EXPLOITATION OF MALE STERILITY IN SESAME

(*Sesamum indicum L.*)

By
VEENA VIGHNESWARAN

THESIS

Submitted in partial fulfillment of the requirement for the degree of **Doctor of Philosophy in Agriculture,** Faculty of Agriculture, Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS
COLLEGE OF HORTICULTURE
KERALA AGRICULTURAL UNIVERSITY
VELLANIKARA, THRISSUR 680 656
KERALA, INDIA
2001

Declaration

I hereby declare that this thesis entitled *Exploitation of male sterility in sesame (Sesamum indicum L.)* is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associate-ship, fellowship or other similar title of any other University or Society.

Vellanikara

VEENA VIGHNESWARAN

Certificate

Certified that this thesis entitled ***Exploitation of male sterility in sesame (Sesamum indicum L.)*** is a record of research work done independently by **Miss. Veena Vighneswaran,** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associate-ship to her.

Vellanikkara

DR. K. KUMARAN

Chairman, Advisory Committee
Associate Director
Directorate of Research
Kerala Agricultural University
Vellanikkara.

Certificate

We, the undersigned members of the Advisory Committee of Miss. Veena Vighneswaran, a candidate for the Degree of **Doctor of Philosophy in Agriculture,** agree that this thesis entitled ***Exploitation of male sterility in sesame (Sesamum indicum L.)*** may be submitted by **Miss. Veena Vighneswaran**, in partial fulfillment of the requirement for the Degree.

DR. K. KUMARAN
(Chairman, Advisory Committee)
Associate Director
Directorate of Research
Kerala Agricultural University
Vellanikkara

DR. K. PUSHKARAN
(Member, Advisory Committee)
Professor & Head (i/c)
Dept. of Plant Breeding & Genetics
College of Horticulture
Vellanikara

DR. ACHAMMA OOMMEN
(Member, Advisory Committee)
Professor
Dept. of Plant Breeding & Genetics
College of Horticulture
Vellanikkara

DR. V.K.G. UNNITHAN
(Member, Advisory Committee)
Associate Professor
Dept. of Agricultural Statistics
College of Horticulture
Vellanikkara

SRI. N. RAMACHANDRAN NAIR
(Member, Advisory Committee)
Associate Professor & Head (i/c)
Sugarcane Breeding Station
Thiruvalla

EXTERNAL EXAMINER
DR. V. NURALEEDHARAN
PROF AND HEAD
CENTRE OF EXCELLENCE IN GENETICS AND PLANT BREEDING
TNAU. COIMBATORE.

Dedicated to my Beloved Parents

ACKNOWLEDGMENT

ACKNOWLEDGMENT

I wish to avail this opportunity and place on record my deep sense gratitude and immense thanks to **Dr. K. Kumaran**, Chairman of my Advisory Committee for his valuable guidance, critical suggestions and constant encouragement throughout the investigations for the successful completion of this programme and for the critical scrutiny of the manuscript.

I am grateful to **Dr. K. Pushkaran**, member of my Advisory Committee for his technical advises and constant encouragement through the period of this research work.

I accost my sincere thanks towards **Dr. Achamma Oommen**, member of Advisory Committee for her valuable help, moral support and advice during the period of this investigation.

I would also like to extend my deep sense gratitude to **Sri. V.K.G. Unnithan**, Member of Advisory Committee for his expert advice, constant inspiration with utmost sense of patience and ever-willing help rendered in the statistical analysis and interpretations.

I defray my profound thanks to **Sri. N. Ramachandran Nair**, Member of Advisory Committee for his never ending encouragement, keen interest, valuable suggestions, constructive criticism and timely help especially during the field work of the investigations.

I gratefully acknowledge the NBPGR Regional Station, Vellanikkara for the supply of accessions maintained there and also I extent my deep sense gratitude for the help and guidance rendered by **Dr. Z. Abraham**, Sr. Scientist, NBPGR Regional Station, Vellanikkara and **Dr. Sucrup John**, Associate Professor, ORARS, Kayamkulam for the collection of accessions and varieties for the study.

Contents

List of Tables

List of figures

List of Plates

INTRODUCTION

INTRODUCTION

The 'Green Revolution' is one of the biggest success stories of Indian agriculture which enabled the country to attain self sufficiency and later to surplus production of food. This was accomplished through application of newer technologies like development of high yielding varieties, better management, plant protection, processing etc. However, in the area of oilseeds which forms the second largest agricultural community in the country, due emphasis on production to meet the internal requirement was lacking. As a result an acute shortage of edible oils continued in the country forcing it for massive import of a million tonnes of oil annually causing heavy drain of the valuable foreign exchange. But the scenario changed with the setting up of the Technology Mission on Oilseeds by the Government of India in 1986 and a dramatic transformation of the Indian oil seeds economy followed. The main contributor to such a significant transformation is the oil seeds production technology the role of which in fostering and sustaining all the oil seeds production needs no emphasis. From the status of a 'net importer' in the eighties India became an exporter in the early nineties, due to the concerted efforts initiated by the Technology Mission on Oilseeds and the process has been projected as 'Yellow Revolution'.

India has the third largest edible oil economy in the world after the United States and China. It occupies a distinct position not only in terms of area under oil seeds, but also in terms of diversity in cultivated oil seeds. This also forms the second largest agricultural commodity after cereals in India, sharing 14 per cent of the country's

gross cropped area and accounting 10 per cent of the value of the all agricultural products.

Sesame *(Sesamum indicum L.)* is one of the oldest oilseed crops known and used by man. It is widely cultivated in India since ancient times. Sesame yields oil and protein of high quality and holds tremendous potential for export. However, it has not contributed its best to the current bright oil seed scenario. The average per hectare yield of sesame in India is very low (295 kg /ha) as compared with other countries in the world. The low yields are due to the lack of improved cultivars. It is important to maintain and enhance the competitive position of sesame in relation to other crops. Only breeding for more productive cultivars will assure its continued production in its traditional area and further expansion in area is very much limited. Improvement of sesame has not been undertaken with adequate interest as the crop has become less and less renumerative. Sesame cultivation is taken up only in marginal situations because of over emphasis and importance of food crops and plantation crops which are more sustainable. In addition, sesame is not mandated to any of the international research institutes of the Consultative Group for International Agricultural Research . The potential of sesame breeding is amply demonstrated by the achievement in South Korea (Lee and Choi, 1985; Kang 1994) and in its traditional areas of production in India (Joshi, 1961; Sharma, 1985; 1994) and in China (Zhao, 1994). Therefore, there is an urgent need to augment its productivity through exploitation of heterosis which is a quick and convenient way of combining desirable traits from diverse parents. However, in order to set a programme of hybrid sesame to its logical ends, choice of suitable

parents through easy and critical evaluation of current available material is of paramount importance. This is because *per se* performance of a parent is not always a true indicator of its potential in cross combinations. The combining ability analysis can be used to understand the inheritance and gene action of the quantitative characters through the predominance of GCA and SCA variances. It also helps to identify the parents with good gca and crosses with good sca effects.

There are two basic pre-requisites for the successful economic exploitation of heterosis on a commercial scale. First, a significant heterotic effect must be present in a hybrid over its parents. Secondly, production of large scale hybrid seed should be possible economically. Though sesame is a self pollinated crop, it is very easy for hand emasculation and pollination and a single attempt gives about 50 to 60 seeds. It is, therefore, easier to exploit its heterosis and high levels of heterosis have been observed in sesame hybrid populations (Riccelli and Mazzani 1964; Sarathe and Dabral, 1969; Murty,1975 and Dixit, 1976a.). In all these studies F_1 populations were developed by hand emasculations and pollinations which are time consuming and cannot be used for the production of hybrid sesame seed for commercial planting. Chemical emasculation has been tried but it has found unreliable (Dubey and Singh, 1968; Chauhan and Singh,1971 and Mazzani *et al.* 1971).

True male sterility has not been described in sesame. Some workers have observed various types of sterility (Kumar and Abraham, 1941; Kumar and Rao, 1945; Malaguti and Mazzani, 1958; Dabral, 1968; Dabral and Mandoli,1974) However, the sterility

encountered was either total ie, male and female (Kumar and Abraham, 1941 and Kumar and Rao, 1945), partial (Malaguti and Mazzani, 1958) or was restricted to an early stage of the reproductive processes (Dabral, 1968; Dabral and Mandoli, 1974). This phenomenon will be much useful in hybrid seed production if stable male sterility, either cytoplasmic-genic or genic, is identified and utilized. Cytoplasmic male sterility (CMS) is a reasonably common characteristic of higher plants and is currently reported in 140 species representing 47 genera and 20 families (Frank, 1989). The discovery of CMS in wild relatives of numerous cultivated plants has contributed enormously to agriculture by making possible large scale production of hybrid seed. CMS is important from an evolutionary stand point as well particularly in the origin of stable gynodioecy in plants (Charles worth; 1981 and Charlesworth and Ganders, 1979). CMS has also been shown to influence gene exchange between populations (Caspari *et al.* 1966) and has been speculated sometimes to account for pattern of differential cytoplasmic versus nuclear introgression often observed in plant hybrid zones. With this background, the present study was formulated with a view to assess the variability and to estimate the combining ability of selected genotypes. Exploitation of male sterility in sesame through mutagenesis and wide hybridization for future development of hybrid sesame was also aimed at.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The genus *Sesamum* belongs to family Pedaliaceae, which contains over 37 species. Though Linnaeus described two species as *S. indicum* and *S. orientale*, it has been further revised by various workers, dividing the genus into subgenera and sections based on morphology of leaves and seeds. Nayar and Mehra (1970) referred to 34 species and Kobayashi (1991) listed 37 species. Analysis of chromosome number of these species showed that there exists three groups with 2 n = 26, 32 and 64, of which the cultivated sesame in 2n = 26 chromosome species.

Interrelationships of the species within and between the chromosome number groups have been studied by Prabakaran (1996). Of the 2n = 26 chromosome species, *S. indicum* and *S. malabaricum* are closely related, there F_1 hybrids have normal meiosis and are fertile (Kobayashi, 1991; Nayar, 1995) In crosses of *S. malabaricum* as female and *S. indicum* as male, the F_1 hybrids were male sterile (Thangavelu, 1994; Prabakaran, 1996), the reciprocal were fully fertile. This indicates some nuclear cytoplasmic interactions and differences between the two species.

Sesame is an indeterminate plant with acropetal flowering with a growing period of 70 to 150 days. The flowers are borne in short pedicles, solitary or a group of three, in leaf axils. The flowers open at dawn, the pollen grains are shed shortly afterwards and remain viable for 24 hours. The stigma remain receptive for two more days, if not fertilized.

Sesame (*S.indicum*. L) is predominantly a self pollinated crop and high levels of heterosis has been observed in sesame hybrid populations. In all such cases, F_1 populations were developed by hand emasculations and pollinations which are time consuming and cannot be used for the production of hybrid sesame seed for commercial purpose. Chemical emasulation has been tried in sesame but has proven unreliable. True male sterility has not been described in sesame. Some workers have observed various types of sterility. The sterility encountered was either total ie, both male and female, partial or restricted to an early stage of the reproductive processes.

The present investigations have been designed to develop a stable male sterile system in sesame. Literature pertinent to areas relating to variability, combining ability, male sterility etc. in sesame is reviewed here under.

2.1 Genetic variability

Shortage of edible oil is resulting into upward price trend. The only remedy to overcome this menace is to improve the yields of oilseed crops through genetic manoeuvring. In sesame, oil content is known to be conditioned by a number of polygenes and hence is quantitative in inheritance. Plant yield, in general, is a complex and quantitatively inherited character but it is highly influenced by environmental fluctuations. Hence it becomes essential to study the genetic variability by observing genotypic coefficient of variation to assess and to select desirable genotypes for any variety improvement programme. Genotypic variance helps to measure the range of genetic variability for the respective plant characters.

Paramasivam and Prasad (1981) reported high GCV for yield of seeds per plant in segregating population of sesame A relatively lower but significant GCV was reported by Solanki and Paliwal (1981) for days to flowering, days to maturity, 1000 seed weight, number of primary branches per plant and oil content. Desai *et al.* (1982) and Rudraradhya *et al* . (1984) reported the highest GCV for the number of branches per plant followed by medium to high values for the capsule number per plant and the seed yield per plant which indicated the wide scope for selection among the cultivars for superior types. Dabral and Holker (1971) observed moderate GCV for seeds per capsule. Joshi (1972) noted moderate GCV for branches per plant. Shukla and Verma (1976) reported low GCV for the days to flowering, plant height , seed weight and capsule length. Murugesan *et al.* (1979) reported high GCV for capsules per plant and yield per plant among thirteen characters studied in sesame.

Dora and Kamala (1986) while studying the heterosis and gene action reported high GCV and PCV for plant height, capsules per plant, seeds per capsules, seed yield, oil content, days to maturity and 1000 seed weight. Hence selection based on phenotype would result in high yielding types. Lee *et al.* (1986) studied the proportion of mature seeds on the basis of branching habit, capsules per axil, and carpel and locule number per capsules. Capsules from different parts of the plant showed different seed filling rates. Unbranching types showed a higher proportion of mature seeds than branching types.

Bakheit and Mahdy (1988) reported high phenotypic and genotypic coefficient of variability for height to first capsules and

branches per plant. Li (1988) observed high genetic variation for capsules per plant and yield per plant and low genetic variation for plant height, branches number and 1000 seed weight. Osman (1988) accounted 87.2 and 95.0 percent of variability in yield of the F_1s and parents for capsules per plant and plant height respectively. He also reported that number of capsules per plant was the most important character followed by number and weight of seeds per capsule, to be considered in selecting yielding strains.

Anitha and Dorairaj (1990) reported high degree of variability for all characters except for plant height and 1000 seed weight. Kamala (1990) reported that phenotypic variance was slightly higher over the genotypic variance for all the characters studied in all the three generations showing the influence of environment. Maximum values were noted for seed yield followed by capsules per plant, branches per plant, plant height and seeds per pod. Capsule length and 1000 seed weight showed low values. It was also suggested that high phenotypic variance with low genotypic variance values indicate the higher degree of environmental variance. Characters with high genotypic variance are genetically more stable and are relatively less influenced by environment. Therefore they serve as good selection criteria in crop improvement. Reddy and Dorairaj (1990) reported high GCV values for the secondary branches followed by the seed yield per plant. The phenotypic and genotypic coefficients of variation were high for number of capsules per axil and total number of capsules followed by total number of branches, seed yield per plant and node of first flowering indicating that substantial variability existed for these characters (Mohanty and Sinha, 1965; Naphade and Kolte, 1972; Gupta and Gupta, 1977; Rai *et al.* 1981

and Chavan and Chopde, 1982). Very high GCV estimates were obtained for number of secondaries, seed yield, number of capsules per plant and height to first fruiting branch (Gupta, 1975). Sawant (1971), Thangavelu (1980) and Pathak and Dixit (1986) observed low GCV values for seed yield and capsules per plant.

Shinde *et al.* (1991) reported high significant genotypic variation for plant height, number of capsules per plant and yield per plant. Adeyemo and Ojo (1993) reported high coefficient of variation for seed yield per plant, number of pods per plant, while low values for days to flowering, plant height and height to first pod. Baruah and Goud (1993) showed high estimates of GCV for seed yield per plant, seed weight per capsule, height of branching, plant height and number of capsules per plant. Mishra *et al.* (1993) observed a wide range of variation for the number of fruiting nodes per plant, seed yield per plant, branches per plant and capsule number per plant. John and Nair (1993) reported high GCV values for number of capsules per branches (45.69), yield of seeds per plant (38.85), number of capsules on main stem (33.61), number of capsules per plant (28.30) and number of branches (27.29). Bhombe *et al.* (1994) in a variability study with eight yield contributing quantitatively inherited traits revealed that the genotypic coefficient of variation was observed to be high for capsules and yield per plant and moderate for branches per plant and seeds per capsule. Patil and Sheriff (1994) showed significant inter-varietal differences in all the traits thereby suggested the scope for selection. Biswas and Akbar (1995) reported high genotypic coefficient of variation for seed yield per plant (34.45) followed by number of branches per plant (19.71). Mishra *et al.* (1995) observed a wide range of variation

for number of fruiting nodes per plant, seed yield per plant, branch number per plant and capsule number per plant. Navadiya *et al.* (1995) reported high genetic variability for all the characters studied viz., yield per plant, number of branches per plant, number of capsules per plant, 1000 seed weight, and oil content. Reddy and Dorairaj (1995) reported highest genotypic coefficient of variability for stem weight. Shadakshari *et al.* (1995) reported highly significant variance for all the characters except capsule length. Joel and Thangavelu (1997) showed close resemblence between GCV and PCV estimates for 1000 seed weight, capsule length, oil content, days to 50 per cent flowering, days to maturity and seed number per capsule. Tak (1997) recorded significant genotypic variability for all the characters studied viz., plant height, primary branches per plant, capsules per plant, seeds per capsules and 1000 seed weight. Shanmugavalli and Vanniarajan (1998) showed high genotypic coefficient of variation for secondary branches per plant, number of capsules per plant and single plant yield.

2.2 Heritability and Genetic advance

Any crop improvement programme heavily leans on the magnitude of genetic variability and the extent to which it is heritable. Unless the genetic gain measured as percentage of mean is substantial, heritability alone cannot depict the possible improvement of a character achievable through selection. Further estimates of heritability together with genetic advance would help the breeders to infer, to a certain extent, about the nature of gene action involved for a character. The genotypic and environmental variation also influence the heritability values. Burton (1952) and Johnson *et al.* (1955a) suggested that high GCV along with

high heritability would provide a better picture of the genetic advance that can be expected by phenotypic selection. Chaudhary (1992) reported that the heritability estimates are helpful in making direct selection of superior genotypes.

High estimates of broad sense heritability in hybrid population of sesame were observed by Salazar and Onoro (1975), Gupta (1981) and Hu (1985a) for plant height, weight of capsule, seed weight per capsule, days to maturity, number of capsules per plant and oil content. Heritability coupled with high genetic advance in F_1 generation was observed for seed yield per plant, seed weight per capsule, height of branching, plant height and number of capsules per plant (Reddy and Reddy, 1976 and Gupta and Gupta, 1977.). High heritability along with low values of genetic advance was recorded for capsule length, seed width, seed thickness, 1000 seed weight , days to flowering and seed per plant which showed non-additive gene action which included both epistasis and dominance (Narasinghani and Kanwal, 1977). Moderate heritability along with low value of genetic advance were recorded for primary and secondary branches, capsule width and seed length by Naphade and Kolte (1972), Gupta (1975), Murugesan *et al.* (1979), Solanki and Paliwal (1981) and Paramasivam and Prasad (1981).

Desai *et al.*(1982) reported the high heritability for the seed yield. Gupta and Chopra (1984) and Rudraradhya *et al.*(1984) reported high heritability for the branches per plant and capsules per plant. Rathinaswamy and Jagethesan (1984) reported high heritability estimates for capsules per plant, branches per plant and capsule length. They also suggested that this would be helpful in selection of superior

genotypes. Chandramony and Nair (1985) reported very high heritability and very low genetic advance for oil content. Hu (1985b) reported low heritability values for seeds per capsule and capsule length and high heritability for capsule number and branch number.

Dora and Kamala (1986) showed high heritability and genetic advance for plant height, capsules per plant, seeds per capsule, seed yield, oil content, days to maturity and 1000 seed weight. They also reported that capsules per plant and seed yield would play a significant role in selections for the improvement of sesamum. Shivaprakash (1986) recorded highest genetic advance for height to first capsule followed by seed yield, while it was least for 1000 seed weight.

Li (1988) reported high heritability for 1000 seed weight (99.6%) followed by seeds per capsule (79.1%) and low for plant height (36.1%) and branch number (33.5%). Genetic variation and expected genetic advance were high for capsules per plant and yield per plant and suggested that would help in direct selection of genotypes by phenotypic selection. This also indicated the predominance of additive gene action in the expression of characters.

Kamala (1990) reported high heritability associated with maximum expected genetic advance for branches per plant and capsule length and high heritability with low genetic advances for plant height, capsules per plant and seeds per pod in all generations. She also suggested that these offer a scope for improvement through selections in this crop. Reddy and Haripriya (1990) reported that the heritability

estimates (narrow sense) were high for LAI and HI while they were moderate for seed yield per plant. Pathak and Dixit (1992) observed high estimates of heritability and genetic advance for protein content, days to flowering and plant height. Baruah and Goud (1993) observed heritability estimates between 80 and 90 percent for all the traits viz, seed yield per plant, seed weight per capsule, height of branching, number of capsules per plant and plant height. John and Nair (1993) reported high heritability associated with genetic advance for seeds per plant followed by number of capsules on main stem. Oil content, protein content and 1000 seed weight had high heritability but the genetic advance was low. Mishra *et al.* (1993) recorded high heritability coupled with high genetic advance for capsules per plant, fruiting nodes per plant and plant height indicating importance of additive gene action for these characters. Reddy *et al.* (1993) reported high heritability estimates for seed yield per plant and oil content.

Bhombe *et al.*(1994) recorded fairly high heritability estimates for days to 50 percent flowering and moderate for seeds per capsule and plant height. High genetic advance over mean was observed for capsules and yield per plant, seeds per capsules and days to 50 percent flowering. Fendel and Monteverde-Penso (1994) reported moderate to high heritability estimates for all the traits viz, number of capsules per plant, capsule length, number of seeds per capsule, seed weight per capsule, 1000 seed weight and yield per plant.

Biswas and Akbar (1995) recorded highest broad sense heritability for days to flowering (89.20%), days to maturity and 1000 seed weight. Mishra *et al.* (1995) recorded high heritability coupled

with high genetic advance for branch number per plant, number of fruiting nodes per plant, capsule number per plant and seed yield. Ramesh *et al.*(1995) reported that additive gene action played an important role in the inheritance of days to maturity, total number of capsules per plant and seed yield per plant. Reddy and Dorairaj (1995) reported high heritability and genetic advance for stem weight, indicating additive gene action. Shadakshari *et al.*(1995) reported that heritability and genetic advance were high for number of capsules per axil, seed yield per plant, number of locules per capsules, number of capsules and number of branches. Capsule length and oil content showed high heritability with low genetic advance.

Joel and Thangavelu (1997) reported high heritability and genetic advance for 1000 seed weight, capsule length, capsule breadth, oil content, days to 50 per cent flowering, days to maturity and seed number per capsule. Das and Samanta (1998) recorded high heritability and partial dominance of gene for oil content. Shanmugavalli and Vanniarajan (1998) recorded high heritability combined with high genetic advance for secondary branches per plant, number of capsules per plant and single plant yield.

Moderate to high values were recorded for days to flowering, days to branching, number of branches, total number of capsules, capsule length, capsule girth, seeds per capsule, seed yield per plant, 1000 seed weight and oil content by Bhargava and Saxena (1964), Dabral and Holker (1971), Sawant (1971), Shukla and Verma (1976), Paramasivam (1980) and Kandasamy (1985).

2.3 Genetic divergence

Sesame has more genetic variability than most of the other self pollinated crops. A wide range of genetic diversity among the parents is an essential feature in any hybridization programme. Hence, plant breeders are interested to estimate the range of genetic diversity among different genotypes which will help the plant breeders to select parents in the hybridization programme to achieve the set goals. Mahalanobis D^2 analysis and canonical vector analysis have been employed by various workers (Ramanujam *et al.*, 1974; Murthy *et al.*, 1966; Chandrasekaraiah *et al* .1969; Xavier, 1979; Subramaniam, 1979; Rathinaswamy, 1980; Achuthan, 1981.) on various crops for group constellation to assess genetic diversity. Most of them have reported that clustering pattern was one and the same in the two methods. Tocher's method available for group constellation based on the Mahalanobis D^2 values helps to avoid personal bias so that clustering pattern could not vary from person to person for a given data. But in canonical vector analysis grouping is done by eye sight of points scattered on a graph sheet which may introduce serious bias. Moreover intra and inter cluster distances could be assessed in Mahalanobis D^2 analysis.

Murthy and Arunachalam (1966) observed that the type from one geographical region were found to be scattered in different clusters. Such a wide adaptability would be possible due to the factors like heterogeneity, genetic architecture of these populations, past history of selections, development traits and degree of general combining ability. Singh and Bains (1968) and Verma and Mehta (1976) reported

that genotypes from different parts of India and also from other countries were grouped together in a cluster. Such grouping of types from different locations might be attributed to the free exchange of breeding materials from one place to another and /or due to unidirectional selection practiced by breeders of different locations.

Thangavelu and Rajasekharan (1983a) reported that clustering pattern of the genotypes clearly indicated that the geographic diversity need not necessarily be related to the genetic diversity. Reddy (1986) studied fifty genotypes in detail for variability, character association and genetic divergence and were grouped into four clusters. Ayyaswamy *et al.* (1987) reported that clustering pattern by Mahalanobis D^2 analysis and canonical vector analysis did not agree with each other.

Anitha and Dorairaj (1990) based on D^2 analysis, eight parents and 56 hybrids (direct and reciprocals) were grouped into 15 clusters. D^2 value varies between 8.423 and 230.352 among the entries. Mahapatra *et al* .(1993) studied the relationship of F_2 segregation pattern with genetic divergence of parents in sesame. Using D^2 analysis and canonical analysis, the 29 varieties were grouped into nine clusters which did not show any relationship with geographical origin.

Patil and Sheriff (1994) used Mahalanobis D^2 statistics in the analysis of genetic diversity for 16 yield related traits in 100 varieties and grouped them into 14 clusters on the basis of genetic distance. The distribution of these varieties in the different clusters was found not to be in accordance with their geographical origin. Wei *et al.* (1994) on the basis of principle component analysis and estimation

of genetic distance using cluster analysis revealed that the 31 varieties could be divided into 14 groups. They also reported that, effects on genetic diversity were more beneficial, if crossing was carried out between genotypes belonging to different groups, especially if their genetic distance (D^2) was greater than 12.5.

Ganesh and Thangavelu (1995) based on D^2 analysis of Mahalanobis, the 50 genotypes were grouped into four clusters. They also reported that the clustering pattern need not necessarily be related to the geographic diversity. They observed genotypes from different eco-geographic regions in one cluster and those from same eco-geographic regions did scatter in four different clusters. Verma and Mahto (1995) studied five characters in 16 genotypes and using D^2 statistics, these 16 genotypes were assigned to four clusters.

Manivannan and Nadarajan (1996) used four characters in 52 genotypes to estimate the genetic diversity by Mahalanobis D^2 analysis by the application of clustering technique, 52 genotypes were grouped into six different clusters indicating the high degree of genetic divergence among them.

Singh *et al.* (1997a) in a D^2 analysis, conducted on 33 diverse genotypes of sesame, indicated high degree of divergence. The 33 genotypes were grouped into 11 clusters. Each clusters was comprised of genotypes with specific characters. Swain and Dikshit (1997) using D^2 statistic, grouped 40 genotypes of *Sesamum indicum* into 14 clusters. They reported that oil content made the largest contribution to total divergence followed by 1000 seed weight.

2.4 Combining ability

Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions involved in the expression of quantitative traits. Further, exploitable heterosis also depends on general combining ability and specific combining ability and the breeding procedure adopted.

Murty (1975) studied combining ability in sesame for days to flowering, plant height, number of branches, number of capsules per plant, seed yield and oil and protein content. He found GCA variance to be larger than SCA variance for all the characters except for oil content, indicating the predominance of additive gene action. The SCA variance was high for seed yield and protein content. Yermanos and Kotecha (1978) in a 8x8 diallel study reported highly significant and larger GCA than SCA for all traits. Similarly in a combining ability analysis carried out with nine sesame varieties and their 36 hybrids, Rathinaswamy (1980) observed greater GCA variance than SCA variance for all characters. Chaudhari *et al.* (1979) found yield to be under the influence of additive gene action.

In a 10x10 diallel conducted by Shrivas and Singh (1981), the existence of non-additive as well as additive types of gene action was revealed for plant height, number of branches per plant, number of capsules per plant and yield. However in all the cases estimates for SCA variance was higher in magnitude than the

corresponding estimates for GCA thereby suggesting the predominance of non additive type of gene action.

The GCA, SCA and reciprocal variances were highly significant for all the characters in a study of combining ability made by Gupta (1981) for four characters in a 6x6 diallel analysis. GCA variances were of higher magnitude for plant height, number of branches and number of capsules per plant. In a 6x6 diallel study made by Fatteh *et al.* (1982), both gca and sca effects were found to be highly significant for all the characters studied. The variance due to GCA were high for all the traits, when compared to those of SCA which suggested that additive type of gene action might be governing the traits such as days to flowering, plant height, number of capsules per plant, capsule length to breadth ratio, days to maturity, yield per plant and 1000 seed weight. The non-additive type of gene action appeared to have been involved for oil content and number of effective branches.

Chaudhari *et al.* (1984) observed higher GCA variance than SCA for six yield related characters studied. Diagma (1984) studied five varieties and their F_1s in a diallel fashion which indicated that additive effects predominated for capsule length and 1000 seed weight and interactions predominated for seed yield, length of main stem and number of capsules. Krishnaswami and Appadurai (1984) reported high GCA for plant height, number of branches, number of capsules per plant and seed yield. Rathinaswamy and Jagathesan (1984) also reported higher GCA variance than SCA variance for all characters studied viz; number of capsules per plant, branches per plant, capsule length, and

seed yield. Reddy *et al.* (1984a) showed a positive general combining ability effect for capsules per plant, seed yield and oil content.

Hu (1985a) in a diallel analysis reported the predominance of overdominance for all the characters studied except, capsule length, number of seeds per capsule, and branch number. GCA variances were higher in magnitude than the corresponding estimates of SCA for all the characters studied by Sharma and Chauhan (1985) in a 10x10 diallel analysis. Both GCA and SCA variance were found to be significant for days to maturity, capsule length, number of branches per plant, number of capsules per plant and 1000 seed weight indicating the preponderance of both additive and non-additive types of gene action in controlling these traits.

Chandraprakash (1987) recorded higher GCA variance than SCA variance for all the 14 characters studied. SCA variance was highly significant for all the characters except capsule length. Dora and Kamala (1987) studied a full diallel set for four varieties for 16 characters. The estimates of GCA variances were found to be much higher than that of SCA variances. Krishnadoss *et al.* (1987) in a line x tester study, reported a predominance of non additive over additive gene action for yield and six yield related and other development traits. Kumar and Rangaswamy (1987) studied combining ability in sesame in a line x tester analysis. SCA variance was found to be higher than GCA variance indicating non-additive gene action for yield. Padmavathi (1987) in a line x tester analysis found that GCA variance were greater than SCA variances for yield, plant height, capsule length and days to maturity. High SCA variances were recorded for 1000 seed weight and oil content.

Anitha (1988) observed higher magnitude of GCA variances than SCA variances for most of the characters studied. Chandramony and Nayar (1988) reported significant GCA and SCA variances for all quantitative characters studied except for oil content. Magnitude of GCA variances was higher than that of SCA. Goyal and Kumar (1988) studied combining ability in sesame and reported high GCA variance over SCA variance for the characters studied. Khorgade *et al.* (1988) reported that both additive and non-additive gene effects for days to maturity, capsule length, branches per plant, capsules per plant and 1000 seed weight. Khorgade *et al.* (1989) reported high gca effects for plant height, capsule length, branches per plant, and seeds per capsule, while high sca effects for seed oil content.

Ramalingam *et al.* (1990) reported that the combining ability analysis indicated the predominant role of non-additive gene action for seed yield per plant, number of branches per plant and number of capsules per plant. Reddy and Haripriya (1990) reported variance due to GCA and SCA were highly significant for LAI, HI and seed yield. Reddy *et al.* (1990) reported significant SCA effects for all the yield components studied.

Ding *et al.* (1991) reported highest specific combining ability for yield per plant. Goyal and Kumar (1991) reported high gca for seeds per capsules, oil content, days to flowering or maturity and number of branches. The estimated components of SCA variance were higher in magnitude for all the traits indicating the predominance of non-additive or dominance gene action for the traits. Narkhede and Kumar (1991a) reported significant GCA and SCA variances for all characters

studied suggesting that both additive and non-additive gene effects. Narkhede and Kumar (1991b) reported that number of primary branches per plant, capsules per plant, length of capsule, seeds per capsule and yield per plant were generally controlled by dominant gene action. Shinde *et al.* (1991) reported good general combining ability effects for plant height and seed yield per plant. Tu *et al.* (1991) reported gca, sca and reciprocal effects for six parents and 30 hybrids for plant height, first capsule position, length of main fruit axis, number of branches, capsules per plant, seeds per capsule, 1000 seed weight, yield per plant and flowering period duration. All the characters except the last exhibited significant heterosis.

Brindha and Sivasubramanian (1992/1993) revealed the presence of reciprocal effects for seed yield per plant, days to flowering, plant height and number of branches per plant. Kadu *et al.* (1992) reported high GCA for branches per plant and capsule length. Reddy *et al.* (1992) observed that inheritance of oil content was predominantly under the control of additive gene action, where as mainly non-additive effects were identified for seed yield.

Dharmalingam and Ramanathan (1993) observed that additivity played a preponderant role in yield and its attributes. Reddy and Haripriya (1993) reported high gca and sca effects for seed yield. Reddy *et al.* (1993) reported the significant general combining ability and specific combining ability effects indicating the importance of both additive and non-additive gene actions. However higher magnitude of gca effects and higher gca/sca ratio (5:1) revealed the preponderance

of additive genes in governing the inheritance of important economic attributes viz., oil content and seed yield.

Durga *et al.* (1994) studied general and specific combining ability variance and observed the predominance of non-additive gene action for a majority of the morpho- physiological and yield attributes. Deenamoni and Dorairaj (1994) reported that dominance effect is greater than additive effect for first capsule bearing node.

Fatteh *et al.* (1995) reported additive, non-additive gene action and material effects were important for number of capsules per plant, yield per plant and 1000 seed weight. Ganesan (1995) reported that Co-1 variety is a good general combiner, which is suitable for hybrid breeding. Kumar and Sivasamy (1995) observed that the sca effects were more than gca effects for almost all economic traits indicating the predominance of non-additive gene action. Quijade and Layrisse (1995) also reported that sca effects were more important than gca effects. Ram (1995) studied combining ability in a line x tester analysis for plant height, number of branches, number of capsules per plant and seed yield per plant which indicated the predominance of non-additive gene action for these characters. Ramesh *et al.* (1995) reported that additive gene effects played an important role in the inheritance of days to maturity, total number of capsules and seed yield per plant. Both additive and non-additive gene effects were involved in the expression of number of seeds per capsules. Sajjanar *et al.* (1995) revealed that both additive and non-additive gene effects were involved in the expression of the characters viz, plant height, number of capsules per plant, 1000 seed weight, oil yield and seed yield. Thiyagarajan and

Ramanathan (1995a) observed the importance of non-additive gene action for number of branches per plant, number of capsules per branch, number of capsules per plant, 1000 seed weight, seed yield and oil content. Predominance of additive gene action was observed for days to 50 per cent flowering, plant height, and harvest index.

