtic curve, negative kurtosis indicated platykurtic curve and if values are not significant or zero indicated mesokurtic *i.e.* normal distribution.

The frequency distribution for quantitative traits in M_2 generations are depicted in Fig. 1 to Fig. 40.

The distribution of mutants in the treated populations indicates the nature of variation. Symmetrical distribution assures equal frequency of minus and plus mutations and hence usable through selection. Any deviation from normality would affect the selection prospect and such deviations are indicated by tests of skewness and kurtosis. In the present study, the distribution remained normal in most of the treated population,

though deviation occurred in few instances. The mutagen resulted in positive skewness in some treatments, while it was negative in others.

In the present study, skewness was observed at gamma rays for different characters. In case of seed yield per plant, plant height, head diameter and 100 seed weight, all the treatments showed significant positive skewness and kurtosis for both the genotypes and for these characters complementary gene action was confirmed. If selection for these characters were made intensively, the gain will be faster. Whereas the trait oil content was exhibited negative skewness and kurtosis for most of the irradiated doses confirmed the presence of duplicate epistasis gene action. If selection for this trait was made intensively, the gain will be faster with mild selection. Earlier reports indicating the presence of positive and negative alterations in the distribution due to mutagenic treatments.

Brock (1967) observed mutagenic treatments generally increased both skewness and kurtosis by ionizing radiations. Goud (1967) observed the differential response to mutagens in wheat, where skewness was positive under gamma treatment. The differential behaviour has been attributed to a diploid effect on the selection efficiency against gametes with unfavourable genes (Bhatia and Swaminathan, 1962) and this explanation may be applicable to the behaviour of the treated population in the present study.

5.4. Study of M₃ generation

In the present investigation, selected individual plants of M₂ generation were forwarded to M₃ generation along with their controls as there were indications to show that successful recombinants could be realized due to the presence of high genetic variability for yield attributing characters. The induced gene mutations facilitate increased crossing over, translocation and breaking of linkage relationships and result in larger genetic variations than expected (Siddiqui, 1971). The radiation induced mutations in polygenic systems controlling quantitative characters might be expected to vary depending upon the influence of other factors such as environment, breeding system of irradiated species, genetic architecture of the particular gene system studied and gene co-adaptation within this system. Evaluation of irradiation for quantitative traits depends

upon the knowledge of the attributes for which mutation can be induced, direction of mutation and the magnitude of change. A detailed study of the mean expression, genotypic variability, heritability and genetic advance as percentage of mean in M_3 generations are discussed here under.

5.4.1. Analysis of variance

The analysis of variance of M_3 for Morden and CO 4 were significantly similar from each other for seven characters studied. The variance for treatments, and test entries recorded were highly significant for all the characters studied except for oil content in both the genotypes.

5.4.2. Mean and variance

In Morden, the mean values for days to first flower, plant height, 100 seed weight, days to maturity and seed yield per plant and in CO 4, for head diameter and 100 seed weight were increased over the respective controls in all the five irradiated doses. However the mean values for head diameter and oil content of Morden and days to first flower, plant height, days to maturity, seed yield per plant and oil content in CO 4 were inconsistent.

The variance and coefficient of variability are discussed for all seven characters in M_3 as follows. In Morden, high genotypic variances were noticed for days to first flower, plant height, head diameter and days to maturity in the progenies of 5 kR and high genotypic variance for seed yield per plant was noticed in 20 kR. Hence, further selection in the families of 5 and 20 kR might give the fruitful results. In CO 4, the genotypic variance was higher in the progenies of 10 kR for head diameter, 100 seed weight and seed yield per plant.

5.4.3. Heritability and genetic advance

In Morden, high heritability estimates combined with high genetic advance as percentage of mean were noticed in the progenies of 20 kR dose for days to first flower, days to maturity, seed yield per plant and oil content. For days to first flower, plant height, head diameter, and days to maturity the progenies of 5 kR recorded high heritability and genetic advance as percentage of mean. Hence, the further selection within the above families would give fruitful results for the selected characters.

In CO 4, the gamma dose 10 kR recorded higher heritability and genetic advance as percentage of mean for head diameter, 100 seed weight, seed yield per plant and oil content and for days to first flower and days to maturity, high heritability coupled with high genetic advance were recorded at 15 kR gamma dose. Hence, selection in the progenies (10 kR and 15 kR) would be highly useful to get higher yield and earliness, respectively.

5.5. Study of M₄ generation

5.5.1. Analysis of variance

The analysis of variance of M₄ generation from Morden and CO 4 were significantly different from each other for seven characters studied. However, plant height recorded significant variances at 5 kR, 10 kR and 15 kR for both the genotypes. For seed yield per plant also significant differences was observed for 10 kR and 20 kR in both the genotypes. However, non significant differences were observed for 100 seed weight and oil content in the treatments of both the genotypes. In between treatments comparison, significant variance were noticed for the characters like days to first flower, plant height, 100 seed weight, days to maturity, seed yield per plant, and oil content.

5.5.2. Mean and variance

The variability spectrum unfold due to mutagenic treatments were large. The shift was more towards larger side with some exceptions on lower side in different doses gamma rays. In Morden, all the treatments exhibited significant mean values for days to first flower, days to maturity, seed yield per plant and oil content. Further, selection within treatments will be helpful for improvement of above mentioned traits. The variance and co-efficient of variability were worked out for all the seven characters in Morden and CO 4.

In general, the treatment dose 25 kR recorded high variability for the traits, plant height, head diameter, 100 seed weight, seed yield per plant and oil content in Morden. The high variability also recorded in CO 4 at 25 kR dose in three traits viz., days to first flower, plant height, and days to maturity. The treatment dose, 15 kR recorded high variability for the characters such as days to first flower, plant height, head diameter, 100 seed weight, days to maturity, seed yield per plant and oil content in Morden and CO 4. Hence, selection within these treatments would be helpful for improvement of above

mentioned traits. In CO 4, plant height and head diameter recorded high mean value in all the treatments studied. The other traits registered inconsistent values. It indicated that there is a good possibilities to improve head diameter, a highly positive associated character with yield.

5.5.3. Heritability and genetic advance

In general, the heritability and genetic advance as percentage of mean is very high for the traits plant height, head diameter, seed yield per plant and oil content for both the genotypes studied. In Morden, the treatment dose 15 kR exhibited very high heritability for days to first flower, plant height, head diameter, 100 seed weight, days to maturity and seed yield per plant. The characters such as plant height, head diameter, and days to maturity recorded had high variability at 15 kR in CO 4. Hence, further selection in 15 kR dose would be useful for further improvement of these traits. In general, characters having high heritability would respond well for selection. Hence, selection based on above traits may be resulted a real genetic improvement *i.e.* the environmental influence may be less.

5.6. Heritability through parent – progeny regression

In the present investigation, heritability has been calculated by the parent – progeny regression method, using the parental values of M_2 (M_3) and mean expression of M_3 (M_4) generations. The broad sense heritability values estimated in conventional breeding methods appear to be too high and such of those characters which recorded very high heritability values did not get reflected in the expected response to selection. The narrow sense heritability estimated from parent- progeny regression method was low in some cases as compared to the heritability values calculated by the components of variance method. Similar results were reported by Raveendran (1995) in sorghum. Regression heritability is considered to represent the portion for the genotypic variation, mainly due to additive gene action.

5.6.1. Heritability (parent – progeny regression) on mutation generations

5.6.1.1. M_2 to M_3 generations

In Morden, almost all the characters should moderate to high narrow sense heritability. However, the narrow sense heritability get reduced when the treatment dose

increased. The heritability was very high in 5 kR and followed by 10 kR progenies. The progenies of 5 kR and 10 kR recorded high narrow sense heritability along with high genetic advance for first flower, head diameter, and plant height. High heritability accompanied by high genetic advance is an indication of additive and fixable nature of gene which could be exploited in selection.

In CO 4, high heritability along with high genetic advance as percentage of mean was recorded for three traits viz., days to first flower, seed yield per plant and head diameter in the families of 5 kR followed by 10 kR and 15 kR reported high heritability for certain traits. Hence, progenies of these treatments could be forwarded for the improvement of yield with early maturing and desirable plant height.

5.6.1.2. M₃ to M₄ generations

The heritability (parent – progeny regression) is also worked out in M₃ to M₄ generations. Similar results were obtained as in M₂ to M₃ generations. The narrow sense heritability was recorded from moderate to high in both the genotypes for all the traits studied. Inconsistent results were obtained in all the treatment doses. However, the high heritability was observed for days to maturity and head diameter at 5 kR in Morden, whereas, 15 kR reported high narrow sense heritability for most of characters studied for both the genotypes; while, plant height, head diameter, days to maturity were had high heritability for most of treatment doses.

Seed yield per plant exhibited high narrow sense heritability and high genetic advance as percentage of mean for 10 kR and 20 kR for Morden and 5 kR and 15 kR for CO 4. There was a maintainable relationship over the mutation generations. Hence, these progenies would be forwarded for the improvement of yield.

5.7. Correlation studies

The present study has brought out the fact that the association of the chosen characters with yield has been altered after irradiation, but with differing intensities. Therefore, it is worthwhile to workout the association of the component characters with yield as well as with the component characters in each irradiation doses in order to suggest a suitable selection index that can be used for selection of progenies in the

mutated population. In the present study, the correlation was worked out by genetic correlation coefficient method and estimated in M_2 , M_3 and M_4 generations for all the characters studied. The genetic correlation coefficient have been presented at treatment wise for both the genotypes.

5.7.1. Correlation on mutation generations in Morden

In Morden positive significant genetic correlation was observed for days to first flower with the seed yield per plant at 5 kR, 10 kR, 20 kR and 25 kR progenies and also 100 seed weight exhibited significantly positive association with seed yield per plant in 5 kR, 10 kR and 15 kR progenies in M_1 generation. Plant height and head diameter exhibited significant and positive association with seed yield per plant at 5 kR, 10 kR and 15 kR progenies of M_4 generation, whereas, inconsistent results were obtained in M_3 generation.

A significant positive correlation was recorded by seed yield per plant with oil content 5 kR , 10 kR, 15 kR and 20 kR in M_2 generation.

Based on these results, some significant correlations were obtained between traits at expected level. The oil content exhibited negative association with all the characters in all the generations.

5.7.2. Correlation on mutation generation in CO 4

In CO 4, a similar trend as in Morden was observed. In M_4 generation, the progenies of 5 kR, 10 kR showed a positively significant association with plant height and seed yield per plant. All the treatment doses exhibited a highly positive significant association between plant height and head diameter. The yield attributing characters like head diameter and 100 seed weight exhibited a positive significant correlation with seed yield per plant in all the treatments studied. When inter correlations were considered, significant and positive relationship were observed between days to first flower and plant height at 5 kR, 10 kR and 15 kR progenies of M_3 and M_4 generations.

The results exhibited a positive impact in the selection procedure at over the generations for different characters. Hence, the selection can be made uniformly in all the

progenies of all irradiated doses studied would be useful for future improvement of these genotypes.

5.8. Foliar disease resistance

Characters like disease resistance are likely to be controlled by many genes. Consequently, the choice between induced mutations and gene transfer is largely determined by the ease with which the gene can be mutated compared with ease with which it can be incorporated from another genotype.

The induction of recessive mutation is a much more likely event than induction of a dominant mutation. This fact, plus the ease of intra specific transfer of a dominant gene by conventional genetic methods, favours hybridization breeding where the desired traits are known or presumed to be conditional by a dominant gene.

In case of recessive genes the induction of mutation is more worthy of consideration. If the gene is available in a genotype closely related to agricultural cultivar, by transfer of gene by back crossing would normally be favour the method more likely to prove successful. However, there are examples of rapid adjustments of single undesirable characteristic by means of mutation such as change of grain colour of the new high yielding wheat genotype, from white to amber to suit local market preference.

If close linkage with undesirable characters or undesirable pleiotropic effects are found to be involved in a gene transfer programme or if transfer of the desirable gene involves inter –specific or intergeneric crossing, induced mutations may be the preferable techniques. If there is no known source from which the gene can be transferred, induced mutations are, of course, the only possibility and the decision to initiate a program based on induced mutations depends largely upon economic considerations such as the importance of the objective and the cost of screening for the desired mutations.

Alternaria leaf spot is a serious disease of sunflower for which so far no resistance source is available. From the present investigation, no fruitful results were obtained for *Alternaria* leaf spot disease resistance. However, some plants have been identified based on stay green trait (Cukadar-Olmedo and Miller, 1997 and Cukadar-

Olmedo *et al.*, 1997), which withholds the disease prevalence over the plant until harvest stage and also three rust free lines have been identified in CO 4 (Plate 8). These lines were on par with the base variety for yield. Further, selection in these lines would improve the yield with disease resistance and it could be useful for future breeding programme and finally to avoid the yield losses by the farming community due to this foliar diseases.

CHAPTER V

SUMMARY

The effect of gamma rays on two improved sunflower cultivars, Morden and CO 4 were studied. The LD₅₀ value was determined based on germination percentage, shoot length, root length and dry matter production and were observed as 15 kR for both Morden and CO 4. The treatments doses were fixed as 5 kR, 10 kR, 15 kR, 20 kR and 25 kR for both the genotypes. The plants arising from all mutagenic treatments in each cultivar were studied along with the controls in M₁ generation.

In M₁ generation, a progressive decrease in germination and survival was observed with an increase in the dosage of gamma rays. The two varieties were identified in their sensitivity to mutagenic treatments with respect to germination and survival percentages.

In morphological traits, the genotypes showed pronounced inhibitory effects due to the mutagenic treatments for most of the characters studied. However, a stimulatory effect was recorded at lower doses of the mutagen for characters such as days to first flower and 100 seed weight for both the genotypes. The difference between the treatments were significant for all the traits studied. Most of the characters such as days to first flower, head diameter, days to maturity and seed yield per plant exhibited a positive shift from the control.

In M₂ generation, increase in the frequency of chlorophyll mutations, observed due to increase in the dosage of treatments. The mutation frequency in terms of chlorophyll mutations was highest in 20 kR for both Morden and CO 4.

The spectrum of chlorophyll included *albina*, *xantha* and *viridis*. The spectrum also showed differential response of the two cultivars to mutagenic treatments. The frequency of viable mutations on M₂ plant basis increased as the dosage of a gamma increased. The frequency was higher in CO 4 than in Morden at most of the treatments.

The spectrum of viable mutations included mutants for plant height, growth habit, leaf modifications, seed colours and male sterility.

Studies on mutagenic effectiveness showed a decreasing trend with increase in dose of mutagen for both chlorophyll and viable mutations, except 15 kR in Morden and CO 4. Mutagenic efficiency decreased with an increase in the dose of gamma rays in both the genotypes.

The effect of mutagenic treatments as quantitative characters in M_2 generation showed the mutagenic effect was less drastic in reducing the mean values than that of M_1 generation. In general, there was an inconsistent trend between dose of the mutagen and the mean expression of the traits studied. There was a decrease in the mean values for characters such as days to first flower, plant height, head diameter and seed yield per plant for both the varieties studied. Considering induced variability for metric traits, there was an increase in genotypic variance in the treated population. The inconsistent values for variance was observed widely depending on the variety, trait and the mutagen employed.