Backiyarani *et al.*(1997) in a diallel analysis indicated significant additive and non-additive genetic effects for all the traits. However additive genetic variance was predominant for days to flowering, plant height, number of primary branches, number of capsules, oil content and seed yield.

Backiyarani *et al.*(1998) reported the preponderance of additive gene action over non-additive gene action for almost all the traits studied. Chakraborti and Basu (1998) also indicated the preponderance of additive gene action in most of the economic characters and also for physiological trait salt tolerance.

2.5 Heterosis

There are two basic prerequisites for the successful exploitation of heterosis economically on a commercial scale. First, a significant heterotic effect must be present in the hybrid over its parents. Secondly, production on large scale of hybrid seed should be possible economically. Though sesame is self pollinated crop, it is very easy for hand emasculation and pollination on large scale. Moreover single crossed capsule gives about 50-60 seeds. It is, therefore, easier to exploit heterosis for commercial purpose.

Varying degrees of natural cross-fertilization have been reported in this species (Joshi, 1961; Khidir, 1972). A considerable amount of heterosis has also been reported (Pal, 1945). Riccelli and Mazzani (1964) noted that heterosis in sesame was more conspicuous in the hybrids of cultivars from distant localities or their derivatives but the information on this aspect is limited and the few estimates of heterosis available have not been related to any particular type of gene action. It was felt that an appraisal of the extent of heterosis and the nature of gene action in sesame would be valuable to breeders, since ultimately it is the nature and magnitude of the genetic variance in the base population that indicate the appropriate breeding procedures to be adopted and the nature of commercial varieties to be produced.

Varying degree of heterosis for seed yield and other traits in sesame has also been reported by other workers (Srivastava and Singh, 1968; Sarathe and Dabral, 1969; Yermanos and Kotecha, 1978; Rathinaswamy, 1980; Krishnadoss, 1984 and Padmavathi, 1987).

In California, 16 F_1 hybrids among the shattering and non shattering cultivar selections yielded on an average, twice as much as their parents and six of these hybrids out yielded their best parents by 200 to 275 percent (Delgado, 1972). Murty (1975) reported that heterosis in Indian x exotic crosses was higher than in Indian x Indian and exotic x exotic crosses. Dixit (1976a) reported 77.39 per cent heterosis over best parent for seed yield on a study with six F_1 developed from six pureline strains. The hybrids showed considerably higher degree of heterosis for all the characters studied viz., days to flowering, number of branches, plant height, number of capsules and yield per plant.

Uzo (1976) and Kinnison (1978) also indicated that heterosis in temperate x tropical, non-branched x branched and shattering x non-shattering crosses was higher than that in hybrids within each group. Chaudhari *et al.* (1979) reported positive and significant heterosis for plant height, number of branches, number of capsules, capsule length, capsule breadth and seed yield per plant.

Tyagi and Singh (1981) reported hybrid vigour for number of branches, plant height, number of capsules and yield. Sharma and Chauhan (1983) in a diallel cross analysis observed heterosis for number of capsule per plant and seed yield. Chaudhari *et al.* (1984) reported high heterosis for seed yield per plant. Desai *et al.* (1984) reported highest heterosis for yield and oil content. Krishnaswami and Appadurai (1984) observed that the extent of heterosis was found to be high for number of capsules and seed yield.

Dora and Kamala (1986) showed that heterosis was more pronounced for branches per plant, capsules per plant, seeds per capsule and seed yield per plants over the midparents. It was significant and positive for primary branches, seeds per capsule, seed length and width and seed yield per plant over the mid parents and heterobeltiosis was significant and positive for only primary branches and seed length. High heterotic values were recorded for plant height, capsule length and number of primary branches and height of first capsule (Shivaprakash, 1986). Singh *et al.*(1986) observed that almost all traits exhibitied significantly high values for heterosis. About 327 per cent heterosis was reported for yield.

Ding *et al.*(1987) suggested that heterosis for number of capsules per plant, 1000 seed weight and number of seeds per capsules in hybird generations was related to parental values for these characters. Jadan and Mehrotra (1988) and Tu *et al.*(1988) reported that heterosis varied greatly among the crosses ranging from -24.8 to 141.8 per cent over the better parent. Osman (1989) reported 51.3 per cent heterosis for yield.

Anitha and Dorairaj (1990) reported significant positive heterobeltiosis and standard heterosis for seed yield. Reddy and Haripriya (1990) recorded 71 and 50 per cent heterosis for yield over mid and better parent respectively. Reddy *et al.* (1990) also reported high heterosis for seed yield. Sasikumar and Sardana (1990) observed heterobeltiosis for yield and capsules per plant. Sodani and Bhatnagar (1990) reported highest heterosis for seed yield per plant. Zhan *et al* . (1990) in a study of heterosis reported that all the F_1s had shown significant heterosis over mid, better and standard cultivars.

Anitha and Dorairaj (1991) reported heterosis for yield and yield attributing characters. Heterobeltiosis and standard heterosis up to 41 per cent for yield per plant (Ding *et al.*, 1991; Brindha and Sivasubramanian, 1992/93). Delgado and Layrisse (1992) reported highest levels of heterosis between indehiscent varieties for highest yield. Ray and Sen (1992) reported that heterosis over better and mid parents were pronounced for plant height, number of days to flowering, 1000 seed weight and seed yield. Heterosis was also significant and positive for number of capsules per plant and number of capsules per main stem in few crosses. Wide ranges of variation in heterosis

estimates of some reciprocal hybrids revealed that choice of pollen and seed parent is important for exploring hybrid vigour. Reddy and Haripriya (1993) studied the performance of 36 hybrids of *Sesamum indicum L.* involving cultivars of diverse origin and recorded -91.9 to 76.3 per cent and -47.1 to 72.5 per cent heterosis for seed yield over mid parent and better parent, respectively.

Fatteh *et al.*(1995) studied the extent of heterosis in a diallel cross of sesame for yield and yield components. Heterosis in yield was influenced by branches per plant and capsules per plant. The best hybrid combination showed 68.95 per cent heterobeltiosis. Navadiya *et al.*(1995) studied heterosis in sesame in a set of 10 x 10 diallel cross excluding reciprocals. The magnitude of heterosis was high for yield per plant, plant height, number of effective branches per plant and number of capsules per plant. Highest heterobeltiosis of 101.59 per cent was recorded for yield per plant. Quijade and Layrisse (1995) reported that mean yield of hybrids was clearly superior to the parental mean. Keneni *et al.*(1997) reported highest heterosis for seed yield. Manoharan *et al.*(1997) suggested that the hybrid vigour of even small magnitude for individual yield components may have additive or synergistic effect on the end product.

2.6 Path Coefficient and Correlation Analysis

The character associationship in a population forms an effective tool for the breeders to design his testing procedures for identifying superior genotypes. However, the extent of contribution of a particular character to any dependent variable may not be judged from

character associations. Path analysis of yield attributes bring out the relative importance of their direct and indirect effects and gives a clear understanding of their association with seed yield.

Rhind and Ba Thein (1933) studied the association of certain characters in the Burmese sesame types, like plant height, number of branches per plant, number of capsules per plant, seed yield per capsule and yield per plant, using the chi-square test. In India, Sikka and Gupta (1949) worked out simple, partial and multiple correlations between plant height, number of branches, number of pods per plant and yield was made by the number of capsules followed successively by the number of branches and plant height.

Angarita (1962) found that height of the first fruit, plant height and total yield were positively correlated. Lopez and Mazzani (1964) stated that pod length and number of seeds per pod were positively correlated. Muhammed and Dorairaj (1964) reported that the number of pods, 1000 seed weight and capsule size showed significant positive association with yield. The capsules per plant and plant height are stressed to be the major yield components by Dabral (1967) and Phadnis *et al.*(1970).

Khidir and Osman (1970) reported that seed size, number of pods per plant and stem height are good selection criteria for the improvement of yields in sesame. Ramachandran *et al.* (1972) and Sanjeeviah and Joshi (1974) reported positive correlations of yield with capsule number on the main branch and number of branches and between plant height and number of branches. Dixit (1976b) observed that the

number of capsules per plant and length of main fruiting branch are important character to be considered for yield improvement. Capsule number per plant had a maximum direct effect on seed yield (Kaushal *et al.* 1974 : Naphade and Kolte, 1974 ; Gupta and Gupta, 1977 ; Chavan and Chopde, 1981).

Thangavelu and Rajasekharan (1983b) in a study involving 40 diverse genotypes, indicated plant height, branch number, capsule number, 1000 seed weight and oil content to be positive association with seed yield per plant. Capsule number exhibited maximum positive direct effect on seed yield followed by 1000 seed weight. Reddy *et al.* (1984b) observed that seed yield was a major component of oil yield. Sharma and Chauhan (1984) concluded that number of capsules per plant, 1000 seed weight and oil content are the most important characters affecting yield. Bhele *et al* .(1987) revealed that a tall growth habit and high values for 1000 seed weight, number of capsules per plant, and number of seeds per capsules had positive direct effect on seed yield.

Ansari *et al.* (1988) revealed that plant yield is significantly correlated with the number of capsules, number of primary and secondary branches per plant. El Hifny *et al.* (1988) reported that capsule length, plant height, and height of first capsules were positively correlated with seed yield. Khan *et al.* (1988) suggested that developmental characters, especially plant height and stem thickness, have profound positive effect on seed yield in sesame. Li (1988) reported significant correlation of capsules per plant, seeds per capsule and 1000 seed weight with yield. Osman (1988) reported that number of capsules per plant was the most important yield attribute followed by

number and weight of seeds per capsule to be considered in selecting high yielding strains. Tu *et al.* (1988) observed that seed yield was significantly correlated with pod number per plant, pod axis length, plant height, and seed number per capsules.

Osman (1989) reported that number of capsules per plant and seeds per capsules were the most important yield contributing characters. Rong and Wu (1989) obtained highly significant positive correlation for seed yield and capsules per plant and they concluded that in selecting for high yielding genotypes, it will be preferable to focus on individual with moderate plant height, densely distributed capsules, large number of capsules per plant and high 1000 seed weight.

Deshmukh and Chavan (1990) revealed that the positive and significant correlation coefficient between seed yield per plant and number of capsules, total dry matter, capsules dry weight and number of seeds per plant at harvest. Rao *et al* .(1990) observed positive and highly significant correlations were observed between seed yield and attributing characters under consideration except 1000 seed weight. Most of the yield components were positively and highly correlated with each other. Raut *et al.* (1990) reported that seed yield showed positive significant association with number of capsules per plant, capsule length and 1000 seed weight. Path analysis indicated the importance of capsule length, number of capsules per plant and 1000 seed weight. Reddy and Ramachandraiah (1990) reported that number of branch and number of capsules per plant showed highly significant correlations with seed yield per plant. Zhan *et al.* (1990) recorded high significant correlation for capsule number per plant and seeds per capsule with yield per plant.

Pathirana and Kitto (1991) reported that the direct effect of 1000 seed weight with seed yield was positive in sesame. Reddy and Haripriya (1991) signed out seed yield per plant in its highest direct and indirect positive contributions to oil yield per plant.

Babu and Sivasubramanian (1992/93) reported significant positive correlation for capsules per plant, number of seeds per capsule and plant height with seed yield per plant. Pathak and Dixit (1992) indicated that the major factors influencing seed yield were days to maturity, numbers of branches per plant and capsule girth where as number of branches per plant, capsule girth and seeds per capsule were important for oil content. Reddy and Haripriya (1992) reported that number of capsules on primaries, number of capsules per plant and seed yield on primaries and secondaries were significantly correlated with seed yield. Path analysis revealed that seed yield on primaries and number of capsules per plant made the greatest direct contribution to seed yield. Vadhvani *et al.* (1992) reported that capsule number had the greatest direct effect on yield.

Adeyemo and Ojo (1993) reported significant and positive correlation for seed yield per plant and days to flowering with seed yield per hectre. Chandrasekhara and Reddy (1993a) reported that oil yield per plant had a positive phenotypic correlation and close genotypic correlation with seed yield, 1000 seed weight and number of seeds per capsule. Path analysis showed that seed yield per plant had the greatest direct effect on oil yield. Le and Zhang (1993) reported that the most important contributors to single plant yield was 1000 seed weight followed by effective pods per plant and number of seeds per

pod. Mishra *et al.* (1993) reported that branches per plant, fruiting nodes per plant and capsules per plant had the positive and significant correlation coefficients with the seed yield. The direct effect of capsules per plant and fruiting nodes per plant were also positive and highest in magnitude.

Fendel and Monteverde - Penso (1994) observed that number of capsules per plant had highest correlation with yield. Reddy and Dorairaj (1994) indicated that dry matter production and harvest index had the greatest positive direct effects on seed yield. Subramanian and Subramanian (1994) in a correlation study revealed the direction and magnitude of correlation between eight pairs of traits plant height, primary branches, secondary branches, capsule number per plant, seed number per capsule, 1000 seed weight, oil content and seed yield per plant. These traits varied with generations in both crosses involving two genotypes reciprocally. Single plant yield had a strong significant and positive relationship with capsule number in both generations of two cross combinations indicating the close link between the two traits.

Biswas and Akbar (1995) reported that seed yield was significantly and positively correlated with days to maturity, plant height, number of branches per plant, number of capsules per plant and 1000 seed weight. Dixit (1995) reported that yield was found to be positively associated with number of capsules per plant, length of main fruiting branch and number of capsules on main fruiting branch. These characters showed direct positive effect on grain yield. The maximum direct effect was observed for number of capsules on main fruiting branch. Mishra *et al.* (1995) reported that number of fruiting nodes per plant and capsule

number per plant had positive significant correlation coefficients with seed yield. The direct effects of these two traits on seed yield were also positive and highest in magnitude.

Kumar and Sivasamy (1996) in a correlation study involving diverse sesame lines revealed that the traits like number of capsules on main stem as well as in branches, leaf area and shoot weight showed positive correlation with yield. Sudharani *et al.* (1996) reported that direct effects of plant height, capsules per main stem and 1000 seed weight were greater for biparental programmes than in F_3 bulk populations. Thiyagarajan and Ramanathan (1996) revealed that seed yield per plant in sesame was positively correlated with number of capsules on branch, total dry matter production, plant height, oil content, capsule bearing portion of main stem, first capsule bearing node, harvest index, 1000 seed weight and capsule length and possessed positive direct effect and positive indirect effect via, other characters on seed yield. Singh *et al* .(1997b) in a study with 35 diverse lines, revealed that capsules per plant were highly significantly and positively associated with seed yield per plant followed by percentage oil content and plant height.

Seed yield exhibited significant and positive correlation with the siliqua per plant, seeds per siliqua and primary branches per plant and 1000 seed weight had maximum direct effect on seed yield (Tak, 1997). Govindarasu *et al.* (1998) reported that capsule number and branch number had consistently strong positive genotypic correlation and high positive direct effects with seed yield in all kinds of populations.

2.7 Male sterility

The occurrence of sterility in plants of economic importance has been observed in a number of cases and the causes leading to this condition were analysed and reported by many observers. In the majority of instances, sterility is confined to either the male or the female sex and even where it affects both, partial sterility is the more common condition.

Compared to female sterility male sterility is mostly seen in higher plants, because the male sporophyte and gametophytes are more vulnerable to intrinsic and extrinsic forces than the protected ovule and embryo sac. Detection is also easy because of the availability of large amount of pollen in the anther and easy testing. Moreover the male steriles have propagation potential in nature and breeding values in cultures which are lacking in female steriles (Kaul, 1988). Dorsey (1914) considered male sterility to be a condition resulting from defects leading to the non-formation of pollen or to the lack of functional pollen in it when formed. In a male sterile, either the pollen is not formed or if formed it is either nonviable or viable but incapable of effective fertilization under normal condition.

Classification of male sterility

Classification of male sterility in plants into various categories has been attempted by many investigators. Earlier classifications were made based on the developmental stage during which the anomaly appeared (Heslop-Harrison, 1971). Gottschalk and Kaul (1974) and Johns *et al.* (1981) classified male sterility into structural

(functional) and non-structural. Structural refers to absence of anther or archesporial tissue, lack of pollination resulting from indehiscence of anthers or spatial separation of male and female organs. Non-structural includes all abnormalities that interrupt micro-sporogenesis and micro-gametogenesis.

Edwardson (1970) classified the cytoplasmic-genic male sterility on the basis of its sources. These sources are from (i) intergeneric crosses. (ii) inter specific crosses (iii) intra-specific crosses. and (iv) apparently occurring spontaneously. But a most acceptable classification was proposed by Kaul (1988) where he had classified based on phenotypic and genotypic basis. On phenotypic basis, sporogenous structural and functional male sterility were grouped while genotypic basis has genic, cytoplasmic and genic-cytoplasmic types. The non-genetic male sterility may arise by chemical treatments, environmental manipulations or physiological and biochemical alterations. Of the various known male sterility types, the genetic types (genic and genic-cytoplasmic) have high breeding values. This is because, in addition to lack of development or functioning of male sex, these have two basic characteristics viz., genetically conditioned male sterility and unimpaired female fertility.

Genetics of male sterility

Frankel and Galum (1977) suggested three categories of inheritance of male sterility viz., Mendelian (genic), maternal (cytoplasmic) or a combination of the two (cytoplasmic -genic). With genic male sterility, only one plasmatype (s) exists, interacting with a

recessive plasmon sensitive (ms) and a dominant fertility restoring (Ms) allele. With cytoplasmic male sterility, normal (N) and male sterility inducing (S) plasmatypes exist, but only recessive plasmon sensitive alleles are present in the population. With cytoplasmic-genic male sterility, normal (N) and male sterility inducing (S) plasmatypes exist, the latter interacting with a recessive plasmon sensitive (ms) and a dominant fertility restoring (Ms) allele.

Genic male sterility

The presence of a single recessive gene in homozygous condition leads to the expression of genic male sterility (Frankel and Galum, 1977). In majority of spontaneously arising and induced mutants, the sterility was controlled by single recessive gene (ms) (Kaul, 1988). A few cases of double recessive male sterility have been reported eg. in cotton by Weaver (1968), in medicago, it is controlled by recessive and polygenes (Childers and Mc Lennan, 1960). The reason for variable gene number reported by various authors is because, the genotypes they studied had already a few ms genes in their genomes and they become steriles when the remaining required number of genes were added to them (Kaul, 1988).

Meiotropic effects of male sterility alleles or close linkages with these alleles have been reported in a number of cases. Certain marker phenotypes associated with male sterility genes can lead to a more efficient hybrid seed production programme (Frankel and Galum, 1977).

Cytoplasmic-genic male sterility

Cytoplasmic-genic male sterility (CGMS) was discovered in 1921 in two stains of flax *(Linum usitatissimum L.)* (Bateson and Gairdner, 1921). Since it has been discovered in over 150 plants species of 50 genera from 20 families (Edwardson, 1970; Laser and Lersten, 1972; Hanson and Coude, 1985; Kaul, 1988). Forms of cms occur frequently in progeny of many controlled crosses (both intra and interspecific) in crop plants and their behaviour has been reviewed by Edwardson (1970). Induction of male sterility and development of male sterile line through genome substitution in the cytoplasm of the wild species through continuous backcrossing with the genome of the cultivated varieties has been successfully attempted in many crop plants (Stephens and Holland, 1954; Burton, 1965; Renard *et al.*, 1992; Rao *et al.,* 1994; Dalmacio *et al.*, 1995; Ariyanayagam *et al.*, 1995).

However reports on male sterility in sesame are a few and that too limited to genic male sterility. Since this sterility was accompanied by female fertility reduction, it could not be used for commercial seed production (Brar, 1982).

Male sterility in sesame was first reported by Roy (1931). Kumar and Abraham (1941) found complete male and female sterility in one or two sterile individuals, observed in a large population of sesame plants of different varieties. They observed no difference between the sterile and fertile plants in somatic chromosome number and morphology. Various types of abnormalities during meiosis in PMC leading to formation of abnormal daughter cells resulted in complete

male sterility. Failure of gametophyte development was responsible for sterility in the female side. Later Kumar and Rao (1945) reported sterility to be controlled by a single pair of recessive gene.

Malaguti and Mazzani (1958) observed male-female sterility to be partial. An abnormal type of sesame shedding of corolla and stamens even before self fertilization, in local and exotic collections was identified by Pathak and Bajpaye (1965). The pollen sterility was only 28 per cent and pollination gave normal seed set. Dabral (1968) identified in F_3 generation of intraspecific crosses, plants showing self incompatibility during early period of flowering which became self compatible at the end of the flowering period. But pollination of these infertile plants led to browning of corolla and stylar base resulting in inhibition of pollentube entry and subsequent non-fertilization. The character was reported to be controlled by one or more recessive genes (Dabral and Mandoli, 1974).

The percentage of pollen fertility decreased with increase in doses of gamma irradiation. Chromosome mutation are probably the major cause of all mutagen induced sterility (Gaul, 1970; Nair and Nair, 1977). Nair and Nair (1978) studied viable mutants with gamma irradiation and reported that dwarf mutants were the most frequent types. Other mutants were lanky, had flat stems and branched early, had twisted, curly, small, clustered or forked leaves and with abnormal flowers. The abnormal flower mutants had their flowers modified into vegetative parts.

Chauhan and Kinoshita (1980) reported pollen sterility in plants treated with gametocides. They classified the treated plants

into four groups namely normal, semisterile a, semisterile b and completely sterile. The abortion of pollen was associated with tapetal abnormalities similar to those exhibited by plants with cytoplasmic or nuclear male sterility. Osman (1981) reported that male sterility in sesame was controlled by a single recessive gene with stable effects in different environment. Brar (1982) studied three genetically diverse single plant selections, exhibited male sterility in the field conditions and reported that this was due to shortened filaments of the anther so that anthers did not reach the stigma, the lack of viable pollen and the failure of the anthers to dehisce at maturity. The male sterility in this case was determined by a single recessive gene pair, the expression of which was controlled by cold night temperature in the field. These had proved to have good male sterility in the green house condition also.

From the progenies of five sesame lines obtained from Venezuelan seed stock, 28 male sterile plants segregated (Osman and Yermanos, 1982). These resembled the male fertiles in height, branching pattern, leaf size and maturity, but had flattened, translucent greenish indehiscent anthers. Microscopic examinations revealed that sterile anthers had no endothecium and that their pollen lacked exine and had no definite wall structure. Observations on segregants indicated that the male sterility was stable and could easily maintained under green house and open field conditions. The anomaly was found to be controlled by a recessive gene. Seed set on male sterile plants following hand pollination with normal pollen was high indicating high female fertility. These lines exhibited complete female fertility and stability under varying growing conditions.

Rangaswamy and Rathinam (1982) studied the effect of gamma rays and EMS on two varieties of sesame and their hybrids. In M_2 generation male sterile plants were noticed in six treatments. About 30 plants were noticed to develop shrivelled anthers containing no pollen at anthesis, pollen stainability ranged from 0-10 per cent, while normal plants showed 79 per cent. Male sterility in these mutants was found to be monogenically recessive.

Reddy (1984) isolated male sterile lines from M_2 generation of gamma irradiated population. He reported reduced pollen and seed fertility with higher doses. Datta and Biswas (1987) revealed 1.08 per cent pollen sterility in untreated plants and pollen sterility also increased ranging from 1.24 to 12.85 per cent with increased dosage of gamma ray. Tu *et al.* (1991) reported high heterosis in a full diallel cross of six varieties, of which two were genic male sterile lines. Zhan *et al.* (1991) reported high heterosis with gametocide applied population. FW 450 gametocide proved to be most effective with 90-100 per cent pollen sterility, and also with long duration of gametocidal effect.

Ganesan (1995) screened M_1 generations of 50 kR. gamma irradiation and 1.0 per cent EMS treated seeds for pollen sterility and two male sterile plants with more than 90 per cent sterile pollens were identified from the EMS treatment. He reported that sibmated progenies segregated as 1:1 in the M_2 generation indicating that the male sterility system in sesame is governed by monogenic recessive allele. Mary and Jayabalan (1995) observed floral and sterile mutants in EMS treated population. Tu *et al.* (1995) reported a male sterile line (ms 86-1) which has good agronomic characters. They also reported that this line

with 100 per cent sterility and a frequency of 50 per cent male sterile plant is usable in hybrid seed production and was bred by several generations of successive sibcrossing and back crossing. Studies in morphology proved that male abortion is complete and that female fertility is normal. Wang *et al* (1995) studied the effectiveness of hybrid seed production by utilizing genic male sterility and reported that sterility of the male sterile lines was as high as 99 per cent and the percentage of cross pollination was over 99.5 per cent. The yield of hybrid seed ranged from 319.5 to 637.5 kg/ha. Pfahler *et al.* (1996) studied the genetic and environmental variation in anther, pollen and pistil dimensions and indicated that these are greatly influenced by genotype, environment and the genotype x environment interaction.

The evidence for cytoplasmic male sterility in sesame was reported for the first time by Prabakaran *et al.* (1995) in wide hybridizations. Interspecific crosses were effected using four genotypes of *Sesamum indicum* and its different wild related species. Among the several different interspecific hybrids produced and analysed, reciprocal difference for male sterility was observed in a cross involved in *S. indicum and S. malabaricum.* The pollen sterility was very high when *S. malabaricum* was used as ovule parent. The highly pollen sterile F_1 plants of *S. malabaricum x S. indicum* upon backcrossing to *S. indicum* parent resulted in higher proportion and frequent occurrence of male sterile plants. The degree of pollen sterility increased by each back cross.

From the foregoing, it is evident that adequate information in respect of variability, heritability and related genetic components is already available from previous investigations. But

pertinent data on cardinal aspects of genetic diversity, scientific basis of male sterility in sesame, economic exploitation of male sterility created through induced mutagenesis and wide hybridization are scanty. Sesame being an underexploited crop of immense potentials deserves detailed investigations through to throw light on the above areas besides developing promising cultures for yield increase through exploitation of male sterility.

MATERIALS & METHODS

3. MATERIALS & METHODS

The present investigations were conducted in the Department of Plant Breeding and Genetics, College of Horticulture, Kerala Agricultural University. Field trials were laid out at Onattukkara Regional Agricultural Research Station, Kayamkulam, of the Kerala Agricultural University during 1997-1999. The soil at this region is predominantly sandy loam and it constitutes the main sesame growing area in the state. All cultural operations were carried out as per the package of practice recommendations of the KAU 1996.

The investigations consisted of three sets of experiments as given below :

Experiment I was aimed to study the relative contribution of different plant characters to total divergence using Mahalanobis D^2 analysis.

Experiment II was aimed at production of intervarietal hybrids through crossing selected lines from experiment I, to study the combining ability in order to identify the best general combiners using Diallel analysis.

Experiment III was aimed at induction of male sterility through physical and chemical mutagens and study the inheritance of male sterility. It also aimed at production of interspecific crosses of the general combiners with the wild *S. malabaricum* L. to explore the possibility of development of cytoplasmic male sterility.

3.1 Experiment

3.1.1. Materials

Sixty genotypes representing accessions and varieties of various eco-geographical conditions through out India constituted the materials for the study. Accessions and varieties with their sources are given in Table 1. Among the sixty genotypes, the five varieties released from KAU were also included.

3.1.2. Methodology

Seeds of all the 60 genotypes were sown in the field during October 1997, with an inter row spacing of 45 cm between genotypes. Plots consisted of two rows of 3m length. Plant to plant spacing was maintained as 15 cm within a genotype. The experiment was conducted in a randomised block design with two replications.

Observations on the following growth and yield parameters were recorded for each genotype, on ten randomly selected plants in each replication.

a. Plant height.

Height of the plant after completion of the flowering was measured in cm from the base to the tip of the main branch.

b. Number of days to 50 percent flowering

Number of days from sowing to flowering of 50 percent of the population was taken.

Table 1 Particulars of genotypes selected for D2 analysis

Sl No.	Genotypes	Sources	Duration
1	IC-131496	Punjab	60 days
2	IC 132681	Amaravathi, Maharashtra	71
3	IC 131566	"	63
4	IC 026303	Amaravathi, Maharashtra	66
5	IC 026304-1	"	69
6	IC 131873-1	Amaravathi, Maharashtra	70
7	IC 204123	Vishahapattanam, Andhra Pradesh	69
8	IC 204126	Namavaram, Andhra Pradesh	70
9	IC 204132	Marripaleni, Andhra Pradesh	67
10	IC 204140	Janakirampuram, Andhra Pradesh	64
11	IC 204141	Janakirampuram, Andhra Pradesh	70
12	IC 204153	Veeralankapally, Andhra Pradesh	67
13	IC 204154	Veeralankapally, Andhra Pradesh	67
14	IC 204156	Gokavasam, Andhra Pradesh	69
15	IC 204167	Narayanapuram,Andhra Pradesh	65
16	IC 204168	Narayanapuram,Andhra Pradesh	62
17	IC 204632	Hosagrara, Karnataka	70
18	IC 204637	Begir, Karnataka	62
19	IC 204643	Dharwad,Karnataka	79
20	IC 204662	Pathanamthitta, Kerala	67
21	IC 204663	Kayamkulam, Kerala	70
22	IC 127285	Chikmangalloor, Karnataka	67
23	IC 204986	Assam	64
24	IC 204991	Assam	66
25	IC 205005	Vaddadi, Andhra Pradesh	62
26	IC 205179	Adilabad, Andhra Pradesh	62
27	NIC 16252	Warangal, Andhra Pradesh	68
28	NIC 16254-A	Warangal, Andhra Pradesh	67

29	NIC 17320-A	Dhrakanal, Orissa	70
30	NIC 17905	Dhrakanal, Orissa	69
31	NIC 17925-A	Jalore, Rajasthan.	63
32	NIC 17936-A	Jodhpur,Rajasthan.	65
33	SI-1225	Himachal Pradesh	69
34	Vellanikkara Local	Vellanikkara, Kerala	70
35	VS-9501	Vridhachalam, Tamil Nadu	63
36	VS-9701	Vridhachalam, Tamil Nadu	65
37	AT-78	Amerli, Gujarat	69
38	JTS-25	Tikamgarh, Madhya Pradesh	58
39	JTS-14	Tikamgarh, Madhya Pradesh	62
40	PKDS-1	Powarkheda, Madhya Pradesh	59
41	PKDS-2	Powarkheda, Madhya Pradesh	70
42	SIK-004	Jalgaon, Maharashtra	66
43	PKDS-3	Powarkheda, Madhya Pradesh	60
44	SIK-113	Jalgaon, Maharashtra	60
45	Mah-60	Jalgaon, Maharashtra	71
46	RT-281	Mandore,Rajasthan.	73
47	RT-283	Mandore,Rajasthan.	63
48	RT-293	Mandore,Rajasthan.	59
49	OS-2	Bhubaneswar,Orissa	57
50	OS-5	Bhubaneswar,Orissa	58
51	OS-15	Bhubaneswar,Orissa	65
52	MT-2	Mauranipur, Uttar Pradesh	70
53	MT-9	Mauranipur, Uttar Pradesh	71
54	VS-350	Vridhachalam, Tamil Nadu	62
55	HT-36	Hissar, Haryana	68
56	Kayamkulam-1	Kayamkulam, Kerala.	69
57	Thilothamma	Kayamkulam, Kerala.	65
58	ACV-1(Surya)	Vellayani,Kerala.	68
59	ACV-2(Soma)	Vellayani,Kerala.	71
60	Thilak	Vellayani,Kerala.	68

c. Number of branches per plant.

Number of branches was counted at physiological maturity, when the leaves turn slightly senile.

d. Percentage pollen sterility.

Anthers were taken from mature flower buds and pollen grains were stained in glycerine-aceto carmine. The well stained and properly filled pollen grains were counted as fertile and the others as sterile. Sterility was estimated as percentage of number of sterile pollen grains to the total number of pollen grains scored.

e. Number of capsules per main stem.

Actual count of capsules on main stem was taken.

f. Number of capsules per plant.

Total number of capsules on each plant was counted.

g. Capsule length.

Length of capsule was measured in cm.

h. Number of locules per capsules.

Number of locules in each capsule was counted.

i. 1000 seed weight.

Weight of 100 seeds (g) was taken and multiplied by 10.

j. Seed yield per capsule.

Weight of seeds (g) in each capsule was taken.

k. Seed yield per plant.

Weight of seeds (g) in each plant was taken.

1.Presence of pest and diseases was noted.

m. Oil Content.

Oil content was estimated by cold percolation method suggested by Kartha and Sethi (1957). One gram of seed was ground with $K_2 SO_4$ and a pinch of granite powder, then the oil was extracted with acetone in percolation tube.

3.1.3 Statistical Analysis

3.1.3.1. Components of heritable variation.

a) Variability

Variability existing in the various characters under observation was estimated as per the procedure suggested by Burton (1952). The estimates of phenotypic coefficient of variation and genotypic coefficient of variation were classified into less than 10 per cent as low, 10-20 per cent as moderate, and more than 20 per cent as high.

b) Heritability

Heritability in broad sense was calculated according to Hanson *et al.* (1956). The heritability was categorised into less than 30 per cent as low, 30-60 per cent moderate and 60-100 per cent as high.

c) Genetic advance

The expected genetic advance under selection was estimated by the formula suggested by Johnson *et al.* (1955b). Genetic advance was categorised as less than 10 per cent as low, 10.20 per cent moderate, and more than 20 per cent as high.

3.1.3.2. Mahalanobis D^2 analysis

Replication wise values for each character of each genotype was used for analysis of variance. After testing the difference, a simultaneous test of significance of differences with regard to the pooled effects of the nine characters under study was carried out using Wilk's criterion (Rao, 1948).

Original mean values were then transformed into uncorrelated mean using pivotal condensation of common dispersion matrix. From the uncorrelated variables, the actual values of D^2 between any two genotypes based on 13 characters were then calculated. In order to determine the population constellation, all the genotypes were grouped into a number of clusters on the basis of D^2 values as suggested by Suresh and Unnithan (1996).

3.2. Experiment II

3.2.1. Materials

Eight genetically diverse genotypes representing the eight clusters identified in Expt.I formed the materials for this experiment. Selection of genotypes from each cluster was done based on multivariate analysis of yield and yield components. Selected genotypes had diverse characteristics, indicating distinct genetic base. Out of the eight genotypes selected, two were popular varieties of Kerala and six belonged to different regions of India. The parentage and source of the selected genotypes are given in Table.2 and Plate 1, 2 and 3.

3.2.2. Methods

3.2.2.1 Crossing

Seeds of the eight selected genotypes for Diallel analysis were raised in a crossing block during January 1998 at Onattukkara Regional Agricultural Research Station, Kayamkulam. Fifty six cross combinations (8x7) between eight genotypes in all possible combinations including reciprocals were effected during March-April 1998. Emasculation and hybridization were carried out as per Thangavelu and Nallathambi (1982). The flowers of the female parents were hand emasculated a day prior to anthesis during evening hour. The corolla tube along with the four epipetalous stamens was removed and the pistil was covered with a small moistened soda straw (4 cm long) until fertilization took place (maximum 3 days).

Table 2 Parents selected for crossing for Diallel analysis.

Sl. No.	Parents	Source	Cluster	Desirable Characters	Designation
1.	Thilothamma	Kayamkulam, Kerala	VIII	Multipoded nature	n_1
2.	Thilak	Vellayani, Kerala	I	Well adapted and popular variety in Kerala	n_2
3.	OS -2	Bhubaneswar, Orissa	V	High yield per plant, capsule length	n_3
4.	VS-350	Vriddhachalam, Tamil Nadu	VII	Capsule length, yield per capsule	n_4
5.	IC 204126	Namavaram, Andhra Pradesh	IV	Number of capsules per plant, and branches per plant	n_5
6.	IC 204156	Gokavasam, Andhra pradesh	VI	1000 seed weight	n_6
6.	NIC 17925-A	Jalore, Rajasthan	II	High oil content	n_7
8.	SI 1225	Himachal Pradesh	III	High oil content	n_8

Crossing was done on the following day between 5.00 to 7.30 AM. Fresh pollen from the selected male parents were collected and dusted on to the stigma of the emasculated flowers. The crossed flowers were again covered with soda straw to avoid contamination. Crossed pods and parental pods were harvested, sundried and storied separately.

3.2.2.2. Raising F_1 generation and parents

F_1 seeds of all 56 cross combinations and eight parental lines were sown in a randomized block design in two replications during October 1998. Each genotype was grown in a single row of six meter and each consisted of 40 plants with a plant to plant and row to row spacing of 15 cm and 25 cm respectively. Data were collected from ten random plants for recording observations as for the previous experiment.

3.2.3. Statistical Analysis

3.2.3.1. Diallel analysis

An 8 x 8 full diallel analysis including reciprocals was carried out. Both Griffing's and Hayman's approaches were employed.

Griffing's approach

One of the four methods suggested by Griffing (1956), involving parents (n), n(n-1)/2 F_1s and reciprocals was utilized. In this method general combining ability, specific combining ability and reciprocal combining ability effects were estimated for 11 characters observed in F_1 generation.

Hayman's approach

Using this approach (Hayman, 1954), the parameters like variation due to additive effect (D), the mean of F_1 over arrays (F), components of variation due to the dominance, effects of the genes (H_1,H_2), dominance effect (h_2), mean degree of dominance (H_1/D)½, proportion of gene with positive and negative effects in the parents (H_2/ $4H_1$), proportion of dominant and recessive genes in the parents (KD/ KR) and the number of genes which control the characters and exhibit dominance were estimated for 11 characters observed in F_1 generation.

3.2.3.2. Heterosis

Different types of heterosis namely standard heterosis (based on standard variety, SV), relative heterosis (based on mid parental value, MP) and heterobeltiosis (based on better parental value, BP) were estimated for 11 characters recorded in the F_1 generation.

3.3. Experiment III

3.3.1. Materials

Two best general combiners selected from the Experiment II were utilized to develop male sterility through induced mutagenesis and wide hybridization with *Sesamum malabaricum*.

3.3.2. Methods

3.3.2.1. Induced mutagenesis

a. Irradiation .

The seed samples, each consists of 600 seeds, of the two selected varieties kept in butter paper bags, were introduced into the Co^{60} Gamma cell installed at Radio Tracer Lab, Kerala Agricultural University, Vellanikkara, and exposed to radiation for appropriate periods to irradiate with gamma rays from 100gy to 600gy.

b. Chemical mutagen

Seeds were presoaked for two hours by submersion in distilled water. The different concentrations of mutagen were prepared using double distilled water. The presoaked seeds were treated by keeping immersed in the mutagen solution of concentration 0.2 to 1.0 per cent for four hours with intermittent shaking. The volume of mutagen solution was about 10 times the volume of seeds. The solution was frequently shaken to facilitate uniform absorption of the mutagen by the seeds. The treatment was conducted at room temperature of 27±1°C. Immediately after treatment, the seeds were thoroughly washed in running tap water for an hour and sown in the field. The standard consisted of seeds soaked in distilled water.

3.3.2.2. Handling of mutagen treated materials

a) M_1 generation

The mutagen treated seeds were sown immediately after the treatments in a randomised block design with four replications at

the rate of 100 seeds per replication. Normal agronomic practices were followed. The following observations were recorded in the M_1 generation.

i) Germination.

The emergence of radicle was taken as the criterion for germination and counts were made daily from fourth to tenth day after sowing.

ii) Survival

The surviving seedlings on the 30th day after sowing were counted. All plants with green leaves were counted as surviving plants.

iii) Pollen fertility

The observations were recorded in 40 randomly selected plants per replication for each treatment. The pollen grains were stained with 1:1 acetocarmine-glycerine solution. The stained and well filled pollen were counted as fertile while the non-stained and shrunken ones were scored as sterile. Based on pollen stainability percentage of sterile pollen to the total number of pollen grains was estimated.

b. M_2 generation

The Seeds of individual M_1 plants which had more than 75% pollen sterility were sown in progeny rows. The M_2 seedlings thus raised were critically examined to spot out sterile mutants. In the sterile plants, flowers of one branch were selfed and in another, flowers were allowed to open pollinate. The remaining branches were sib-mated with

normal fertile sister plants and the seeds were collected separately. Screening for viable mutants was done at the time of flowering.

3.3.2.3. Estimation of mutagenic effectiveness and efficiency.

The mutagenic effectiveness and efficiency for sterility based on the recovery of viable mutants were estimated by adopting the formulae suggested by Konzak *et al* (1965).

$$\text{Mutagenic effectiveness} = \frac{M}{\text{t.c or kR.}} \times 100$$

$$\text{Mutagenic efficiency} = \frac{M}{L} \times 100 = \frac{M}{S} \times 100$$

where; M - Viable mutation per 100 M_2 plants

t - Period of chemical mutagen treatment in hrs

c - Concentration of chemical mutagen in millimoles.

kR - Dose of gamma rays in kilorads.

L - percentage of lethality (Survival reduction among thirty days old M_1 seedings)

S - percentage of sterility (Reduction in M_1 seed fertility).

3.3.2.4. Screening for sterile plants in M_3 generation

Seeds collected from sibmated, selfed and open pollinated capsules of sterile plants isolated in M_2 were sown in M_3 generation as individual progeny rows to study the breeding behaviour. The plants raised in M_3 generation were screened for pollen stainability.

Viable mutants obtained from M_2 plants with floral abnormalities were also screened and examined for pollen fertility. The segregation patterns of sterile and fertile plants were also calculated.

3.3.2.5 Inter specific hybridization

Selfed seeds of the best combiners viz, Thilak and OS-2 selected from Experiment II were sown along with seeds of wild species *S. malabaricum* in earthen pots.

a) Emasculation and crossing.

Emasculation of female flowers was done during evening hours a day prior to anthesis and crossing was done on the following day between 5.00 and 7.30A.M.

3.3.2.6. Evaluation of F_1 interspecific hybrid.

The seeds extracted from crossed capsules were raised along with the selfed seeds of the parents in earthen pots during following season. The germination percentage, duration taken for germination and survival percentage were recorded. At the time of flowering all the plants were screened for pollen stainability.

In order to compare the behaviour of F_1s and progenies of the inter-specific combinations with reference to a few distinct phenotypic characters, the following plant parts were also studied.

Stem - Colour, hairiness

Leaf - shape, margin, size and colour

Seeds - size, colour, surface.

The reciprocal differences were also recorded.

3.3.2.7. Backcross 1.

All the surviving F_1 plants of the cross *S. malabaricum* x *S. indicum* [viz, Thilak and OS-2] which showed high percentage of sterility were backcrossed with respective cultivar parent as recurrent pollen parent.

The seeds obtained from backcrossed capsules of F_1 sterile plants were sown in BC_1 generation along with selfed seeds of cultivar parents. They were subjected to screening for sterile plants based on pollen stainability. Only those which showed high percentage of sterile pollen were labelled and backcrossed to recurrent parents.

3.3.2.8. Backcross 2

Only those plants showing high percentage of pollen sterility were selected and backcrossed with respective recurring pollen parent. Seeds thus obtained were sown in BC_2 generation along with selfed seeds of cultivar parents. Screening of sterile plants were carried out and sterile plants were labelled.

3.3.8. Backcross. 3.

Labelled sterile plants in BC_2 generations were backcrossed with respective recurrent pollen parent. Crossed seeds were collected in each case for future studies.

RESULTS

4. RESULTS

Success in crop improvement depends on the magnitude of genetic variability and the extent to which the desirable characters are heritable. The estimates of variability in respect of yield and associated characters and their heritable components in the materials with which the breeder is working are therefore, prerequisites for any crop breeding programme. In the present study, the extent of genetic variability for nine quantitative characters in a set of 60 diverse genotypes was estimated.

4.1 Experimental I

4.1.1. Genetic Variability

The abstract of analysis of variance of nine quantitative characters is presented in Table 3. The analysis of variance in general, revealed highly significant differences among the 60 genotypes for all characters studied.

The data on range, mean and estimates of genetic parameters are presented in Table 4. The genotypes showed wide range of variation for all the characters studied plant height varied from 95.05 cm to 148.15 cm with a mean value of 116.82cm. Number of days to 50 per cent flowering varied from 28 to 41.5 days with its average 35.8 days. Number of branches per plant ranged from 0.40 to 4.40 with mean value of 2.12. Number of capsules per mainstem and per plant ranged from 15.0 to 29.3 and 22.5 to 45.1 and its average 20.37 and

Table 3 Analysis of variance for important quantitative characters of 60 sesame accessions

Sources of variation	Degrees of freedom	Mean Squares								
		Plant height	No. of days to 50% flowering	No. of branches per plant	Capsules per main stem	Capsules per plant	Capsule length	1000 seed weight	seed yield per capsule plant	Seed yield per
Replication	1	146.269	8.0437	0.5880	19.5213	39.7701	0.0121	0.1654	0.0028	0.560
Genotypes	59	271.905**	33.1496**	1.2193**	27.9848**	55.1791**	0.0854	0.1917**	0.0031**	1.767**
Error	59	80.883	5.0524	0.1860	6.7527	15.0650	0.0295	0.0749	0.0007	0.156

Table 4 Range, Mean and Estimates of genetic parameters for important quantitative character of 60 sesame accessions

Sl No	Characters	Range	Mean	PCV(%)	GCV(%)	Heritability (broad sense) h^2	GA as percent of mean
x_1	Plant height	95.05-148.15	116.82	150.99	81.76	0.5415	12.67
x_2	Number of days to 50% flowering	28.0-41.5	35.8	53.35	39.24	0.7356	18.49
x_3	Number of branches per plant	0.40-4.40	2.12	33.02	24.52	0.7426	52.83
x_4	Capsules per main stem	15.0-29.3	20.37	85.27	52.13	0.6114	22.34
x_5	Capsules per plant	22.5-45.1	30.70	114.40	65.34	0.5712	22.70
x_6	Capsule length	1.92-2.64	2.30	2.18	1.31	0.6009	11.76
x_7	1000 seed weight	2.20-3.47	2.82	4.61	2.13	0.4620	12.05
x_8	Seed yield per capsule	0.08-0.21	0.14	0.70	0.21	0.3000	7.04
x_9	Seed yield per plant	1.65-7.25	2.98	32.20	27.17	0.8438	57.12

30.70 respectively. Capsule length varied from 1.92 cm to 2.64cm with a mean value of 2.30 cm. In the case of 1000 seed weight, range of variation was from 2.20 g to 3.47g with an average of 2.82 g. Seed yield per capsule and seed yield per plant ranged from 0.08 to 0.21g and 1.65 to 7.25 g with averages of 0.14g and 2.98g respectively.

4.1.2 Phenotypic and Genotypic coefficient of variation.

Among the quantitative characters studied, high magnitude of phenotypic and genotypic coefficient of variations (PCV and GCV) were observed for plant height (150.99 and 81.76), capsules per plant (114.40 and 65.34) and capsules per mainstem (85.27 and 52.13). Number of days to 50 percent flowering (53.35 and 39.24), number of branches per plant (33.02 and 24.52) and seed yield per plant (32.20 and 27.17) recorded moderate GCV and PCV. Very low value of PCV and GCV was recorded for seed yield per capsule, (0.70 and 0.21), 1000 seed weight (4.61 and 2.13) and capsule length (2.18 and 1.31).

4.1.3 Heritability

Among the nine quantitative characters studied the heritability estimate in the broad sense ranged from 30 per cent for seed yield per capsule to 84.38 percent for seed yield per plant. Heritability estimates of characters namely, number of branches per plant (74.26%), number of days to 50 percent flowering (73.56%), capsules per mainstem (61.14%) and capsule length (60.09%) were found to be high. Capsules per plant (57.12%), plant height (54.15%) and 1000 seed weight (46.20%) exhibited moderate heritability.

Characters, plant height and capsules per plant exhibited high genotypic coefficient of variation but with moderate heritability in broad sense. Number of branches per plant, number of days to 50 per cent flowering, capsules per main stem and seed yield per plant exhibited high values for genotypic coefficient of variation and heritability in the broad sense.

4.1.4 Correlation

The genotypic and phenotypic correlation coefficients between yield and eight yield component characters and the genotypic and phenotypic correlation coefficients among the component characters *inter se* are presented in Table 5.

The magnitude of genotypic correlations with yield were found to be higher than phenotypic correlations for all characters except for number of days to 50 per cent flowering, number of branches per plant, 1000 seed weight and seed yield per capsule. The characters number of days to flowering, number of branches per plant and seed yield per capsule recorded significant negative values for genotypic correlation coefficient. The phenotypic correlation for number of branches per plant with yield was nonsignificant, while for seed yield per capsule recorded positive and significant phenotypic correlation with yield per plant. Except 1000 seed weight, all other characters recorded highly significant genotypic correlation with seed yield per plant. Maximum correlation (0.929) was recorded for capsules per main stem with seed yield, followed by capsules per plant (0.773) and capsule length (0.722).

Table 5 Genotypic (Upper Diagonal) and phenotypic (lower diagonal) correlation coefficients between yield and assoicated character in 60 accessions

Characters	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
x_1		0.302*	0.344**	0.054	0.355**	0.389**	-0.178	0.389**	0.484**
x_2	0.168		0.937**	-0.713**	0.605**	-0.211	-0.734**	0.107	-0.298*
x_3	0.310*	0.273*		-0.558**	0.975**	-0.845**	-0.612**	-0.043	-0.737**
x_4	0.145	-0.312*	-0.305*		0.549**	0.365**	0.955**	0.144	0.929**
x_5	0.432**	-0.068	0.259*	0.318*		0.261*	0.295*	0.172	0.773**
x_6	0.010	-0.366**	-0.176	0.340**	0.201		0.840**	-0.338**	0.722**
x_7	0.027	-0.408**	-0.059	0.211	0.035	0.311*		0.007	0.067
x_8	0.046	-0.081	0.000	0.034	-0.026	0.216	0.286*		-0.749**
x_9	0.069	-0.0330**	-0.181	0.431**	0.066	0.337**	0.337**	0.301*	

Correlation coefficient among yield components showed that number of branches per plant had significant positive association with capsules per plant and recorded the maximum value for genotypic correlation coefficient (0.975), intercorrelation between capsules per mainstem and 1000 seed weight recorded a value of 0.955 and that between number of days to 50 per cent flowering and number of branches per plant recorded a value of 0.937.

With 1000 seed weight, all the characters except plant height recorded significant genotypic correlation coefficient values. However, number of days to 50 per cent flowering and number of branches per plant were negatively correlated with 1000 seed weight. Number of capsules per plant recorded highly significant positive correlations with all the characters except seed yield per capsule. Plant height was found to be positively and significantly correlated at genotypic level with number of days to 50 per cent flowering, number of branches per plant, capsules per plant, capsule length, seed yield per capsule and seed yield per plant.

4.1.5. Genetic diversity

Potent variability in indigenous cultivars is the result of prolonged natural and artificial selection which is heritable and hence important. The D^2 statistic permits precise comparison among all possible pairs of populations before effecting actual crosses in modelling the varieties in a desired genetic architecture.

4.1.5.1. Clustering

The analysis of variance presented above clearly revealed highly significant variability among the genotypes in respect of all the nine characters studied (table 3).

Clustering pattern of 60 genotypes is given in Table 6. Based on the relative magnitude of D^2 values these genotypes were grouped into eight clusters (Table 6). Clustering pattern revealed that cluster I and III were the largest groups, each consisting of 13 genotypes. The next highest number of nine genotypes was present in cluster VII. Cluster II consisted of eight genotypes, cluster VIII had seven genotypes, clusters IV and VI, had four genotypes each while cluster V had only two genotypes.

It was noticed that the genotypes developed at the same location were grouped into different clusters. For example, of the five varieties from Kerala, Kayamkulam 1 and Thilak were grouped in cluster I, ACV 2 in cluster VI, ACV 1 in cluster VII and Thilothamma in cluster VIII. Similarly varieties developed from Vriddhachalam, Tamil Nadu went to different clusters.

4.1.5.2. Intra and Inter cluster distances

Average D^2 values at intra and inter cluster levels are presented in Table 7. On the basis of D^2 values spacial diagram of clusters and their mutual relationship is represented in fig.1.The computed D^2 values varied from 15.90 to 389.75 showing divergence among different strains.

Table 6 Clustering pattern of 60 sesame genotypes

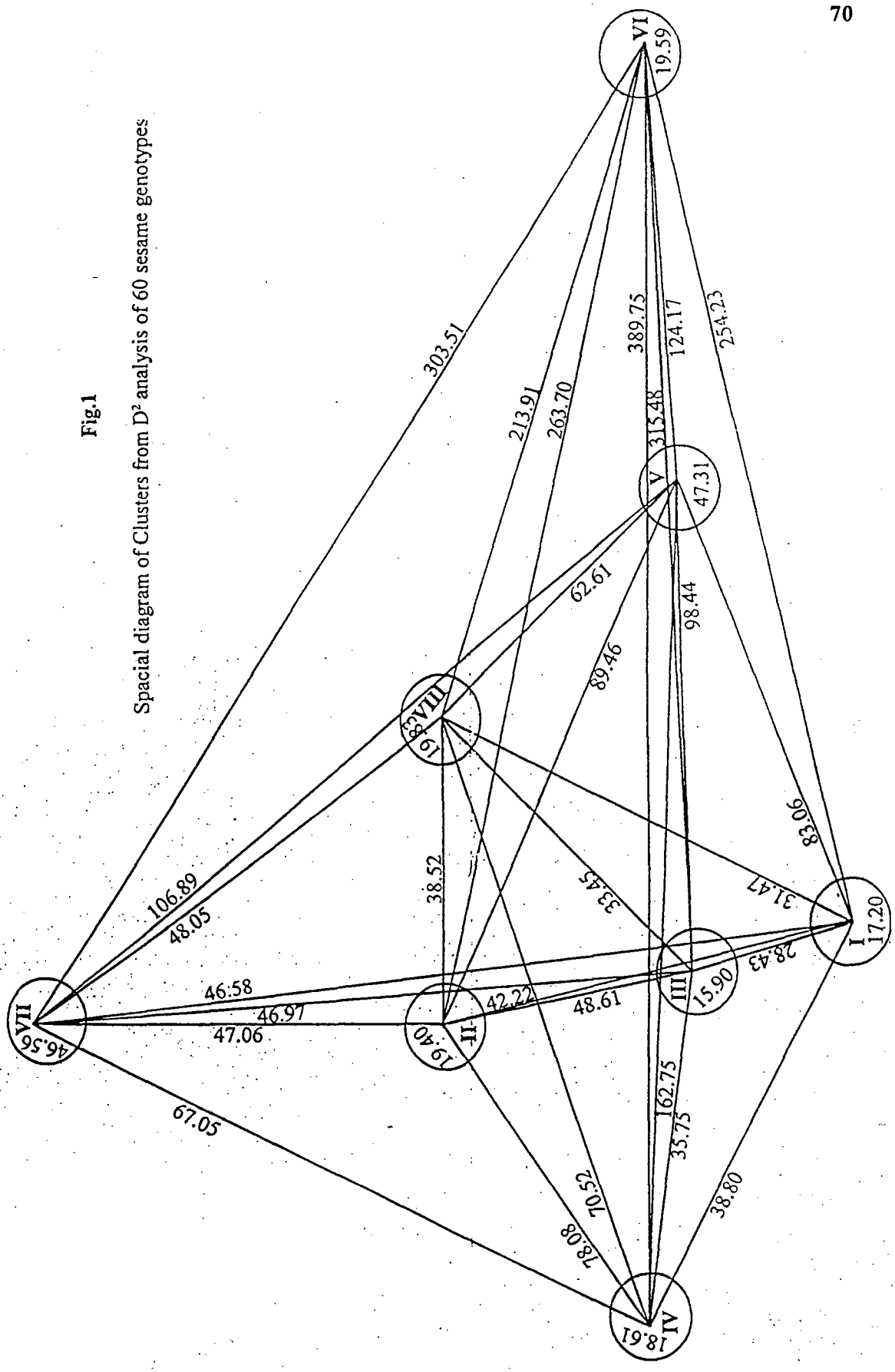
Cluster	Number of genotypes	Genotypes	Selected genotypes for diallel analysis
I	13	IC 204140, IC 204141, IC 204662, IC 204167, IC 204632, IC 204986, IC 204991, NIC 162549, MT - 9, Vellanikkara Local, VS-9701, Kayamkulam - 1, Thilak.	Thilak
II	8	IC 131496, NIC 17925 A, AT-78, PKDS-1, PKDS-3, SIK-113, RT-283, OS-5	NIC 17925 A
III	13	IC 131873-1, IC 204123, IC 204132, IC 204153, IC 204154, IC 204643, IC 204663, IC 127285, IC 205179, NIC 16252, NIC 17936 A, SI 1225, SIK - 004.	SI - 1225
IV	4	IC 204126, PKDS-2, Mah-60, RT - 281	IC 204126
V	2	JTS-14, OS-2	OS-2
VI	4	IC 204156, NIC 17905, HT - 1, ACV-2	IC 204156
VII	9	IC 132681, IC 131566, IC 26303, IC 26304, NIC 17320 A, OS-15, MT-2, VS-350, ACV-1	VS-350
VIII	7	IC 204168, IC 204637, IC 205005, VS- 9501, RT - 293, Thilothamma	Thilothamma

Table 7 Intra and Inter cluster average D^2 values

	I	II	III	IV	V	VI	VII	VIII
I	17.20							
II	42.22	19.40						
III	28.43	48.61	15.90					
IV	38.80	78.08	35.75	18.61				
V	83.06	89.46	98.44	162.75	47.31			
VI	254.23	263.70	315.48	389.75	124.17	19.59		
VII	46.58	47.06	46.97	67.05	106.89	303.51	46.56	
VIII	31.47	38.52	33.45	70.52	62.61	213.91	48.05	19.83

Fig.1

Spacial diagram of Clusters from D^2 analysis of 60 sesame genotypes



Divergence at intra cluster level, the maximum distance (47.31) was noticed in cluster V which consisted of two genotypes and the minimum value (15.90) was recorded in cluster III which included 13 genotypes of which 12 were indigenous cultures collected from NBPGR regional station, Vellanikkara.

The maximum inter cluster distance (389.75) was observed between cluster IV and VI followed by that between cluster III and VI (315.48), and the minimum distance of 28.43 was recorded between clusters I and III.

An overall assessment of the clusters revealed that cluster VI was highly divergent from other clusters. Intra cluster distance in cluster VI was only 19.59 indicating almost closely associated genotypes.

4.2 Experiment II

Eight genetically diverse genotypes having different origin and wider genetic base, representing one each from eight clusters in experiment I, were subject to 8 x 8 full diallel analysis (including reciprocals). Based on high degree of correlation of yield components with yield and also on their intercorrelations, 10 characters were selected for combining ability and heterosis studies.

4.2.1 Combining ability analysis

The data on analysis of variance (ANOVA) for hybrids and parents (Table 8) showed that hybrids and parents (treatments)

Table 8 Analysis of variance for treatments including parents used for 8 x8 full diallel analysis using Griffing's method - I

Sources of variation	Degrees of freedom	Mean sum of Squares									
		Plant height	No. of days to 50% flowering	No. of branches per plant	Capsules per main stem	Capsules per plant	Capsules length	1000 seed weight	seed yield per capsule plant	Seed yield per	Oil content
Treatment	63	771.0076**	12.0763**	1.0923**	63.7541**	823.3709**	0.0368**	0.1551**	0.0021**	36.6342**	21.6900**

* Significant at 5% level

** Significant at 1% level

differed significantly for all the characters studied. Further, analysis of variance for combining ability (Table 9) showed that mean squares due to general combining ability **(GCA)** was significant for all the characters studied. Mean squares due to specific combining ability **(SCA)** and that due to reciprocals were also significant for all the characters. **GCA/SCA** ratio was higher than unity for characters viz., plant height, days to 50 per cent flowering, number of branches per plant, capsule length, seed yield per capsules and oil content. Number of days to 50 per cent flowering recorded maximum value of 10.8914. Capsules per mainstem, capsules per plant, 1000 seed weight and seed yield per plant recorded values less than unity. Lowest value recorded was 0.2798 by seed yield per plant.

The estimates of components of variance are given in Table 10. The estimates of variance due to genetic effects and their ratio showed that variance due to non-additive genetic effect and reciprocal effects were higher than that due to additive genetic effect for all the characters studied. Also variance due to non-additive genetic effect was higher than that due to reciprocal effects for all the characters except number of days to 50 per cent flowering. Ratio of variance due to additive genetic effect to that due to non-additive genetic effect recorded values less than unity for all the characters studied.

4.2.1 General combining ability

General combining ability effects estimated for the quantitative characters are presented in Table 12. Mean performance of these attributes are given in Table 11.

Table 9 Analysis of variance for combining ability in 8 x8 full diallel analysis using Griffing's method - I

Sources of variation	Mean sum of Squares										
	Degrees of freedom	Plant height	No. of days to 50% flowering	No. of branches per plant	Capsules per main stem	Capsules per plant	Capsule length	1000 seed weight	seed yield per capsule	Seed yield per plant	Oil content
GCA	7	372.6661**	24.6875**	1.2087**	20.2327**	259.1368**	0.0294**	0.0394**	0.0034**	5.1877**	17.9420
SCA	28	323.4965**	2.2667**	0.5244**	33.0643	424.9057**	0.0160**	0.0793**	0.0007**	18.5410**	7.4336**
Reciprocal	28	450.7299**	5.1473**	0.4023**	33.6002**	436.6013**	0.0180**	0.0853**	0.0007**	21.3756**	12.4821**
Error	63	14.4120	0.7162	0.0265	3.5103	9.0976	0.0055	0.0117	0.0001	0.6963	1.4442
GCA/SCA	-	1.1520	10.8914	2.3049	0.69119	0.6099	1.8375	0.4968	4.2500	0.2798	2.4136

* Significant at 5% level

** Significant at 1% level

Table 10. Estimates of Components of Genetic variance from 8x8 diallel analysis using Griffing's method I

Components	Plant height	Number of days to 50 % flowering	Number of branches / plant	Capsules/ mainstem	Capsules/ plant	Capsule length	1000 Seed weight	Seed yield /capsule	Seed yield /plant	Oil content
Variance due to additive genetic effect	22.3909	1.4982	0.0739	0.2049	15.6275	0.0015	0.0017	0.0002	0.2809	1.0311
Variance due to non-additive genetic effect	309.0845	1.5505	0.4979	29.5540	415.8081	0.0105	0.0676	0.0007	17.2447	5.9894
Variance due to reciprocal effect	218.1590	2.2156	0.1879	15.0450	213.7519	0.0063	0.0368	0.0043	10.3397	5.5190
Variance due to error	14.4120	0.7162	0.0265	3.5103	9.0976	0.0055	0.0117	0.0001	0.6963	1.4442
Ratio of variance due to additive genetic effect to variance due to non additive genetic effect	0.07	0.97	0.15	0.01	0.04	0.14	0.03	0.29	0.02	0.17

Table . 11 Table of Means of Parents , Hybrids and Reciprocals

Parent/ hybrids	Plant height	No.of days to 50% flowering	No.of branches/ plant	Capsules/ mainstem	Capsules/ plant	Capsule length	1000seed weight	Seed yield/ capsule	Seed yield /plant	Oil content(%)
n_1	94.40	36.00	2.30	20.30	45.50	2.35	3.15	0.12	5.78	45
n_2	136.20	37.50	2.10	25.70	31.40	2.40	3.40	0.21	6.62	55
n_3	112.80	36.00	2.40	23.30	34.80	2.50	3.35	0.19	6.45	47
n_4	104.90	36.00	2.30	12.80	20.20	2.30	3.10	0.19	3.97	46
n_5	107.40	40.00	2.60	16.60	30.90	2.40	3.40	0.19	5.91	47
n_6	116.00	44.00	1.30	23.80	33.40	2.70	3.80	0.25	8.18	53
n_7	129.70	40.50	3.70	25.40	69.10	2.25	3.30	0.19	12.65	52
n_8	77.90	36.00	1.70	18.80	17.50	2.35	3.90	0.22	3.74	53
$n_1 \times n_2$	95.50	40.00	2.40	14.80	32.20	2.30	3.30	0.18	5.66	50
$n_1 \times n_3$	133.80	39.00	2.60	26.60	64.90	2.40	2.90	0.19	12.08	45
$n_1 \times n_4$	119.70	41.00	2.90	24.40	56.50	2.50	3.35	0.22	12.43	46
$n_1 \times n_5$	118.60	37.50	3.40	23.30	73.00	2.55	3.40	0.22	16.12	51
$n_1 \times n_6$	116.70	41.50	3.10	26.10	68.40	2.20	2.45	0.14	9.67	42
$n_1 \times n_7$	123.80	41.00	3.40	19.60	52.30	2.35	3.45	0.20	10.81	46
$n_1 \times n_8$	121.00	37.50	2.80	24.40	49.25	2.55	3.30	0.19	9.81	44
$n_2 \times n_1$	147.70	39.00	3.70	32.20	82.70	2.40	3.25	0.17	13.97	42
$n_2 \times n_3$	136.70	37.50	2.70	25.50	65.90	2.55	3.25	0.20	18.18	49

Table . 11 Table of Means of Parents , Hybrids and Reciprocals (continued)

Parent/ hybrids	Plant height	No.of days to 50% flowering	No.of branches/ plant	Capsules/ mainstem	Capsules/ plant	Capsule length	1000seed weight	Seed yield/ capsule	Seed yield /plant	Oil content(%
$n_2 \times n_4$	161.60	36.00	3.40	29.80	69.30	2.60	3.45	0.23	16.17	49
$n_2 \times n_5$	160.50	40.00	3.40	28.50	59.10	2.45	3.55	0.20	11.93	51
$n_2 \times n_6$	145.00	40.00	2.80	26.00	56.50	2.40	3.35	0.19	10.70	41
$n_2 \times n_7$	142.80	42.00	4.10	25.60	52.10	2.50	3.50	0.22	13.19	50
$n_2 \times n_8$	140.80	37.50	3.30	28.30	73.30	2.55	3.40	0.22	16.50	49
$n_3 \times n_1$	131.90	36.00	2.60	27.70	77.00	2.40	3.20	0.13	10.16	50
$n_3 \times n_2$	89.40	36.00	2.90	13.90	80.90	2.40	2.60	0.19	15.66	46
$n_3 \times n_4$	97.40	38.50	2.30	24.10	47.70	2.55	3.35	0.23	11.25	44
$n_3 \times n_5$	150.00	43.00	3.60	35.00	77.60	2.80	3.40	0.26	20.23	48
$n_3 \times n_6$	127.30	39.00	3.40	25.50	74.50	2.80	3.40	0.23	14.60	50
$n_3 \times n_7$	101.30	33.00	2.90	16.00	37.90	2.60	3.35	0.22	34.22	46
$n_3 \times n_8$	142.60	36.00	3.60	24.00	70.10	2.50	3.35	0.18	12.35	46
$n_4 \times n_1$	132.10	36.00	2.50	27.00	54.50	2.60	3.55	0.21	11.42	46
$n_4 \times n_2$	102.70	37.50	2.40	15.50	26.60	2.55	3.60	0.22	6.02	44
$n_4 \times n_3$	113.10	36.00	2.40	23.30	44.00	2.55	3.40	0.24	10.36	46
$n_4 \times n_5$	131.60	40.00	2.80	21.60	63.20	2.50	3.50	0.22	13.99	50

Table . 11 Table of Means of Parents , Hybrids and Reciprocals (continued)