Considerable increase in genotypic variance was observed for the characters such as plant height, seed yield per plant and oil content. Variance increased for certain characters such as days to first flower, plant height and seed yield per plant in all the treatments in CO 4 unlike in Morden, indicating that differential response of genotypes to induced mutagenesis. Though the mean values in general shifted towards negative direction the enlarged genotypic variability offered scope for further selection, especially for oil content.

The trend observed for genotypic variance was maintained for heritability also, though genetic advance as percentage of mean showed slight deviations. High heritability and high genetic advance as percentage of mean were observed for seed yield per plant and oil content. However, moderate heritability with moderate genetic advance as percentage of mean were observed for most of the characters except 100 grain weight.

Studies on measures of dispersion such as skewness and kurtosis indicated that the distribution remained normal in most of the treated populations, though deviations

occurred in few instances. The asymmetry of distribution did not follow any generalised trend. In case of seed yield per plant, positive and significant skewness and kurtosis were observed for all the treatments studied. The yield contributing characters also exhibited positive skewness and kurtosis for most of the treatments in both the genotypes.

In M_3 generations, the general ANOVA for treatments and various progenies recorded highly significant for all the characters studied except oil content in both the genotypes.

In M_3 generations of Morden the mean and genetic variance were high for days to first flower, plant height, 100 seed weight, days to maturity and seed yield per plant and in CO 4 the traits, head diameter and 100 seed weight were increased over the respective controls. But some traits viz., head diameter and oil content of Morden and days to first flower, plant height, days to maturity and seed yield per plant of CO 4 registered inconsistent mean values.

The high genotypic variance was noticed in most of the traits in the progenies of 5 kR and 20 kR in Morden and also 10 kR in CO 4. Hence, further selection in the progenies will give the fruitful results.

The high heritability coupled with high genetic advance as percentage of mean were recorded for most of the traits of 20 kR and 5 kR progenies in Morden. The progenies of 10 kR and 15 kR recorded high heritability with genetic advance as percentage of mean. In CO 4, the population of these progenies could be forwarded for selection to improve most of the traits.

In M_4 generations, the combined ANOVA for Morden and CO 4 were significantly different from each other for all the characters studied. However, significant variance recorded for 5 kR, 10 kR and 15 kR for both the genotypes. In between treatment comparison, significant variance were noticed for almost all the characters studied.

The mean value and genotypic variance was high for days to first flower, days to maturity, seed yield per plant and oil content in all the treatment progenies. However, the

progenies of 25 kR in Morden and 25 kR and 15 kR in CO 4 had high variability. Hence, the progenies of these treatments could be subjected to advancement for further improvement of many traits.

High heritability estimates combined with high genetic advance as percentage of mean were noticed in the progenies of 15 kR for both the genotypes. The results indicated presence of additive gene action and further advancement of these progenies will result in fixing of the most of the traits.

In Morden, the progenies of 5 and 10 kR recorded high narrow sense heritability with high genetic advance for days to first flower, head diameter and plant height, whereas, 5 kR had best heritability in CO 4. These treatments can be advanced to successive generations for the improvement of most of there traits.

The correlation was worked out by genetic correlation coefficient method in M₂, M₃ and M₄ generations for all the characters studied in both the genotypes. In Morden, the yield contributing characters such as 100 seed weight and head diameter exhibited significant and positive association with seed yield per plant in 5 kR, 10 kR and 15 kR progenies in M₃ and M₄ generations.

In CO 4, a similar trend was observed as in Morden. The progenies of 5 kR, 10 kR and 15 kR recorded positively significant correlation between plant height and seed yield per plant. The yield attributing characters such as head diameter and 100 seed weight exhibited positive significant association with seed yield per plant for most of the treatments studied. The negative correlation was obtained between oil content and most of the traits in both the genotypes.

Mutations in the different treatments could not produce distinct *Alternaria* leaf spot resistant types. However, some stay green trait plants and rust resistant were isolated and confirmed in M₄ generations. So, further improvement in these lines would yield a fruitful genotype for farming community.

The present study also reported in the identification of two high yielding economic mutants each one from Morden and CO 4. A dwarf (35 cm) mutant with

earliness (65days) from Morden was identified which can be forwarded for further exploitation.

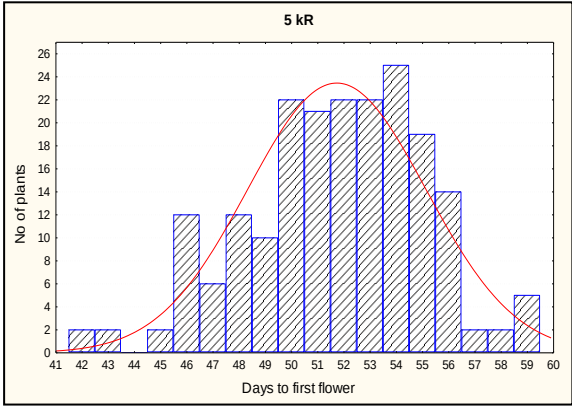


Fig. 1.

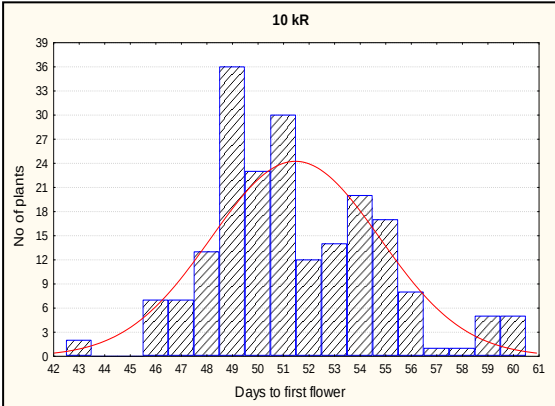


Fig. 2.

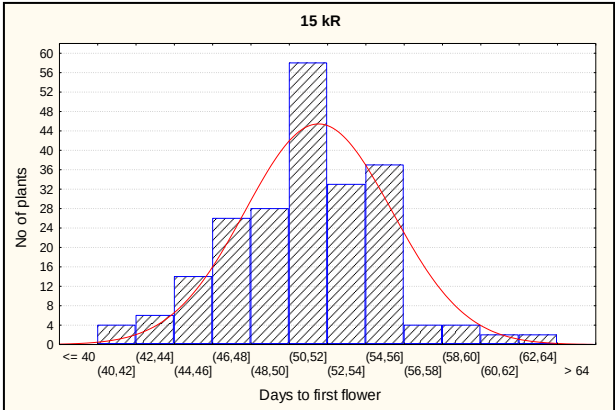


Fig. 3.

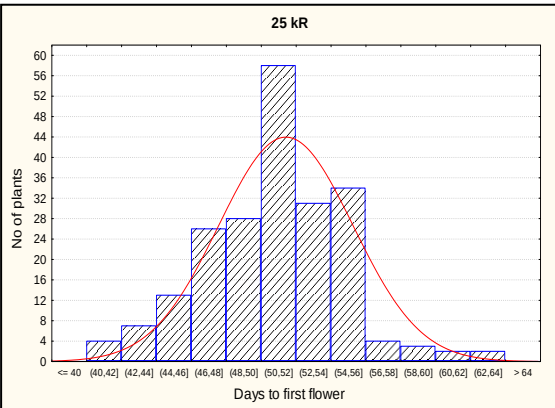
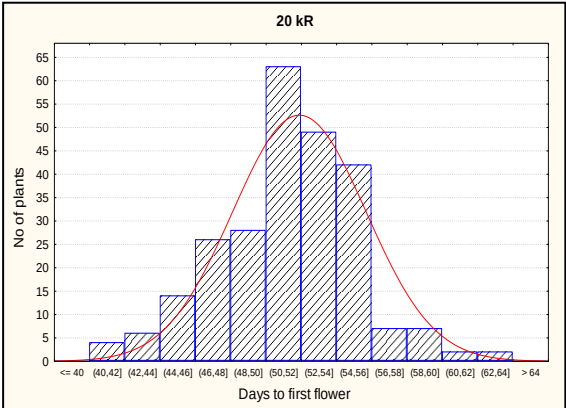


Fig. 4.

Fig. 5.

Fig. 1, 2, 3, 4 & 5. Frequency distribution for days to first flower in the M2 generation of Morden

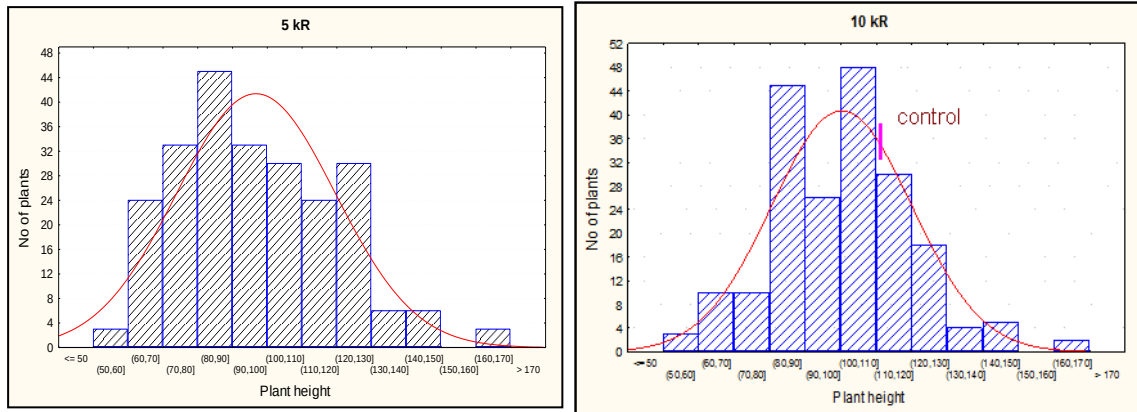


Fig. 6.

Fig. 7.

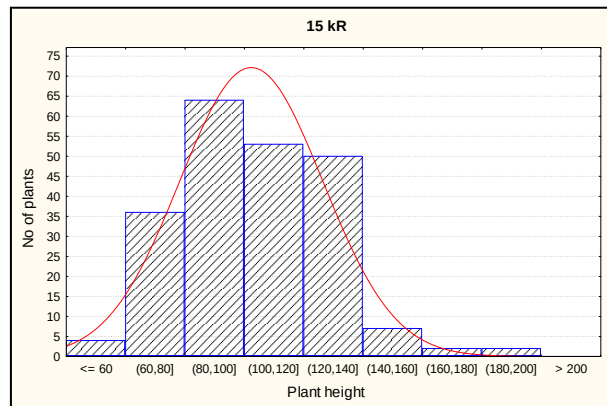


Fig. 8.

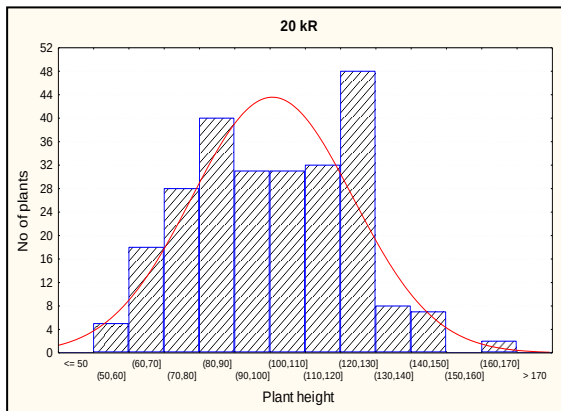


Fig. 9.

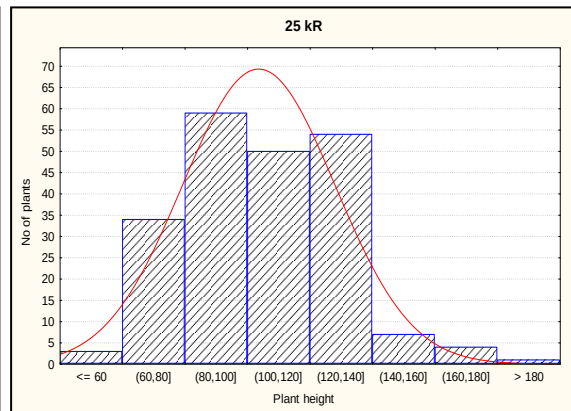


Fig. 10.

Fig. 6, 7, 8, 9 & 10. Frequency distribution for plant height in the M2 generation of Morden

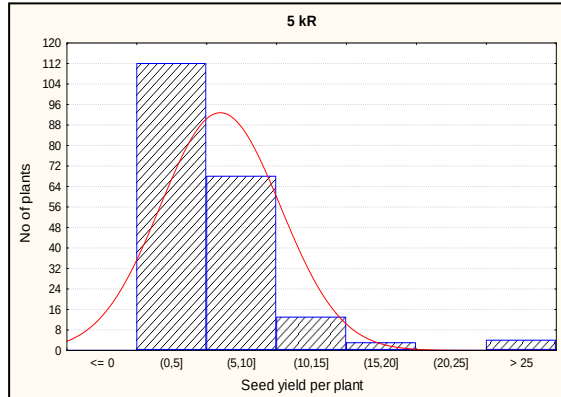


Fig. 11.

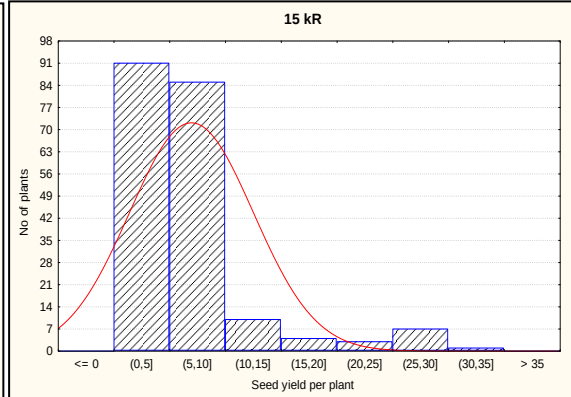


Fig. 12.