Parent/ hybrids	Plant height	No.of days to 50% flowering	No.of branches/ plant	Capsules/ mainstem	Capsules/ plant	Capsule length	1000seed weight	Seed yield/ capsule	Seed yield /plant	Oil content(%)
$n_4 \times n_6$	111.70	40.00	2.10	14.00	22.70	2.20	3.25	0.25	5.52	47
$n_4 \times n_7$	112.40	32.00	3.20	23.30	50.80	2.55	3.45	0.25	12.73	48
$n_4 \times n_8$	102.60	36.00	2.10	18.40	27.40	2.60	3.75	0.25	6.88	49
$n_5 \times n_1$	107.70	40.00	2.20	16.50	40.30	2.35	3.20	0.19	7.35	49
$n_5 \times n_2$	112.50	40.00	2.70	20.40	36.10	2.30	3.30	0.20	7.22	52
$n_5 \times n_3$	103.70	36.00	2.40	17.70	32.00	2.40	3.40	0.19	6.23	46
$n_5 \times n_4$	128.30	37.50	3.00	25.00	69.60	2.45	2.35	0.16	10.80	42
$n_5 \times n_6$	111.20	39.00	2.20	15.30	20.40	2.45	2.90	0.18	3.59	49
$n_5 \times n_7$	124.10	37.50	3.50	12.80	28.00	2.25	3.30	0.16	4.52	49
$n_5 \times n_8$	117.60	40.00	2.90	23.60	42.70	2.25	3.10	0.19	7.94	44
$n_6 \times n_1$	123.90	39.50	2.20	24.20	37.70	2.55	3.40	0.20	7.75	51
$n_6 \times n_2$	140.30	39.50	3.10	22.10	58.70	2.40	3.30	0.19	11.23	50
$n_6 \times n_3$	125.70	41.00	3.20	19.20	41.30	2.45	3.20	0.18	7.36	51
$n_6 \times n_4$	133.70	44.00	2.90	23.90	50.70	2.60	3.45	0.28	14.17	50
$n_6 \times n_5$	129.00	44.00	3.00	22.40	49.10	2.50	3.30	0.19	9.62	50
$n_6 \times n_7$	141.40	44.00	1.90	17.20	22.20	2.55	3.80	0.22	4.82	51
$n_6 \times n_8$	147.60	44.00	2.70	25.70	50.80	2.60	3.30	0.20	10.29	52

Table . 11 Table of Means of Parents , Hybrids and Reciprocals (continued)

Parent/ hybrids	Plant height	No.of days to 50% flowering	No.of branches/ plant	Capsules/ mainstem	Capsules/ plant	Capsule length	1000seed weight	Seed yield/ capsule	Seed yield /plant	Oil content(%)
$n_7 \times n_1$	132.10	37.50	3.70	24.20	47.80	2.40	3.15	0.14	6.84	47
$n_7 \times n_2$	167.60	41.00	5.60	32.80	103.90	2.30	3.25	0.18	18.60	54
$n_7 \times n_3$	152.30	37.50	3.80	31.00	70.00	2.30	2.95	0.16	11.70	46
$n_7 \times n_4$	142.80	44.00	2.90	22.20	46.60	2.40	2.80	0.17	8.03	48
$n_7 \times n_5$	101.30	41.00	3.00	11.10	19.10	2.20	3.30	0.13	2.55	51
$n_7 \times n_6$	102.50	40.00	2.20	12.80	22.80	2.50	3.20	0.19	4.47	44
$n_7 \times n_8$	112.80	40.00	2.60	21.60	40.20	2.55	3.35	0.19	7.71	50
$n_8 \times n_1$	124.40	39.00	2.30	18.50	35.10	2.60	3.10	0.19	6.49	54
$n_8 \times n_2$	138.60	39.00	2.50	22.10	41.20	2.65	3.15	0.23	9.69	48
$n_8 \times n_3$	124.20	37.50	1.00	18.40	22.10	2.55	3.65	0.22	4.89	52
$n_8 \times n_4$	131.80	37.50	1.70	21.10	34.00	2.30	3.35	0.25	8.55	52
$n_8 \times n_5$	172.00	36.00	4.30	36.40	109.10	2.50	3.20	0.22	23.29	54
$n_8 \times n_6$	149.50	41.00	2.90	25.10	59.10	2.55	2.90	0.19	10.77	51
$n_8 \times n_7$	136.00	41.00	2.50	23.60	43.30	2.50	3.25	0.22	9.54	47
SE	1.54	1.20	0.23	2.65	4.27	0.11	0.15	0.01	1.18	1.69

Table 12. General Combining ability effects of the parents in 8 x 8 diallel analysis using griffing's method - I

Parents	Plant height	Number of days to 50 % flowering	Number of branches/ plant	Capsules/ mainstem	Capsules/ plant	Capsule length	1000 Seed weight	Seed yield /capsule	Seed yield/ plant	Oil content
n_1	-5.52**	-0.68*	-0.02	0.77	5.12**	-0.03	-0.08	-0.02	-0.24	-1.33**
n_2	9.25**	-0.46	0.21	1.95**	4.78**	-0.01	0.03	0.00	1.06**	0.67*
n_3	-3.19**	-1.21**	-0.10	1.05*	2.80**	0.05	-0.03	0.00	0.51*	-0.95*
n_4	-4.67**	-0.77**	-0.22	-1.16*	-4.80**	0.01	0.01	0.02	0.02	-1.33**
n_5	-1.45	0.26	0.18	-0.93	0.02	-0.04	-0.04	-0.01	0.08	0.36
n_6	1.97**	2.32**	-0.28	-0.67	-4.94**	0.05	0.01	0.01	-0.75**	0.67*
n_7	2.91**	1.38**	0.50	-0.82	0.03	-0.06	0.01	-0.01	-0.44	0.42
n_8	0.70	-0.84**	-0.26	-0.18	-3.01**	0.04	0.09	0.01	-0.24	1.48**

* Significant at 5% level
** Significant at 1% level

a) Plant height : The parent n_2 (9.25**) ranked first in positive significant **gca** effect followed by n_7 (2.91**). Both exhibited positive and significant **gca** effects along with n_6 (1.97**). Parents n_1, n_3 and n_4 recorded negative and significant **gca** effects. Comparing the *per se* performance too, n_2 recorded the maximum height of 136.20cm followed by n_7 (129.70cm) (Table. 11).

b) Number of days to 50 per cent flowering : The parent n_3 (-1.21**) ranked first in negative significant **gca** effect (desirable) followed by n_8(-0.84**). The parents n_6 and n_7 exhibited positive significant **gca** effect. Similarly mean performance of parents n_1, n_3, n_4 and n_8 showed that they were early flowering types with 36 days to attain 50 per cent flowering.

c) Number of branches per plant : None of the parents recorded significant **gca** effect. Maximum value of **gca** effect was recorded by n_7 (0.50) followed by n_2 (0.21). In mean performance also n_7 recorded the maximum value of 3.70.

d) Capsules per mainstem : The parent n_2 (1.95**) recorded maximum **gca** effect followed by n_3 (1.05 *). Both exhibited positive and significant **gca** effect. Significant negative gca effect (-1.16*) was recorded by n_4. In *per se* performance, n_2 recorded maximum number of capsules per mainstem (25.7) closely followed by n_7 (25.40). But **gca** effect of n_7 was not significant.

e) Capsules per plant : The maximum **gca** effect was recorded by n_1 (5.12**) followed by n_2 (4.78**) and n_3 (2.80**). These parents recorded positive and highly significant **gca** effects, where as n_4, n_6,. and n_8 recorded negative and significant gca effect. With respect to mean performance, highest value was recorded by n_7 (69.10) followed by n_1 (45.50) and least value for capsules per plant was recorded by n_8 (17.50)

f. Capsule length : For capsule length none of the parents recorded significant values for **gca** effects. Mean performance of capsule length varied from 2.25 cm to 2.70 cm among the parents. Least value was recorded by n_7 and highest value by n_6.

g. 1000 seed weight : For 1000 seed weight also, none of the parents recorded significant values for **gca** effect. In the case of *per se* performance, 1000 seed weight values ranged from 3.1 g to 3.9 g. Highest value for mean performance was recorded by n_8 and least by n_4.

h. Seed yield per capsule : For seed yield per capsule, none of the parents recorded significant values for **gca** effect. Mean performance ranged from 0.12g to 0.25g. Lowest value was recorded by n_1 and highest by n_6.

i Seed yield per plant : Parents n_2 and n_3 recorded positive and significant **gca** effects and parents n_6 recorded negative and significant **gca** effect. In case of *per se* performance n_7 recorded highest value of 12.65g and lowest values was recorded by n_8 (3.74g). Parents n_2 and n_3 recorded 6.62g and 6.45 g respectively.

j. Oil content : For oil content, parents n_2, n_6 and n_8 recorded positive and significant **gca** effect, while parents n_1, n_3 and n_4 recorded negative and significant **gca** effect. Comparing *per se* performance, n_2 recorded maximum oil content of 55 per cent and n_6 and n_8 recorded 53 per cent each. Lowest value was recorded by n_1.

In brief, among the eight parents n_2 recorded significant **gca** effects for five characters, plant height, capsules per main stem, capsules per plant, seed yield per plant and oil content, while n_3 recorded significant **gca** effects for four characters, number of days to 50 per cent flowering, capsules per mainstem, capsules per plant and seed yield per plant.

4.2.1.2 Specific combining ability effects and reciprocal effects

The specific combining ability effects for different characters of 28 crosses and their reciprocal combining ability effects were estimated and are given in Tables 13 to 22. Important results are summarised and presented below.

i. Plant height

Specific combining ability effects for all the crosses recorded significant values except $n_4 \times n_6$ (Table 13). A negative direction was observed for $n_1 \times n_2$, $n_1 \times n_5$, $n_1 \times n_6$, $n_3 \times n_4$, $n_4 \times n_8$, $n_5 \times n_6$, $n_5 \times n_7$, $n_6 \times n_7$ and $n_7 \times n_8$. Maximum negative value was recorded by $n_5 \times n_7$ (-14.14**). Maximum positive **sca** effect was recorded by $n_6 \times n_8$ (20.50**).

Table 13. Specific combining ability effects (Upper diagonal) and reciprocal effects (Lower diagonal) for plant height

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-7.51**	16.72**	10.72**	-5.26**	-1.52**	5.18**	2.14**
n_2	26.10**		18.39**	2.19**	3.32**	6.05**	17.66**	4.37**
n_3	-0.95*	23.65**		-12.27**	6.11**	2.35**	1.70**	1.51**
n_4	6.20**	-29.45**	7.82**		10.69**	0.03	3.98**	-4.21**
n_5	-5.45**	-24.00**	-23.15**	-1.65**		-5.80**	-14.14**	20.17**
n_6	3.60**	-2.35**	-0.80**	11.00**	8.90**		-8.30**	20.50**
n_7	4.15**	12.40**	25.50**	15.20**	-11.40**	-19.45**		-4.59**
n_8	1.70**	-1.10**	-9.20	14.60**	27.20**	0.95**	11.60**	

SE of sca (ij) 0.2373.
SE of reciprocal (ij) 0.2684.
* Significant at 5% level
** Significant at 1% level

All crosses recorded significant reciprocal effect. Maximum positive values for reciprocal combining ability effect was recorded by n_8 x n_5 (27.20**) followed by n_2 xn_1 (26.10**). The highest negative value was recorded by n_4 x n_2 (-29.45**).

Comparing mean performance, maximum mean value was recorded by n_7 x n_2 (167.60cm). Its reciprocal cross recorded 142.80 cm. Among direct crosses maximum mean value was recorded by n_3 x n_5 of 150 cm, while its reciprocal recorded only 103.70 cm. Least mean value was recorded by n_3 x n_2 (89.40 cm), its reciprocal cross recorded 136.70 cm.

ii. Number of days to 50 per cent flowering

Specific combining ability effects, number of days to 50 per cent flowering were positive and significant for crosses n_1 x n_2, n_2 x n_7, n_3 x n_5, n_4 x n_6, n_4 x n_7 and n_6 x n_8 (Table 14). Maximum positive value was recorded by n_6 x n_8 (1.80**). Crosses n_2 x n_4, n_2 x n_6 and n_5 x n_7 had negative and significant values for sca effect, which was desirable for this character. Maximum value was recorded by n_6 x n_7 (-1.60**). However, the **gca** effects of n_6 and n_7 were positive and significant.

In the case of reciprocal effect of the maximum value was recorded by n_5 x n_3 (-3.50**), which is desirable. The positive and significant reciprocal effect was recorded by n_4 x n_2, n_5 x n_1, n_6 x n_4, n_6 x n_5, n_7 x n_4 and n_7 x n_5. High value of 2.50 was recorded by n_6 x n_5 and n_7 x n_4, followed by n_6 x n_4 (2.00**) and n_7 x n_5 (1.75**). Cross n_5 x n_2 had reciprocal combining ability effect of zero.

Table 14. Specific combining ability effects (Upper diagonal) and reciprocal effects (Lower diagonal) for number of days to 50 percent flowering

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		1.43*	0.12	0.74	-0.04	-0.35	-0.66	0.55
n_2	-0.50		-0.79	-1.23*	0.99	-1.32*	1.37*	0.34
n_3	-1.50*	-0.75*		0.02	1.24*	-0.32	0.87	-0.41
n_4	-2.50**	0.75*	-1.25*		0.05	1.24*	1.68**	-0.85
n_5	1.25*	0.00	-3.50**	-1.25*		-0.29	-1.60**	-0.63
n_6	-1.00	-0.25	1.00	2.00**	2.50**		-0.91	1.80**
n_7	-1.75**	-0.50	-2.75**	2.50**	1.75**	-2.00**		0.74
n_8	0.75	0.75	0.75	0.75	-2.00**	-1.50	0.50	

SE for sca (ij) - 0.5289
SE for reciprocal (ij) - 0.5984
* Significant at 5% level
** Significant at 1% level

For *per se* performance, the value varied between 36 days and 44 days. Nine crosses recorded the lowest value (n_2 x n_4, n_3 x n_1, n_3 x n_2, n_3 x n_8, n_4 x n_1, n_4 x n_3, n_4 x n_8, n_5 x n_3 and n_8 x n_5)

iii. Number of branches per plant

For number of branches per plant, crosses n_1 x n_7, n_2 x n_3, n_2 x n_6, n_2 x n_7, n_3 x n_6, n_5 x n_8 and n_6 x n_8 recorded positive and significant specific combining ability effects (Table 15). Negative and significant values were recorded by n_4 x n_8, n_5 x n_7, n_6 x n_7 and n_7 x n_8. Maximum positive value was recorded by n_2 x n_7 (1.34**) and maximum negative value by n_6 x n_7 (-0.96**).

In the case of reciprocal effect, crosses n_2 x n_1, n_3 x n_2, n_6 x n_4, n_6 x n_5, n_7 x n_2 and n_8 x n_5 recorded positive and significant effect and highest value was recorded by n_7 x n_2 (0.75**). Maximum negative effect was recorded by n_8 x n_3 (-1.30**).

Comparing *per se* performance too n_7 x n_2 recorded highest mean number of branches per plant of 5.6, while its direct cross recorded 4.10 (n_2 x n_7)and minimum value was recorded by n_8 x n_3 (1.00), its direct cross recorded 3.6 (n_3 x n_8).

iv. Number of capsules per mainstem

All crosses recorded significant **sca** effect for number of capsules per main stem (Table 16). Maximum **sca** effect (8.76**) was recorded by n_5 x n_8 and it was positive and highly significant. Maximum negative and significant **sca** effect was recorded by n_5 x n_7 (-8.65**).

Table 15. Specific combining ability effects (Upper diagonal) and reciprocal effects (Lower diagonal) for number of branches per plant

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		0.08	-0.08	0.15	-0.15	0.15	0.28*	0.04
n_2	0.65**		0.61**	0.11	-0.14	0.22*	1.34**	0.15
n_3	0.00	0.40**		-0.13	0.12	0.88**	0.15	-0.14
n_4	-0.20	-0.50**	0.05		0.15	0.20	-0.02	-0.41**
n_5	-0.60**	-0.35**	0.60**	0.10		-0.10	-0.22*	0.89**
n_6	-0.45**	0.15	-0.10	0.40**	0.40**		-0.96**	0.54**
n_7	0.15	0.75**	0.45**	-0.15	-0.25*	0.15		-0.48**
n_8	-0.25*	-0.40**	-1.30**	-0.20	0.70**	0.10	-0.05	

SE for sca (ij) - 0.1018
SE for reciprocal (ij) - 0.1152
* Significant at 5% level
** Significant at 1% level

Table 16. Specific combining ability effects (Upper diagonal) and reciprocal effects (Lower diagonal) for capsules per mainstem

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-1.58**	2.98**	3.73**	-2.30**	2.68**	-0.41**	-1.50**
n_2	8.70**		5.65**	-0.50**	1.08**	0.41**	5.72**	1.08**
n_3	0.55**	5.80**		1.45**	3.88**	0.39**	0.92**	-2.02**
n_4	1.30**	-7.15**	0.40**		3.03**	-1.58**	2.37**	-1.27**
n_5	-3.40**	-4.05**	-8.65**	1.70**		1.91**	-8.65**	8.76**
n_6	-0.95**	-1.95**	-3.15**	4.95**	3.55**		-5.87**	3.89**
n_7	2.30**	3.60**	7.50**	-0.55**	-0.85**	-2.20**		1.25**
n_8	-2.95**	-3.10**	-2.80**	1.35**	6.40**	-0.30*	1.00**	

SE for sca (ij) - 0.1171
SE for reciprocal (ij) - 0.1325
* Significant at 5% level
** Significant at 1% level

For reciprocal effects also, all crosses had significant values. Maximum positive value was recorded by n_2 x n_1 (8.70**) followed by n_7 x n3 (7.50**). While maximum negative value recorded was (-8.65**) by n_5 x n_3.

In the case of mean performance, maximum value was recorded by n_8 x n_5 (36.40) which ranks third in reciprocal effect. It recorded a positive and significant reciprocal effect of 6.40**. Lowest mean value was 11.10 by n_7 x n_5. Its direct cross (n_5 x n_7) also recorded a value close by (12.80) which had highest negative sca effect.

v. Number of capsules per plant

All crosses recorded significant **sca** effect. Thirteen of the crosses recorded positive values with maximum of 30.09** recorded by n_5 x n_8 (Table 17). Maximum negative and significant sca effects was recorded by n_5 x n_7 (-25.30**).

In the case of reciprocal combining ability effect also, all crosses exhibited significant values except n_7 x n_6 (0.30). Maximum positive significant value was recorded by n_8 x n_5 (33.20**). Highest negative significant value for reciprocal effect was recorded by n_8 x n_3 (-24.0**).

In *per-se* performance, high mean value for number of capsules per plant was recorded by n_8 x n_5 (109.10) which had highest positive combining ability effect. Its reciprocal cross had a mean value of 42.70. Least value for mean performance was recorded by n_7 x n_5 (19.10). Its reciprocal cross had a mean value of 28.00. Both recorded

Table 17 Specific combining ability effects (upper diagonal) and reciprocal effects (lower diagonal) for capsules per plant

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-1.25**	14.24**	6.38**	2.71**	4.08**	-3.89**	-8.73**
n_2	25.25**		7.98**	-0.83**	-6.00**	8.96**	27.39**	6.68**
n_3	6.05**	17.50**		-0.95**	3.19**	11.25**	2.33**	-2.49*
n_4	-1.00**	-21.35**	-1.85**		22.38**	-2.36**	4.67**	-10.29**
n_5	-16.35**	-11.50**	-22.80**	3.20**		-9.13**	-25.30**	30.09**
n_6	-15.35**	1.10**	-16.60**	14.00**	14.38**		-21.38**	14.10**
n_7	-2.25**	22.90**	-16.05**	-2.10**	-4.45**	0.30		-4.07**
n_8	7.08**	-16.05**	-24.00**	3.30**	33.20**	4.15**	1.55**	

SE for sca (ij) - 0.1885
SE for reciprocal (ij) 0.2133

* Significant at 5% level
** Significant at 1% level

negative combining ability effect. Cross n_5 x n_7 had the highest negative and significant specific combining ability effect.

vi. Capsule length

For capsule length, none of the crosses recorded significant sca effects (Table 18). Similarly none of the crosses recorded significant reciprocal effect.

In the case of mean performance also, there was not much variation. Capsule length varied between 2.20 cm and 2.80 cm. Minimum value was recorded by n_1 x n_6, n_4 x n_6 and n_7 x n_5 and maximum value by n_3 x n_5 and n_3 x n_6.

vii. 1000 seed weight

None of the crosses recorded significant specific combining ability effects (Table 19). Similarly none of the crosses recorded significant reciprocal effect.

In the case of *per se* performance, the 1000 seed weight varied between 2.35 and 3.75g. Lowest value was recorded by n_5 x n_4, its direct cross (n_4 x n_5) had a mean value of 3.5g. Among direct crosses, lowest value was recorded by n_4 x n_8. Its reciprocal (n_8 x n_4) had mean value of 3.35g.

viii. Seed yield per capsule

None of the crosses had significant **sca** effect for seed yield per capsule (Table 20). Similarly, in case of reciprocal effect also none of the crosses had significant value.

Table 18. Specific combining ability effects (Upper diagonal) and reciprocal effects (Lower diagonal) for Capsule length

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-0.06	-0.08	0.11	0.06	-0.10	0.00	0.11
n_2	0.05		-0.03	0.12	-0.03	-0.09	0.01	0.12
n_3	0.00	-0.07		0.02	0.12	0.06	-0.01	-0.03
n_4	0.05	-0.02	0.00		0.04	-0.12	0.06	-0.06
n_5	-0.10	-0.07	-0.20	-0.02		0.01	-0.14	-0.08
n_6	0.18	0.00	-0.17	0.20	0.02		0.07	0.03
n_7	0.03	-0.10	-0.15	-0.07	-0.03	-0.02		0.09
n_8	0.02	0.05	0.02	-0.15	0.12	-0.02	-0.02	

SE for sca (ij) - 0.4653
SE for reciprocal (ij) - 0.5264

Table 19. Specific combining ability effects (Upper diagonal) and reciprocal effects (Lower diagonal) for 1000 seed weight

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		0.04	-0.13	0.23	0.13	0.29	0.09	-0.09
n_2	-0.02		-0.36	0.20	0.15	0.00	0.05	-0.13
n_3	0.15	-0.33		0.11	0.18	0.03	-0.11	0.16
n_4	0.10	0.07	0.03		-0.34	0.04	-0.18	0.16
n_5	-0.10	-0.12	0.00	-0.58		-0.16	0.04	-0.16
n_6	0.42	-0.02	-0.10	0.10	0.20		0.19	-0.29
n_7	-0.15	-0.12	-0.20	-0.32	0.00	-0.30		-0.08
n_8	-0.10	-0.12	0.15	-0.20	0.05	-0.20	0.05	

SE for sca (ij) - 0.6749
SE for reciprocal (ij) - 0.7635

Table 20 Specific combining ability effects (upper diagonal) and reciprocal effects (lower diagonal) for seed yield per capsule

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-0.01	-0.02	0.02	0.03	-0.01	0.01	0.00
n_2	0.00		-0.01	0.00	0.00	-0.02	0.01	0.02
n_3	-0.03	-0.01		0.01	0.04	0.00	0.00	-0.01
n_4	0.00	0.00	0.00		-0.03	0.03	0.00	0.02
n_5	-0.02	0.00	-0.03	-0.03		-0.02	-0.04	0.00
n_6	0.03	0.00	-0.03	0.02	0.01		0.01	-0.02
n_7	-0.03	-0.02	-0.03	-0.04	-0.02	-0.01		0.01
n_8	0.00	-0.01	-0.02	0.00	0.01	-0.01	-0.02	

SE for sca (ij) - 0.5525
SE for reciprocal (ij) 0.6251

The *per se* performance varied from 0.13g to 0.28g. Lowest value was recorded by crosses n_3 x n_1 and n_7 x n_5. Their direct crosses n_1 x n_3 and n_5 x n_7 had mean values of 0.19g and 0.16g. Highest mean performance was recorded by n_6 x n_4 (0.28g). Its reciprocal cross (n_4 x n_6) had mean value of 0.25g.

ix. Seed yield per plant

Ten crosses recorded significant positive **sca** effect (Table 21). Highest value was recorded by n_5 x n_8 (6.03**). Seven crosses had negative and significant sca effect. Highest negative effect was recorded by n_5 x n_7 (-5.86**).

In case of reciprocal effect, only seven crosses viz. n_2 x n_1, n_3 x n_2, n_6 x n_4, n_6 x n_5, n_7 x n_2, n_7 x n_3 and n_8 x n_5 recorded positive and significant values. Highest value was for n_8 x n_5 (7.67**) followed by n_6 x n_4 (4.33**). Eleven crosses recorded significant negative effect. Cross n_5 x n_3 had highest negative reciprocal effect (-7.00**) followed by n_6 x n_3 (-5.12**).

Comparing *per se* performance also cross n_7 x n_5 recorded least mean value (2.55). Its reciprocal cross n_5 x n_7 had a mean value of 4.52g. The cross n_8 x n_5 recorded highest value (23.29), which was followed by n_3 x n_5 (20.23), while n_5 x n_8 (reciprocal cross of n_8 x n_5) and n_5 x n_3 (reciprocal of n_3 x n_5) recorded 7.94g and 6.23g respectively showing high reciprocal difference in the yield character.

Table 21 Specific combining ability effects (upper diagonal) and reciprocal effects (lower diagonal) for seed yield per plant

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-0.75	1.10	2.40**	2.15**	-0.04	-0.25	-1.12*
n_2	4.15**		1.91**	0.26	-1.31*	0.91	5.52**	2.52**
n_3	-0.96	3.76		0.53	2.89**	2.97**	0.13	-1.40*
n_4	-0.51	-5.08**	-0.45		2.55**	0.83	1.05	-1.82**
n_5	-4.38**	-2.36**	-7.00**	-1.60*		-2.47**	-5.86**	6.03**
n_6	-0.96	0.26	-5.12**	4.33**	3.02**		-3.91**	1.77**
n_7	-1.99**	2.71**	1.74**	-2.35**	-0.99	-0.18		-0.45
n_8	-1.66**	-3.40**	-3.73**	0.83	7.67**	0.24	0.91	

SE for sca (ij) - 0.5215
SE for reciprocal (ij) 0.5901

* Significant at 5% level
** Significant at 1% level

x. Oil content

Crosses n_1 x n_5, n_2 x n_5, n_2 x n_7, n_3 x n_6 and n_4 x n_8 recorded significant positive **sca** effect for oil content (Table 22). Highest positive value was recorded by n_1 x n_5 (2.58**) followed by n_2 x n_7(2.52**) and n_2 x n_5 (2.08**). Six crosses recorded negative significant **sca** effect. Maximum negative value was recorded by n_2 x n_6(-4.23**).

For reciprocal effect, highest positive specific combining ability effect was recorded by n_8 x n_1, and n_8 x n_5 (5.00** each). Both recorded positive and significant reciprocal combining ability effect, followed by n_6 x n_1 and n_6 x n_2 with a value of 4.50** each. Crosses viz., n_3 x n_1, n_7 x n_2 and n_8 x n_3 also recorded positive and significant reciprocal combining ability effect. Crosses n_2 x n_1, n_4 x n_2, n_5 x n_4 and n_7 x n_6 recorded negative significant reciprocal effect.

Comparing *per se* performance, mean value ranged from 41 to 54 per cent. Highest oil content was observed for n_7 x n_2, n_8 x n_1 and n_8 x n_5. These crosses also showed significant and positive reciprocal combining ability effect, while their direct crosses viz. n_2 x n_7, n_1 x n_8 and n_5 x n_8 recorded mean values of 50, 44 and 44 percent respectively. Lowest mean value of 41 per cent was recorded by n_2 x n_6 which recorded high negative specific combining ability effects and it's reciprocal cross had a mean value of 50 percent.

Table 22 Specific combining ability effects (upper diagonal) and reciprocal effects (lower diagonal) Oil content

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-1.73*	1.39	0.27	2.58**	1.23	-0.98	0.45
n_2	-4.00**		-0.61	-1.23	2.08**	-4.23**	2.52**	-0.25*
n_3	2.50**	1.50		-1.11	-0.80	2.39**	-1.86*	0.08
n_4	0.00	-2.50**	1.00		-1.42	0.77	0.52	1.95*
n_5	-1.00	0.50	-1.00	-4.00**		0.08	0.83	-1.23
n_6	4.50**	4.50**	0.50	1.50	0.50		-1.98*	0.95
n_7	0.50	2.00*	0.00	0.00	1.00	-3.50**		-1.80*
n_8	5.00**	0.50	3.00**	1.50	5.00**	-0.50	-1.50	

SE for sca (ij) - 0.7511
SE for reciprocal (ij) 0.8498
* Significant at 5% level
** Significant at 1% level

4.2.2 Estimation of components of variation and genetic parameters by Hayman's approach

Diallel analysis by Hayman's method provides overall genetic evaluation which would be helpful in selecting the parents and their potential crosses in early segregating generations. With this view, the genetic components of variance were worked out in an 8 x 8 full diallel analysis using Hayman's approach (1954) for ten characters in the present study and the data are presented in Table 23. The t^2 was estimated for all the characters and was found to be non-significant justifying the validity of the assumptions conceived for the approach.

It was clear from the table that the additive component (D) of variance was significant for the characters plant height, number of days to 50 per cent flowering, number of branches per plant, number of capsules per mainstem, number of capsules per plant, capsule length, 1000 seed weight and oil content. The non-additive components (H_1 & H_2) of variance were also significant for all the characters studied. For seed yield per plant only non-additive variance was significant. Seed yield per capsule recorded a value of zero for all the genetic components. H_2 was less than H_1 for all the characters. The magnitude of both H_1 and H_2 were much greater than that of additive genetic components (D) for all the characters except days to 50 percent flowering. For days to 50 per cent flowering additive variance (D) recorded a value of 8.14 while H_1 and H_2 recorded 3.24 and 3.10 respectively. The value of h^2, which gives the dominance effect was significant for all the characters except number of capsules per mainstem which recorded a value of 21.44.

Table 23 Estimates of genetic components of variance for 10 different quantitative characters by Hayman's approach

	Additive variance	Dominance variance		Dominance effect	Covariance of additive and dominance effect	Environmental variance	Mean degree of dominance	Proportion of genes with postive and negative effects in parents	Proportion of dominant and recessive genes in parents	Number of groups of genes controlling the character and exihibiting dominance	Hertibility % (Narrow sense)		
	D	H_1	H_2	h^2	F	E	$(H_1/D)^{1/2}$	$H_2/4H_1$	KD/KR	h^2/H_2	h^2ns	t^2	$(ML_1-ML_0)^2$
Plant height	332.00**	821.92**	618.17**	950.44**	446.19**	14.41^{NS}	1.57	0.19	2.49	1.54	43.38	0.04	239.18
No of days to 50% flowering	8.14**	3.24**	3.10**	3.38**	2.28**	0.72**	0.63	0.24	1.57	1.09	68.09	0.71	0.92
No. of branches per plant	0.47**	1.13**	1.00**	0.98**	3.30^{NS}	0.03^{NS}	1.55	0.22	1.52	0.98	33.47	5.48	0.24
Capsules per main stem	27.59**	80.72**	59.11**	21.44^{NS}	45.02^{NS}	3.51^{NS}	1.71	0.18	2.82	0.36	35.68	0.27	5.71
Capsules per plant	252.29**	1054.78**	831.62**	719.38**	412.94^{NS}	9.10^{NS}	2.04	0.20	2.33	0.87	27.11	0.04	180.90
Capsules length	0.01**	0.03**	0.02**	0.01**	0.02**	0.01**	1.41	0.19	2.00	0.50	28.67	5.12	0.00
1000 seed weight	0.07**	0.18**	0.14**	0.07**	0.11**	0.01^{NS}	1.61	0.19	3.00	0.50	36.93	0.07	0.02
Seed yield per capsule	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.18	0.00	0.00	42.69	0.19	0.00
Seed yield per plant	7.20^{NS}	46.13**	35.69**	37.80**	16.51^{NS}	0.70^{NS}	2.53	0.19	2.66	1.06	18.18	0.10	9.25
Oil content	13.63**	16.51**	11.98**	6.76**	14.03**	1.44**	1.10	0.18	2.76	0.56	62.28	0.72	0.12

* Significant at 5% level
** Significant at 1% level

The F value was positive and significant for the characters, plant height (446.19), number of days to 50 percent flowering (2.28), capsule length (0.02), 1000 seed weight (0.11) and oil content (14.03). Though non-significant others also recorded positive values. The potent ratio $(H_1/D)^{½}$ was less than one for number of days to 50 percent flowering (0.63). All other characters recorded values greater than one.

The proportion of genes with positive and negative effects in the parents is given by the ratio $H_2/4\ H_1$. The value of this ratio was less than 0.25 for all the characters studied. Value ranges from 0.18 to 0.24. Maximum value was recorded by days to 50 per cent flowering. Proportion of dominant and recessive genes in parents (KD/KR) was greater than unity for all characters except seed yield per capsules.

The ratio of h^2 / H_2 was greater than one for characters namely plant height (1.54), number of days to 50 percent flowering (1.09), and seed yield per plant (1.06) while for the remaining character the ratio was less than one. The environmental effect was significant for number of days to 50 percent flowering, capsule length and oil content. High estimates of heritability (>60%) in narrow sense was observed for the characters number of days to 50 percent flowering (68.09) and oil content (62.28). Moderate estimates of narrow sense heritability (30-60%) was recorded for plant height (43.38), number of branches per plant (33.47), number of capsules per mainstem (35.68), 1000 seed weight (36.93) and seed yield per capsule (42.69).

The $(ML_1-ML_0)^2$ was a positive value for all the characters studied except seed yield per capsule, capsule length for which the value was zero.

The value of Vr + Wr are presented in Table 24. Among the eight parents lowest value of Vr +Wr for the character, plant height, number of branches per plant, number of capsules per mainstem and oil content were observed in the variety OS-2. At the same time OS-2 recorded high value for capsule length. Thilak had low value for capsule length and highest value for number of branches per plant and oil content. Maximum value for number of capsule per plant, capsule length, 1000 seed weight and oil content were found with the variety Thilothamma. This variety possessed VR + Wr value of zero for 1000 seed weight and seed yield per capsule. VS 350 recorded low value for capsule length but highest value for number of days to 50 percent flowering. IC 204126 had lowest value for number of branches per plant, it was also found to have high value of 0.02 for capsule length, while culture IC 204156 was found to have lowest value of 1.67 for seed yield per plant and high value of 0.02 for capsule length and 0.10 for 1000 seed weight which is the highest. Culture NIC 17925 A possessed lowest value for number of days to 50 per cent flowering (2.03) and capsule length (0.01). SI 1225 also had the value of 0.01 for capsule length SI 1225 was also found to have highest value for plant height and number of capsule per mainstem. Culture NIC 17925 A recorded highest value for number of capsules per plant.

Table24 Estimates of Vr + Wr values for ten characters in 8 x 8 full diallel cross (Hayman's Approach)

	Plant height	No. of days to 50% flowering	No. of branches per plant	Capsules per main stem	Capsules per plant	Capsules length	1000 seed weight	Seed yield per capsule	Seed yield per plant	Oil content
Thilothamma	215.97	4.89	0.33	10.22	67.56	0.01	0.00	0.00	3.40	3.12
Thilak	234.73	6.29	1.08	10.49	353.78	0.01	0.02	0.00	11.24	18.19
OS-2	22.65	7.07	0.30	3.52	177.43	0.02	0.06	0.00	5.06	6.23
VS-350	134.05	10.89	0.31	28.01	320.43	0.01	0.08	0.00	10.56	7.91
IC 204126	110.34	3.73	0.15	19.59	126.32	0.02	0.03	0.00	7.84	8.50
IC 204156	95.59	4.73	0.43	12.01	82.16	0.02	0.10	0.00	1.67	7.62
NIC 17925 A	270.30	2.03	0.97	39.47	530.68	0.01	0.03	0.00	18.34	10.66
SI 1225	797.69	10.50	0.42	42.89	363.23	0.01	0.09	0.00	15.11	4.38

4.2.3. Estimation of heterosis

Analysis of variance of all the 56 hybrids and eight parents indicated that there was significant difference among genotypes for all characters studied.

The heterobeltiosis (over better parent), relative heterosis (over mid parent) and standard heterosis (over standard variety) for 10 traits are given in Tables 25 to 34.

a. **Plant height :** In the present study, tall type was considered as the better parent. The extent of heterosis over mid parent ranged from -14.81 (n_4 x n_2) to 85.64 (n_8 x n_5) (Table 25). Thirty nine crosses showed significant positive relative heterosis, while seven crosses showed significant negative heterosis. The extent of heterosis over better parent ranged from - 24.60 (n_4 x n_2) to 60.15 per cent (n_8 x n_5). Only twenty crosses showed significant positive heterobeltiosis and ten crosses showed significant negative heterobeltiosis. The extent of heterosis over standard check (Thilak) ranged from -34.36 (n_3 x n_2) to 26.28 (n_8 x n_5) per cent. Eight crosses recorded significant positive heterosis while 26 crosses recorded significant negative heterosis over standard check variety.

b. **Number of days to 50 per cent flowering** : Early flowering type was considered as the better parent. Thirty four hybrids showed significant postive heterosis and eleven hybrids showed significant negative heterosis over mid parents (Table 26). Over the better parent, fifteen hybrids showed significant positive

Table 25: Estimates of heterosis - Percentage deviation over better, mid and standard parent - plant height

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-29.88**	18.62**	14.11**	10.43**	0.60^{NS}	-4.5*	28.18**
		-17.17**	29.15**	20.12**	17.54**	10.93**	10.49**	40.45**
		-29.88**	-1.76^{NS}	-12.11**	-12.92**	-14.32**	-9.10**	-11.16**
n_2	8.44**		0.37^{NS}	18.65**	17.84**	6.46**	4.85**	3.38**
	28.10**		9.80**	34.05**	31.77**	14.99**	7.41**	31.53**
	8.44**		0.37^{NS}	18.65**	17.84**	6.46**	4.85**	3.38**
n_3	16.93**	34.36**		13.65**	32.98**	9.74**	-21.90**	26.42**
	27.32**	28.19**		-10.52**	36.24**	11.28**	-16.45**	49.55**
	-3.16^{NS}	34.36**		-28.49**	10.13**	6.53^{NS}	-25.62**	4.70^{NS}
n_4	25.93**	-24.60^{NS}	0.27**		22.53**	-3.71*	13.34*	-2.19**
	32.56**	-14.81**	3.90^{NS}		23.98**	1.13^{NS}	-4.18*	12.25**
	-3.01^{NS}	-24.60**	-16.96**		-3.38^{NS}	-17.99**	-17.47**	-24.67**
n_5	0.28**	-17.40^{NS}	-8.07^{NS}	19.46**		-4.14^{NS}	-4.32^{NS}	9.50**
	6.74**	7.64**	5.81*	20.87**		-0.45^{NS}	4.68^{NS}	26.93**
	-20.93**	-17.40**	-23.86**	-5.80^{NS}		-18.36**	-8.88**	-13.66**
n_6	6.81**	3.01**	8.36**	15.26**	11.21**		9.02**	27.24**
	17.78**	11.26**	9.88**	21.05**	15.49**		15.10**	52.24**
	-9.03**	3.01**	-7.71**	-1.84^{NS}	-5.29**		3.82^{NS}	8.37**
n_7	1.85**	23.05**	17.42**	10.10**	-21.90*	-20.97**		-13.03**
	17.89**	26.06**	25.61**	21.74**	-14.55**	-16.56**		8.67**
	-3.01^{NS}	23.05**	11.82**	4.85^{NS}	-25.62**	-24.74**		-17.18**
n_8	31.78**	1.76**	10.11**	25.64**	60.15**	28.88**	4.86**	
	44.40**	22.47**	30.26**	44.20**	85.64**	54.20**	31.02**	
	-8.66**	1.76^{NS}	-8.81**	-3.23^{NS}	26.28**	9.77**	-0.15^{NS}	

Table 26: Estimates of heterosis - Percentage deviation over better, mid and standard parent -Number of days to 50 per cent flowering

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		6.67**	8.33**	13.89**	-6.25**	-5.68**	1.23**	4.17**
		8.84**	8.33**	13.89**	-1.32^{NS}	3.75**	7.19**	4.17**
		6.67**	4.00^{NS}	9.33**	0.00	10.67**	9.33**	0.00
n_2	4.00**		0.00	-4.00**	0.00	-9.09**	3.70**	0.00
	6.12**		2.04^{NS}	2.04^{NS}	3.23*	-1.84^{NS}	7.69**	2.04^{NS}
	4.00^{NS}		0.00	-4.00^{NS}	6.67*	6.67*	12.0	0.00
n_3	0.00	-4.00**		6.94**	7.50**	-11.36**	6.17**	0.00
	0.00	-2.04^{NS}		6.94**	13.16**	-2.50**	12.42**	0.00
	-4.00^{NS}	0.00		2.67^{NS}	14.67**	4.00^{NS}	14.67**	-4.0^{NS}
n_4	0.00	0.00	0.00		11.11**	11.11**	8.33**	0.00
	0.00	2.04^{NS}	0.00		5.26**	0.00	1.96^{NS}	0.00
	-4.00^{NS}	0.00	-4.00^{NS}		6.67*	6.67*	4.0^{NS}	4.00^{NS}
n_5	0.00	0.00	-10.00**	-6.25**		-11.36**	-7.41**	0.00
	5.26**	3.23*	-5.26**	-1.32^{NS}		-7.14**	-6.83**	5.26**
	6.67*	6.67*	-4.00^{NS}	0.00		4.00^{NS}	0.00	6.67*
n_6	-10.23**	-10.23**	-6.82**	0.00	0.00		0.00	0.00
	-1.25^{NS}	-3.07**	2.50**	10.00**	4.76**		4.14**	10.00**
	5.33^{NS}	5.33^{NS}	9.33**	17.33**	17.33**		17.33**	17.33**
n_7	-7.41**	1.23^{NS}	-7.41**	8.64**	1.23^{NS}	-9.09**		-1.23^{NS}
	-1.96^{NS}	5.13**	-1.96^{NS}	15.03**	1.86^{NS}	-5.33**		4.58**
	0.00	9.33**	0.00	17.33**	9.33**	6.67*		6.67*
n_8	8.33**	4.00**	4.17**	4.17**	-10.00**	-6.82**	1.23^{NS}	
	8.33**	6.12**	4.17**	4.17**	-5.26**	2.50**	7.19**	
	4.0^{NS}	4.0^{NS}	0.00	0.00	-4.0^{NS}	9.33**	9.33**	

heterosis and eighteen hybrids showed significant negative heterosis. Heterosis ranged from - 7.14 per cent (n_5 x n_6) to 15.03 (n_7 x n_4) over mid parent where as the range was - 11.36 per cent (n_3 x n_6 & n_5 x n_6) to 13.89 per cent (n_1 x n_4) over better parent. Twenty six crosses recorded significant positive heterosis over check vareity. The heterosis over standard variety ranged from -4.0 to 17.33 per cent. Nine crosses were earlier than the standard check but the heterosis recorded were nonsignificant.

c. **Number of branches per plant :** Relative heterosis ranged from - 51.22 per cent (n_8 x n_3) to 100.00 per cent (n_8 x n_5) and heterobeltiosis ranged from - 58.33 per cent (n_8 x n_3) to 70.59 per cent (n_8 x n_6) (Table 27). Forty three crosses showed positive significant relative heterosis, while 31 crosses showed positive significant heterobeltiosis. Only five crosses showed negative significant relative heterosis and 16 crosses showed negative significant heterobeltiosis. The standard heterosis ranged from -52.38 (n_8 x n_3) to 166.67 per cent (n_7 x n_2). Forty one crosses showed positive significant standard heterosis while two crosses (n_8 x n_3 and n_8 x n_4) recorded negative significant heterosis.

d. **Number of capsules per mainstem :** Heterosis ranged from - 47.97 per cent (n_7 x n_6) to 156.34 per cent (n_8 x n_5) over the mid parent and 35 crosses showed positive significant heterosis, while 13 crosses showed negative significant heterosis (Table 28). The range of heterosis was -56.30 percent (n_7 x n_5) to 119.28 per cent (n_8 x n_5) over the better parent . Twenty one

Table 27: Estimates of heterosis - Percentage deviation over better, mid and standard parent - Number of branches per plant.

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n8
n_1		4.35^{NS}	8.33**	26.09**	30.77**	34.78**	-8.11**	21.74**
		9.09*	10.64**	26.09**	38.78**	72.22**	13.33**	40.00**
		14.29^{NS}	23.81*	38.10**	61.90**	47.62**	61.90**	33.33**
n_2	60.87**		12.50**	47.83**	30.77**	33.33**	10.81**	57.14**
	68.18**		20.00**	54.55**	44.68**	64.71**	41.38**	73.68**
	76.19**		28.57**	61.90**	61.90**	33.33**	95.24**	57.14**
n_3	8.33**	20.83**		-4.17^{NS}	38.46**	41.67**	-21.62**	50.00**
	10.64**	15.56**		-2.13^{NS}	44.00**	83.78**	-4.92^{NS}	75.61**
	23.81*	38.10**		9.52^{NS}	71.43**	61.90**	38.10**	71.43**
n_4	8.70*	4.35^{NS}	0.00^{NS}		7.69*	-8.70**	-13.51**	-8.70*
	8.70*	9.09*	2.13^{NS}		14.29**	16.67**	6.67*	5.00^{NS}
	19.05*	14.29^{NS}	14.29^{NS}		33.33**	0.00	52.38**	0.00
n_5	-15.38**	3.85^{NS}	-7.69*	15.38**		-15.38**	-5.41*	11.84**
	-10.20**	14.89**	-4.00^{NS}	22.45**		12.82**	11.11**	34.88**
	4.76	28.57**	14.29^{NS}	42.86**		4.76^{NS}	66.67**	38.10**
n_6	4.35^{NS}	47.62**	33.33**	26.09**	15.38**		48.65**	58.82**
	22.22**	82.35**	72.97**	61.11**	53.85**		24.00**	80.00**
	4.76^{NS}	47.62**	52.38**	38.10**	42.86**		-9.52^{NS}	28.57**
n_7	0.00^{NS}	51.35**	2.70^{NS}	-21.62**	-18.92**	-40.54**		-29.73**
	23.33**	93.10**	24.59**	-3.33^{NS}	-4.76^{NS}	-12.00**		-3.70^{NS}
	76.19**	166.67**	80.95**	38.10**	42.86**	4.76^{NS}		23.81*
n_8	0.00^{NS}	19.05**	-58.33**	-29.09**	65.38**	70.59**	-32.43**	
	15.00**	31.58**	-51.22**	-15.00**	100.00**	93.33**	-7.41*	
	9.52^{NS}	19.05*	-52.38**	-19.05*	104.76**	38.10**	19.05*	

Table 28: Estimates of heterosis - Percentage deviation over better, mid and standard parent - Number of capsules per mainstem.

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-42.41**	14.16**	20.20**	14.78*	9.66*	-22.83**	20.20**
		-35.65**	22.02**	47.43**	26.29**	18.37**	-14.22**	52.02**
		-42.41**	3.50^{NS}	-5.06^{NS}	9.34^{NS}	1.56^{NS}	-23.74**	-5.06^{NS}
n_2	25.29**		-0.78^{NS}	15.95**	10.89*	1.17^{NS}	-0.39^{NS}	10.12*
	40.00**		4.08^{NS}	54.81**	34.75**	5.05^{NS}	0.20^{NS}	50.93**
	25.29**		-0.78^{NS}	15.95*	10.89*	1.17^{NS}	-0.39^{NS}	10.12^{NS}
n_3	18.88**	45.91**		3.43^{NS}	50.21**	7.14^{NS}	-37.01**	3.00^{NS}
	27.06**	43.27**		33.52**	75.44**	8.28^{NS}	-34.29**	36.75**
	7.78^{NS}	26.46**		-6.23^{NS}	36.19**	-0.78^{NS}	-37.74**	-6.61^{NS}
n_4	33.00**	-39.69**	0.00^{NS}		30.12**	-41.18**	-8.27^{NS}	43.75**
	63.14**	-19.48**	29.09**		46.94**	-23.50**	21.99**	49.59**
	5.06^{NS}	-39.69**	-9.34^{NS}		-15.65**	-45.53**	-9.34^{NS}	-28.40**
n_5	-18.72**	-20.62**	-24.03**	50.60**		-35.71**	-49.61*	42.17**
	-10.57^{NS}	-3.55^{NS}	-11.28*	70.07**		-24.26**	-39.05**	66.20**
	-35.80**	-20.62*	-31.13**	-2.72^{NS}		-40.47**	-50.19**	-8.17^{NS}
n_6	1.68^{NS}	-14.01**	-19.33**	0.42^{NS}	-5.86^{NS}		-32.28**	7.89^{NS}
	9.75*	-10.71*	-18.47**	30.60**	10.89*		-30.08**	44.38**
	-5.84^{NS}	-14.04^{NS}	-25.29**	-7.00^{NS}	-12.84^{NS}		-33.07**	0.00
n_7	-4.72^{NS}	27.63**	22.05**	-12.60**	-56.30**	-49.61**		-14.96**
	5.91^{NS}	28.38**	27.31**	-16.23**	-47.14**	-47.97**		16.13**
	-5.84^{NS}	27.63**	20.62*	-13.62^{NS}	-56.81**	-50.19**		-15.95^{NS}
n_8	-8.87^{NS}	-14.01**	-21.03**	64.84**	119.28**	5.46^{NS}	-7.09^{NS}	
	15.26*	17.87**	4.84^{NS}	71.54**	156.34**	41.01**	26.88**	
	-28.02**	-14.01^{NS}	-28.40**	-17.90*	41.63**	-2.33^{NS}	-8.17^{NS}	

crosses showed significant heterobeltiosis in the positive direction and 17 crosses showed significant heterobeltiosis in the negative direction. The range of heterosis over standard variety was -56.81 (n_7 x n_5) to 41.63 per cent (n_8 x n_5). Only five crosses recorded positive significant heterosis while 19 crosses recorded negative significant heterosis over standard variety.

e. **Number of capsules per plant :** The range of heterosis over the mid parent was - 61.80 per cent (n_7 x n_5) to 350.83 per cent (n_8 x n_5), over the better parent was - 72.36 per cent (n_7 x n_5) and 253.07 per cent (n_8 x n_5) and over standard check was -39.17 (n_7 x n_5) to 247.45 per cent (n_8 x n_5) (Table 29). Thirty seven crosses showed positive significant heterosis over the mid parent, 32 crosses showed positive significant heterosis over the better parent and 35 crosses showed positive significant heterosis over standard check. Only eight crosses showed negative and significant relative heterosis and 17 crosses recorded negative significant heterobeltiosis while only a single cross showed negative significant standard heterosis.

f. **Capsule length :** Relative heterosis ranged from- 12.87 per cent (n_1x n_6) to 14.29 per cent (n_3x n_5), heterobeltiosis ranged from- 18.52 per cent (n_1 x n_6 & n_4 x n_6) to 12.00 per cent (n_3 x n_5) and standard heterosis ranged from -8.33(n_1 x n_6, n_4 x n_6 and n_7 x n_5) to 16.67 per cent (n_3 x n_5 and n_3 x n_6) (Table 30). Twenty seven crosses exihibited significant positive relative heterosis while only ten crosses showed significant negative relative heterosis. When twenty one crosses showed significant positive

Table 29 Estimates of heterosis - Percentage deviation over better, mid and standard parent - Capsules per plant

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-29.23**	42.64**	24.18**	60.44**	50.33**	-24.31**	8.24^{NS}
		-16.25**	61.64**	71.99**	91.10**	73.38**	-8.73**	56.35**
		2.55^{NS}	106.69**	79.94**	132.48**	117.83**	66.56**	56.85**
n_2	81.76**		89.37**	120.70**	88.22**	69.16**	-15.92**	133.44**
	115.08**		99.09**	168.60**	89.73**	74.38**	15.62**	199.80**
	163.38**		109.87**	120.70**	88.22**	79.94**	85.03**	133.44**
n_3	69.23**	11.21^{NS}		37.07**	122.99**	114.08**	-45.15**	101.44**
	91.78**	6.65^{NS}		73.45**	136.23**	118.48**	-27.05**	168.07**
	145.22**	157.64**		51.91**	147.13**	137.26**	20.70^{NS}	123.25**
n_4	19.78**	-15.29^{NS}	26.44**		104.53**	-32.04**	-26.48**	56.57**
	65.91**	3.10^{NS}	60.00**		147.36**	-15.30^{NS}	13.77**	45.36**
	73.57**	-15.29^{NS}	40.13*		101.27**	-27.70^{NS}	61.78**	-12.74^{NS}
n_5	-11.43^{NS}	14.97^{NS}	-8.05^{NS}	125.24**		-38.92**	-59.48**	38.19**
	5.50^{NS}	15.89*	-2.59^{NS}	172.41**		-36.55**	-44.00**	76.45**
	28.34^{NS}	14.97^{NS}	1.91^{NS}	121.65**		-35.03^{NS}	-10.83^{NS}	35.99**
n_6	-17.14**	75.75**	18.68*	51.80**	47.01**		-67.87**	52.10**
	-4.44^{NS}	81.17**	21.11**	89.18**	52.72**		-56.68**	99.61**
	20.06^{NS}	86.94**	31.53^{NS}	61.46**	56.37**		-29.30^{NS}	61.78**
n_7	-30.82**	50.36**	1.30^{NS}	-32.56**	-72.36**	-67.00**		-41.82**
	-16.58**	106.77**	34.74**	4.37^{NS}	-61.80**	-55.50**		-7.16^{NS}
	52.23**	230.89**	122.93**	48.41**	-39.17*	-27.39^{NS}		28.03^{NS}
n_8	-22.86**	31.21**	-36.49**	68.32**	253.07**	76.95**	-37.34**	
	11.43^{NS}	68.51**	-15.49^{NS}	80.37**	350.83**	132.22**	0.00^{NS}	
	11.78^{NS}	31.21^{NS}	-29.62^{NS}	8.28^{NS}	247.45**	88.22**	37.90*	

Table 30 Estimates of heterosis - Percentage deviation over better, mid and standard parent - Capsule length

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-4.17*	-4.00*	6.38**	6.25**	-18.52**	0.00^{NS}	8.51**
		-3.16^{NS}	-1.03^{NS}	7.53**	7.37**	-12.87**	2.17^{NS}	8.51**
		-4.17^{NS}	0.00^{NS}	4.17^{NS}	6.25^{NS}	-8.33*	-2.08^{NS}	6.25^{NS}
n_2	0.00^{NS}		2.00^{NS}	8.33**	2.08^{NS}	-11.11**	4.17*	6.25**
	1.05^{NS}		4.08*	10.64**	2.08^{NS}	-5.88**	7.53**	7.37**
	0.00^{NS}		6.25^{NS}	8.33*	2.08^{NS}	0.00	4.17^{NS}	6.25^{NS}
n_3	-4.00*	4.00*		2.00^{NS}	12.00**	3.70*	4.00*	0.00^{NS}
	-1.03^{NS}	2.04^{NS}		6.25**	14.29**	7.69**	9.47**	3.09^{NS}
	0.00^{NS}	0.00^{NS}		6.25^{NS}	16.67**	16.67**	8.33*	4.17^{NS}
n_4	10.64**	6.25**	2.00^{NS}		4.17*	-18.52**	10.87**	10.64**
	11.83**	8.51**	6.25**		6.38**	-12.00**	12.09**	11.83**
	8.33*	6.25^{NS}	6.25^{NS}		4.17^{NS}	-8.33^{NS}	6.25^{NS}	8.33*
n_5	-2.08^{NS}	-4.17*	-4.00*	2.08^{NS}		-9.26**	-6.25**	-6.25**
	-1.05^{NS}	-4.17*	-2.04^{NS}	4.26*		-3.92**	-3.23^{NS}	-5.26**
	-2.08^{NS}	-4.17^{NS}	0.00^{NS}	2.08^{NS}		2.08^{NS}	-6.25^{NS}	-6.25^{NS}
n_6	-5.56**	-11.11**	-9.26**	-3.70*	-7.41**		-5.56**	-3.70*
	0.99^{NS}	-5.88**	-5.77**	4.00*	-1.96^{NS}		3.03^{NS}**	2.97^{NS}
	6.25^{NS}	0.00^{NS}	2.08^{NS}	8.33*	4.17^{NS}		6.25^{NS}	8.33*
n_7	2.13^{NS}	4.17*	-8.00**	4.35**	-8.33**	-7.41**		8.51**
	4.35*	-1.08^{NS}	-3.16^{NS}	5.49**	-5.38**	1.01^{NS}		10.87**
	0.00^{NS}	-4.17	-4.17^{NS}	0.00^{NS}	-8.33^{NS}	4.17^{NS}		6.25^{NS}
n_8	10.64**	10.42**	2.00^{NS}	-2.13^{NS}	4.17*	-5.56**	6.38**	
	10.64**	11.58**	5.15**	-1.08^{NS}	5.26**	0.99^{NS}	8.70**	
	8.33*	10.42*	6.25^{NS}	-4.17^{NS}	4.17^{NS}	6.25^{NS}	4.17^{NS}	

heterobeltiosis, 23 crosses exihibited significant heterobeltiosis in the negative direction. When 10 crosses recorded significant positve standard heterosis only three exihibited negative significant standard heterosis.

g. **1000 Seed weight :** Heterosis ranged from -29.50 per cent (n_1 x n_6) to 13.60 per cent (n_4 x n_1) over the mid parent, - 35.53 per cent (n_1 x n_6) to 30.88 per cent (n_5 x n_4) over the better parent and -30.88 per cent (n_5 x n_4) to 11.76 per cent (n_6 x n_7) over the standard variety (Table 31). Only 12 crosses showed significant favourable heterosis over the mid parent, eleven crosses showed favourable better parent heterosis and one cross showed favourable heterosis over standard variety. Twenty six crosses showed unfavourable heterosis over the mid parent, 33 crosses showed unfavourable heterosis over the better parent and ten crosses showed unfavourable heterosis over standard variety.

h. **Seed yield per capsule :** Heterosis over the mid parent ranged from- 31.58 per cent (n_7 x n_5)to 37.50 per cent, (n_1 x n_4 & n_1 x n_5), heterosis over the better parent ranged from -42.86 per cent (n_1 x n_6) to 33.33 per cent (n_3 x n_5) and heterosis over standard variety ranged from -38.10 (n_3 x n_1 and n_7 x n_5) to 33.33 (n_6 x n_4) per cent (Table 32). Thirty crosses recorded significant positive heterosis over the mid parent while 20 crosses recorded significant relative heterosis in the negative direction. When 21 crosses showed significant positive heterosis over the better parent 30 crosses recorded significant heterobeltiosis in the negative direction. Eleven crosses recorded significant positive

Table 31 Estimates of heterosis - Percentage deviation over better, mid and standard parent - 1000 Seed weight

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-2.94^{NS}	-13.43**	6.35**	0.00^{NS}	-35.53**	4.55*	-15.38**
		0.76^{NS}	-10.77**	7.20**	3.82^{NS}	-29.50**	6.98**	-6.38**
		-2.94^{NS}	-14.71**	-1.47^{NS}	0.00	-27.94**	1.47^{NS}	-2.94^{NS}
n_2	-4.41*		-4.41*	1.47^{NS}	4.41*	-11.84**	2.94^{NS}	-12.82**
	-0.76^{NS}		-3.70^{NS}	6.15**	4.41*	-6.94**	4.48*	-6.85**
	-4.41^{NS}		-4.41^{NS}	1.47^{NS}	4.41^{NS}	-1.47^{NS}	2.94^{NS}	0.00*
n_3	-4.48*	-23.53**		0.00	0.00	-10.53**	0.00^{NS}	-14.10**
	-1.54^{NS}	-22.96**		3.83^{NS}	0.74^{NS}	4.90**	0.75^{NS}	-7.59**
	-5.88^{NS}	-23.53**		-1.47^{NS}	0.00	0.00	-1.47^{NS}	1.47^{NS}
n_4	14.52**	16.13**	9.68**		12.90**	4.84**	11.29**	20.97**
	13.60**	10.77**	5.43**		7.69**	-5.80**	7.81**	7.14**
	4.41^{NS}	5.88^{NS}	0.00		2.94^{NS}	-4.41^{NS}	1.47^{NS}	10.29*
n_5	-5.88**	-2.94^{NS}	0.00^{NS}	30.88**		-23.68**	-2.94^{NS}	-20.51**
	-2.29^{NS}	-2.94^{NS}	0.74^{NS}	27.69**		-19.44**	-1.49^{NS}	-15.07**
	-5.88	-2.94	0.00	30.88**		-14.71**	-2.94^{NS}	-8.82*
n_6	-10.53**	-13.16**	-15.79**	-9.21**	-13.16**		0.00^{NS}	-15.38**
	-2.16^{NS}	-8.33**	-10.49**	0.00^{NS}	-8.33**		7.04**	-14.29**
	0.00	-2.94^{NS}	-5.80^{NS}	1.47^{NS}	-2.94^{NS}		11.76**	-2.94^{NS}
n_7	-4.55*	-4.41*	-11.94**	-15.15**	-2.94^{NS}	-15.79**		-14.10**
	-2.33^{NS}	-2.99^{NS}	-11.28^{NS}	-12.50**	-1.49^{NS}	-9.86**		-6.94**
	-7.35^{NS}	-4.41^{NS}	-13.24**	-17.65**	-2.94^{NS}	-5.88^{NS}		-1.47^{NS}
n_8	-20.51**	-19.23**	-6.41**	-14.10**	-17.95**	-25.64**	-16.67**	
	-12.06**	-13.70**	0.69^{NS}	-4.29*	-12.33**	-24.68**	-9.72**	
	-8.82*	-7.35^{NS}	7.35^{NS}	-1.47^{NS}	-5.88^{NS}	-14.71**	-4.41^{NS}	

Table 32 Estimates of heterosis - Percentage deviation over better, mid and standard parent - Seed yield per capsule

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-16.67**	0.00	12.82**	12.82**	-42.86**	10.81**	-9.30**
		4.48*	19.35**	37.50**	37.50**	-24.32**	32.26**	14.71**
		-14.29**	-9.52*	4.76^{NS}	4.76^{NS}	-3.33**	-4.76^{NS}	-9.52*
n_2	-19.05**		4.76*	9.52**	-4.76*	-22.45**	7.14**	4.65*
	1.49^{NS}		1.27^{NS}	13.58**	-1.23^{NS}	-16.48**	13.92**	5.88**
	-19.05**		4.76^{NS}	9.52*	-4.76^{NS}	-9.52*	4.76^{NS}	4.76^{NS}
n_3	-29.73**	11.90**		20.51**	33.33**	-4.08**	16.22**	18.60**
	-16.13**	6.33**		23.68**	36.84**	9.30**	16.22**	24.39**
	-38.10**	9.52*		9.52*	23.81**	9.52*	4.76	-14.29**
n_4	7.69**	7.14**	29.73**		12.82**	0.00^{NS}	28.21**	18.60**
	31.25**	11.11**	26.32**		12.82**	11.36**	31.58**	24.39**
	0.00	4.76^{NS}	14.29**		4.76^{NS}	19.05**	19.05**	19.05**
n_5	-5.13*	-4.76*	5.41*	-17.95**		-28.57**	-13.51**	-11.63**
	15.63**	-1.23^{NS}	2.63^{NS}	-17.95**		-20.45**	-15.79**	-7.32**
	-9.52*	-4.76^{NS}	9.52*	-23.81**		-14.29**	-23.81**	-9.52*
n_6	-16.33**	-22.45**	-26.53**	14.29**	-20.41**		-12.24**	-16.33**
	10.81**	-16.48**	-16.28**	27.27**	-11.36**		0.00^{NS}	-10.07**
	-4.76	-9.52*	-14.29**	33.33**	-9.52*		4.76^{NS}	-4.76^{NS}
n_7	-24.32**	-14.29**	-10.81**	-12.82**	-33.33**	-20.41**		-14.63**
	-9.68**	-8.86**	-10.81**	-10.53**	-31.58**	-9.30**		-5.00*
	-33.33**	-14.29**	-23.81**	-19.05**	-38.10**	-9.52*		-9.52
n_8	-13.95**	9.30**	2.33^{NS}	16.28**	0.00^{NS}	-24.49**	2.33^{NS}	
	8.82**	10.59**	10.00**	21.95**	4.88*	-19.57**	10.00**	
	-9.52*	9.52*	4.76^{NS}	19.05**	4.76^{NS}	-9.52*	4.76^{NS}	

heterosis while 27 crosses recorded significant negative heterosis over standard variety.

i. **Seed yield per plant :** Percentage heterosis over the midparent ranged from -72.58 (n_7 x n_5) to 382.44 (n_8 x n_5), the range was -79.87 (n_7 x n_5) to 293.74 (n_8 x n_5) over the better parent and the range was -61.48 (n_7 x n_5) to 251.81 (n_3 x n_5) over standard variety (Table 33). Thirty nine crosses showed positive significant heterosis while only six crosses showed negative significant heterosis over the mid parent. Thirty two crosses showed positive significant heterosis while thirteen crosses showed negative significant heterosis over the better parent. Thirty four crosses showed positive significant heterosis while only two crosses recorded negative significant heterosis over standard variety.

j. **Oil content :** Heterosis ranged from -24.07 per cent (n_2 x n_6) to 10.87 per cent (n_1 x n_5) over the midparent, -25.45 per cent (n_2 x n_6) to 8.51 per cent (n_1 x n_5) over the better parent and -25.45 per cent (n_2 x n_6) to 16.36 per cent (n_3 x n_2) over standard variety (Table 34). Twelve crosses showed positive significant heterosis, while 24 crosses showed negative significant heterosis over the mid parent. Only six crosses did show positive significant heterosis, while 38 crosses showed negative significant heterosis over the better parent. Only the crosses n_2 x n_3 and reciprocal n_3 x n_2 did show positive significant heterosis over standard variety.

Table.33 Estimates of heterosis - Percentage deviation over better, mid and standard parent - seed yield per plant

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-14.49^{NS}	87.14**	115.32**	172.53**	18.35*	-14.55**	69.78**
		8.63^{NS}	97.55**	155.21**	175.79**	38.71**	17.32**	106.10**
		-14.50^{NS}	82.25**	87.76**	143.50**	46.07*	63.29**	48.19*
n_2	110.79**		98.87**	144.08**	80.15**	30.95**	4.31^{NS}	149.06 **
	125.24**		101.45**	205.24**	90.35**	44.66**	36.90**	218.38 **
	111.03**		174.62**	144.26**	80.21**	61.63**	99.24**	149.24**
n_3	57.40**	94.57**		74.36**	213.32**	115.23**	-35.03**	91.25 **
	66.15**	93.46**		115.92**	227.00**	140.53**	-13.98*	142.18**
	53.47**	136.56**		69.94**	205.59**	165.86**	24.17^{NS}	86.56**
n_4	97.84**	9.21^{NS}	60.50**		136.60**	-32.48**	0.67^{NS}	73.30**
	134.48**	13.54^{NS}	98.75**		183.16**	-9.10^{NS}	53.24**	78.47**
	72.51**	-9.06^{NS}	56.40**		11.34**	-16.62^{NS}	92.30**	3.93^{NS}
n_5	24.26**	8.91^{NS}	-3.41^{NS}	82.50**	_	-56.09**	-64.29**	34.32**
	25.75**	15.07^{NS}	0.81^{NS}	118.41**	_	49.04**	-51.35**	64.58**
	11.03^{NS}	9.06^{NS}	-5.89^{NS}	63.14**		-45.77*	-31.72^{NS}	19.94^{NS}
n_6	-5.20^{NS}	37.37**	-9.97^{NS}	73.39**	17.68*	_	-61.84**	25.87**
	11.11^{NS}	51.76**	0.62^{NS}	133.43**	36.55**	_	-53.65**	72.72 **
	17.07^{NS}	69.64**	11.18^{NS}	114.05**	45.32*		-27.19^{NS}	55.44**
n_7	-45.95**	47.13**	-7.47^{NS}	-36.46**	-79.87**	-64.69**	_	-39.03**
	-25.79**	93.10**	22.51**	-3.28^{NS}	-72.58**	-57.11**	_	-5.89 ^{NS}
	3.32^{NS}	180.97**	76.74**	21.30^{NS}	-61.48**	-32.48^{NS}		16.47^{NS}
n_8	12.47^{NS}	46.34**	-24.17*	115.37**	293.74**	31.68**	-24.56**	_
	36.52*	87.07**	-3.97^{NS}	121.79**	382.44**	80.70**	16.45*	
	-1.96^{NS}	46.37*	-26.13^{NS}	29.15^{NS}	251.81**	62.69**	44.11*	

Table 34 Estimates of heterosis - Percentage deviation over better, mid and standard parent - Oil Content

	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n_1		-9.09**	-4.26*	0.00^{NS}	8.51**	-20.75**	-11.54**	-16.98**
		0.00^{NS}	2.17^{NS}	1.10^{NS}	10.87**	-14.29**	-5.15**	-10.20**
		-9.09**	-18.18**	-16.36**	-7.27*	-23.64**	-16.36**	-20.0**
n_2	-23.64**		10.91**	-10.91**	-7.27**	-25.45**	-9.09**	-10.91**
	-16.00**		3.92**	-2.97	0.00^{NS}	-24.07**	-6.54**	-9.26**
	-23.64**		10.91**	-10.91**	-7.27*	-25.45**	-9.09**	-10.91**
n_3	6.38**	16.36**		-6.38**	2.13^{NS}	-5.66**	-11.54**	-13.21**
	8.70**	9.80**		-5.38**	2.13^{NS}	0.00^{NS}	-7.07**	-8.00**
	-9.09**	16.36**		-20.0**	-12.73**	-9.09**	-16.36**	-16.36**
n_4	0.00^{NS}	-20.00**	-2.13^{NS}		6.38**	-11.32**	-7.69**	-7.55^{NS}
	1.10^{NS}	-12.87**	-1.08^{NS}		7.53**	-5.05**	-2.04^{NS}	-1.01^{NS}
	-16.36**	-20.0**	-16.36**		-9.09**	-14.55**	-12.73**	-10.91
n_5	4.26*	-5.45**	-2.13^{NS}	-10.64**		-7.55**	-5.77**	-16.98**
	6.52**	1.96^{NS}	-2.13^{NS}	-9.68**		-2.00^{NS}	-1.01^{NS}	-12.00**
	-10.91**	-5.45	-16.36**	-23.64**		-10.91	-10.91**	-20.0**
n_6	-3.77**	-9.09**	-3.77*	-5.66**	-5.66**		-3.77*	-1.89^{NS}
	4.08**	-7.41**	2.00^{NS}	1.01^{NS}	0.00^{NS}		-2.66*	-1.89^{NS}
	-7.27*	-9.09**	-7.27*	-9.09**	-9.09**		-7.27*	-5.45^{NS}
n_7	-9.62**	-1.82^{NS}	-11.54**	7.69**	-1.92^{NS}	-16.98**		-5.66**
	-3.09*	0.93^{NS}	-7.07**	-2.04NS	3.03*	-16.98**		-4.76**
	-14.55**	1.82^{NS}	-16.36**	-12.73**	-7.27*	-20.0**		-9.09**
n_8	1.899^{NS}	12.73**	-1.89^{NS}	-1.89^{NS}	1.89^{NS}	-3.77**	-11.32**	
	10.20**	11.11**	4.00**	5.05**	8.00*	-3.77**	-10.48**	
	-1.82^{NS}	-12.73**	-5.45^{NS}	-5.45^{NS}	-1.82^{NS}	-7.27*	-14.55**	

4.3 Experiment III

The two best general combiners from the results of Experiment II based on seed yield and highly correlated yield components viz., number of capsules per mainstem and number of capsules per plant, were subjected to induction of male sterility through both induced mutagenesis and wide hybridization.