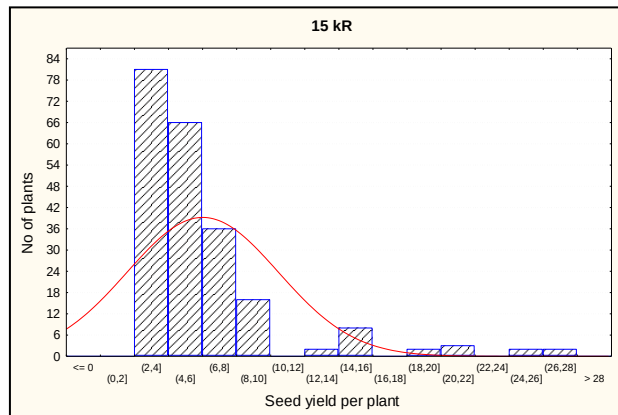


**Fig.
13.**

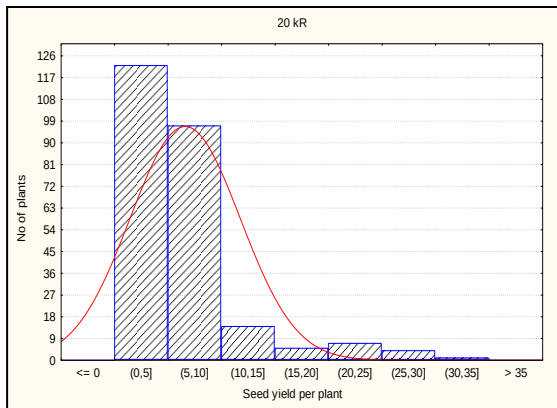


**Fig.
14.**

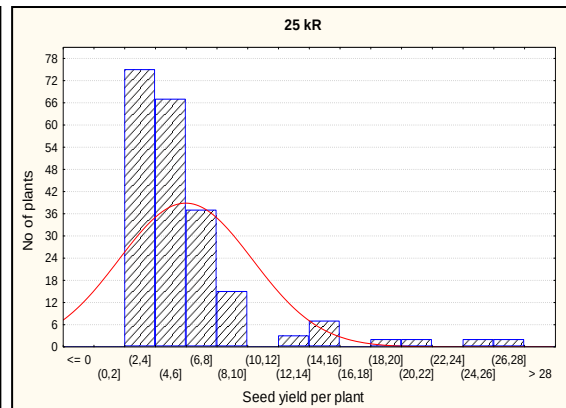


**Fig.
15.**

Fig. 11,12, 13, 14 & 15. Frequency distribution for seed yield per plant in M2 generation of Morden

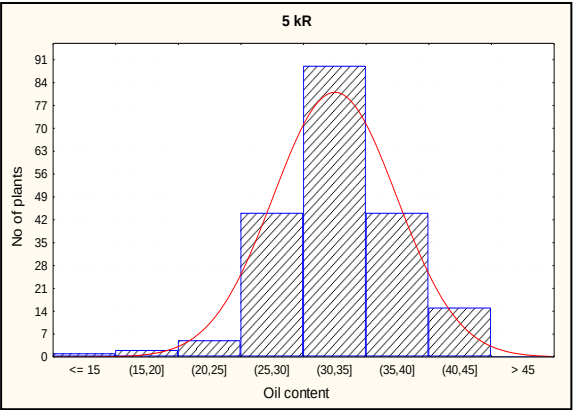


Fig.
16.

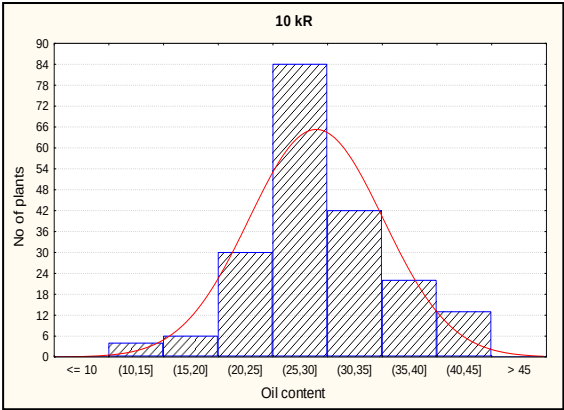


Fig.
17.

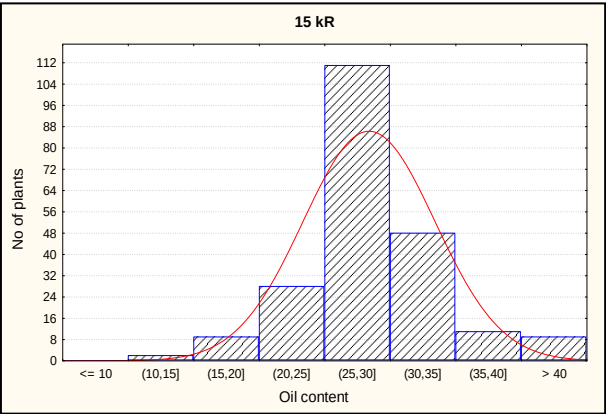


Fig.
18.

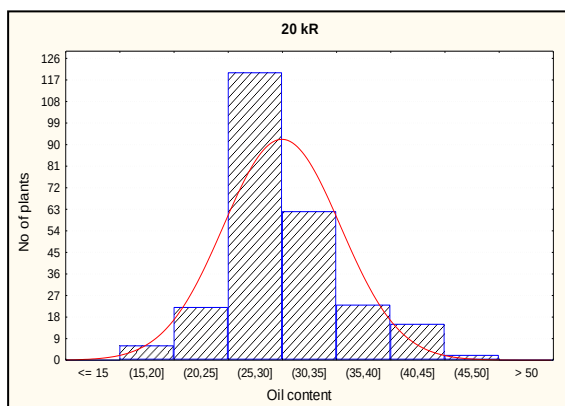


**Fig.
19.**

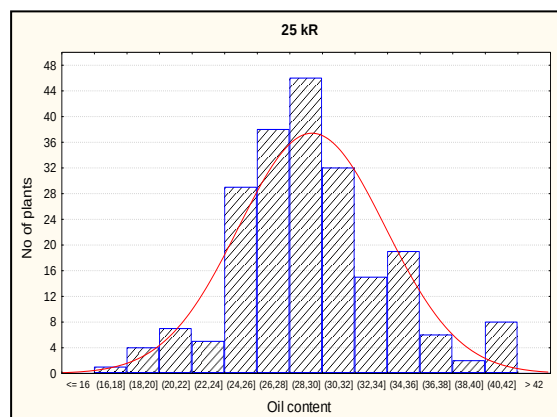


**Fig.
20.**

Fig. 16, 17, 18, 19 & 20. Frequency distribution for oil content in the M2 generation of Morden

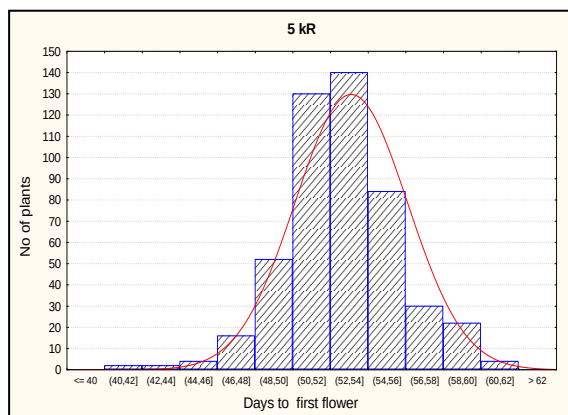


**Fig.
21.**

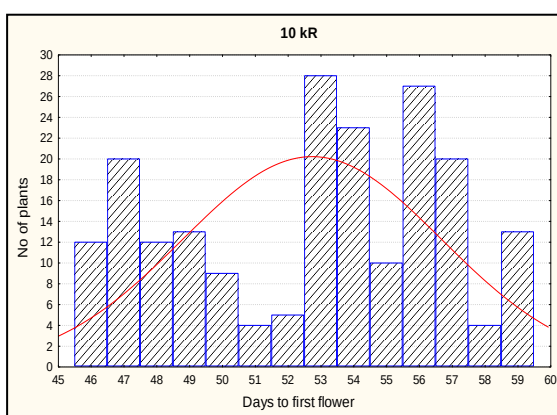
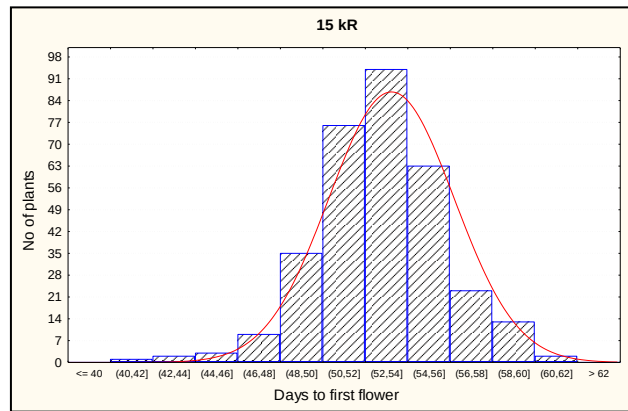


**Fig.
22.**



Fig,
23.

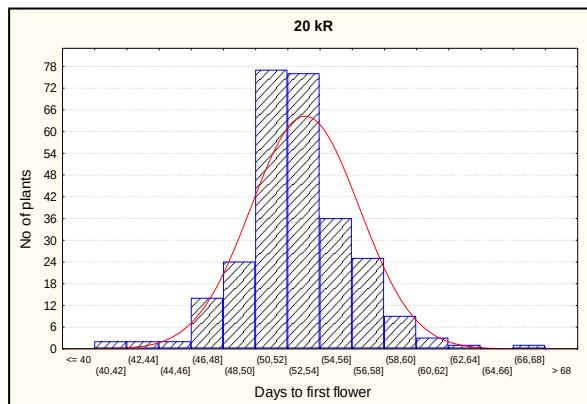


**Fig.
24.**

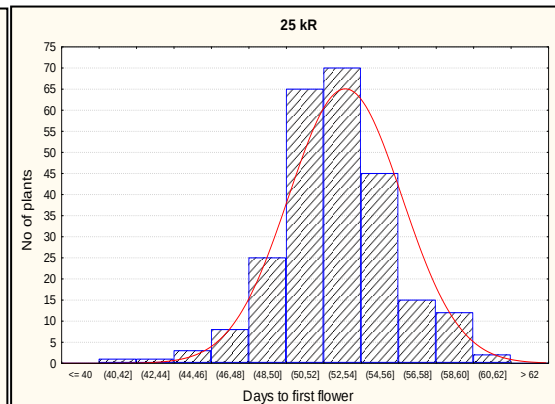


**Fig.
25.**

Fig. 21, 22, 23, 24 & 25. Frequency distribution for days to first flower in the M2 generation

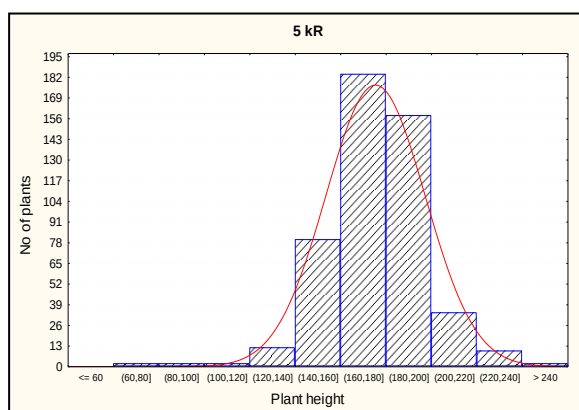


**Fig.
26.**

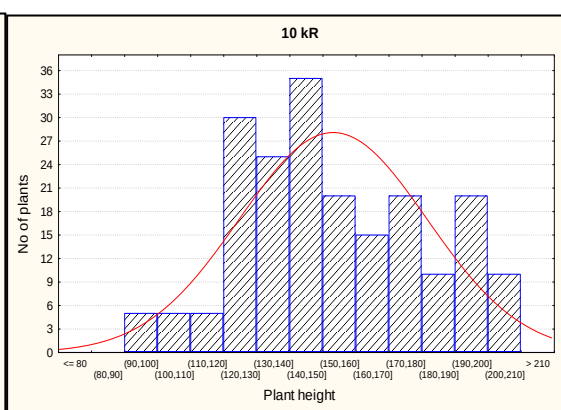


**Fig.
27.**

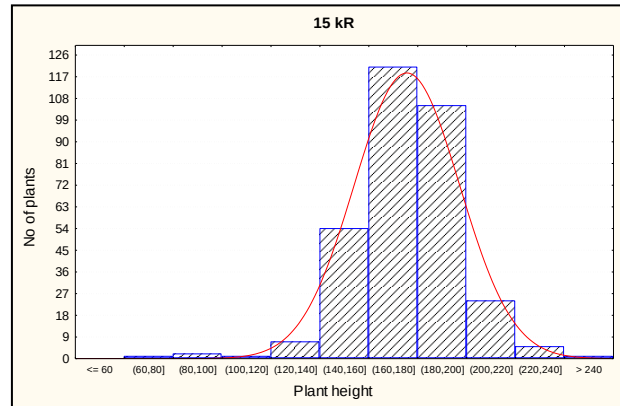


**Fig.
28.**

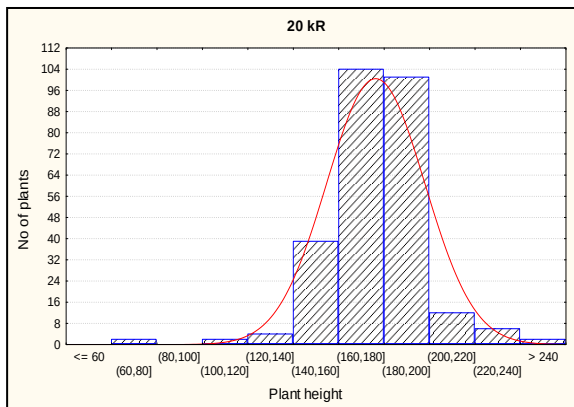


**Fig.
29.**

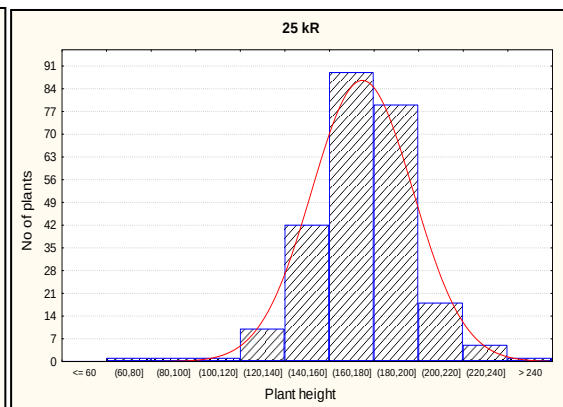


**Fig.
30.**

Fig. 26, 27, 28, 29 & 30. Frequency distribution for plant height in the M2 generation of CO 4

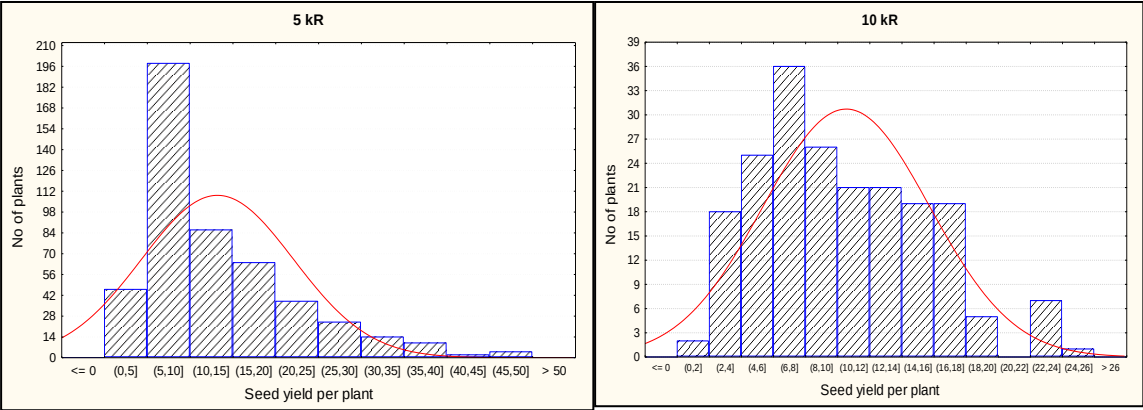


**Fig.
31.**

**Fig.
32.**

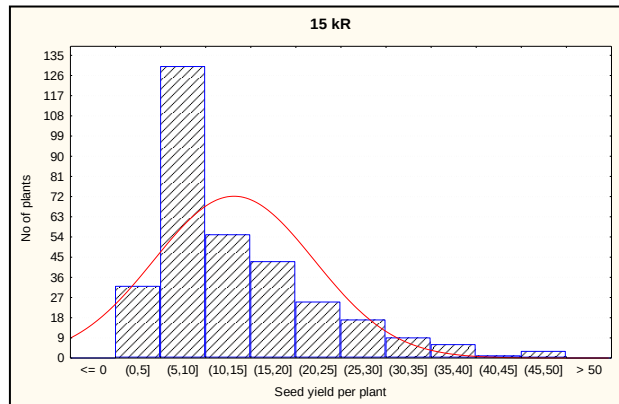


**Fig.
33.**

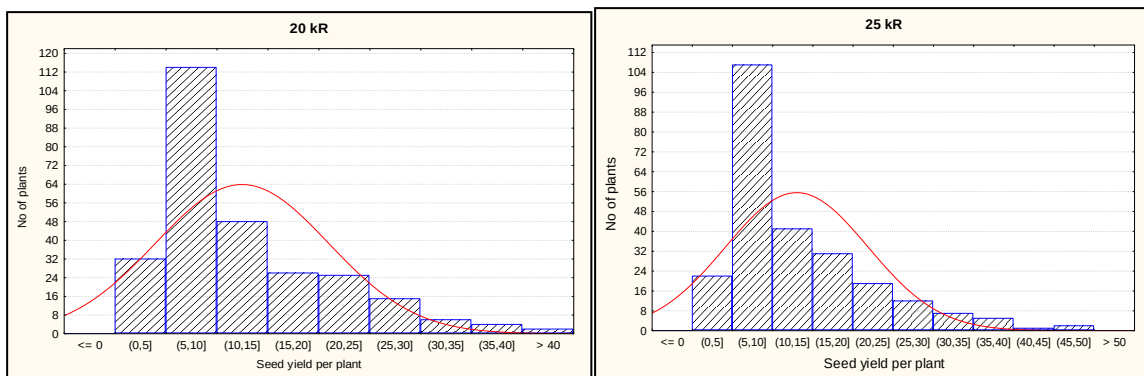


**Fig.
34.**

**Fig.
35.**

Fig. 31, 32, 33, 34 & 35. Frequency distribution for seed yield per plant in the M2 generation of CO
4

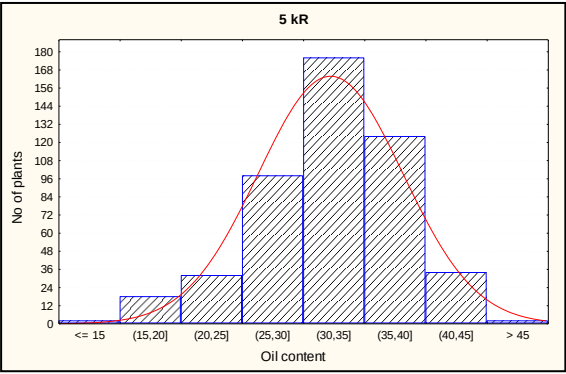


**Fig.
36.**

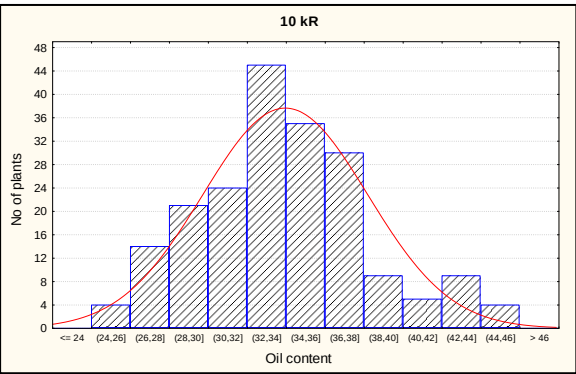


**Fig.
37.**

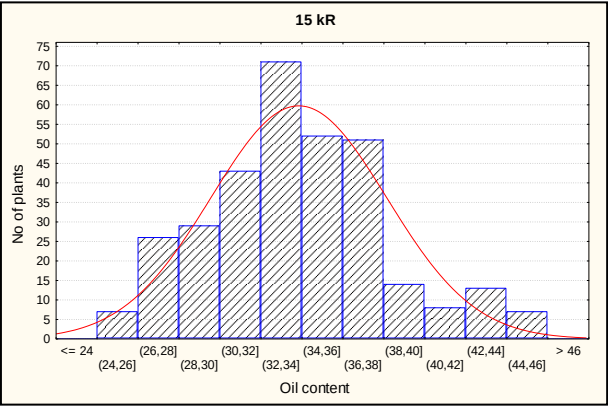


**Fig.
38.**

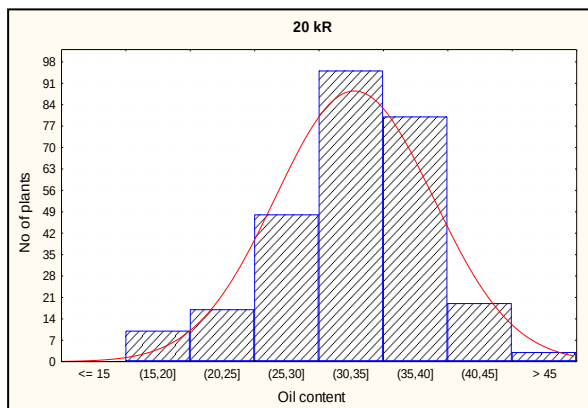


**Fig.
39.**

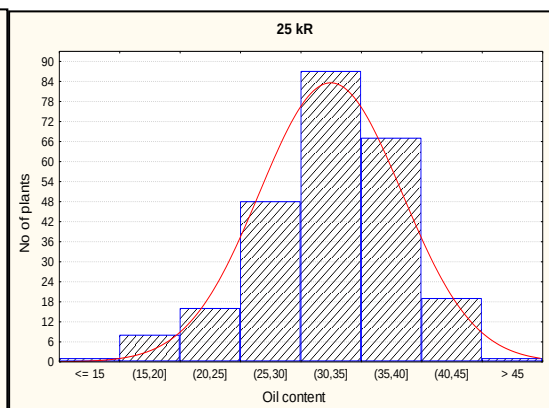


**Fig.
40.**

Fig. 36, 37, 38, 39 & 40. Frequency distribution for oil content in the M2 generation of CO 4.

Table 44. Estimates of genetic correlation coefficient between different traits in M₂, M₃ and M₄ generations of Morden and CO 4 (5KR)

Charac ter	Gener at- ions	MORDEN							CO 4						
		Days to first flowe r	Plant heigh t	Head diam eter	100 seed weig ht	Days to matu rity	Seed yield per plant	Oil cont ent	Days to first flowe r	Plant heigh t	Head diam eter	100 seed weig ht	Days to matu rity	Seed yield per plant	Oil cont ent
Days to first flower	M2	1.000							1.000						
	M3	1.000							1.000						
	M4	1.000							1.000						
Plant height	M2	0.040	1.000						0.252 **	1.000					
	M3	0.012	1.000						0.128	1.000					
	M4	0.203	1.000						0.102	1.000					
Head diamet er	M2	- 0.208 **	0.273 **	1.000					0.175 **	0.456 **	1.000				
	M3	- 0.027	0.043	1.000					0.130	0.108	1.000				
	M4	0.201	- 0.452 **	1.000					0.207 *	0.585 **	1.000				
100 seed weight	M2	- 0.345 **	- 0.116	0.220 **	1.000				0.053	0.150 **	0.345 **	1.000			

	M3	- 0.230	- 0.027	-0.059	1.000				- 0.276 **	0.276 **	0.165	1.000			
	M4	0.024	- 0.126	-0.026	1.000				0.232 *	0.104	0.227 *	1.000			
Days to maturity	M2	- 0.015	0.015	0.015	0.109	1.000			- 0.105 *	- 0.043	0.031	- 0.053	1.000		
	M3	0.855 **	0.012	-0.027	- 0.230	1.000			0.658 **	0.128	0.130	- 0.276	1.000		
	M4	0.965 **	0.203	0.201	0.024	1.000			0.856 **	0.102	0.207 *	0.232 *	1.000		
Seed yield per plant	M2	- 0.079	0.125	0.371 **	0.339 **	-0.072	1.000		0.081	0.069	0.106	0.037	- 0.152 **	1.000	
	M3	- 0.415 **	0.276 **	0.030	- 0.049	- 0.415 **	1.000		- 0.069	0.092	0.193	0.266 *	-0.069	1.000	
	M4	0.281	0.473 **	0.535 **	0.022	0.281	1.000		0.124	0.632 **	0.781 **	0.060	0.124	1.000	
Oil content	M2	- 0.132	- 0.004	0.161	0.333 **	0.061	0.427 **	1.00 0	- 0.037	0.105 *	0.061	0.058	- 0.109 *	0.103	1.000
	M3	0.160	0.246	0.301 **	- 0.324 **	0.160	-0.111	1.00 0	- 0.019	- 0.042	-0.081	- 0.092	-0.019	- 0.036	1.000
	M4	- 0.198	0.151	0.003	- 0.086	-0.198	0.085	1.00 0	- 0.141	0.054	0.071	- 0.012	-0.141	0.117	1.000

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 45. Estimates of genetic correlation coefficient between different traits in M₂, M₃ and M₄ generations of Morden and CO 4 (10KR)

Charac ter	Gener at- ions	MORDEN							CO 4						
		Days to first flowe r	Plant heigh t	Head diam eter	100 seed weig ht	Days to matu rity	Seed yield per plant	Oil cont ent	Days to first flowe r	Plant heigh t	Head diam eter	100 seed weigh t	Days to matu rity	Seed yield per plant	Oil cont ent
Days to first flower	M2	1.000							1.000						
	M3	1.000							1.000						
	M4	1.000							1.000						
Plant height	M2	- 0.060	1.000						0.321 **	1.000					
	M3	- 0.016	1.000						0.366 *	1.000					
	M4	0.261	1.000						0.022	1.000					
Head diamet er	M2	- 0.125	0.299 **	1.000					0.183	0.564 **	1.000				
	M3	0.016	0.282	1.000					0.103	0.178	1.000				
	M4	0.144	0.585 **	1.000					- 0.019	0.321 *	1.000				
100 seed weight	M2	- 0.031	0.104	0.418 **	1.00 0				0.144	0.178	0.434 **	1.000			
	M3	- 0.251	- 0.108	-0.051	1.00 0				- 0.120	0.175	0.268	1.000			
	M4	- 0.251	- 0.108	-0.051	1.00 0				- 0.105	0.122	-0.062	1.000			

Days to maturity	M2	0.122	- 0.201	0.020	- 0.044	1.000			0.013	- 0.209	0.094	0.322 **	1.000		
	M3	0.855 **	- 0.016	0.016	- 0.251	1.000			0.236	- 0.366*	0.103	- 0.120	1.000		
	M4	0.365 *	0.261	0.144	0.324	1.000			0.757 **	0.022	-0.019	- 0.105	1.000		
Seed yield per plant	M2	0.302 **	- 0.026	0.182	0.389 **	0.149	1.000		0.142	0.090	0.228	0.377	- 0.016	1.000	
	M3	- 0.258	0.280	0.481 **	- 0.218	-0.258	1.000		- 0.246	0.314	0.005	0.015	- 0.246	1.000	
	M4	0.134	0.514 **	0.736 **	- 0.140	0.134	1.000		- 0.026	0.661 **	0.333	0.031	- 0.026	1.000	
Oil content	M2	- 0.087	0.306 **	0.282 **	0.181	-0.015	0.266 *	1.000	- 0.052	- 0.001	-0.027	0.265 *	0.100	0.204	1.000
	M3	- 0.383	0.256	0.190	- 0.014	- 0.383 **	-0.045	1.000	- 0.210	0.056	0.214	- 0.041	- 0.210	- 0.199	1.000
	M4	0.006	- 0.074	0.029	- 0.121	0.006	0.042	1.000	0.207	- 0.110	0.092	- 0.132	0.207	- 0.033	1.000

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 46. Estimates of genetic correlation coefficient between different traits in M₂, M₃ and M₄ generations of Morden and CO 4 (15KR)

Charac ter	Gener at- ions	MORDEN							CO 4						
		Days to first flowe r	Plant heigh t	Head diamo ter	100 seed weig ht	Days to matu rity	Seed yield per plant	Oil conte nt	Days to first flowe r	Plant heigh t	Head diamo ter	100 seed weig ht	Days to matu rity	Seed yield per plant	Oil cont ent
Days to first flower	M2	1.000							1.000						
	M3	1.000							1.000						
	M4	1.000							1.000						
Plant height	M2	0.652 **	1.000						0.345 *	1.000					
	M3	0.392 **	1.000						0.083	1.000					
	M4	0.326 *	1.000						0.200	1.000					
Head diamet er	M2	0.247 *	0.576 **	1.000					0.345 *	0.371 **	1.000				
	M3	- 0.046	- 0.063	1.000					- 0.050	0.004	1.000				
	M4	0.197	0.529	1.000					0.253 *	0.597 **	1.000				
100 seed weight	M2	- 0.284 **	- 0.142	0.099	1.000				- 0.042	0.073	0.058	1.000			
	M3	- 0.107	- 0.363 *	-0.188	1.000				0.266	0.030	-0.108	1.000			

	M4	0.393	0.382	0.158	1.000				0.152	- 0.023	0.135	1.000			
Days to maturity	M2	0.160	0.026	0.088	0.048	1.000			0.093	0.025	0.096	0.391 **	1.000		
	M3	0.987 **	0.351 *	0.057	- 0.142	1.000			0.984 **	0.058	-0.067	0.263	1.000		
	M4	0.912 **	0.292	0.125	0.393 **	1.000			0.966 **	0.200	0.253 *	0.152	1.000		
Seed yield per plant	M2	0.016	0.027	0.132	0.321 **	-0.167	1.000		- 0.248	0.180	0.288	0.095	-0.156	1.000	
	M3	- 0.320	- 0.140	0.136	0.098	-0.323	1.000		- 0.104	0.047	0.308	- 0.064	-0.099	1.000	
	M4	0.076	0.449 **	0.701 **	0.171	0.100	1.000		0.201	0.516 **	0.790 **	0.239 *	0.201	1.000	
Oil content	M2	0.073	0.163	0.122	0.067	-0.163	0.212 *	1.000	0.346 *	0.195	0.185	- 0.203	0.139	0.125	1.000
	M3	- 0.162	0.144	0.029	- 0.285	-0.126	- 0.236	1.000	- 0.265	- 0.002	0.192	- 0.43* *	-0.232	- 0.079	1.000
	M4	- 0.218	- 0.031	-0.143	- 0.141	-0.051	0.117	1.000	- 0.488 **	- 0.334 **	-0.122	0.209	- 0.488 **	- 0.032	1.000