4.3.1 Induced mutagenesis

The mutagen treated seeds of the two genotypes viz., Thilak and OS-2 were sown in the field and studied in the M_1 generation for the effects of mutagens on germination, survival, pollen fertility and seed fertility. The results are given in Table 35 to 38.

4.3.1.1 Effects of mutagens in the M_1 generations.

The percentage of germination recorded are presented in the Table 35. Germination was adversely influenced by the mutagens and the germination percentage decreased with increased dose of physical as well as chemical mutagen. Both the genotypes exihibited a reduction in germination with increase in doses of mutagen. Significant differences were observed among different doses of mutagen. Reduction was drastic at higher doses of chemical mutagen.

The survival percentage of seedlings on the 30th day are given in Table 36. There was a decrease in survival with increase in doses of mutagens. Both genotypes showed considerable reduction in survival at higher doses of mutagens. The survival percentage

Table35 Effect of mutagens on germination in M_1 Generation

Mutagen/Dose	Thilak		OS - 2	
	Mean (%)	Per cent of control	Mean (%)	Per cent of control
1. Gamma rays (Gy)				
Control	94.00	100.00	95.20	100.00
100 Gy	83.60	88.94	89.60	94.12
200	76.20	81.06	78.20	82.14
300	69.50	73.94	66.60	69.96
400	59.40	63.19	54.80	57.56
500	46.30	49.26	40.20	42.23
600	36.50	38.83	36.00	37.82
2. EMS (%)				
Control	92.50	100.00	91.60	100.00
0.2	76.30	82.49	81.70	89.19
0.4	59.20	64.00	69.20	75.33
0.6	46.40	50.16	56.20	61.35
0.8	24.40	26.38	40.60	44.32
1.0	20.90	22.59	26.40	28.82

Table 36 Effect of mutagens on survival of plants in M_1 Generation on 30th day.

Mutagen/Dose	Thilak		OS - 2	
	Mean (%)	Per cent of control	Mean (%)	Per cent of control
1. Gamma rays (Gy)				
Control	91.2	100.00	92.8	100.00
100 Gy	84.9	93.09	80.3	86.53
200	67.3	73.79	70.2	75.65
300	55.8	61.18	57.6	62.07
400	48.4	53.07	46.2	49.78
500	35.3	38.71	30.5	32.87
600	30.2	33.11	24.6	26.51
2. EMS (%)				
Control	90.6	100.00	92.8	100.00
0.2	81.7	90.18	83.6	90.09
0.4	69.2	76.38	76.4	82.33
0.6	58.2	64.24	53.8	57.97
0.8	46.3	51.10	44.5	47.95
1.0	31.9	35.21	30.2	32.54

reduced considerably at 500 and 600 Gy of gamma rays and also at higher doses of EMS.

The percentage of pollen fertility was found to decrease with increase in doses of mutagens (Table 37). The reduction in fertility was more drastic in treatments with EMS than with gamma rays. The pollen fertility ranged from 39.37 (EMS) to 89. 94 (gamma rays) per cent of control in Thilak and 37.22 (Gamma rays) to 82.96 (gamma ray) per cent of control in OS-2.

There was considerable reduction in seed fertility in both the genotypes studied with increase in doses of mutagens (Table 38). The seed fertility varied from 35.22 (EMS, gamma ray) to 86. 91 (Gamma ray) per cent of control in Thilak and 35.71(EMS) to 86.31 (Gamma ray) per cent of control in OS-2. The reduction was very high at higher doses when compared to control.

4.3.1.2 Screening for sterility in M_2 generations

The study of viable sterile mutations was confined to those doses in which pollen fertility reduced to less than 50 percent. All mutants in which pollen fertility was completely affected were classified as viable sterile mutations. These were observed in individual M_2 plants through microscopic examinations of pollen.

The viable sterile mutants were screened in M_1 plant progenies. Thirty plant progenies were screened and selected at random under each doses viz., gamma ray (500 gy and 600 gy) and EMS (0.8% & 1.0%). The viable sterile mutants were screened and the frequencies

Table 37 Effect of mutagens on pollen fertility in M_1 Generation

Mutagen/Dose	Thilak		OS - 2	
	Mean (%)	Per cent of control	Mean (%)	Per cent of control
1. Gamma rays (Gy)				
Control	94.40	100.00	92.7	100.00
100 Gy	84.9	89.94	76.9	82.96
200	72.7	77.01	73.9	79.72
300	62.4	66.10	65.6	70.77
400	54.6	57.84	53.4	57.61
500	42.6	45.13	47.6	51.35
600	38.4	40.68	34.5	37.22
2. EMS (%)				
Control	95.5	100.00	93.5	100.00
0.2	84.2	88.17	75.0	80.21
0.4	70.6	73.93	69.5	74.33
0.6	61.0	63.87	56.8	60.75
0.8	41.9	43.87	49.3	52.73
1.0	37.6	39.37	35.4	37.86

Table 38 Effect of mutagens on seed fertility in M_1 Generation

Mutagen/Dose	Thilak		OS - 2	
	Mean (%)	Per cent of control	Mean (%)	Per cent of control
1. Gamma rays (Gy)				
Control	91.7	100.00	93.5	100.00
100 Gy	79.7	86.91	80.7	86.31
200	69.7	76.01	69.4	74.22
300	61.8	67.39	56.8	60.75
400	50.2	54.74	49.3	52.73
500	49.3	53.76	43.9	46.95
600	32.3	35.22	40.5	43.32
2. EMS (%)				
Control	91.7	100.00	96.9	100.00
0.2	75.6	82.44	80.6	83.18
0.4	67.9	74.05	72.9	75.23
0.6	50.2	54.74	61.2	63.16
0.8	47.8	52.13	42.3	43.65
1.0	32.3	35.22	34.6	35.71

were estimated as mutations per 100 M_1 plants and 100 M_2 plants (Table 39). Among the genotypes Thilak produced more sterile mutants and chemical mutagen EMS was found to induce more number of sterile mutants than gamma rays.

The data on sibmating and open pollination of screened sterile mutants in M_2 generations are furnished in Table 40. On sibmating and open pollination, capsule set was not noticed in all the sterile plants. In Thilak, out of four sterile plants, only two plants set capsules on cross pollination whereas in OS- 2 only one of the two sterile plants set capsules on crossing. Similarly capsule set on sibmating and open pollination was observed in two out of four and one of the two with Thilak and OS-2 respectively. The sibmating and open pollination failed to set capsules in the remaining plants which showed cent per cent pollen sterility. This was indicative of total female sterility in these plants along with complete male sterility resulting in total absence of capsules.

All flower parts except anthers were normal in size and colour in the male sterile plants. Anthers of male sterile plants were flatter and greenish than those of the normal which are whitish and plumpy. However, these mutants exihibited partial sterility and have only little scope for commercial hybrid seed production.

4.3.1.3 Mutagenic effectiveness and efficiency

Mutagenic effectiveness denotes the frequency of mutations induced by a unit dose of a mutagen while mutagenic efficiency is a measure of the proportion of mutations in relation to

Table 39 Frequency of viable sterile mutants in the M_2 Generation

	Number of M_1 plants			Number of M_2 plants		
Mutagen/Dose/ Genotype	Scored	Viable sterile mutants	Frequency (%)	Scored	Viable sterile mutants	Frequency (%)
Control (dry) Thilak	30	0	-	100	0	-
OS-2	30	0	-	100	0	-
Gamma rays						
500 Gy Thilak	30	0	-	100	0	-
OS-2	30	0	-	100	0	-
600 Gy Thilak	30	2	6.66	175	1	0.57
OS-2	30	1	3.33	215	1	0.47
Control (wet) Thilak	30	0	-	100	0	-
OS-2	30	0	-	100	0	-
EMS						
O.8 Thilak	30	1	3.33	168	1	0.59
OS-2	30	1	3.33	150	-	-
1.0 Thilak	30	3	10.00	250	2	0.80
OS-2	30	2	6.66	200	1	0.50

Table 40 Details of sibmating and open pollination in sterile mutants in M_2 generation

Mutagen/Dose	No. of plants					
	Steriles		Sibmating		Open pollination	
	Thilak	OS-2	Thilak	OS-2	Thilak	OS-2
Gamma rays						
600 Gy	1	1	1	1	1	1
EMS 0.8	1	0	0	0	0	0
1.0	2	1	1	0	1	0

undesirable effects like lethality, injury and sterility. The usefulness of any mutagen would therefore, depends on its effectiveness as well as efficiency.

The effectiveness and efficiency of mutagens in inducing viable sterile mutants were estimated and are presented in Table 41.

In both varieties, chemical mutagen was more effective in inducing sterile plants. Both the mutagens showed different degrees of efficiency in those genotypes. Gamma radiation at different doses showed greater efficiency in genotype OS-2 while EMS at different doses were more efficient with Thilak. EMS treatment at 1% level was more effective than other levels and also over gamma radiation. It also showed greater efficiency in inducing sterility.

4.3.1.4 Pollen sterility in M_3 generation

The study was confined to two genotypes and three doses, one in gamma radiation and two in EMS, along with two controls. Among the two genotypes, three sterile mutants were isolated in Thilak and two in OS-2. The pollen sterility percentage ranged from 70. 91 to 88.67 per cent in steriles of Thilak and it was 61.02 to 90.86 per cent in steriles of OS-2. However, the frequency of sterile plants was very low.

Table 41 Mutagenic effectiveness and efficiency

Mutagen/Dose	Effectiveness M x100 tc/kR	Efficiency			
		Mx100 L		M x 100 S	
		Thilak	OS-2	Thilak	OS-2
Gamma rays (Gy)					
400	0.36	0.42	0.18	0.33	0.20
500	0.22	0.25	0.31	0.22	0.20
600	0.08	0.13	0.10	0.10	0.08
EMS (%)					
0.6	0.01	0.08	0.00	0.10	0.00
0.8	0.01	0.07	0.18	0.08	0.13
1.0	0.004	0.06	0.06	0.05	0.06

4.3.1.5 Breeding behaviour of sterile mutants

The sibmated and open pollinated seeds obtained from sterile plants screened in M_2 generation were raised in M_3 generation as individual plant families. The plants in each family were screened for sterility. Sibmated progenies segregated as 1fertile :1sterile in the M_2 and M_3 generations indicating that the male sterility system in sesame is governed by monogenic recessive allelles.

4.3.2. Interspecific hybridization

Inter specific hybridization was performed between the two selected best general combiners and the wild species of sesame (*Sesamum malabaricum*. L.) and the hybrids were evaluated for morphological features and pollen sterility.

The details of crosses, both direct and reciprocals between the cultivated and the wild relative *S. malabaricum,* are presented in Table 42. From the data on number of flowers pollinated, capsules set, and hybrid seeds obtained, the crossability between these two species were brought out. Both direct and reciprocal crosses effected between the two cultivars of *S. indicum* and *S. malabaricum*, resulted in successful capsule and seed set. However, the crosses with *S. indicum* cultivars as female parent yielded more capsule set than their reciprocals. Seeds per capsule were also high in these crosses. Seed obtained in both the combinations were fully filled.

Table 42 Details of Crosses betwen *S. indicum* and *S. malabaricum*

Ovule parent	Pollen parent	Number of flowers pollinated	Number of capsules set	Percentage of setting	Remarks
Thilak	*S. malabaricum*	15	10	66.66	Seed well filled and viable
OS-2	*S. malabaricum*	20	9	45.00	"
S. malabaricum	Thilak	25	12	48.00	"
S. malabaricum	OS-2	25	10	40.00	"

4.3.2.1. Mean performance of hybrids between *S. indicum* and *S. malabaricum*

The interspecific hybrids direct and reciprocals exhibited no heterogeneity in general morphological characters (Table 43). Among the parents *S. indicum* cultivars flowered much earlier (31.5 days and 37.5 days) compared to wild parent (57 days). In F_1s, both direct and reciprocals, the days taken for flowering exceeded the *S. indicum* parent, but were earlier than wild parent (46 to 51.5 days). The *S. indicum* plants were shorter than wild parent. Hybrids exhibited an average height between their parents. In the case of number of branches per plant, wild parent was a very profusely branching type. F_1s were also profusely branching similar to their wild parents. Hybrids with *S. malabaricum* as ovule parent also showed a very high percentage of sterility than the reciprocal F_1s

In order to compare, the mean performance of different cross combinations in different generations viz. F_1, BC_1 and BC_2., the values were expressed as percentage over *S. indicum* parental mean (Table 44). With regard to days to first flowering, F_1s of both the combinations were very late in flowering than the cultivar parents. As generations advanced to BC_1 and BC_2, by addition of each dose of cultivars genome there was decrease in the number of days to flowering.

In case of plant height, at maturity both combinations showed a static trend in different generations. In these, eventhough plant height was higher in F_1, BC_1 and BC_2 over the cultivar parents, plant height remained unchanged over generations.

Table 43 Mean performance of the parents, direct and reciprocal cross hybirds of the cross *S. indicum x S. malabaricum*

	Days to 50% flowering	Plant height	Number of branches per plant
Thilak	37.50	129.6	2.2
Thilak x *S. malabaricum*	49.50	135.2	4.4
S. malabaricum x Thilak	51.50	133.4	4.8
OS-2	31.5	117.5	2.5
OS-2 x *S. malabaricum*	48.5	128.2	4.1
S. malabaricum x OS-2	46.0	132.5	4.3
S. malabaricum	57.0	146.2	4.0

Table 44 Percentage performance of cross combinations in different generations over cultivar parent

Cross combination	Generations	Days to 50% flowering	Plant height	Number of branches per plant
S. malabaricum x Thilak	F_1	137.33	102.93	218.18
	BC_1	131.23	108.54	187.24
	BC_2	125.13	103.65	143.75
S. malabaricum x OS-2	F_1	146.03	112.76	172.00
	BC_1	132.84	110.80	141.88
	BC_2	111.02	117.09	126.65

Similar deceasing trend in number of branches per plant was also exhibited by both the combinations over the cultivar parent. With Thilak, F_1 exhibited about 200 per cent increase, gradually decreases in subsequent generations as 187 per cent in BC_1 and 144 per cent in BC_2 while with OS -2 it was 172 per cent in F_1, 142 per cent in BC_1 and 127 per cent in BC_2. The percentage over cultivar parental mean fall from 137.32 to 125.13 in the cross with Thilak and from 146.03 to 111.02 in the case with OS-2 for days to 50 per cent flowering.

The F_1 hybrids and back crossed progenies exihibited detectable spectrum of variation in qualitative and quantitative attributes. The variation observed in different qualitative attributes in different generation were listed in Table 45. In both the combinations the F_1 plants showed purple corolla with dark purple lip indicating the dominance of the wild parent *S. malabaricum* for colour. In the back cross generations colour of corolla and lip of the progenies segregated for both malabaricum type (purple corolla with dark purple lip) and indicum type (white corolla with yellow tinged lip). The expected back cross ratio of 1:1 for single gene control of corolla colour was observed in the BC_1 generation.

Similarly in the BC_2 generation progenies of individual families were observed for flower type and sterility. In the families raised from plants that showed indicum type of flowers in BC_1 generation, there was no segregation and the plants had white flower. Whereas in the families that were raised from plants with malabaricum type of flowers in BC_1 segregation was observed for both indicum and malabaricum type as in BC_1 generation.

Table 46 Morphological characteristics of parents, hybrids and backcross progenies

Character	*S. indicum*	*S. malabaricum*	F_1	BC_1	BC_2
1. Habit	Annual, erect	Annual, erect	Annual, erect	Annual, erect	Annual, erect
2. Stem	Pale green, quadrangular at the base, rounded above, sparsely hairy.	Green with purple tinge, quadrangular, densely hairy	Green with purple tinge, quadrangular, less moderately hairy	Green with or without purple tinge, quadrangular, slightly rounded, less hairy	Green with or without purple tinge, quadrangular base and rounded above sparsely hairy
3. Branching	Moderate branching with few primaries and secondaries	Profusely branching with so many secondaries	Profusely branching with many secondaries	Profusely branching with many secondaries	Profusely branching with many secondaries
4. Leaves	Simple, medium, ovate or linear with wavy or entire margin	Heteromorphic, larger trilobed leaves with dentate margin	Heteromorphic, larger, few trilobed leaves basally and upper simple leaves	Simple, larger rarely trilobed leaves	Simple, medium leaves ovate or linear with wavy or entire margin
5. Flowers	Solitary, medium, zygomorphic, yellowish white anthers.	Solitary, larger, zygomorphic, yellowish white anthers	Solitary, slightly bigger, zygomorphic, pale to greenish yellow anthers	Solitary, medium, zygomorphic, pale yellowish anthers.	Solitary medium, zygomorphic, pale to greenish anthers.
6. Corolla colour	Pale white	Purple	Purple	1:1 segregation for purple and white	Purple flowered plants segregated as 1:1 for purple and white

7. Lip colour	Yellowish with purple tinge	Dark Purple	Deep purple	Segregated as light purple and yellowish with purple tinge.	Segregated as light purple and yellowish with purple tinge.
8. Capsules	Moderately set, medium long, moderately hairy, septically dehiscing. acute tip.	Good set, long, hairy, septically dehiscing, rounded tip.	Good set, long, hairy, septically dehiscing, acute to rounded tip.	Good set, long, hairy, septically dehiscing, acute tip.	Good set, long, hairy, septically dehiscing, acute tip.
9. Seeds	Many, medium, brown to black, smooth surface.	Many, medium, black rough surface.	Many, medium, black rough surface.	Many, medium, black rough but smoother than F_1. (Plate 4)	Many, medium, black, smooth

Study of sterile plants.

The details on pollen sterility and sterile plants screened and identified in F_1, BC_1 and BC_2 generations of the crosses involving *S.malabaricum* are furnished in Tables 46 and 47.

It is evidented that in the F_1 plants the percentage of sterility observed was very high when *S. malabaricum* was used as female parent. The hybrids also showed high fertility in crosses with the two indicum cultivars as ovule parent. In both combinations, difference in pollen sterility percentage was observed between direct and reciprocal hybrids (Table 46). Plants with high percentage of sterility were observed when OS-2 was used as pollen parent (85. 73%), where as with Thilak it was 82.07 per cent.

In BC_1 and BC_2 generations, sterile plants showed different degrees of sterility. The frequency distribution of these are depicted in Table 47. In both the combinations the occurence of sterile plants varied which is evident in Table 47 and only those plants with high percentage of sterility were selected for further backcrossing.

Study of Capsule set in sterile plants

The details of backcrossing, selfing and open pollination, are presented in Table 48. which showed more than 75% sterility. Ten sterile plants were backcrossed to their respective recurrent parents, in each generations, leaving few for selfing and open pollination. Among the F_1 and BC_1 generations studied, crossing success was normal indicating female fertility.

Table 46 Pollen sterility percentage observed in F_1 hybrids of both combinations of *S. malabaricum and S. indicum*

Cross Combination	Direct cross		Reciprocal Cross	
	Percentage	Number of plants	Percentage	Number of plants
S. malabaricum x Thilak	82.07	15	15.94	16
S. malabaricum x OS-2	85.73	12	20.14	14

Table 47 Pollen sterility observed BC_1 and BC_2 of both combinations

Combination	Generations	Showing Pollen sterility percentage						
		<50	50-75	75-85	85-90	90-95	95-100	Total
S. malabaricum x Thilak	BC_1	19 (38%)	7 (14%)	12 (24%)	6 (12%)	6 (12%)	-	50
	BC_2	11 (22%)	6 (12%)	14 (28%)	9 (18%)	10 (20%)	-	50
S. malabaricum x OS-2	BC_1	23 (46%)	9 (18%)	5 (10%)	10 (20%)	3 (6%)	-	50
	BC_2	12 (24%)	12 (24%)	5 (10%)	12 (24%)	9 (18%)	-	50

Figures in parathesis represents the percentage of sterile population in each class

Table 48 Details of Backcross, self and open pollination insterile plants in F_1 and BC_1 generations

Combination	Generations		Back cross			Self pollination			Open pollination		
		Number of plants used	Number of flowers	Number of capsuels	Percentage setting	Number of flowers	Number of capsules	Percentage setting	Number of of flowers	Number of capsules	Percentage setting
S. malabaricum x Thilak	F_1	10	53	27	50.94	30	3	10	35	13	37.14
	BC_1	10	58	28	48.28	42	2	4.76	40	37	92.50
S. malabaricum x OS-2	F_1	10	49	21	42.86	35	5	14.28	45	26	57.77
	BC_1	10	56	34	60.71	38	2	5.26	47	39	82.98

Selfing of sterile plants resulted in only a very low percentage of capsule set in F_1 and in BC_1. BC_1 recorded even less percentage of setting than F_1. F_1 with Thilak and OS -2 recorded 10.0 and 14.28 percentage respectively while BC_1 recorded 4.76 and 5.26 percentage respectively.

For open pollination both the crosses exhibited a similar trend in percentage of setting. BC_1 recorded much higher percentage than F_1. Setting percentage was 37.14 and 92.50 for F_1 and BC_1 when Thilak was used as pollen parent and 57.77 and 82.98 when OS - 2 was used an pollen percent.

Floral characters of sterile plants

Flowers collected from sterile plants were also examined for anther and pollen characters. Anthers of male sterile plants were flatter than normal, non-dehiscent, slightly malformed and greenish in colour, which could be easily distinguished from the normal, plumpy, whitish anthers. This difference in appearance of anthers proved to be very stable in both cases of induced mutagenesis and wide hybridization and again in F_1 and BC_1 (plate 5).

Microscopic examination of pollen grains also revealed shrivelled and unstained pollen grains in most of the anthers observed, some with few stained pollen grains partial sterility were also observed. While fertile pollengrains were well formed and stained ones (plate 6).

DISCUSSION

5. DISCUSSION

Improvement over existing varieties is a continuous process in plant breeding. Any successful hybridization programme for varietal improvement depends mainly on the selection of parents having genetic variability so that the desirable character combinations may be selected for higher grain yield. Thus the genetic diversity in breeding for higher productivity has obvious importance. For improvement of any plant character through hybridization it is necessary to understand the nature of gene action and genetic architecture of the donor parents for that character. The present investigations were carried out with a view to assess the variability and to estimate the combining ability of selected lines and aimed at exploitation of male sterility in sesame through induced mutagenesis and wide hybridization for future development of hybrid sesame. The results are discussed below.

Experiment I

Genetic variability

In the investigations conducted, the analysis of variance showed highly significant differences among the genotypes for all the characters suggesting the presence of substantial genetic variability among the genotypes (Table 3). The genotypes showed wide range of variation for all the characters studied. Plant height varied from 95.05 to 148.15 cm, number of days to 50 percent flowering varied from 28 to 41.5 days, number of branches per plant ranged from 0 to 5, capsules per main stem and per plant ranged from 15.0 to 29.3 and 22.5 to 45.1,

capsule length varied from 1.9 to 2.65 cm, 1000 seed weight varied from 2.20 to 3.47g and seed yield per capsule and per plant ranged from 0.08 g to 0.21 g and 1.65g to 7.25 g respectively. The wide range of variation noticed in all the characters confirmed that the materials selected were genetically diverse and thus were appropriate for the study. Variability for different characters was previously observed by several workers for plant height, 50 per cent flowering, days to branching, number of branches per plant, number of capsules per plant, capsule length, capsule girth, seed number per capsule, 1000 seed weight and single plant yield (Ibrahim and Ragab, 1991; Baruah and Goud, 1993; John and Nair, 1993; Mishra *et al.,* 1993; Bhombe *et al.*, 1994; Shadakshari *et al.,* 1995; Joel and Thangavelu, 1997 and Shanmugavalli and Vanniarajan, 1998). Mishra *et al* (1993) reported a wide range of variation for the number of fruiting nodes per plant, seed yield per plant, branches per plant and capsule number per plant. Tak (1997) also reported significant genotypic variability for all the characters studied viz., plant height, primary branches per plant, capsules per plant, seeds per capsules and 1000 seed weight.

The genetic variability for yield within regions has been well appreciated in sesame and a break through in productivity is expected only from controlled crosses designed to create new and increased variability by utilising the available genetic diversity. Thus variability among the genotypes suggests the scope for selection of suitable initial material in breeding for further improvement.

5.1.1 Genotypic and phenotypic coefficients of variation

High magnitude of phenotypic and genotypic coefficients of variation observed for plant height, number of days to 50 percent flowering, number of branches per plant, capsules per mainstem, capsules per plant and seed yield per plant suggests the existence of large variability and scope of genetic improvement of these traits (Table 4). Selection based on these characters would facilitate successful isolation of desirable types. Similar findings were reported for the characters viz., plant height, secondary branches per plant, number of capsules per plant and single plant yield (Dabral and Holker, 1971; Sawant, 1971; Naphade and Kolte, 1972; Murugesan *et al.*, 1979; Thangavelu, 1980; Rai *et al*, 1981; Pathak and Dixit, 1986 and Shanmugavalli and Vanniarajan, 1998). Although the values of PCV were higher than GCV for all the characters, the low-magnitude difference between the two parameters for majority of characters implied that phenotypic variability is a reliable measure of genotypic variability except for plant height (69.23), number of capsules per mainstem (33.14) and number of capsules per plant (49.06) where the difference was relatively very high. The low margin of difference between PCV and GCV of the characters indicated that these characters were relatively less influenced by the environment and were comparatively stable. This also indicates that variation of genotype contributed markedly to the total variability for these characters which will be of great use in the crop improvement programme.

High GCV indicates higher degree of genetic variability which may be exploited for improvement of a given character. The

GCV ranged from 0.21 for seed yield per capsule to 81.76 for plant height. High GCV provides wider scope for selection. Desai *et al.* (1982) and Rudraradhya *et al.* (1984) reported highest GCV for branches per plant followed by medium to high values for capsule number per plant and seed yield per plant. Reddy and Dorairaj (1990) also reported high GCV values for secondary branches followed by seed yield per plant.

5.1.2. Heritability

Knowledge of the heritable fraction of the variability enables the plant breeder to base selection on the phenotypic performances. Heritability indicates only the effectiveness with which selection of genotypes can be based on the phenotypic performance but fail to show the genetic progress (Johnson *et al.* 1955a). High heritability does not therefore, necessarily mean greater genetic gain. Genetic advance as the percent of mean was calculated in order to ascertain the relative utility of genetic gain.

In the present investigation among the nine characters studied, number of branches per plant (74.26 & 52.83), capsules per mainstem (61.14 & 22.34) and seed yield per plant (84.38 & 57.12) had high heritability and genetic advance indicating additive inheritance for these characters. Heritability estimates would indicate the heritable portion of the variation and the estimation of genetic advance would show the extent of genetic gain that could be expected through selection in the character to be improved upon. This is in conformity with the findings of Kamala (1990), reported a high heritability associated with

maximum expected genetic advance for number of branches per plant. Similarly plant height and 1000 seed weight recorded moderate heritability and genetic advance indicating epistasis for these characters while seed yield per capsule had low values for heritability and genetic advance indicating that this character was influenced by environment. This also indicate that only indirect selection through other characters could improve seed yield. As heritability in the broad sense includes additive, dominance and epistatic genetic effects, it will be reliable only if there are accompanied by high genetic advance expressed as percentage of mean (Johnson *et al.* 1955b).

According to Panse (1957), a high heritability value does not necessarily lead to a high genetic gain. If the heritability is mainly due to the non-additive genetic effects (dominance and epistasis), the expected genetic gain would be low and when it is chiefly due to the additive gene effects a high genetic advance would be expected. Similarly, in the present investigation, though capsule length recorded high heritability of 60.09 per cent, the genetic advance as percentage mean was moderate indicating presence of non-additive genetic effects. Number of days to 50 percent flowering also recorded high heritability (73.56%) along with moderate genetic advance (18.49%).

5.1.3. Correlation

Crop yield is the end product of the interaction of a number of other interrelated attributes. Hence the efficiency of selection for yield considerably depends on the direction and magnitude of association between yield and its components and among the components themselves.

In the present investigations, all the characters except days to 50 per cent flowering, number of branches per plant, and seed yield per capsule, phenotypic correlation coefficients were lower than the genotypic correlation coefficients which indicate that the influence of environment was less on these characters or otherwise these characters are more stable. This also provide support of the contentions from the studies on genetic variability (Table 5).

Except 1000 seed weight, all characters recorded significant genotypic correlation with yield per plant. But 1000 seed weight recorded significant phenotypic correlation indicating the higher influence of environment on this character. These findings are in accordance with the results of previous works by Sikka and Gupta (1949), Angarita (1962), Muhammed and Dorairaj (1964) and Khidir and Osman (1970). It has been generally accepted that the correlations between different characters represent a coordination of physiological processes which is often achieved through gene linkage (Mather and Harrison, 1949, Mather and Jinks, 1971). A knowledge of strength and type of such associations is therefore an important pre-requisite for the formulation of breeding procedures (Breese and Haywards, 1972).

The difference between phenotypic and genotypic correlations was the lowest between capsules per mainstem and capsule length indicating genetic stability in their association. Moreover, genotypic correlations have their own importance because of their stability and reliability as these relationships arise through genetic reasons namely, linkage or pleiotropy. Therefore the knowledge of

interrelationships of characters, is also essential in developing appropriate selection criteria for the improvement of complex characters like yield. The present study clearly revealed that direct selection for seed yield will not help because this character is influenced more by environment.

Highest correlation coefficient was recorded between days to 50 percent flowering and number of branches per plant (0.937), but both these characters recorded negative significant correlation (-0.298 and -0.737) with seed yield per plant indicating ineffectiveness of these characters for the improvement of seed yield per plant. Capsules per mainstem recorded highest correlation (0.929) with seed yield per plant. Both phenotypic and genotypic correlation coefficient values were significant. Based on this, it could inferred that while selecting for high yielding genotypes selection pressure should be exercised for capsules per mainstem. Results similar to those obtained here were reported by Desai *et al.* (1982) in a study with 36 genotypes of sesame. Also the positive direct effect of capsules per plant on seed yield was in conformity with the results reported by Varisai and Stephen (1964), Asthana and Rai (1970), Gupta and Gupta (1977), Chavan and Chopde (1981), Desai *et al.* (1982), Shukla (1983), Gupta and Chopra (1984), Reddy *et al.* (1984b), Bhele *et al.* (1987), Osman (1988), Raut *et al.* (1990), Zhan *et al.* (1990) and Reddy and Haripriya (1992).

The highly significant positive association both at phenotypic and genotypic levels between capsules per mainstem and yield suggest that capsules per mainstem is a highly reliable component

of yield and can very well be utilized as an indicator in yield traits. The strong and negative correlation of days to 50 per cent flowering with seed yield (-0.713) suggests the possibility of developing high yielding genotypes coupled with earliness. Intercorrelations among yield components revealed that heavy selection pressure on capsules per mainstem would bring forth correlated response for desirable characters such as total capsules per plant, capsule length and 1000 seed weight. The results were in agreement with previous findings of Delgado and Yermanos (1975), Osman (1986), Ansari *et al.* (1988), Rao *et al.* (1990), Kumar (1991) and Chandrasekhara and Reddy (1993b) that plant yield had significant correlations with capsules number, number of seeds per capsule and 1000 seed weight.

5.14. Genetic diversity

Genetic improvement mainly depends upon the amount of genetic variability present in the population. The more diverse the parents, the greater are the chances of obtaining higher amount of heterotic expression in F_1s and broad spectrum of variability in segregating populations.

5.1.4.1 Clustering

D^2 analysis employing a combined classificatory approach with respect to nine important yield characters revealed that the 60 genotypes studied could be grouped into eight clusters (Table 6 and Fig.1). The clustering pattern showed that each cluster contained genotypes from different geographical regions. This leads to the inference that factors other than geographic diversity might be

responsible for such grouping and that geographical distribution alone could not be attributed to the manifestation of genetic diversity. It might also be due to contributions from.

a. free exchange of breeding materials from one place to other (Verma and Mehta, 1976)

b. clustering of varieties subject to identical selection pressure irrespective of their geographic origin (Singh and Bains, 1968) and

c. interaction of some similar genotypes at different places (Singh *et al.* 1980).