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 47. Estimates of genetic correlation coefficient between different traits in M₂, M₃ and M₄ generations of Morden and CO 4 (20KR)

Charac ter	Gener at- ions	MORDEN							CO 4						
		Days to first flowe r	Plant heigh t	Head diam eter	100 seed weig ht	Days to matur ity	Seed yield per plant	Oil conte nt	Days to first flowe r	Plant heigh t	Head diam eter	100 seed weig ht	Days to matu rity	Seed yield per plant	Oil conte nt
Days to first flower	M2	1.000							1.000						
	M3	1.000							1.000						
	M4	1.000							1.000						
Plant height	M2	0.479 **	1.000						0.110	1.000					
	M3	- 0.043	1.000						0.146	1.000					
	M4	0.298 **	1.000						- 0.004	1.000					
Head diamet er	M2	- 0.237	0.211	1.000					0.129	0.642 **	1.000				
	M3	- 0.054	0.098	1.000					- 0.047	0.405 *	1.000				
	M4	0.226	0.543 **	1.000					- 0.198	0.162	1.000				
100 seed weight	M2	- 0.462 **	- 0.116	0.494 **	1.000				- 0.052	0.090	0.316 **	1.000			
	M3	0.152	- 0.081	0.230	1.000				0.006	- 0.097	0.032	1.000			

	M4	0.092	0.019	-0.145	1.000				- 0.275	- 0.054	- 0.269 *	1.000			
Days to maturity	M2	0.209	0.029	0.038	- 0.019	1.000			- 0.007	0.100	0.077	0.109	1.000		
	M3	0.865 **	- 0.043	-0.054	0.152	1.000			0.966 **	0.146	-0.047	0.006	1.000		
	M4	0.999 **	0.296 *	0.224	0.081	1.000			0.992 **	0.002	-0.201	0.292	1.000		
Seed yield per plant	M2	0.078	0.605 **	0.227	0.071	0.270	1.000		0.250 *	0.279 *	0.308 **	0.115	- 0.142	1.000	
	M3	- 0.239	- 0.181	0.638 **	0.185	-0.239	1.000		- 0.066	0.128	0.336	0.389 *	- 0.066	1.000	
	M4	0.268	0.255	0.308 *	- 0.163	0.295 *	1.000		0.167	0.183	0.633 **	0.026	0.176	1.000	
Oil content	M2	0.223	0.265	0.113	0.049	0.230	0.492 **	1.000	0.235	0.041	0.128	- 0.043	- 0.031	0.013	1.000
	M3	0.178	0.178	-0.222	- 0.246	0.178	- 0.314	1.000	0.215	0.376	0.165	- 0.054	0.215	- 0.030	1.000
	M4	- 0.026	0.172	-0.031	- 0.153	-0.021	0.241	1.000	0.059	- 0.116	-0.011	- 0.043	0.030	0.040	1.000

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 48. Estimates of genetic correlation coefficient between different traits in M₂, M₃ and M₄ generations of Morden and CO 4 (25KR)

Charac ter	Gener at- ions	MORDEN							CO 4						
		Days to first flowe r	Plant heigh t	Head diam eter	100 seed weig ht	Days to matur ity	Seed yield per plant	Oil conte nt	Days to first flowe r	Plant heigh t	Head diam eter	100 seed weig ht	Days to matu rity	Seed yield per plant	Oil conte nt
Days to first flower	M2	1.000							1.000						
	M3	1.000							1.000						
	M4	1.000							1.000						
Plant height	M2	0.561 **	1.000						0.110	1.000					
	M3	- 0.529 **	1.000						- 0.078	1.000					
	M4	- 0.329	1.000						0.372	1.000					
Head diamet er	M2	- 0.305	- 0.158	1.000					0.129	0.642 **	1.000				
	M3	- 0.234	0.523	1.000					- 0.047	0.503 **	1.000				
	M4	0.249	0.583 *	1.000					0.074	0.341	1.000				
100 seed weight	M2	- 0.214	0.097	0.399 *	1.000				- 0.052	0.090	0.316	1.000			
	M3	0.336	- 0.249	-0.019	1.000				- 0.532 **	0.271	0.274	1.000			

	M4	- 0.069	0.213	-0.008	1.000				0.288	0.113	-0.099	1.000			
Days to maturity	M2	0.296	- 0.016	0.155	0.024	1.000			- 0.007	0.100	0.077	0.109	1.000		
	M3	0.855 **	- 0.529 **	-0.234	0.336	1.000			0.882 **	0.000	0.121	- 0.357	1.000		
	M4	0.755 **	- 0.329	0.249	- 0.069	1.000			0.856 **	0.372	0.074	0.288	1.000		
Seed yield per plant	M2	- 0.239	0.021	0.500 **	0.731 **	0.197	1.000		0.250	0.279	0.308	0.115	- 0.142	1.000	
	M3	0.052	- 0.293	0.189	0.238	0.052	1.000		- 0.204	- 0.048	0.061	0.272	- 0.376	1.000	
	M4	0.491	- 0.352	-0.176	- 0.509 *	0.491	1.000		0.291	0.755 **	0.117	- 0.093	0.291	1.000	
Oil content	M2	- 0.244	- 0.317	- 0.355 *	- 0.106	-0.154	0.115	1.000	0.235	0.041	0.128	- 0.043	- 0.031	0.013	1.000
	M3	- 0.091	0.365	-0.110	- 0.009	-0.091	- 0.476 *	1.000	0.039	- 0.018	0.278	0.281	0.166	0.004	1.000
	M4	0.597 *	- 0.653 **	-0.232	0.198	0.597 *	0.212	1.000	0.057	0.086	0.102	- 0.037	0.057	0.177	1.000

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 1. Mean value for germination, shoot length, root length and dry matter production in roll towel method.

Varieties	Doses of gamma rays	Germination (%)		Shoot length (cm)		Root length (cm)		Dry matter production (g)	
		Mean	Percentage over control	Mean	Percentage over control	Mean	Percentage over control	Mean	Percentage over control
MORDEN	Control	96.67	100.00	16.73	100.00	15.15	100.00	45.78	100.00
	5 kR	84.00	86.90	16.58	99.10	12.56	82.90	46.65	101.90
	10 kR	73.33	75.86	15.46	92.41	8.35	55.12	35.64	77.85
	15 kR	54.67	56.55	10.56	63.12	6.55	43.23	31.25	68.26
	20 kR	36.67	37.93	10.64	63.60	7.54	49.77	24.56	53.65
	25 kR	21.33	22.07	6.53	39.03	5.68	37.49	20.66	45.13
	30 kR	13.33	13.79	7.56	45.19	5.64	37.23	19.56	42.73
	35 kR	15.33	15.86	5.46	32.64	4.36	28.78	20.45	44.67
	40 kR	10.67	11.03	5.32	31.80	3.26	21.52	18.65	40.74
	45 kR	10.67	11.03	6.87	41.06	2.54	16.77	16.54	36.13
	50 kR	4.00	4.14	6.54	39.09	3.25	21.45	10.56	23.07
CO 4	Control	97.33	100.00	20.16	100.00	15.32	100.00	46.87	100.00
	5 kR	88.00	90.41	16.54	82.04	13.5	88.12	42.15	89.93
	10 kR	96.67	99.32	15.46	76.69	14.56	95.04	43.56	92.94
	15 kR	56.67	58.22	13.3	65.97	10.7	69.84	34.56	73.74
	20 kR	36.67	37.67	13.25	65.72	9.35	61.03	26.58	56.71
	25 kR	26.00	26.71	8.56	42.46	5.68	37.08	18.54	39.56
	30 kR	37.33	38.36	7.56	37.50	4.56	29.77	19.56	41.73
	35 kR	24.00	24.66	8.56	42.46	5.21	34.01	18.54	39.56
	40 kR	10.00	10.27	5.64	27.98	2.36	15.40	17.63	37.61
	45 kR	14.00	14.38	4.25	21.08	5.36	34.99	20.56	43.87
	50 kR	10.67	10.96	5.23	25.94	2.35	15.34	15.64	33.37

Table 2. Effect of gamma rays on germination and survival in M₁ generation (Angular transformed values within brackets).

Varieties	Treatments	Germination percentage		Survival percentage	
		Mean (%)	Percentage over control	Mean (%)	Percentage over control
MORDEN	Control	90.50 (76.47)	100.00	91.00 (74.56)	100.00
	5kR	75.00 (64.23)	82.87	72.50 (62.58)	79.67
	10kR	66.00 (54.48)	72.93	63.00 (52.48)	69.23
	15kR	55.00 (46.64)	60.77	51.50 (43.59)	56.59
	20kR	41.00 (35.42)	45.30	37.50 (31.54)	41.21
	25kR	25.00 (20.46)	27.62	21.50 (17.56)	23.63
CO 4	Control	95.00 (79.65)	100.00	95.00 (78.56)	100.00
	5kR	87.50 (78.14)	92.11	85.00 (75.48)	89.47
	10kR	71.00 (65.40)	74.74	64.50 (63.48)	67.89
	15kR	57.50 (48.25)	60.53	52.50 (46.87)	55.26
	20kR	43.50 (38.64)	45.79	41.00 (36.64)	43.16
	25kR	37.00 (30.10)	38.95	33.50 (28.67)	35.26
	SE_d	6.551		6.83	
	CD	13.10		13.66	

Table 3. Effect of gamma rays in days to first flower, plant height, head diameter and 100 seed weight in M₁ generation (Angular transformed values within brackets)

Varieties	Treatments	Days to first flower		Plant height		Head diameter		100 seed weight	
		Mean (%)	Percentage over control	Mean (cm)	Percentage over control	Mean (cm)	Percentage over control	Mean (g)	Percentage over control
MORDEN	Control	53.03 (48.56)	100.00	69.63	100.00	8.48	100.00	3.73	100.00
	5kR	51.94 (48.56)	97.95	61.66	88.56	8.20	96.68	3.92	105.24
	10kR	52.31 (50.16)	98.65	56.73	81.48	8.29	97.77	4.10	109.91
	15kR	53.03 (50.16)	100.01	58.04	83.35	8.90	104.94	3.29	88.22
	20kR	52.73 (49.86)	99.44	57.96	83.24	8.39	98.88	3.60	96.42
	25kR	52.96 (51.46)	99.89	47.36	68.01	6.94	81.82	3.58	96.06
CO 4	Control	57.08 (53.46)	100.00	118.89	100.00	14.75	100.00	4.60	100.00
	5kR	56.90 (53.87)	99.69	115.39	97.05	11.05	74.91	4.65	101.06

	10kR	57.12 (54.68)	100.08	104.88	88.21	11.91	80.73	4.69	102.11
	15kR	56.31 (53.46)	98.65	99.32	83.54	9.70	65.77	4.35	94.72
	20kR	56.83 (53.21)	99.56	95.49	80.32	10.07	68.30	3.75	81.62
	25kR	56.53(54.21)	99.04	76.32	64.20	7.53	51.03	4.07	88.48
	SE_d	0.74		9.39		1.70		0.44	
	CD	1.63		20.67		3.76		0.98	

Table 4. Effect of gamma rays in days to maturity, seed yield per plant and oil content in M₁ generation (Angular transformed values within brackets)

Varieties	Treatments	Days to maturity		Seed yield per plant		Oil content	
		Mean (%)	Percentage over control	Mean (g)	Percentage over control	Mean (%)	Percentage over control
MORDEN	Control	83.03 (82.41)	100.00	7.15	100.00	30.93 (27.65)	100.00
	5kR	81.94 (78.56)	98.69	6.58	92.11	28.57 (26.53)	92.36
	10kR	82.31 (79.64)	99.14	6.63	92.76	30.17 (28.46)	97.53
	15kR	83.03 (81.54)	100.00	8.38	117.22	29.99 (26.84)	96.96
	20kR	82.73 (80.46)	99.64	6.71	93.96	32.15 (30.46)	103.92

	25kR	82.67 (81.54)	99.57	6.01	84.12	25.88 (23.46)	83.65
CO 4	Control	87.08 (84.62)	100.00	11.57	100.00	31.77 (28.45)	100.00
	5kR	86.90 (83.65)	99.79	14.35	124.02	32.32 (30.45)	101.72
	10kR	87.12 (85.10)	100.05	11.02	95.21	30.62 (28.61)	96.38
	15kR	86.31 (84.59)	99.12	10.94	94.58	31.07 (28.42)	97.78
	20kR	86.83 (86.32)	99.71	14.12	122.00	29.42 (26.87)	92.59
	25kR	86.53 (86.37)	99.37	16.02	138.48	35.02 (33.45)	110.21
	SE_d	0.74		1.51		2.28	
	CD	1.63		3.33		5.03	

Table 5. Frequency and spectrum of chlorophyll mutations in M₂ generation

Varieties	Gamma doses	No. of M ₂ plants studied	No. of chlorophyll mutations	Per cent of M ₂ plants mutated	Spectrum of chlorophyll mutations			
					<i>Albina</i>	<i>Xantha</i>	<i>Viridis</i>	<i>Striata</i>
MORDEN	5 kR	509	5	0.98	2	2	1	-
	10 kR	517	8	1.55	4	3	1	-
	15 kR	520	6	1.15	3	3	-	--
	20 kR	418	9	2.15	3	4	2	-
	25 kR	321	8	2.49	3	2	3	-
CO 4	5 kR	518	4	0.77	1	2	1	-
	10 kR	517	5	0.97	2	1	2	-
	15 kR	526	4	0.76	2	1	1	-
	20 kR	432	6	1.39	3	1	2	-
	25 kR	418	9	2.15	4	3	1	-

Table 6. Frequency and spectrum of viable mutations in M₂ generation

Varieties	Gamma doses	No. of M ₂ plants studied	No. of chlorophyll mutations	Per cent of M ₂ plants mutated	Spectrum of viable mutations				
					Plant height type	Growth habit	Leaf modifications	Seed colour	Sterile plants
MORDEN	5 kR	496	5	1.00	1	-	2	-	2
	10 kR	487	9	1.85	3	1	1	2	3
	15 kR	484	7	1.45	2	-	3	1	1
	20 kR	408	6	1.47	2	-	3	-	1
	25 kR	313	9	2.88	3	1	4	1	-
CO 4	5 kR	491	7	1.43	2	2	3	1	-
	10 kR	484	6	1.24	2	-	2	1	1
	15 kR	473	8	1.69	3	-	1	1	3
	20 kR	415	10	2.41	3	2	3	1	1
	25 kR	402	10	2.49	3	1	3	1	2

Table 7. Mutagenic effectiveness and efficiency of gamma radiation based on chlorophyll mutations in M₂ generations

Varieties	Gamma dose	Lethality (%)	Chlorophyll mutation			Viable mutation		
			Mutation rate (%)	Mutation effectiveness (%)	Mutation efficiency (%)	Mutation rate (%)	Mutation frequency (%)	Mutation efficiency (%)
MORDEN	5 kR	10.77	0.98	19.6	9.10	1.00	20.0	9.28
	10 kR	13.58	1.55	15.5	11.41	1.85	18.5	13.62
	15 kR	8.00	1.15	7.67	14.37	1.45	9.67	18.12
	20 kR	6.25	2.15	10.75	34.40	1.47	7.35	23.52
	25 kR	6.25	2.49	9.96	39.84	2.88	11.52	46.08
CO 4	5 kR	10.31	0.77	15.4	7.47	1.43	28.6	13.87
	10 kR	18.69	0.97	9.70	5.19	1.24	12.4	6.63
	15 kR	15.00	0.76	5.07	5.07	1.69	11.27	11.27
	20 kR	15.89	1.39	6.98	8.75	2.41	12.05	15.17
	25 kR	5.26	2.15	8.6	40.64	2.49	9.96	47.33

Table 8. Mean, components of variance and measures of dispersion for days to first flower in M₂ generation

Treatments	Mean (days)	Percentage over control	PV	GV	PCV (%)	GCV (%)	h²(%)	GA	GA as percentage of mean	Range	Skewness	Kurtosis
Morden												
5kR	50.43	96.76	12.53	5.62	7.02	4.70	44.81	3.27	6.48	14.00	-0.39	-0.18
10kR	51.54	98.89	10.21	3.30	6.20	3.52	32.29	0.09	0.18	13.00	1.17**	0.96
15kR	51.07	97.99	15.03	8.11	7.59	5.58	53.99	7.95	15.56	21.00	0.15	1.40**
20kR	54.34	104.26	15.88	8.96	7.33	5.51	56.45	8.57	15.78	9.00	0.76*	0.13
25kR	51.14	98.12	10.73	3.81	6.40	3.82	35.55	5.24	10.24	15.00	0.38	1.05
Control	52.12	100.00	6.92									
CO 4												
5kR	53.10	98.49	13.57	4.60	6.94	4.04	33.93	2.57	4.85	20.00	-0.09	1.16**
10kR	53.23	98.72	14.23	5.27	7.09	4.31	37.00	2.88	5.40	13.00	-0.41	-0.79
15kR	53.18	98.63	12.67	3.71	6.69	3.62	29.25	2.14	4.03	14.00	-0.85*	0.50
20kR	54.02	100.20	16.60	7.63	7.54	5.11	45.99	3.86	7.15	19.00	0.89**	1.20*
25kR	53.43	99.10	15.65	6.68	7.40	4.84	42.71	3.48	6.51	13.00	-0.50	0.80
Control	53.92	100.00	8.96									

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 9. Mean, components of variance and measures of dispersion for plant height in M₂ generation

Treatments	Mean (cm)	Percentage over control	PV	GV	PCV (%)	GCV (%)	h ² (%)	GA	GA as percentage of mean	Range	Skewness	Kurtosis
Morden												
5kR	102.31	92.87	531.08	149.15	22.52	11.94	28.08	13.33	13.03	104.50	0.49*	-0.19
10kR	98.40	89.31	450.23	68.31	21.56	8.40	15.17	0.03	0.03	89.80	0.19	2.05**
15kR	110.67	100.45	878.47	496.55	26.78	20.13	56.52	12.25	11.07	165.50	1.34**	3.41**
20kR	142.29	129.16	502.36	120.44	15.75	7.71	23.97	5.89	4.14	79.40	0.71*	-0.41
25kR	116.77	105.99	716.79	334.87	22.93	15.67	46.72	10.40	8.91	92.20	1.04**	0.25
Control	110.17	100.00	381.92									
CO 4												
5kR	175.30	94.23	479.93	137.63	12.50	6.69	28.68	12.94	7.38	172.80	-0.68**	2.85**
10kR	153.10	82.30	823.23	480.93	18.74	14.32	58.42	34.53	22.55	114.60	0.10	-0.65
15kR	177.46	95.40	540.83	198.53	13.10	7.94	36.71	17.59	9.91	76.00	0.25	-1.08
20kR	172.92	92.95	495.71	153.41	12.88	7.16	30.95	14.19	8.21	92.80	0.21	0.04
25kR	163.34	87.80	771.41	429.11	17.00	12.68	55.63	31.83	19.49	81.50	0.01	-1.30
Control	186.03	100.00	342.30									

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 10. Mean, components of variance and measures of dispersion for head diameter in M₂ generation

Treatments	Mean (cm)	Percentage over control	PV	GV	PCV (%)	GCV (%)	h²(%)	GA	GA as percent age of mean	Range	Skewness	Kurtosis
Morden												
5kR	9.65	105.88	10.44	5.11	33.49	23.43	48.94	3.26	33.77	13.90	1.13**	1.17**
10kR	9.93	109.00	10.44	5.11	32.54	21.76	48.94	0.32	3.22	12.10	0.12	-1.02
15kR	10.35	113.58	11.32	5.99	32.51	25.74	52.89	3.50	34.23	17.70	0.93**	1.34**
20kR	8.86	97.19	9.66	4.33	35.09	22.76	44.80	2.75	31.01	9.20	0.43	0.33
25kR	8.89	97.57	10.57	5.24	36.57	25.74	49.55	3.04	33.23	7.70	1.11**	0.80
Control	9.11	100.00	5.33									
CO 4												
5kR	10.58	95.94	10.57	4.69	30.74	24.47	44.36	2.97	28.09	13.90	0.51**	0.20
10kR	9.32	84.50	8.97	3.09	32.15	18.86	34.42	2.12	22.79	9.70	0.03	-0.67
15kR	8.60	78.01	7.47	1.59	31.78	14.65	21.26	1.20	13.92	14.30	0.01	1.71*
20kR	8.80	79.83	8.65	2.77	33.42	18.91	32.02	1.94	22.04	6.40	0.25	-0.64
25kR	9.34	84.75	10.55	4.67	34.76	23.12	44.25	2.96	31.68	8.00	0.54	-0.86
Control	11.02	100.00	5.88									

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 11. Mean, components of variance and measures of dispersion for 100 seed weight in M₂ generation

Treatments	Mean (g)	Percentage over control	PV	GV	PCV (%)	GCV (%)	h ² (%)	GA	GA as percentage of mean	Range	Skewness	Kurtosis
Morden												
5kR	3.78	117.88	2.87	2.02	44.86	37.62	70.31	2.45	64.97	7.68	0.85**	0.66
10kR	4.36	136.19	2.29	1.44	34.70	27.51	62.83	0.62	14.21	5.36	0.09	-1.24*
15kR	3.98	124.23	1.90	1.05	34.69	25.79	55.29	2.27	57.10	6.91	0.42	0.37
20kR	3.68	114.97	2.29	1.44	41.14	32.63	62.88	2.49	67.51	5.09	0.96**	0.00
25kR	3.77	117.57	2.34	1.49	40.62	32.40	63.60	2.54	67.52	6.33	1.21**	2.35**
Control	3.20	100.00	0.85									
CO 4												
5kR	4.78	102.86	1.99	0.61	29.57	16.39	30.72	0.89	18.71	7.23	0.27*	-0.25
10kR	4.40	94.84	1.91	0.53	31.41	16.56	27.78	0.79	17.98	5.49	-0.03	-0.67
15kR	4.46	96.11	2.62	1.24	36.25	24.91	47.22	1.57	35.27	6.42	0.90**	0.33
20kR	4.48	96.45	2.03	0.65	31.85	18.04	32.08	0.94	21.05	5.34	0.28	-0.74
25kR	4.87	104.84	3.56	2.18	38.78	30.35	61.24	2.38	48.92	4.15	0.05	-1.19
Control	4.64	100.00	1.38									

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 12. Mean, components of variance and measures of dispersion for days to maturity in M₂ generation

Treatment s	Mean (days)	Percentag e over control	PV	GV	PCV (%)	GCV (%)	h²(%)	GA	GA as percentag e of mean	Range	Skewnes s	Kurtosi s
Morden												
5kR	82.74	101.27	10.25	3.13	3.87	2.14	30.51	2.01	2.43	14.00	0.32**	0.05
10kR	81.44	99.67	15.23	8.11	4.79	3.50	53.23	7.12	8.15	10.00	-0.05	-0.49
15kR	82.75	101.27	9.05	1.93	3.64	1.68	21.33	4.00	4.83	14.00	0.36	0.29
20kR	82.09	100.47	10.57	3.44	3.96	2.26	32.60	6.08	7.41	9.00	0.25	-1.00
25kR	82.33	100.77	8.93	1.81	3.63	1.63	20.26	3.79	4.60	11.00	0.38	-0.26
Control	81.71	100.00	7.12									
CO 4												
5kR	86.90	99.46	8.97	4.50	3.45	2.44	50.09	3.09	3.56	12.00	-0.10	-0.13
10kR	86.80	99.34	8.97	4.49	3.45	2.44	50.05	3.09	3.56	8.00	-0.02	-0.47
15kR	87.57	100.23	7.87	3.39	3.20	2.10	43.08	2.49	2.84	8.00	0.24	-0.64
20kR	86.76	99.30	7.65	3.17	3.19	2.05	41.42	2.36	2.72	9.00	0.14	-0.15
25kR	87.43	100.06	7.34	2.86	3.10	1.93	38.98	2.18	2.49	9.00	0.09	-0.91
Control	87.37	100.00	4.47									

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 13. Mean, components of variance and measures of dispersion for seed yield per plant in M₂ generation

Treatments	Mean (g)	Percentage over control	PV	GV	PCV (%)	GCV (%)	h ² (%)	GA	GA as percentage of mean	Range	Skewness	Kurtosis
Morden												
5kR	6.26	110.16	40.89	10.74	77.19	30.56	26.26	1.01	12.27	25.61	2.37**	6.21**
10kR	8.28	145.78	45.69	15.54	54.70	31.90	34.01	2.46	19.93	32.53	2.23**	5.11**
15kR	12.36	217.45	45.69	15.54	54.70	31.90	34.01	2.46	19.93	19.37	2.23**	5.11**
20kR	10.55	185.67	57.12	26.97	71.64	49.22	47.21	3.16	29.94	30.77	1.33**	1.32*
25kR	5.64	99.32	40.99	10.84	113.44	58.33	26.44	1.29	22.93	12.02	1.72**	2.85**
Control	5.68	100.00	30.15									
CO 4												
5kR	13.19	105.71	78.89	48.34	67.31	52.69	61.28	5.21	48.98	45.11	1.42**	1.87**
10kR	8.15	65.28	35.65	5.10	73.27	27.72	14.31	1.76	21.60	23.39	1.71**	2.51**
15kR	7.40	59.29	36.55	6.00	81.68	33.10	16.42	2.05	27.63	22.64	2.44**	7.71**
20kR	8.97	71.88	37.38	6.83	68.14	29.14	18.28	2.30	25.66	26.24	1.54**	2.07**
25kR	7.44	59.63	36.55	6.00	81.22	32.91	16.42	2.05	27.48	21.72	3.37**	12.02**
Control	12.48	100.00	30.51									

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 14. Mean, components of variance and measures of dispersion for oil content in M₂ generation

Treatments	Mean (%)	Percentage over control	PV	GV	PCV (%)	GCV (%)	h ² (%)	GA	GA as percentage of mean	Range	Skewness	Kurtosis
Morden												
5kR	29.78	103.98	33.58	8.30	19.46	9.67	24.71	2.95	9.90	24.45	0.27	-0.09
10kR	30.13	105.18	47.29	22.01	22.83	15.57	46.54	3.17	9.58	32.55	-0.34	0.64
15kR	28.96	101.11	32.85	7.57	19.79	9.50	23.04	2.55	8.82	28.25	-0.41	1.40**
20kR	34.16	119.25	68.72	43.44	24.27	19.30	63.21	7.61	22.28	31.28	-0.20	-0.88
25kR	25.56	89.24	45.79	20.51	26.47	17.72	44.79	4.66	18.25	22.75	-1.09**	0.15
Control	28.64	100.00	25.38									
CO 4												
5kR	32.21	102.00	35.08	9.58	18.39	9.61	27.30	3.33	10.34	31.64	-0.59**	0.23
10kR	32.69	103.54	51.80	26.30	22.01	15.69	50.77	7.53	23.02	42.17	-1.83**	6.72**
15kR	32.02	101.39	26.84	1.34	16.18	3.61	4.98	0.53	1.66	19.64	0.02	-0.79
20kR	33.94	107.49	35.65	10.15	17.59	9.38	28.46	3.50	10.31	20.85	-0.05	-0.12
25kR	35.90	113.70	40.25	14.74	17.67	10.69	36.63	4.79	13.33	18.13	0.07	1.10
Control	31.58	100.00	25.50									

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 17 . Analysis of variance for different characters in M₃ generation of Morden (5 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	37	18.85**	1438.87**	12.01**	1.98**	18.85**	63.32*	25.08
Checks	1	198.84**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	35	11.77**	883.92**	12.16**	1.80**	11.77**	17.01	25.37
Checks Vs Tests	1	86.75**	9116.88**	9.06**	9.74**	86.75**	1746.27**	6.06
Error	22	1.08	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 18 . Analysis of variance for different characters in M₃ generation of Morden (10 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	27	14.22**	1207.72**	3.96**	2.19**	12.80**	89.68**	34.27*
Checks	1	198.84**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	25	5.33**	397.82**	3.24**	1.92**	5.33*	19.97	30.70
Checks Vs Tests	1	51.87**	9478.81**	15.93**	10.79**	13.46**	1920.91**	123.71*
Error	22	1.08	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 19. Analysis of variance for different characters in M₃ generation of Morden (15 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	26	16.96**	912.59**	4.39**	2.24**	17.84**	72.52*	28.49
Checks	1	198.84**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	24	9.63**	289.34**	3.35**	2.19**	9.81**	13.47	26.51
Checks Vs Tests	1	11.22**	3599.27**	23.80**	5.27**	29.69**	1561.32**	70.71*
Error	22	1.08	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 20. Analysis of variance for different characters in M₃ generation of Morden (20 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	26	11.02**	857.48**	5.57**	1.99**	11.03**	75.44**	15.27
Checks	1	198.83**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	24	2.69*	322.91**	3.95**	2.15**	2.70*	34.26	13.49
Checks Vs Tests	1	23.15**	1360.38**	40.22**	0.01	23.16**	1138.18**	39.31
Error	22	1.07	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 21. Analysis of variance for different characters in M₃ generation of Morden (25 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	15	18.65**	1110.05**	5.33**	2.14**	18.66**	84.85**	15.77
Checks	1	198.83**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	13	6.23**	252.21**	2.08*	2.34**	6.23**	15.52	8.37
Checks Vs Tests	1	0.01	188.03*	43.08**	1.34	0.00	1069.85**	93.78*
Error	22	1.07	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 22. Analysis of variance for different characters in M₃ generation of CO 4 (5 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	52	14.37**	949.80**	18.70**	0.77*	14.37**	44.84	12.10
Checks	1	198.84**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	50	6.94**	254.37**	19.25**	0.12	6.94**	30.50	11.90
Checks Vs Tests	1	201.32**	537.85**	0.31	33.39**	201.32**	805.49**	0.66
Error	22	1.08	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 23. Analysis of variance for different characters in M₃ generation of CO 4 (10 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	26	13.27**	859.09**	34.34**	0.73*	15.47**	72.38*	17.16
Checks	1	198.83**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	24	4.38**	375.17**	36.77**	0.77*	4.39**	53.27	17.11
Checks Vs Tests	1	41.05**	148.13*	0.54	0.02	98.15**	602.32**	1.71
Error	22	1.08	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 24. Analysis of variance for different characters in M₃ generation of CO 4 (15 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	19	22.69**	949.80**	4.23**	0.68	23.37**	76.05*	24.74
Checks	1	198.83**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	17	7.27**	254.37**	2.83**	0.73	6.15**	39.23	25.66
Checks Vs Tests	1	108.86**	537.85**	22.51**	0.03	140.64**	776.94**	0.00
Error	22	1.08	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 25. Analysis of variance for different characters in M₃ generation of CO 4 (20 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	34	15.23**	722.41**	8.28**	0.75*	15.22**	56.62*	8.61
Checks	1	198.83**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	32	2.16*	322.91**	8.12**	0.77*	2.16*	22.63	7.98
Checks Vs Tests	1	249.38**	1044.57**	11.88**	0.63	249.38**	1199.84**	3.70
Error	22	1.08	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 26. Analysis of variance for different characters in M₃ generation of CO 4 (25 kR)