Similar observations with regard to lack of associations between genetic divergence and geographic distribution were made by Ghorai and Pande (1982) Singh (1983), Kotatah *et al.* (1986), De and Rao (1987), Singh *et al.*(1987), Selvakumar *et al.* (1989), Anandakumar and Subramanian (1989), De *et al.* (1992), Kumar and Subramanian (1992), Roy and Panwar (1993) and Vivekanandan and Subramanian (1993).

Murthy and Arunachalam (1966) explained that wide adaptability of divergent types could be possible due to reasons such as heterogeneity, genetic architecture of the populations, past history of the selection, developmental factors and degree of general combining ability. Hence for pedigree breeding, intercrossing these groups of parents from the same geographic region which were divergent among themselves are more desirable than choosing the parents from other regions (Kumar and Subramanian, 1992). In the present study varieties

developed at the same location were found to be grouped in different clusters indicating more divergence. For example, sesame varieties from Kerala Agricultural University were found to be grouped in clusters I, VI, VII and VIII. These conform to earlier findings of Raut *et al.* (1985) who suggested that genetic drift and human selection could cause greater diversity than the geographic spacing. It is, therefore, suggested that genetic diversity must form the sound base for the selection of parents for hybridization. Similar results were reported by Thangavelu and Rajasekharan (1983a), Anitha and Dorairaj (1990) and Ganesh and Thangavelu (1995).

5.1.4.2. Inter and Intra cluster distances

Estimates on intra and inter cluster distances (Table 7) represent the index of genetic diversity among clusters. The magnitude of heterosis was largely dependent on the degree of genetic diversity in the parental lines. The greater the distance between the clusters the wider will be the genetic diversity between the genotypes. Clusters separated by largest statistical distance (D^2) show the maximum divergence such as clusters IV and VI in the present investigation.

Intra-cluster D^2 distance was the minimum for the cluster III. This is perhaps due to the fact that unidirectional selection exercised in the past had resulted in uniform features with the consequence of less divergence between the genotypes. The maximum intra cluster distance observed in cluster V (47.31) indicates that there existed wide genetic divergence among members. This can be made use of in yield improvement through combination breeding.

Angadi (1976) reported that varieties in a cluster with high order of divergence among themselves would be the best breeding materials for achieving maximum genetic advance with regard to yield. Selection within a cluster might also be exercised based on the highest mean performance of the varieties for desirable traits such as seed yield.

It was well established by several workers, Ramanujam *et al* (1974), Reddy (1986), Singh *et al.* (1987), De *et al.* (1988), Roy and Panwar (1993) that the intercluster distance in D^2 analysis plays a key role in the selection of varieties, as parents for hybridization. Varieties belonging to the clusters with maximum intercluster distances were obviously genetically more divergent. In the present study, varieties in the clusters IV and cluster VI (389.75) were the most genetically divergent followed by varieties in clusters III and cluster VI (315.48). If crosses could be done using the above varieties, wider range of recombinants should be expected. The highest divergence between cluster IV and VI could be made use of in heterosis as well as in recombination breeding. The least intercluster distance was registered between clusters I and III (28.43). Both these clusters comprised of high yielding strains originated in various geographical areas. This finding again support the fact that geographical distribution was not related to genetic diversity.

5.2. Experiment II

5.2.1 Combining ability analysis

The success of a plant breeding programme greatly depends on correct choice of parents for hybridization and the type of gene action of different economic traits. Combining ability analysis provides such information so as to frame the breeding programme effectively. Combining ability studies in general reveal the nature of gene action and lead to identification of parents with general combining ability effects **(gca)** and the cross combinations with high specific combining ability **(sca)** effects. In the present investigation, combining ability analysis was undertaken to gather information on general combining ability **(gca)** effects, specific combining ability **(sca)** effects and reciprocal cross effects **(rca)** in relation to yield and yield components. Eight genetically diverse parents selected from eight clusters were subjected to 8x8 full diallel analysis. All the cross combinations successfully set seeds which indicates the cross compatability among the sesame varieties even at the level of geographical races.

5.2.1.1. Combining ability variances

In the 8x8 full diallel analysis, estimates of mean squares due to progenies were highly significant for all the characters studied (Table 8 & 9). This indicates the varibility among progenies. Further analysis of combining ability revealed that mean squares due to general combining ability was highly significant for all the characters. Similarly the mean squares due to specific combining ability

and reciprocal combining ability was highly significant for all the characters studied. This is an indicative of the significant role played by all the three factors additive, non-additive gene effects and maternal effects in the expression of characters namely plant height, number of days to 50 per cent flowering, number of branches per plant, number of capsules per mainstem, number of capsules per plant, capsule length, 1000 seed weight, seed yield per capsules, seed yield per plant and oil content. Hence any approach that facilitates simultaneous exploitation of both additive and non-additive gene action would be the most desirable for the improvement of these traits. Perhaps diallel selective mating, recurrent selection and reciprocal recurrent selection might prove valuable under such situation for the improvement of these characters. Similar findings were also reported by Thiyagarajan and Ramanathan (1995 a), Fatteh *et al.* (1995). They also suggested the importance of all the three factors, additive, non-additive and maternal effects in the expression of number of capsules per plant, yield per plant and 1000 seed weight.

The ratio of components of variance **(σgca^2 / $\sigma^2 sca$ or GCA/SCA)** was found to be greater than unity for characters namely plant height, days to 50 per cent flowering, branches per plant, capsule length, seed yield per capsule and oil content. It is thus clear that although the mean squares for **sca** which suggests the non-additive genetic variances was significant the additive components appears to be predominant for these characters in their inheritance. Low values of the ratio indicated the predominant role of non-additive gene effects in the expression of characters namely capsules per mainstem, capsules per plant, 1000 seed weight and seed yield per plant. These results are

in agreement with those of Murty and Hasim (1973), Dixit (1976a, 1978) Sengupta (1980), Shrivas and Singh (1981), Kumar and Ragaswamy (1987). The predominance of non-additive gene effects for oil content and number of branches per plant were also reported by Fatteh *et al* (1982), Khorgade *et al.* (1989), Ramalingam *et al.* (1990) and Fatteh *et al.* (1995). Pedigree method of selection can be followed to exploit additive genetic variance for those traits in which additive component was predominant. Since in self pollinated crops, additive genetic variance was fixed rapidly after F_2 generation resulting in restricted recombination, biparental mating can be followed in subsequent generations.

High values of variance due to **GCA** and **SCA** components revealed the predominance of both additive and non-additive components of gene action. High **GCA** variance were recorded for plant height, number of days to 50 per cent flowering, number of branches per plant, capsule length, seed yield per capsule and oil content showing that the major part of gene action was due to additive effect for these characters. This was in conformity with the works of Chaudhari *et al.* (1984), Reddy *et al.* (1984b), Dora and Kamala (1987) and Backiyarani *et al.* (1997). For other characters, **SCA** variance was high indicating the preponderance of non-additive type of gene action.

5.2.1.2 General combining ability effects

Among the eight parents taken for combining ability studies none of the parents was a good combiner for all the traits (Table 12). Nevertheless, the estimates of **gca** effects indicated that

the genotypes n_2 (Thilak) and n_3 (OS 2) were good general combiners for seed yield per plant. Considering all characters in general n_2 (Thilak) recorded significant **gca** for plant height, capsules per mainstem, capsules per plant, seeds per plant and oil content. Further n_3 (OS 2) was also found to be a good combiner for the characters number of days to 50 per cent flowering, capsules per mainstem, capsules per plant and seed yield per plant. The parent n_1 (Thilothamma) was found to be a good general combiner for number of days to 50 per cent flowering , and capsules per plant. Parent n_4 (VS-350) was found to be a good combiner for earliness, and Parent n_6 (IC 204156) for oil content and earliness. Parents n_6 (IC 204156) and n_7 (NIC 17925 A) were found to be good general combiners for tall plant type.

Selection of parents depends upon the objectives and the target environment the breeder has in mind. For tallness, the parents n_6 and n_7 were the best general combiners. For dwarf nature and earliness together parents n_1, n_3 and n_4 were better and for yield parents n_2, n_6 and n_8 were the general combiners. From correlation (Table.5), it was clear that characters capsules per mainstem and capsules per plant are highly correlated with yield per plant. For these characters also Thilak and OS-2 were good general combiners.

A perusal of the mean performance of parents and their **gca** effects revealed that *per se* performance of the parents was not a clear indicator of their **gca** effects. Thus the **gca** effects which reflect the breeding behaviour of an individual, should be used as the criterion for the selection of parents in hybridization programme. The estimates

of **gca** effects revealed that the parents Thilak and OS-2 recorded high significant values in the desirable direction for five and four yield components respectively. Hence these two parents are suggested to be used as base parent in crossing programme for improving the seed yield per plant, along with the other component traits.

5.2.1.3. Specific combining ability effects

The specific combining ability of 56 hybrids which could be analysed through the 8x8 full diallel analysis is discussed below (Table 13-22).

The high specific combining ability **(sca)** is mainly due to dominance and interaction effects existing between the hybridizing parents. Also the two parents, if they carry different genes for the traits in question, will tend to complement each other and would produce hybrids of superior genetic constitution.

In the present study the direct crosses n_1xn_3, n_1xn_4, n_1xn_5, n_2xn_3, n_2xn_7, n_2xn_8, n_3xn_5, n_3xn_6, n_4xn_5, n_5xn_8 and n_6xn_8 and the reciprocals and n_2xn_1, n_3xn_2, n_6xn_4, n_6xn_5, n_7xn_2, n_7xn_3 and n_8xn_5 exhibited significant **sca** effect for the character seed yield per plant. The crosses n_3xn_2 and n_8xn_5 showed significant **sca** effect for seven yield components out of ten yield components studied. n_2xn_7, n_7xn_2 and n_7xn_3 showed significant **sca** effect for six yield components, n_2xn_3, n_3xn_6, n_5xn_8, n_2xn_1 and n_6xn_4 showed significant **sca** effects for five yield components, n_1xn_3, n_1xn_4, n_2xn_8, n_3xn_5, n_4xn_5 showed significant **sca** effects for four yield components; and $n_1x\ n_5$ showed significant

sca effect for three yield components. Thus the crosses which were high in **sca** effects for seeed yield per plant were also high in **sca** effects for most of the yield components.

The parents Thilak and OS-2 which showed significant and high **gca** effect for seed yield per plant and other highly correlated yield components viz, capsules per main stem and capsules per plant gave desirable **sca** effect in their direct and reciprocal crosses. Also the crosses of these two parents have desirable **sca** effects for most of the yield contributing traits. This may be due to the interaction among positive alleles from both parents and hence can be fixable in subsequent generations in the absence of repulsion phase linkage. Hence these parents may be utilized for hybrid seed production programme and also for different selection procedures. This particular hybrid was a good cross combination for five yield components in direct cross and for seven yield components in the reciprocal way. In the case of crosses n_2xn_7 n_7xn_3 n_3xn_6 and n_2xn_1 which were good specific combinations for yield were also having at least one parent with good general combining ability for seed yield per plant. These cross combinations could give desirable transgressive segregants, if the additive genetic system present in the good general combiners is complemented by epistatic effects in the non allelic genes in them. In the cross n_8xn_5 with significant specific combining ability effect for seed yield per plant, had both the parents as low general combiners. The crosses n_6xn_4 and n_6xn_5, which were good cross combinations based on specific combining ability effects for seed yield per plant, were good for important yield components. But both the parents of these cross were poor general combiners for yield. From this observation, it

could be inferred that a combination of two good general combiners need not be necessarily the best and two low combination a poor one either. Backiyarani *et al.* (1998) reported a similar high heterosis from parents with low general combining ability effects for leaf area index. Reports of Murty (1975) Sharma and Chauhan (1983). Dora and Kamala (1986) and Anitha (1988) were also similar. The superiority of these crosses may be due to complementary and duplicate type gene interactions. This also indicates that in a sesame hybridization programme, improvement in yield and yield components can be achieved by incorporating poor general combiners also as parents.

A comparison of *per se* performance with their specific combining ability effects revealed that, in general, there was no correspondence between *per se* performance of a cross combination and its corresponding **sca** effect, but the selected cross combinations exhibited high values for both *per se* performance and **sca** effects. For example, the combination SI-1225 x I.C. 204126 recorded highest *per se* performance and highest **sca** effect for seed yield, but the parents were low general combiners. Thus the combining ability analysis indicated the predominant role of non-additive gene action for all the yield components. This is in agreement with the findings of Ramalingam *et al* (1990) and Thiyagarajan and Ramanathan (1995b).

Improvement in characters would be possible by the simultaneous exploitation of both additive and nonadditive genetic effects. Hence biparental mating followed by recurrent selection may hasten the genetic improvement of these characters in sesame. Dominant x recessive type of interaction might yield combinations with

non-additive and non-fixable genetic components for seed yield per plant. Hence these cross would serve as source populations for producing desirable early transgressive segregants and in later generations it could be exploited by sibmating followed by selection among the segregants. Biparental mating and selection procedures may result in rapid gain. Similar results were reported by Reddy and Haripriya (1990) and Reddy *et al.* (1993). The predominance of this non-additive gene action is suggestive of the high scope for exploitation of heterosis in sesame. The results of other workers (Godawat and Gupta, 1985; Hu, 1985a; Dora and Kamala, 1987; Kumar and Rangaswamy, 1987; Khorgade *et al.* (1988); Ramakrishnan and Soundrapandian, 1990) also indicated that non-additive gene action was generally operating for the character under study in sesame. On the other hand, Rathinaswamy and Jagathesan (1984) reported that additive genetic variance was more important than non- additive for most of the characters studied by them in sesame.

The **sca** effects along with the *per se* performance provides information about the parental utility for heterosis breeding programme. The crosses which showed high **sca** effect along with high *per se* performance may, therefore, be considered for the production of sesame hybrids subject to incorporation of male sterility in an effective manner.

5.2.1.2. Reciprocal combining ability effects

Variation due to reciprocal cross effects in the 8x8 full diallel analysis was significant for all the characters (Table 13-22).

Reciprocal cross effects usually arise due to the cytoplasmic determinants which are transmitted from the gamete to the zygote. It is an established fact that the seed characters are influenced considerably by cytoplasmic factors mainly due to the contribution of the female parent in seed development. To know which particular parent is contributing towards the cytoplasmic effect in the present investigation, the array means of the progenies were compared when a particular parent was used as a male or as a female parent (Table 49). The parents showing pronounced cytoplasmic effect were Thilak, OS-2, and IC 204156 for most of the characters studied, SI 1225 for plant height, seed yield per plant and oil content, NIC 17925A for number of branches per plant, capsules per mainstem and capsules per plant, and VS - 350 for 1000 seed weight. Similar results on maternal effects were obtained by Murty (1975) for seed yield and protein content and Fatteh *et al.* (1995) reported the maternal effect for seed yield per plant, capsules per plant and 1000 seed weight. Pal (1945) observed several instances of reciprocal differences in sesame crosses but he felt that they were, on the whole, unimportant.

Among the parents showing cytoplasmic effect for various characters, Thilak, OS-2 and IC 204156 exihibited cytoplasmic effect on important yield attributes namely, number of branches per plant, capsules per main stem, capsules per plant, capsule length, 1000 seed weight and seed yield per plant. Thus the cytoplasmic factors of these parents can also be utilized for the exploitation of heterosis and development of hybrid derivatives.

Table 49. Array means of the progenies, for different characters when each genotypes used as male and female parents.

Commen parents male/female	Other parent	Plant height		Number of Days to 50 % flowering		Number of branches per plant		Capsules per main stem		Capsules per plant		Capsule length		1000 seed weight		Seed yield per capsule		Seed yield per plant		Oil content	
		Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
n_1	n_2	95.50	147.70	40.00	39.00	2.40	3.70	14.80	32.20	32.20	82.70	2.30	2.40	3.30	3.25	0.18	0.17	5.66	13.97	50	42
	n_3	133.80	131.90	39.00	36.00	2.60	2.60	26.60	27.70	64.90	77.00	2.40	2.40	2.90	3.20	0.19	0.13	12.08	10.16	45	50
	n_4	119.70	132.10	41.00	36.00	2.90	2.50	24.40	27.00	56.50	54.50	2.50	2.60	3.35	3.55	0.22	0.21	12.43	11.42	46	46
	n_5	118.60	107.70	37.50	40.00	3.40	2.20	23.30	16.50	73.00	40.30	2.55	2.35	3.40	3.20	0.22	0.19	16.12	7.35	51	49
	n_6	116.70	123.90	41.50	39.50	3.10	2.20	26.10	24.20	68.40	37.70	2.20	2.55	2.45	3.40	0.14	0.20	9.67	7.75	42	51
	n_7	123.80	132.10	41.00	37.50	3.40	3.70	19.60	24.20	52.30	47.80	2.35	2.40	3.45	3.15	0.20	0.14	10.81	7.64	46	47
	n_8	121.00	124.40	37.50	39.00	2.80	2.30	24.40	18.50	49.25	35.10	2.55	2.60	3.30	3.10	0.19	0.19	9.81	7.49	44	54
	Mean	118.44	128.54	39.64	38.14	2.94	2.74	22.74	24.33	56.65	4359	2.41	2.47	3.16	3.26	0.19	0.18	10.94	9.14	46.29	48.43
n_2	n_1	147.70	95.50	39.00	40.00	3.70	2.40	32.20	14.80	82.70	32.20	2.40	2.30	3.25	3.30	0.17	0.18	13.97	5.66	42	50
	n_3	136.70	89.40	37.50	36.00	2.70	2.90	25.50	18.90	65.90	80.90	2.55	2.40	3.25	2.60	0.20	0.19	18.18	15.66	49	46
	n_4	161.60	102.70	36.00	37.50	3.40	2.40	29.80	15.50	69.30	26.60	2.60	2.55	3.45	3.60	0.23	0.22	16.17	6.02	49	44
	n_5	160.50	112.50	40.00	40.00	3.40	2.70	28.50	20.40	59.10	36.10	2.45	2.30	3.55	3.30	0.20	0.20	11.93	7.22	51	52
	n_6	145.00	140.30	40.00	39.50	2.80	3.10	26.00	22.10	56.50	58.70	2.40	2.40	3.25	3.30	0.19	0.19	10.70	11.23	41	50
	n_7	142.80	167.60	42.00	41.00	4.10	5.60	25.60	32.80	58.10	103.90	2.50	2.30	3.50	3.25	0.22	0.18	13.19	18.60	50	54
	n_8	140.80	138.60	37.50	39.00	3.30	2.50	28.30	22.10	73.30	41.20	2.55	2.65	3.40	3.15	0.22	0.23	16.50	9.69	49	48
	Mean	147.87	120.94	38.86	39.00	3.34	3.09	27.99	20.94	66.41	54.23	2.49	2.41	3.39	3.21	0.20	0.20	14.38	10.58	47.29	49.14
n_3	n_1	131.90	133.80	36.00	39.00	2.60	2.60	27.70	26.60	77.00	64.90	2.40	2.40	3.20	2.90	0.13	0.19	10.16	12.08	50	45
	n_2	89.40	136.70	36.00	37.50	2.90	2.70	18.90	25.50	80.90	65.90	2.40	2.55	2.60	2.25	0.19	0.20	15.66	18.18	46	49
	n_4	97.40	113.10	38.50	36.00	2.30	2.40	24.10	23.30	47.70	44.00	2.55	2.55	3.35	3.40	0.23	0.24	11.25	10.36	44	46
	n_5	150.00	103.70	43.00	36.00	3.60	2.40	35.00	17.70	77.60	32.00	2.80	2.40	3.40	3.40	0.26	0.19	20.23	6.23	48	46
	n_6	127.30	125.70	39.00	41.00	3.40	3.20	25.50	19.20	74.50	41.30	2.80	2.45	3.40	3.20	0.23	0.18	17.60	7.36	50	51

Table 49. Array means of the progenies, for different characters when each genotypes used as male and female parents. (continued)

Commen parents male/female	Other parent	Plant height		Number of Days to 50 % flowering		Number of branches per plant		Capsules per main stem		Capsules per plant		Capsule length		1000 seed weight		Seed yield per capsule		Seed yield per plant		Oil content	
		Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
n_3	n_7	101.30	152.30	43.00	37.50	2.90	3.80	16.00	31.00	37.90	70.00	2.60	2.30	3.35	2.95	0.22	0.16	8.22	11.70	46	46
	n_8	142.60	124.20	36.00	37.50	3.60	1.00	24.00	18.40	70.10	22.10	2.50	2.55	3.35	3.65	0.18	0.22	12.35	4.89	46	52
	Mean	119.99	127.07	38.75	37.79	3.04	2.59	24.46	23.10	66.53	48.6	2.58	2.48	3.24	3.25	0.20	0.19	13.64	10.11	47.14	47.85
	n_1	132.10	119.70	36.00	41.00	2.50	2.90	27.00	24.40	54.50	56.50	2.60	2.50	3.55	3.35	0.21	0.22	11.42	12.43	46	46
	n_2	102.70	161.60	37.50	36.00	2.40	3.40	15.50	29.80	26.60	69.30	2.55	2.60	3.60	3.45	0.22	0.23	6.02	16.17	44	49
	n_3	113.10	97.40	36.00	38.50	2.40	2.30	23.30	24.10	44.00	47.70	2.55	2.55	3.40	3.35	0.24	0.23	10.36	11.25	46	44
	n_5	131.60	128.30	40.00	37.50	2.80	3.00	21.60	25.00	63.20	69.60	2.50	2.45	3.50	2.35	0.22	0.16	13.99	10.80	50	42
	n_6	111.70	133.70	40.00	44.00	2.10	2.90	14.00	23.90	22.70	50.70	2.20	2.60	3.25	3.45	0.25	0.28	5.52	14.17	47	50
n_4	n_7	112.40	142.80	39.00	44.00	3.20	2.90	23.30	22.20	50.80	46.60	2.55	2.40	3.45	2.80	0.25	0.17	12.73	8.03	48	48
	n_8	102.60	131.80	36.00	37.50	2.10	1.70	18.40	21.10	27.40	34.00	2.60	2.30	3.75	3.35	0.25	0.25	6.88	8.55	49	52
	Mean	115.17	130.76	37.79	39.79	2.50	2.73	20.44	32.51	41.31	53.49	2.51	2.49	3.50	3.16	0.23	0.22	9.56	11.63	47.14	47.29
	n_1	107.70	118.60	40.00	37.50	2.20	3.40	16.50	23.30	40.30	73.00	2.35	2.55	3.20	3.40	0.19	0.22	7.35	16.12	49	51
	n_2	112.50	160.50	40.00	40.00	2.70	3.40	20.40	28.50	36.10	59.10	2.30	2.45	3.30	3.55	0.20	0.20	7.22	11.93	52	51
	n_3	103.70	150.00	36.00	43.00	2.40	3.60	17.70	35.00	32.00	77.60	2.40	2.80	3.40	3.40	0.19	0.26	6.23	20.23	46	48
	n_4	128.30	131.60	37.50	40.00	3.00	2.80	25.00	21.60	69.60	63.20	2.45	2.50	2.35	3.50	0.16	0.22	10.20	13.99	42	50
	n_6	111.20	129.00	39.00	44.00	2.20	3.00	15.30	22.40	20.40	49.10	2.45	2.50	2.90	3.30	0.18	0.16	3.59	9.62	49	50
n_5	n_7	124.10	101.30	37.50	41.00	3.50	3.00	12.80	11.10	28.00	19.10	2.25	2.20	3.30	3.30	0.16	0.13	4.52	2.55	49	51
	n_8	117.60	172.00	40.00	36.00	2.90	4.30	23.60	36.40	42.70	109.10	2.25	2.50	3.10	3.20	0.19	0.22	7.94	23.29	44	54
	Mean	115.01	137.57	38.57	40.21	2.70	3.36	18.76	25.47	38.44	64.31	2.35	2.50	3.08	3.38	0.18	0.21	6.81	13.96	47.29	50.71
n_6	n_1	123.90	116.70	39.50	41.50	2.20	3.10	24.20	26.10	37.70	68.40	2.55	2.20	3.40	2.45	0.20	0.14	7.75	9.67	51	42
	n_2	140.30	145.00	39.50	40.00	3.10	2.80	22.10	26.00	58.70	56.50	2.40	2.40	3.30	3.35	0.19	0.19	11.23	10.70	50	41

Table 49. Array means of the progenies, for different characters when each genotypes used as male and female parents. (continued)

Commen parents male/female	Other parent	Plant height		Number of Days to 50 % flowering		Number of branches per plant		Capsules per main stem		Capsules per plant		Capsule length		1000 seed weight		Seed yield per capsule		Seed yield per plant		Oil content	
		Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
n_6	n_3	125.70	127.30	41.00	39.00	3.20	3.40	19.20	25.50	41.30	74.50	2.45	2.80	3.20	3.40	0.18	0.23	7.36	17.60	51	50
	n_4	133.70	111.70	44.00	40.00	2.90	2.10	23.90	14.00	50.70	22.70	2.60	2.20	3.45	3.25	0.28	0.25	14.17	5.52	50	47
	n_5	129.00	111.20	44.00	39.00	3.00	2.20	22.40	15.30	49.10	20.40	2.50	2.45	3.30	2.90	0.19	0.18	9.62	3.59	50	49
	n_7	141.40	102.50	44.00	40.00	1.90	2.20	17.20	12.80	22.20	22.80	2.55	2.50	3.80	3.20	0.22	0.19	4.82	4.47	51	44
	n_8	157.60	149.50	44.00	41.00	2.70	2.90	25.70	25.10	50.80	59.10	2.60	2.55	3.30	2.90	0.20	0.19	10.29	10.77	52	51
	Mean	134.51	123.41	42.29	40.07	2.71	2.67	22.10	20.69	44.36	46.34	2.52	2.44	3.39	3.06	0.21	0.20	9.32	8.90	50.71	46.29
	n_1	132.10	123.80	27.50	41.00	3.70	3.40	24.20	19.60	47.80	52.30	2.40	2.35	3.15	3.45	0.14	0.20	6.34	10.81	47	46
	n_2	167.60	142.80	41.00	42.00	5.60	4.10	32.80	25.60	103.90	58.10	2.30	2.50	3.25	3.50	0.18	0.22	18.60	13.19	54	50
n_7	n_3	152.30	152.30	37.50	43.00	3.80	3.90	31.00	16.00	70.00	32.90	2.30	2.60	2.95	3.35	0.16	0.22	11.70	8.22	46	46
	n_4	142.80	142.80	44.00	39.00	2.90	3.20	22.20	23.30	46.60	50.80	2.40	2.55	2.80	3.45	0.17	0.25	8.03	12.73	48	48
	n_5	101.30	124.10	41.00	37.50	3.00	3.50	11.10	12.80	19.10	28.00	2.20	2.25	3.30	3.30	0.13	0.16	2.55	4.52	51	49
	n_6	102.50	141.40	40.00	44.00	2.20	1.90	12.80	17.20	22.80	22.20	2.50	2.55	3.20	3.80	0.19	0.22	4.47	4.82	44	51
	n_8	112.80	136.00	40.00	41.00	2.60	2.50	21.60	23.60	40.20	43.30	2.55	2.50	3.35	3.25	0.19	0.22	7.71	9.54	50	47
	Mean	130.2	137.6	40.14	41.07	3.40	3.07	22.24	19.73	50.06	41.80	2.38	2.47	3.14	3.44	0.17	0.21	8.56	9..12	48.57	48.14
	n_1	124.40	121.00	39.00	37.50	2.80	2.80	18.50	24.40	35.10	49.28	2.10	2.55	3.10	3.30	0.19	0.19	6.49	9.81	54	44
	n_2	138.60	140.80	39.00	37.50	2.50	3.30	22.10	28.30	41.20	73.30	2.65	2.55	3.15	3.40	0.23	0.22	9.69	16.50	48	49
n_5	n_3	124.20	124.20	37.50	36.00	1.00	3.60	18.40	24.00	22.10	70.10	2.55	2.50	3.65	3.35	0.22	0.18	4.89	12.35	52	46
	n_4	131.80	131.80	37.50	36.00	1.70	2.10	21.10	18.40	34.00	27.40	2.30	2.60	3.35	3.15	0.25	0.25	8.55	6.88	52	49
	n_5	172.00	117.60	36.00	40.00	4.30	2.90	36.40	23.60	109.10	42.70	2.50	2.25	3.20	3.10	0.22	0.19	23.29	7.94	54	44
n_6	n_8	149.50	167.60	41.00	44.00	2.90	2.70	25.10	26.70	59.10	5080	2.55	2.60	2.90	3.30	0.19	0.20	10.77	10.29	51	52
	n_7	136.00	112.80	41.00	40.00	2.50	2.60	23.60	21.60	43.30	40.20	2.50	2.55	3.25	3.35	0.22	0.19	9.54	7.71	47	50
	Mean	139.50	127.97	30.71	38.71	2.46	2.86	23.60	23.71	49.13	50.54	2.52	2.57	3.23	3.36	0.27	0.20	10.46	10.21	51.44	47.71

5.2.2. Estimation of components of variation and genetic parameters by Hayman's approach

The analysis of variance for parents and hybrids together already showed substantial genetic variability among the progeny of the crosses for all the characters studied.

In diallel analysis, Hayman (1954) emphasized the fulfilment of certain assumptions. In the present study of 8 x 8 full diallel analysis, the t^2 values were non significant for all the ten characters indicating the fulfilment of diallel assumptions for these traits (Table 23).

The presence of positive and significant additive component (D) and non-additive component (H_1) for the character plant height, number of days to 50 per cent flowering, number of branches per plant, capsules per main stem, capsules per plant, capsule length, 1000 seed weight and oil content suggest that both additive and non additive gene action have significant roles in the inheritance of these characters.

The components of variance and their proportions for the different characters which satisfied the diallel assumptions, are presented in Table 23. The D component which measures the additive variation was highly significant for all the characters studied except seed yield per capsule and seed yield per plant. The D component for seed yield per capsule was zero and for the seed yield per plant it recorded a non- significant value of 7.20. The H_1 component which

measures the dominance variation was also highly significant and larger in magnitude than D components for all characters except number of days to 50 per cent flowering. This suggests that dominance was the major contributor to the total genetic variation for these characters. $(H_1/D)^{1/2}$ values were greater than unity for all the characters except number of days to 50 per cent flowering. So overdominance is the general trend. However, Hayman (1954) pointed out that overestimation of the degree of dominance may occur due to lack of independence of the genes in the parents and when dominance at all loci was in the direction of plus alleles. The H_2 value which estimates the dominance effect as the algebric sum over all loci in heterozygous phase in all crosses were highly significant and positive for all characters except capsules per main stem and seed yield per capsules. So dominance was in the positive direction for all these characters which might have caused some over estimation of the degree of dominance. The H_2 values were smaller than H_1 values and $H_2/4H_1$ ratios were less than the estimated value of 0.25 for all the characters. This confirmed the unequal allelic frequencies and the asymmetry in the proportion of positive and negative genes showing dominance for these characters. The ratio $[(4DH_1)^{1/2} + F] / [(4DH_1)^{1/2} - F]$ expressed as KD/KR value measures the proportion of dominant and recessive genes in parents. The value is greater than unity for all the characters except seed yield per capsule. So an excess of dominant genes for these characters might be present in the parents for controlling these characters. F value which was positive for these characters also provided the same information. The value h^2/H_2 indicated the number of groups of dominant genes controlling the characters, but greater reliance cannot be placed on it as it under estimates the number of

genes exhibiting little or no dominance (Gilbert, 1958). In the present study, for number of branches per plant, capsules per main stem, capsules per plant, capsule length, 1000 seed weight and oil content it was estimated below one which could be due to the presence of complementary interaction or asymmetrical distribution of positive and negative alleles in the parents (Mather and Jinks, 1971). However, these values indicated that at least one or two groups of dominant genes were controlling seed yield per plant. The narrow sense heritability (h^2ns) calculated from this analysis showed that the number of days to 50 per cent flowering and oil content had comparatively higher (> 60%) heritability. Similar results of high heritability and dominance of gene for oil content were reported by Das and Samanta (1998).

It appears from the present analysis that dominance effect had an overall important role for controlling yield components of sesame. However, significant additive variance was also observed except for seed yield per capsule and seed yield per plant. The importance of dominant gene action for oil content in sesame was also reported by Yadav and Gupta (1988) and Das and Samanta (1998).

The present study revealed the overall importance of dominant gene action for the characters studied as stated above. However, additive genetic effect also had contributed along with the major role of dominance effect for controlling the yield components. Sesame is a self pollinated crop and can tolerate inbreeding without loss of vigour. The development of stable homozygous lines from F_1 hybrids of selected combiners following the pedigree method of breeding is usually recommended for this type of crops. The characters

with prominent additive effect can be easily improved in the form of F_1 hybrids, since these traits are fixable in early generations. Exploitation of non-additive genetic effects in the form of F_1 hybrids in sesame can also be explored, since these plants are easily crossable. Homozygous lines equal to or better than F_1 have been developed from highly heterotic crosses in self pollinated crops (Singh *et al* 1992).

The value for $(ML_1 - ML_0)^2$ was positive for all the characters except capsule length and seed yield per capsule. This indicates that dominance was in the direction of higher magnitude for characters except capsule length and seed yield per capsule. For these two characters $(ML_1 - ML_0)^2$ was zero, which indicates that the dominance effect is insignificant with respect to these characters.

The lowest value of Vr+ Wr corroborates with the presence of more number of dominant genes while the highest value to more number of recessive genes (Mohanty *et al.*, 1995). From Vr+ Wr values of different characters for eight parents, Thilothamma, Thilak, OS-2, VS - 350, IC 204126, IC 204156, NIC 17925 A and SI - 1225, it was revealed that among these eight parents, SI-1225 possessed more number of recessive genes for the characters plant height and capsules per mainstem. Similarly NIC 17925 A possessed more number of recessive genes for capsules per plant and seed yield per plant and more number of dominant genes for number of days to 50 per cent flowering, 1C 204156 possessed more number of recessive gene for capsule length and 1000 seed weight and more number of dominant gene for seed yield per plant. Similarly, VS-350 possessed more number of recessive genes for number of days to 50 per cent flowering, OS-2

possessed more number of dominant gene for plant height and capsules per mainstem and Thilak possessed more number of recessive genes for number of branches per plant. Vr - Wr graph in fig 2-9 also confirms the above findings. According to Vr-Wr, those parents which fall close around the origin and possessed with more of dominant genes while those far off had more of recessive genes..