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content (%)
Entries	18	22.73**	886.26**	4.75**	1.44**	23.38**	53.05	20.76
Checks	1	198.83**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	16	2.32*	128.58**	3.77**	0.16	2.11	17.87	21.23
Checks Vs Tests	1	173.14**	711.23**	15.35**	23.03**	188.11**	667.89**	0.08
Error	22	1.08	32.36	0.76	0.36	1.08	27.42	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 15 . Pooled analysis of variance for different characters in M₃ generation of Morden

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content
Treatments	127	11.5732**	527.30**	6.17**	2.11**	11.54**	39.51	23.37
Checks	1	198.84**	13184.06**	9.83**	0.35	198.84**	1.06	33.92
Test Entries	125	10.10**	364.96**	5.90**	2.09**	10.13**	20.33	22.81
Checks Vs Tests	1	8.78**	8162.94**	36.26**	7.12**	2.25	2475.88**	83.01*
Error	22	1.08	32.40	0.76	0.36	1.08	27.421	16.10

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 16 . Pooled analysis of variance for different characters in M₃ generation of CO 4.

Sources of variation	df	Days to flower	Plant height	Head diameter	100 seed weight	Days to maturity	Seed yield per plant	Oil content
Treatments	146	8.39**	365.85**	15.55**	0.99**	8.09**	40.4665	14.4248
Checks	1	198.83**	13184.06**	9.83**	0.35	198.84**	1.0584	33.915
Test Entries	144	5.43**	268.71**	15.64**	0.92**	4.86**	32.0882	14.387
Checks Vs Tests	1	244.55**	1536.36**	8.06**	11.36**	281.06**	1286.36**	0.3799
Error	22	1.08	32.36	0.76	0.36	1.078	27.421	16.1035

* and ** - significant at 0.05 and 0.01 probability levels, respectively.

Table 27. Mean, Range, variance, coefficient of variability, heritability and genetic advance for days to first flower in M₃ generation

Treatments	Mean (days)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	50.03	13.83	11.77	7.20	48.51	37.94	61.19
10kR	50.44	9.33	8.97	4.40	42.16	29.53	49.06
15kR	53.44	15.17	9.62	5.05	42.43	30.75	52.51
20kR	53.86	4.92	8.55	3.98	39.84	27.18	46.55
25kR	52.48	8.37	6.24	1.67	34.47	17.83	26.74
Control	49.15	10.50	4.568				
CO 4							
5kR	55.99	13.50	6.94	3.79	35.20	26.03	54.67
10kR	54.31	7.67	4.39	1.24	28.42	15.12	28.29
15kR	55.74	10.67	7.27	4.12	36.12	27.20	56.73
20kR	56.72	7.00	5.33	2.18	30.64	19.61	40.94
25kR	56.65	5.75	4.99	1.84	29.67	18.03	36.93
Control	56.49	6.88	3.15				

Table 28. Mean, Range, variance, coefficient of variability, heritability and genetic advance for plant height in M₃ generation

Treatments	Mean (cm)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	82.68	182.01	883.89	533.75	326.97	254.09	60.39
10kR	80.28	84.80	450.27	100.12	236.83	111.68	22.24
15kR	90.69	81.88	468.97	118.82	227.40	114.46	25.34
20kR	97.30	73.01	423.66	73.51	208.67	86.92	17.35
25kR	103.23	53.33	512.65	162.50	222.85	125.47	31.70
Control	81.95	67.33	350.15				
CO 4							
5kR	119.44	95.90	532.15	245.25	211.08	143.30	46.09
10kR	111.31	68.08	375.14	88.24	183.58	89.03	23.52
15kR	115.07	62.83	350.47	63.57	174.52	74.33	18.14
20kR	116.51	63.59	389.27	102.36	182.79	93.73	26.30
25kR	116.29	38.83	450.27	163.37	196.77	118.52	36.28
Control	115.62	58.00	286.90				

Table 29. Mean, Range, variance, coefficient of variability, heritability and genetic advance for head diameter in M₃ generation

Treatments	Mean (cm)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	11.68	22.09	12.16	9.21	102.03	88.77	75.70
10kR	11.35	7.53	5.65	2.69	70.55	48.71	47.67
15kR	11.08	8.32	4.57	1.61	64.20	38.15	35.31
20kR	10.66	7.43	3.94	0.99	60.82	30.47	25.10
25kR	10.27	5.50	3.65	0.69	59.61	25.99	19.02
Control	10.83	7.55	2.95				
CO 4							
5kR	12.34	31.19	19.25	16.43	124.89	115.41	85.39
10kR	12.27	32.13	36.78	33.97	173.15	166.40	92.35
15kR	11.00	5.57	3.65	0.84	57.65	27.68	23.06
20kR	11.55	13.78	8.12	5.31	83.86	67.81	65.38
25kR	11.24	7.73	3.77	0.96	57.95	29.25	25.47
Control	10.09	5.67	2.81				

Table 30. Mean, Range, variance, coefficient of variability, heritability and genetic advance for 100 seed weight in M₃ generation

Treatments	Mean (g)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	3.83	5.14	1.80	0.28	68.65	27.10	15.59
10kR	3.72	6.67	1.92	0.39	71.78	32.54	20.55
15kR	3.99	6.00	2.19	0.67	74.09	40.95	30.54
20kR	4.68	5.10	2.15	0.62	67.70	36.46	29.01
25kR	4.26	5.73	2.35	0.82	74.19	43.93	35.07
Control	3.75	4.52	1.52				
CO 4							
5kR	3.22	1.64	0.45	0.34	37.52	32.59	75.47
10kR	4.61	3.67	0.77	0.66	40.96	37.90	85.63
15kR	4.70	3.08	0.74	0.62	39.54	36.43	84.88
20kR	4.44	4.48	0.77	0.66	41.58	38.45	85.51
25kR	3.13	1.26	0.38	0.26	34.64	29.07	70.41
Control	2.97	1.18	0.11				

Table 31. Mean, Range, variance, coefficient of variability, heritability and genetic advance for days to maturity in M₃ generation

Treatments	Mean (days)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	80.03	13.83	11.77	6.44	38.35	28.37	54.71
10kR	81.44	9.33	8.65	3.32	32.60	20.20	38.40
15kR	84.04	15.17	9.80	4.47	34.15	23.06	45.60
20kR	83.86	4.92	8.98	3.65	32.72	20.85	40.61
25kR	82.48	8.37	6.24	0.90	27.50	10.47	14.50
Control	80.15	10.50	5.33				
CO 4							
5kR	85.99	13.50	6.94	3.79	28.41	21.00	54.67
10kR	85.31	7.67	4.39	1.24	22.68	12.06	28.29
15kR	86.18	9.67	6.15	3.01	26.72	18.67	48.85
20kR	86.72	7.00	5.65	2.50	25.52	16.99	44.31
25kR	86.83	5.75	4.57	1.42	22.94	12.81	31.16
Control	86.49	6.88	3.15				

Table 32. Mean, Range, variance, coefficient of variability, heritability and genetic advance for seed yield per plant in M₃ generation

Treatments	Mean (g)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	11.10	16.75	20.17	5.60	134.81	71.02	27.75
10kR	9.70	15.82	19.97	5.40	143.47	74.61	27.05
15kR	10.82	14.09	20.57	6.00	137.90	74.47	29.17
20kR	12.47	22.02	34.25	19.68	165.75	125.65	57.47
25kR	11.11	14.09	26.35	11.79	154.03	103.01	44.72
Control	9.65	15.60	14.57				
CO 4							
5kR	15.08	24.24	30.50	5.89	142.21	62.50	19.32
10kR	15.09	25.86	53.27	28.66	187.86	137.79	53.80
15kR	13.42	20.82	39.23	14.62	171.00	104.40	37.27
20kR	12.82	16.62	30.27	5.66	153.67	66.43	18.69
25kR	13.92	17.04	30.56	5.96	148.21	65.42	19.48
Control	13.66	14.11	24.61				

Table 33. Mean, Range, variance, coefficient of variability, heritability and genetic advance for oil content in M₃ generation

Treatments	Mean (%)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	31.17	19.68	25.37	4.01	90.22	35.87	15.80
10kR	28.67	27.18	30.70	9.35	103.49	57.10	30.44
15kR	29.41	17.59	26.50	5.14	94.93	41.82	19.41
20kR	30.02	15.05	31.66	10.30	102.69	58.58	32.54
25kR	28.56	8.78	30.27	8.91	102.95	55.86	29.44
Control	29.66	27.18	21.35				
CO 4							
5kR	31.61	14.49	25.35	11.69	89.54	60.81	46.13
10kR	32.19	17.46	22.35	8.69	83.32	51.96	38.89
15kR	31.83	19.36	25.66	12.00	89.78	61.40	46.78
20kR	32.33	10.65	25.44	11.78	88.70	60.37	46.32
25kR	31.72	14.49	21.54	7.88	82.40	49.85	36.60
Control	32.03	9.29	13.65				

Table 27. Mean, Range, variance, coefficient of variability, heritability and genetic advance for days to first flower in M₃ generation

Treatments	Mean (days)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	50.03	13.83	11.77	7.20	48.51	37.94	61.19
10kR	50.44	9.33	8.97	4.40	42.16	29.53	49.06
15kR	53.44	15.17	9.62	5.05	42.43	30.75	52.51
20kR	53.86	4.92	8.55	3.98	39.84	27.18	46.55
25kR	52.48	8.37	6.24	1.67	34.47	17.83	26.74
Control	49.15	10.50	4.568				
CO 4							
5kR	55.99	13.50	6.94	3.79	35.20	26.03	54.67
10kR	54.31	7.67	4.39	1.24	28.42	15.12	28.29
15kR	55.74	10.67	7.27	4.12	36.12	27.20	56.73
20kR	56.72	7.00	5.33	2.18	30.64	19.61	40.94
25kR	56.65	5.75	4.99	1.84	29.67	18.03	36.93
Control	56.49	6.88	3.15				

Table 28. Mean, Range, variance, coefficient of variability, heritability and genetic advance for plant height in M₃ generation

Treatments	Mean (cm)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	82.68	182.01	883.89	533.75	326.97	254.09	60.39
10kR	80.28	84.80	450.27	100.12	236.83	111.68	22.24
15kR	90.69	81.88	468.97	118.82	227.40	114.46	25.34
20kR	97.30	73.01	423.66	73.51	208.67	86.92	17.35
25kR	103.23	53.33	512.65	162.50	222.85	125.47	31.70
Control	81.95	67.33	350.15				
CO 4							
5kR	119.44	95.90	532.15	245.25	211.08	143.30	46.09
10kR	111.31	68.08	375.14	88.24	183.58	89.03	23.52
15kR	115.07	62.83	350.47	63.57	174.52	74.33	18.14
20kR	116.51	63.59	389.27	102.36	182.79	93.73	26.30
25kR	116.29	38.83	450.27	163.37	196.77	118.52	36.28
Control	115.62	58.00	286.90				

Table 29. Mean, Range, variance, coefficient of variability, heritability and genetic advance for head diameter in M₃ generation

Treatments	Mean (cm)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	11.68	22.09	12.16	9.21	102.03	88.77	75.70
10kR	11.35	7.53	5.65	2.69	70.55	48.71	47.67
15kR	11.08	8.32	4.57	1.61	64.20	38.15	35.31
20kR	10.66	7.43	3.94	0.99	60.82	30.47	25.10
25kR	10.27	5.50	3.65	0.69	59.61	25.99	19.02
Control	10.83	7.55	2.95				
CO 4							
5kR	12.34	31.19	19.25	16.43	124.89	115.41	85.39
10kR	12.27	32.13	36.78	33.97	173.15	166.40	92.35
15kR	11.00	5.57	3.65	0.84	57.65	27.68	23.06
20kR	11.55	13.78	8.12	5.31	83.86	67.81	65.38
25kR	11.24	7.73	3.77	0.96	57.95	29.25	25.47
Control	10.09	5.67	2.81				

Table 30. Mean, Range, variance, coefficient of variability, heritability and genetic advance for 100 seed weight in M₃ generation

Treatments	Mean (g)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	3.83	5.14	1.80	0.28	68.65	27.10	15.59
10kR	3.72	6.67	1.92	0.39	71.78	32.54	20.55
15kR	3.99	6.00	2.19	0.67	74.09	40.95	30.54
20kR	4.68	5.10	2.15	0.62	67.70	36.46	29.01
25kR	4.26	5.73	2.35	0.82	74.19	43.93	35.07
Control	3.75	4.52	1.52				
CO 4							
5kR	3.22	1.64	0.45	0.34	37.52	32.59	75.47
10kR	4.61	3.67	0.77	0.66	40.96	37.90	85.63
15kR	4.70	3.08	0.74	0.62	39.54	36.43	84.88
20kR	4.44	4.48	0.77	0.66	41.58	38.45	85.51
25kR	3.13	1.26	0.38	0.26	34.64	29.07	70.41
Control	2.97	1.18	0.11				

Table 31. Mean, Range, variance, coefficient of variability, heritability and genetic advance for days to maturity in M₃ generation

Treatments	Mean (days)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	80.03	13.83	11.77	6.44	38.35	28.37	54.71
10kR	81.44	9.33	8.65	3.32	32.60	20.20	38.40
15kR	84.04	15.17	9.80	4.47	34.15	23.06	45.60
20kR	83.86	4.92	8.98	3.65	32.72	20.85	40.61
25kR	82.48	8.37	6.24	0.90	27.50	10.47	14.50
Control	80.15	10.50	5.33				
CO 4							
5kR	85.99	13.50	6.94	3.79	28.41	21.00	54.67
10kR	85.31	7.67	4.39	1.24	22.68	12.06	28.29
15kR	86.18	9.67	6.15	3.01	26.72	18.67	48.85
20kR	86.72	7.00	5.65	2.50	25.52	16.99	44.31
25kR	86.83	5.75	4.57	1.42	22.94	12.81	31.16
Control	86.49	6.88	3.15				

Table 32. Mean, Range, variance, coefficient of variability, heritability and genetic advance for seed yield per plant in M₃ generation

Treatments	Mean (g)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	11.10	16.75	20.17	5.60	134.81	71.02	27.75
10kR	9.70	15.82	19.97	5.40	143.47	74.61	27.05
15kR	10.82	14.09	20.57	6.00	137.90	74.47	29.17
20kR	12.47	22.02	34.25	19.68	165.75	125.65	57.47
25kR	11.11	14.09	26.35	11.79	154.03	103.01	44.72
Control	9.65	15.60	14.57				
CO 4							
5kR	15.08	24.24	30.50	5.89	142.21	62.50	19.32
10kR	15.09	25.86	53.27	28.66	187.86	137.79	53.80
15kR	13.42	20.82	39.23	14.62	171.00	104.40	37.27
20kR	12.82	16.62	30.27	5.66	153.67	66.43	18.69
25kR	13.92	17.04	30.56	5.96	148.21	65.42	19.48
Control	13.66	14.11	24.61				

Table 33. Mean, Range, variance, coefficient of variability, heritability and genetic advance for oil content in M₃ generation

Treatments	Mean (%)	Range	PV	GV	PCV (%)	GCV (%)	h²(%)
MORDEN							
5kR	31.17	19.68	25.37	4.01	90.22	35.87	15.80
10kR	28.67	27.18	30.70	9.35	103.49	57.10	30.44
15kR	29.41	17.59	26.50	5.14	94.93	41.82	19.41
20kR	30.02	15.05	31.66	10.30	102.69	58.58	32.54
25kR	28.56	8.78	30.27	8.91	102.95	55.86	29.44
Control	29.66	27.18	21.35				
CO 4							
5kR	31.61	14.49	25.35	11.69	89.54	60.81	46.13
10kR	32.19	17.46	22.35	8.69	83.32	51.96	38.89
15kR	31.83	19.36	25.66	12.00	89.78	61.40	46.78
20kR	32.33	10.65	25.44	11.78	88.70	60.37	46.32
25kR	31.72	14.49	21.54	7.88	82.40	49.85	36.60
Control	32.03	9.29	13.65				

Table 35. Mean and variability between treatments for days to first flower in M₄ generation

Varieties	Treatment	Mean (days)	SE	CD (5%)	GCV (%)	PCV (%)	h ² (%)	GA as percentage mean
MORDEN	5kR	51.00	2.18	6.37	3.93	7.42	28.03	4.29
	10kR	52.35	2.39	7.37	7.08	13.00	29.69	7.95
	15kR	50.38	1.61	4.97	27.86	28.89	93.01	55.35
	20kR	54.00	2.34	7.01	1.26	7.99	2.50	0.41
	25kR	54.63	1.25	5.63	17.38	24.83	48.98	25.05
	Control	50.30	2.65	2.56				
CO 4	5kR	51.50	0.02	5.82	3.09	4.99	38.47	3.95
	10kR	51.74	1.92	7.23	8.58	10.92	61.75	13.89
	15kR	52.40	1.84	5.90	9.31	14.34	42.16	12.46
	20kR	51.29	1.90	5.69	6.53	9.41	48.25	9.35
	25kR	52.44	0.86	2.89	19.65	20.66	90.46	38.50
	Control	52.50	2.78	6.16				

Table 36. Mean and variability between treatments for plant height in M₄ generation

Varieties	Treatments	Mean (cm)	SE	CD (5%)	GCV (%)	PCV (%)	h ² (%)	GA as percentage mean
MORDEN	5kR	84.09	6.74	30.09	34.12	38.62	78.08	62.11
	10kR	103.90	7.77	23.94	44.80	48.22	86.33	85.75
	15kR	103.61	9.55	29.43	51.89	56.35	84.79	98.42
	20kR	123.29	7.70	23.10	26.04	28.43	83.93	49.15
	25kR	105.07	7.69	34.58	218.94	226.16	93.72	436.61
	Control	101.04	7.16	28.09				
CO 4	5kR	136.31	4.25	12.27	11.84	12.24	93.51	23.58
	10kR	132.31	8.16	24.36	25.00	27.41	83.18	46.97
	15kR	134.68	7.26	23.23	30.25	34.57	76.61	54.55
	20kR	142.93	6.79	50.15	16.53	27.06	37.34	20.81

	25kR	121.98	1.50	34.35	60.55	70.72	73.31	106.80
	Control	133.32	9.47	12.01				

Table 37. Mean and variability between treatments for head diameter in M₄ generation

Varieties	Treatments	Mean (cm)	SE	CD(5%)	GCV (%)	PCV (%)	h ² (%)	GA as percentage mean
MORDEN	5kR	11.71	0.83	2.43	19.58	22.20	77.78	35.58
	10kR	13.48	0.51	1.58	27.17	28.65	89.94	53.08
	15kR	12.04	0.53	1.62	29.48	31.27	88.85	57.24
	20kR	11.21	0.74	2.22	23.56	26.46	79.24	43.20
	25kR	12.53	2.11	11.43	149.24	216.73	47.42	211.71
	Control	11.51	2.54	8.30				
CO 4	5kR	12.32	0.95	2.75	13.66	15.70	75.69	24.48
	10kR	12.33	0.89	2.67	8.21	15.58	27.79	8.92
	15kR	11.31	0.97	4.67	34.93	53.14	43.20	47.29
	20kR	11.00	0.95	2.84	12.42	20.08	38.25	15.83
	25kR	12.28	1.07	3.59	25.82	42.55	36.82	32.28
	Control	10.73	1.46	3.35				

Table 38. Mean and variability of between treatments of 100 seed weight in M₄ generation

Varieties	Treatments	Mean (g)	SE	CD(5%)	GCV (%)	PCV (%)	h ² (%)	GA as percentage mean
MORDEN	5kR	4.54	0.45	1.32	12.58	19.34	42.33	16.87
	10kR	4.71	0.62	1.90	7.07	32.04	4.88	3.22
	15kR	4.46	0.46	1.40	31.18	39.62	61.92	50.53
	20kR	4.63	0.47	1.42	10.47	21.43	23.88	10.54
	25kR	4.92	0.38	1.70	61.84	85.90	51.84	91.72
	Control	4.63	0.21	0.84				
CO 4	5kR	4.55	0.61	1.76	3.42	13.87	6.09	1.74
	10kR	4.34	0.41	1.23	14.42	22.48	41.17	19.06
	15kR	4.50	0.59	1.89	28.21	49.59	32.35	33.05

	20kR	4.71	0.51	1.53	4.99	20.44	5.96	2.51
	25kR	4.02	0.62	2.09	6.16	60.40	1.04	1.29
	Control	4.82	0.58	2.02				

Table 39. Mean and variability between treatments for days to maturity in M₄ generation

Varieties	Treatments	Mean (days)	SE	CD(5%)	GCV (%)	PCV (%)	h² (%)	GA as percentage mean
MORDEN	5kR	81.07	2.10	6.14	0.90	3.93	5.27	0.43
	10kR	82.73	2.55	7.85	0.52	7.36	0.49	0.07
	15kR	79.73	1.14	9.74	15.82	18.42	73.69	27.97
	20kR	83.91	2.50	7.50	0.56	5.46	1.05	0.12
	25kR	84.63	1.25	5.63	11.22	16.03	48.98	16.17
	Control	79.70	3.16	4.20				
CO 4	5kR	81.50	1.78	5.82	1.96	3.15	38.47	2.50
	10kR	81.79	1.92	5.74	5.88	7.28	65.37	9.80
	15kR	82.75	1.59	5.08	10.18	11.79	74.50	18.09
	20kR	81.22	1.93	5.77	4.32	6.12	49.76	6.28
	25kR	82.19	1.00	2.98	11.69	12.60	86.05	22.33
	Control	82.29	2.02	6.17				

Table 40. Mean and variability between treatments for seed yield per plant in M₄ generation

Varieties	Treatments	Mean (g)	SE	CD(5%)	GCV (%)	PCV (%)	h² (%)	GA as percentage mean
MORDEN	5kR	16.45	2.28	6.67	54.80	58.50	87.73	105.73
	10kR	21.30	2.79	8.61	68.08	74.91	82.58	127.44
	15kR	16.51	2.95	9.08	70.49	82.34	73.29	124.30
	20kR	17.35	4.64	13.92	101.95	113.04	81.34	189.42
	25kR	20.06	2.89	24.88	469.38	515.70	82.84	880.08
	Control	15.11	4.29	11.36				
CO 4	5kR	19.41	2.29	6.61	23.90	26.65	80.42	44.15

	10kR	17.88	3.88	11.60	36.37	53.77	45.76	50.69
	15kR	14.40	2.84	9.10	57.93	84.27	47.26	82.03
	20kR	15.98	2.86	8.53	76.12	82.81	84.51	144.16
	25kR	15.46	2.51	12.80	43.15	115.75	13.90	33.13
	Control	16.95	4.29	8.69				

Table 41. Mean and variability between treatments for oil content in M₄ generation

Varieties	Treatments	Mean (%)	SE	CD(5%)	GCV (%)	PCV (%)	h² (%)	GA as percentage mean
MORDEN	5kR	30.34	2.07	7.37	3.52	12.76	7.60	2.00
	10kR	30.87	2.32	7.14	18.91	26.04	52.72	28.28
	15kR	31.72	2.51	7.74	19.61	27.22	51.90	29.10
	20kR	33.86	1.44	4.32	12.81	14.98	73.20	22.58
	25kR	34.32	1.96	8.84	73.10	85.50	73.11	128.76
	Control	32.00	2.52	8.14				
CO 4	5kR	31.03	1.71	9.11	5.53	11.58	22.85	5.45
	10kR	29.79	2.15	6.42	10.24	16.68	37.73	12.96
	15kR	31.17	2.93	9.38	15.30	33.16	21.30	14.55
	20kR	31.75	2.47	7.39	5.18	15.12	11.73	3.65
	25kR	30.82	1.81	5.42	13.43	26.47	25.75	14.04
	Control	30.32	3.16	5.93				



**Plate 5. Bushy mutant in Morden
- M_1 generation (15 kR)**



**Plate 6. Missing flower mutant
in CO 4 - M_2 generation (10 kR)**



**Plate 7. Sterile mutants with different stigma colours in CO 4 -
 M_2 generation (20 kR)**



**Plate 9. Dwarf and early mutant in Morden -
M₂ generation (20 kR)**

**Plate 10. Dwarf and early mutant in Morden -
M₃ generation (20 kR)**





Plate 1. Field view of M_1 generation (Rabi, 2002)



Plate 2. Field view of M_2 generation (Rabi, 2002)



Plate 3. Field view of M_3 generation (Kharif, 2003)



Plate 4. Field view of M_4 generation (Kharif, 2003)



Plate 12. High yielding mutant in CO 4 - M_4 generation (15kR)



Plate 13. Multi head mutants in Morden - M_4 generation (20kR)



Plate 14. White pollen multi head types in CO 4 - M_4 generation (5kR)



Plate 15. Leafy mutant progenies in Morden and CO 4 - M₄ generation

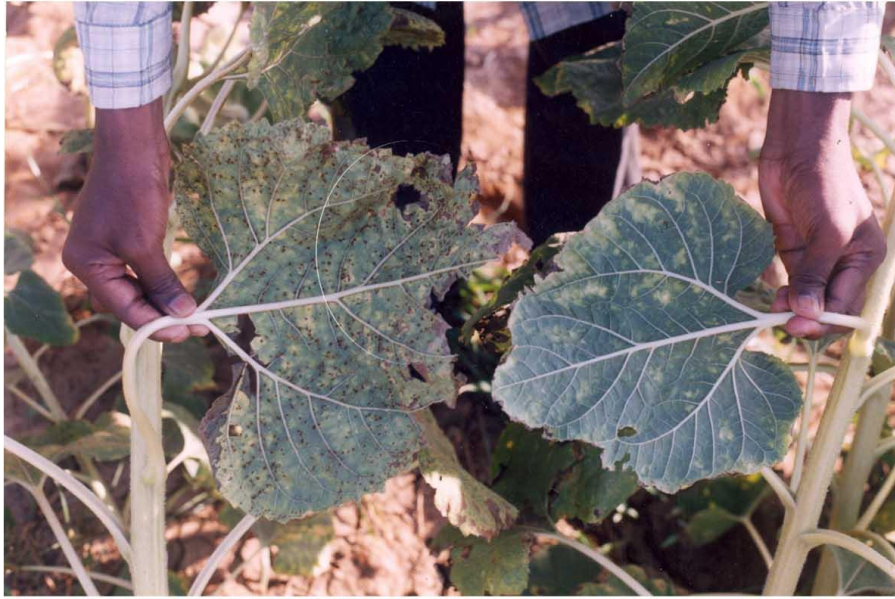


Plate 18. Rust free line in CO 4 - M_3 generation (15 kR)

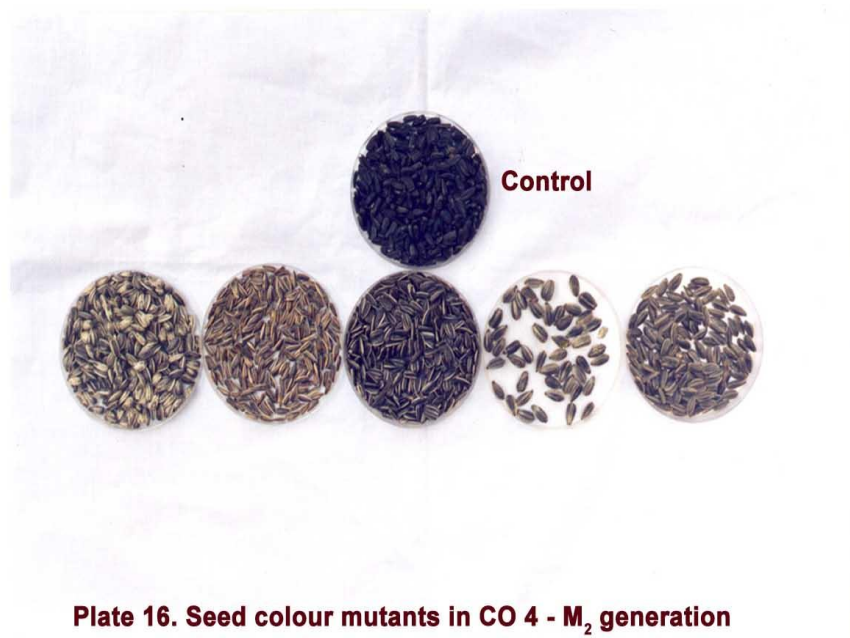




Plate 19. Stem mutants in Morden - M_2 generation



Plate 20. Stem mutants in CO 4 - M_1 generation (5kR)