5.2.3. Estimation of heterosis

Commercial exploitation of heterosis in cereal crops is regularly attempted at present in different countries. Hybrid vigour has been extensively exploited in rice for enhancing the yield. In sesame too, some attempts were done in China. To identify the potential of hybrids, the magnitude and direction of heterosis are of paramount importance. Before undertaking a hybrid breeding programme it is essential to determine the presence of significant heterosis in yield and yield contributing characters for exploitation of hybrid vigour.

The analysis of variances with parents and hybrids discussed above indicated significant differences among genotypes for yield and yield components suggesting that there is wide variability among the genotypes. The extent of heterosis has often been measured in terms of heterosis over mid parent, better parent and standard variety. In the present investigation, it was observed that heterotic effects were conspicuous for most of the characters at all the levels.

Estimates of relative heterosis, heterobeltiosis and standard heterosis for yield (Table 33) indicated that 22 hybrids out of

Fig. 2
Vr-Wr graph for plant height

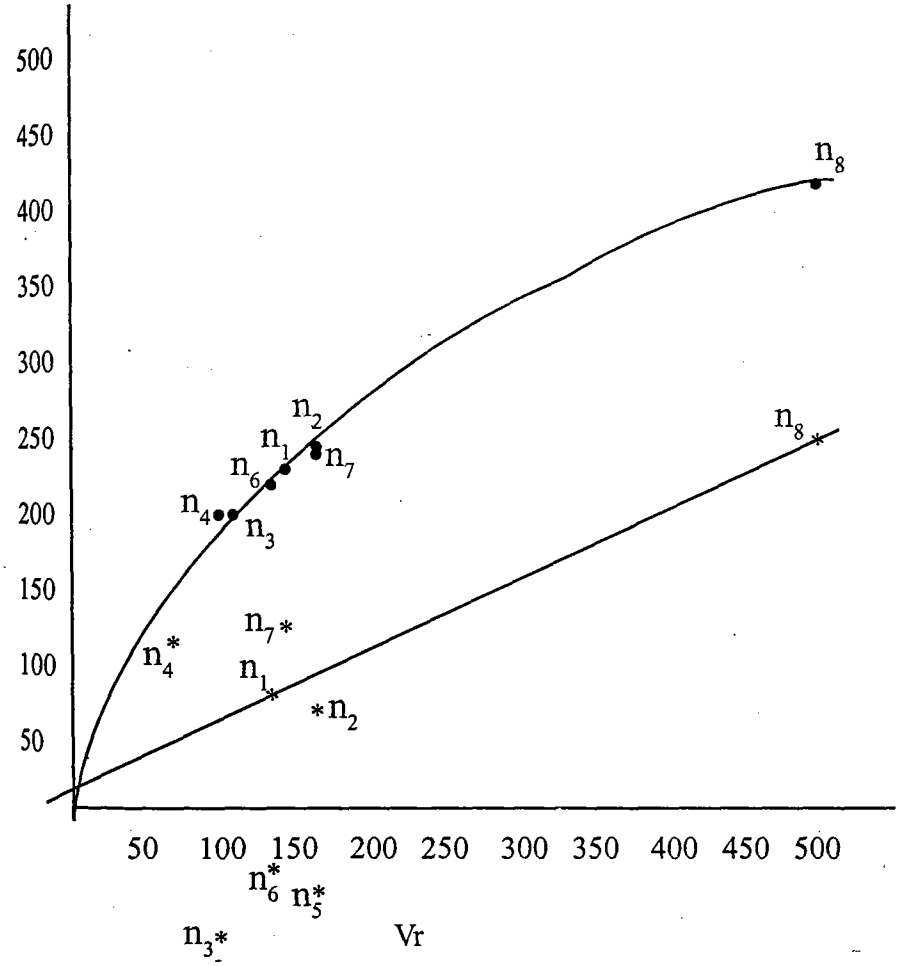


Fig. 3
Vr-Wr Graph for No of Days to 50% flowering

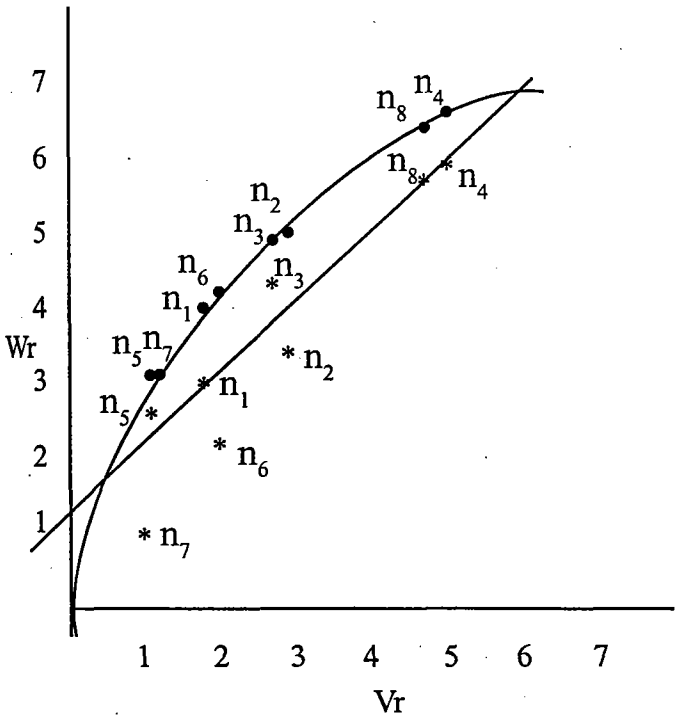


Fig. 4
Vr-Wr Graph for No. of Branches per plant

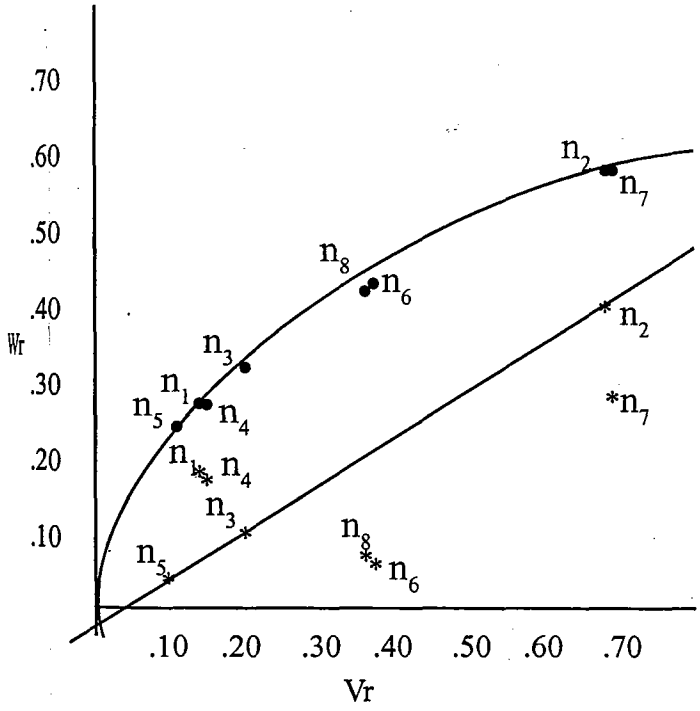


Fig. 5
Vr-Wr Graph for Capsules per Main stem

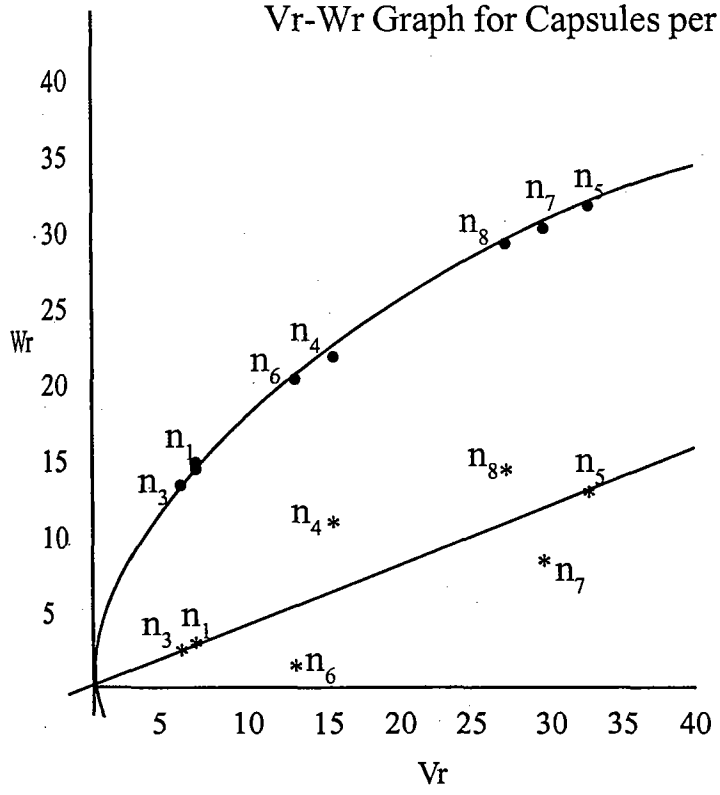


Fig. 6
Vr-Wr Graph for Capsules per Plant

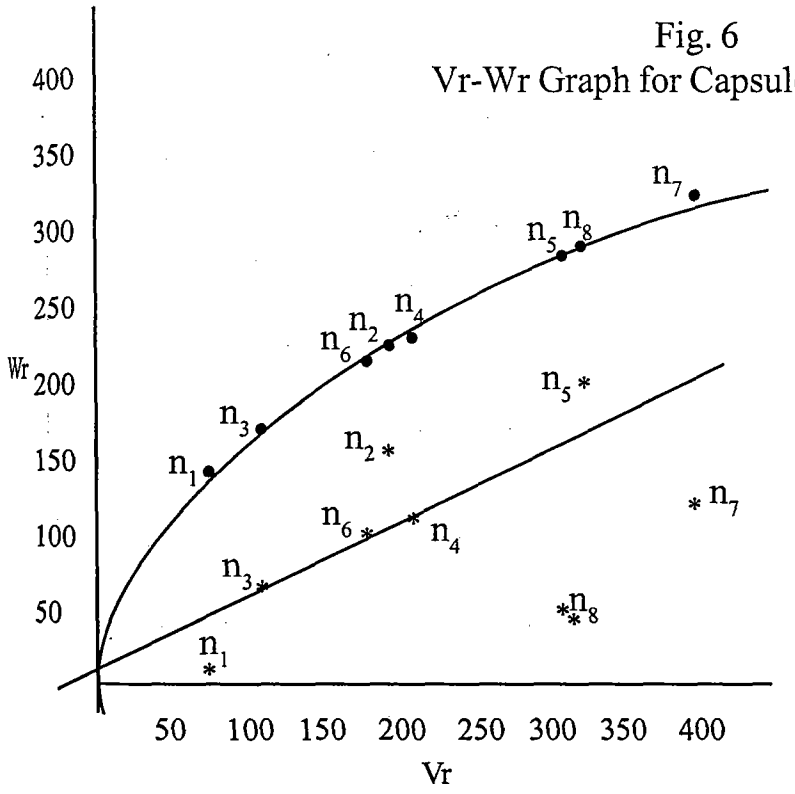


Fig. 7
Vr-Wr Graph for 1000 seed weight

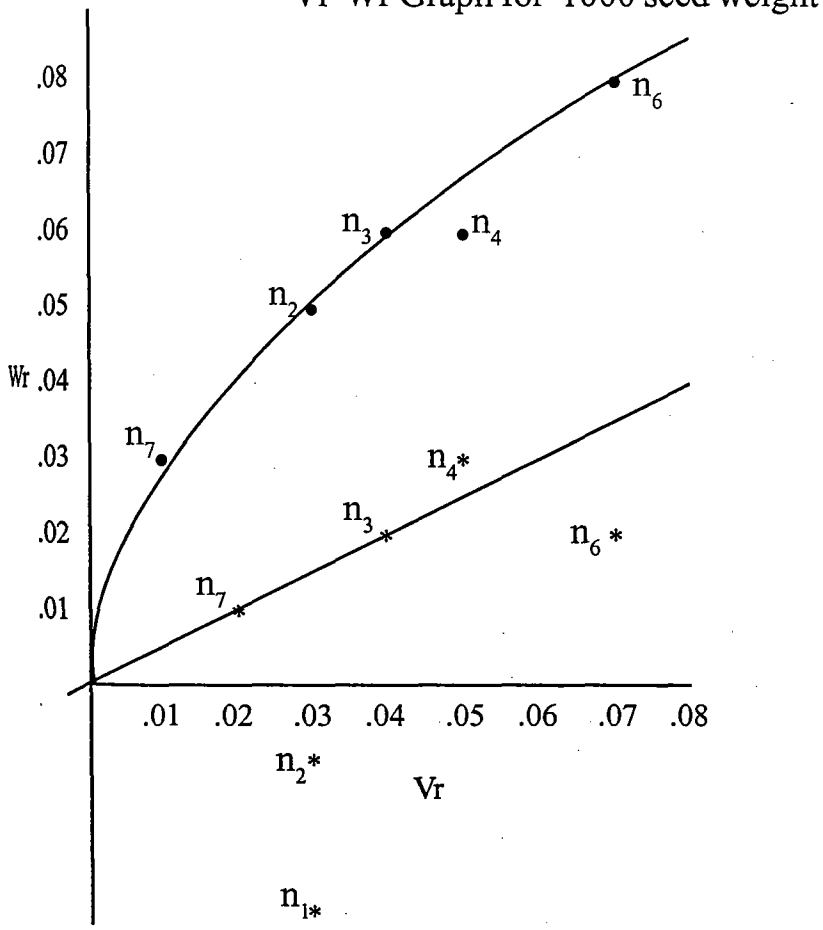


Fig. 8
Vr-Wr Graph for Seed yeild per plant

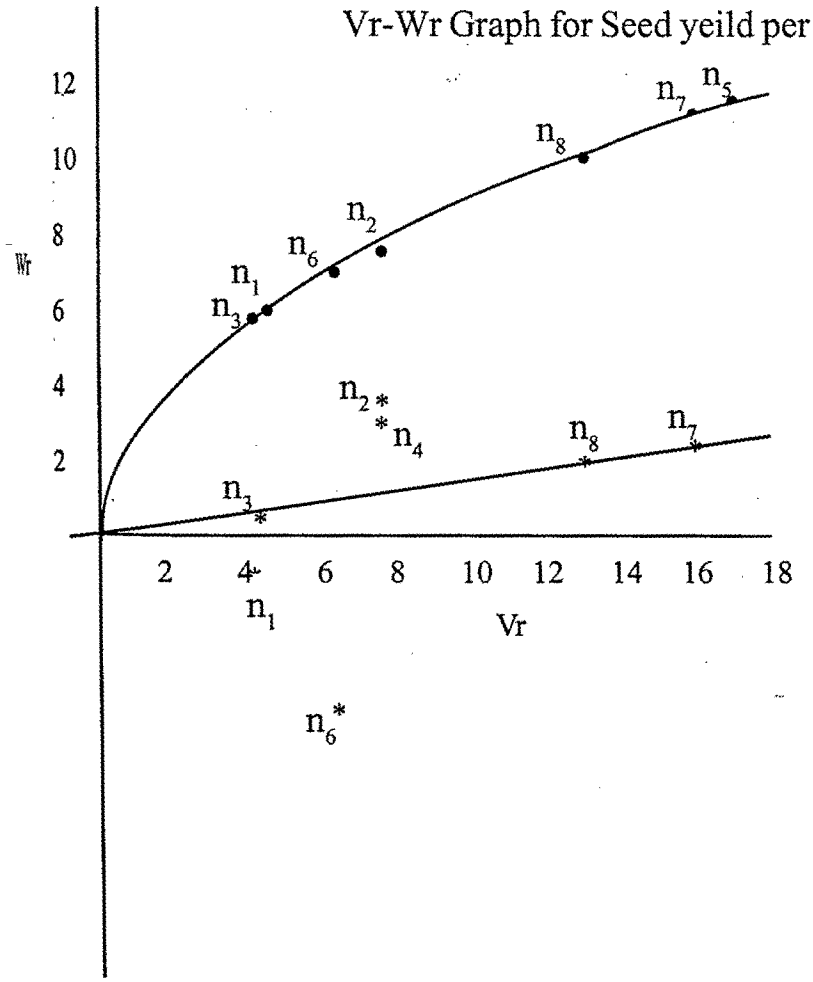
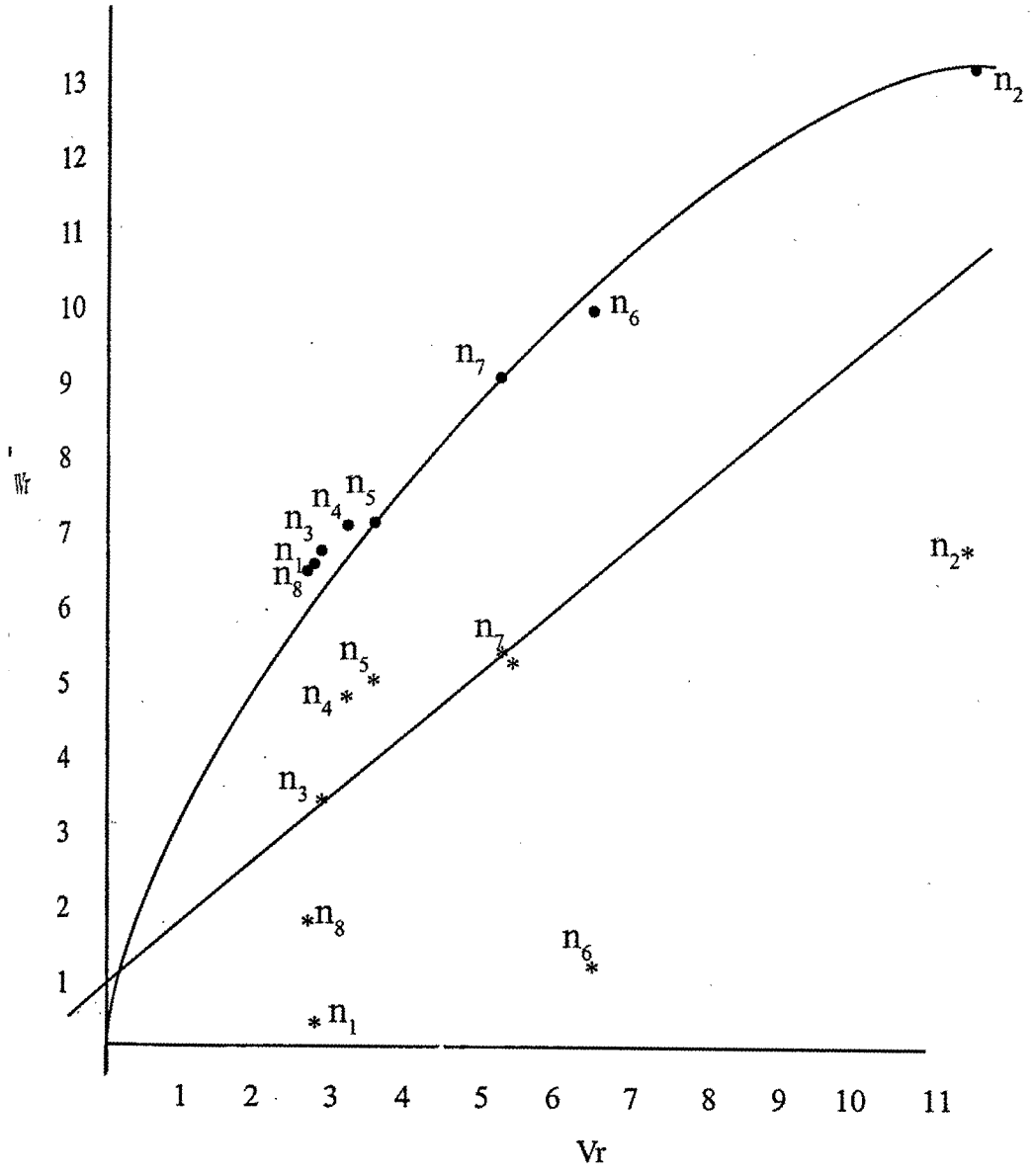


Fig. 9
Vr-Wr Graph for oil content



28 direct crosses and 19 hybrids out of 28 reciprocals gave significantly higher yield than the mid parent, 18 direct crosses and 15 reciprocals were better than their respective better parent which ranged from 0.67 to 293.74 per cent, while 19 direct crosses and 15 reciprocals gave significantly higher yield than the standard check (Thilak) ranging from 44.11 per cent to 251.81 per cent.

Reports indicated that in self pollinated crops, the hybrid to be economically advantageous, must give 20-50 per cent higher seed yield than the best average commercial variety and the better parents (Swaminathan *et al.* 1972). Fourteen out of 18 direct crosses and nine out of 15 reciprocals recorded more than 50 percent heterobeltiosis and 17 out of 19 direct crosses and 12 out of 15 reciprocals recorded more than 50 per cent hetrosis over standard variety (Table 33). This suggests that the extent of heterosis in sesame is significant enough to explore the prospects of commercial exploitation. Thus for sesame as other self fertilized crops, cytoplasmic male sterility system should be incorporated for commercial hybrid seed production.

Estimates of relative heterosis, heterobeltiosis and standard heterosis for yield and yield components of hybrids indicated that significant favourable heterosis existed in the component characters namely plant height, number of days to 50 per cent flowering number of branches per plant, capsules per mainstem, capsules per plant, capsule length, 1000 seed weight, seed yield per capsules and seed yield per plant and oil content (Table 25-34). It also reveals that there is ample scope for obtaining high yielding lines if the selection is based on plant height, number of branches per plant, capsules per mainstem,

capsules per plant, seed yield per capsule and seed yield per plant. Riccelli and Mazzani (1964), Murty (1975), Dixit (1976a) Kotecha and Yermanos (1978), Chaudhari *et al.* (1979) Tyagi and Singh (1981), Krishnaswami and Appadurai (1984), Sasikumar and Sardana (1990), Ray and Sen (1992), Reddy and Haripriya (1993) and Fatteh *et al.* (1995) had also reported similar results.

Grafius (1959) suggested that there would be no separate gene system for yield *per se* and that the yield is an end product of the multiplicative interaction between the yield and its components. This would indicate that heterosis for yield should be through heterosis for individual yield components or of partial dominance of component characters. This was confirmed in the present investigations, where none of the superior crosses showed heterosis for yield alone.

Over dominance effects may be the chief genetic cause for heterobeltiosis based on inter and intra allelic interaction (Singh and Richharia, 1980). In the present study, for yield and yield components more than 50 percent of hybrids showed significant heterobeltiosis (including both favourable and unfavourable). This indicates the overdominance effect for these characters. Almost all these hybrids have significant favourable standard heterosis also for these characters. For the characters 1000 seed weight and oil content, more than 50 per cent of hybrids showed either non significant or significant heterosis over mid, better parent and standard variety in the negative direction. This may be due to the disharmony between gene combinations of the different parental lines. This can also be attributed to the fact that all the parents involved in the crosses were

high yielding varieties in which 1000 seed weight and oil content as such were high, which might be the maximum limit for high yield potential for these two characters. This indicates further scope for improving these two characters by utilizing better combiners other than the varieties used in the present study.

The criterion for selection of hybrids for recombination breeding is that the parents should have significant desirable **gca** effect and the hybrids with nonsignificant **sca** effect (Verma *et al*., 1995; Vivekanandan and Giridharan, 1997). Accordingly hybrids were evaluated and suitable hybrid combinations for yield alone are identified as OS-2 x Thilak, Thilak x Thilothamma and Thilak x NIC 17925A. Among these four parents OS-2 and Thilak also showed high **gca** for yield. The cross OS-2 x Thilak is also a good combination for the character capsules per main stem, which is considered as the most closely related yield component. Thus, Thilak and OS-2 can be selected for recombination breeding and heterosis breeding.

5.2.4. Relationship between heterosis and genetic divergence

Results from the present investigation revealed that there is no clear relationship between genetic divergence and heterosis as is evident from the Table 50. It is further revealed that superior hybrids were obtained from parents representing divergent groups irrespective of the extent of divergence among them. It was interesting to observe that the maximum number of superior hybrids were derived from parents of intermediate divergent groups. The top ten hybrids which showed significant heterobeltiosis for yield are $n_8 \times n_5$, $n_3 \times n_5$, $n_1 \times n_5$, $n_2 \times n_8$,

Table 50

Best 5 crosses based on standard heterosis (with divergence in parathesis) and sca effects (with gca effects of parents in parathesis)

Character	Heterosis	sca effects
Plant height	n_3xn_2 (low) n_8xn_5 (medium) n_7xn_2 (low) n_2xn_5 (medium) n_2xn_5 (medium)	$n_8 \times n_5$ (LxL) n_2xn_1 (HxL) n_7xn_5 (HxL) n_3xn_2 (LxH) n_6xn_8 (HxL)
No. of days to 5% flowering	n_6xn_4 (high) n_6xn_5 (high) n_2xn_7 (high) n_6xn_8 (high) n_7xn_6 (high)	$n_5 \times n_3$ (HxH) n_7xn_3 (LxH) n_4xn_1 (HxH) n_6xn_7 (LxL) n_7xn_1 (LxH)
No. of branches per plant	n_7xn_2 (low) n_8xn_5 (medium) n_2xn_7 (low) n_2xn_1 (low) n_7xn_1 (low)	n_2xn_7 (HxH) n_5xn_8 (HxL) n_3xn_6 (LxL) n_7xn_2 (HxH) n_8xn_5 (LxH)
Capsules per main stem	n_8xn_5 (medium) n_3xn_5 (medium) n_7xn_2 (low) n_3xn_2 (low) n_2xn_1 (low)	n_5xn_8 (LxL) n_2xn_1 (HxL) n_7xn_3 (LxH) n_8xn_5 (LxL) n_3xn_2 (HxH)
Capsules per plant	n_8xn_5 (medium) n_7xn_2 (low) n_2xn_1 (low) n_3xn_2 (low) n_3xn_5 (medium)	n_8xn_5 (LxL) n_5xn_8 (LxL) n_2xn_7 (HxL) n_2xn_1 (HxH) n_7xn_2 (LxH)
Seed yield per plant	n_6xn_4 (high) n_3xn_5 (medium) n_4xn_6 (high) n_4xn_7 (medium) n_4xn_8 (medium) n_8xn_4 (medium)	n_8xn_5 (LxL) n_5xn_8 (LxL) n_2xn_7 (HxL) n_6xn_4 (LxL) n_2xn_1 (HxL)
Oil content	n_8xn_5 (medium) n_3xn_5 (medium) n_7xn_2 (low) n_2xn_3 (low) n_3xn_6 (high)	n_8xn_1 (HxL) n_8xn_5 (HxL) n_6xn_1 (HxL) n_6xn_2 (HxH) n_1xn_5 (LxL)

n_2 x n_4, n_4 x n_5, n_8 x n_4, n_1 x n_4, n_3 x n_6 and n_2 x n_1 in the decreasing order of heterosis. Among these the cross n_3 x n_6 was from parents of high divergent groups. Similarly n_8 x n_5 , n_3x n_5, n_1 x n_5, n_2 x n_4, n_4 x n_5 and n_3 x n_4 were derived from parents of intermediate divergent group and the other three were from parents of low divergent groups.

The cross OS-2 x Thilak which is selected for both recombination and heterosis breeding, was produced by crossing parents belonging to low divergent group. The existence of useful heterosis at the intermediate and low genetic distance level indicates that desirable gene combinations existed which could result in good yield performance. Chauhan and Singh (1982) observed heterosis upto a certain level (optimum level) beyond which the overall heterosis for yield is partly cancelled due to a negative heterosis for certain components. Sarathe and Perraju (1990) opined that parents having fairly high to medium genetic diversity may be selected for hybridization programme in order to get a good opportunity for getting high heterotic effects and its utilization in different breeding procedures for better recombinants.

Thus the genetic divergence for very high expression of heterosis has its limitations and the possibility of obtaining high heterotic hybrid from highly divergent groups though less in frequency, cannot be ruled out. It is observed that the crosses between extremely divergent parents created a situation where the harmonious functioning of alleles to produce desirable enzyme system was disturbed (Prasad and Singh, 1986). Consequently the physiological functions were not as efficient as in a situation, where the alleles had a similar pressure

(Singh *et al.* 1981). In the present study, only one cross n_3 x n_6 which was derived from parents of high divergent groups gain position among the top ten in respect of good yield performance. However, reciprocal cross of n_3 x n_6 was not an outstanding one making it difficult to conclude that the high performance of n_3 x n_6 was the effect of divergence. The high seed yield per plant of this cross may be due to cyloplasmic or maternal effect. Taking this into consideration it is suggested that for heterosis breeding, parents can be selected from all the divergent groups.

Experience III

5.3 Development of male sterile lines

The results of combining ability analysis and heterosis studies revealed the possibility of production of hybrids in sesame, with incorporation of male sterility for exploiting heterosis in an effective manner.

If heterosis is very high for a specific cross for an economic character like yield, it is possible to utilize the cross as a commercial hybrid provided the pollinating system of the crop permits commercial seed production (Arunachalam, 1989). In the present study, both the hybrid Thilak x OS-2, and its reciprocal showed significant positive heterosis and sca effect for the characters namely seed yield per plant, capsules per main stem, seed yield per capsule, number of branches per plant and plant height. So these parents will be ideal combiners for developing a male sterile line.

5.3.1. Induced mutagenesis

Expansion in the knowledge of the mutation process, has enabled induced mutagenesis to develop into an important tool for the plant breeders. The induction of mutation is recognised as one of the refined techniques that can be best adapted for use in the more sophisticated breeding programmes of the day. These mutations are helpful in generating variations supplementary to that occuring in nature.

Induced mutagenesis has been widely used to induce 'ms' plants in many of the crop plants. But the success was limited to a few crop species only. In sesame, much work has been done in the past to induce and recover mutants of practical value but further utility is not known. Both physical and chemical mutagens have produced 'ms' mutants in many crop species (Kaul, 1988). Hence the present study was taken up to explore the possibilities of inducing viable 'ms' mutants with the help of both physical (gamma radiation) and chemical (EMS) mutagens.

Germination was reduced by irradiation at higher doses in the present investigations. At higher doses germination was very poor (Table 35). Similarly EMS reduced germination from the lowest dose onwards and the reduction was progressive with increasing doses. The effect of alkylating agents and their mechanism of action in biological systems were reviewed by Ross (1962), Fishbein *et al.* (1970) and Sun and Singer (1975). The decrease in germination contributed mainly to the lethality of the seeds from physiological injuries,

chromosomal abberations and the toxic effect of hydrolytic products of the mutagen (Freese-Gertzen *et al.* 1964). According to Selima *et al.* (1974), reduction in germination is mainly due to the increase in the production of active radicals. Konzak *et al.* (1965) reported that the alkyl sulphonates and alkyl sulphates form strong acids upon hydrolysis. Since hydrolysis may occur not only externally in the treatment solution, but also inside the cells during treatment, significant amount of acids may become available which cause toxicity. Here in sesame, the reduction in germination with EMS treatment can be attributed to one or more of the above causes.

Seeds treated with gamma radiation and EMS took more time for germination than the control. Delay in germination was more drastic following treatment with EMS. The late germination observed in the present study may be due to the influence of mutagens on plant hormones and plant growth regulators leading to a delay in the initiation of germination as reported by Casarett (1968) in higher plants.

The percentage of survival of mutants was found to decrease with increase in doses of all mutagens. The reduction in survival is an index of post germination morality in the treated material as a result of radiation effect. Mitotic abnormalities due to irradiation results in structural changes in the chromosomal complements and these interfere with the normal growth and development of organs leading to a decrease in survival with increasing doses. Sato and Gaul (1967) were of opinion that the reduction in survival could be attributed to physiological disturbances. In the present study, the reduction in survival was observed up to 30th day beyond which there was no further

reduction. According to Mc Mahan and Gerhold (1965), the ability of the plants to recover from the radiation effect may be either by actual repair or by elimination of severely damaged cells.

Reduction in pollen fertility of M_1 plants is a reliable parameter indicating the effectiveness of mutagenic treatment (Kivi, 1962). In the present study, physical as well as chemical mutagens induced pollen sterility. The magnitude of reduction in pollen fertility was identical for physical and chemical mutagens. A linear increase in the sterility with increase in the doses of the mutagens was noted. Decrease in fertility with increasing dose of mutagen was reported by Chaudhari and Das (1956), Chauhan and Singh (1971), Nair and Nair (1977), Nair and Nair (1978) and Ganesan (1995). Ehrenberg *et al.* (1966) suggested that dose dependency of sterility could be on account of frequency of chromosomal rearrangements and gene mutations. According to Bender and Gaul (1966, 1967) and Sato and Gaul (1967), radiation induced M_1 sterility might be due to the detectable chromosomal aberrations and cryptic deficiencies where as the sterility induced by chemical mutagens might be due to specific gene mutations in addition to cryptic structural deficiencies. But Gaul (1970) pointed out that sterility counts provide better indications than meiotic investigations for a quantitative determination of sum total of chromosome mutation, which have survived the sporophytic generation. Accordingly M_1 plant progenies were studied in M_2 generation for sterility in the present investigations.

In M_2 only male sterile mutants were screened. Chemical mutagen was found to induce more number of steriles than the physical

mutagen. Male sterile types isolated were characterised by complete absence of pollen or by the presence of very large amount of sterile pollen in the anther. The male sterile types did not differ in habit from the normal plant except for the presence of either shrunken or green anthers and reduction in the size of the anthers. Rangaswamy and Rathinam (1982) observed male sterile plants in sesame with shrivelled anthers containing no pollen following gamma irradiation. Brar (1982) obtained male sterile plants in sesame which had shortened filaments of anthers, lack of viable pollen and failure of anthers to dehisce at maturity. The pollen sterility in each case was determined by a single recessive gene pair.

Crossing success on male sterile plants however, was normal indicating female fertility. Inheritance studies indicated that male sterility observed in the present case was also governed by a single recessive allele. Similarly green anther mutants with complete male sterility were isolated by Brar (1982) and Osman and Yermanos (1982), and hence they used this traits to differentiate male sterile and fertile plants.

A detailed treatment of the concepts of mutagenic effectiveness and efficiency was presented by Konzak *et al.* (1965). They proposed the term 'effectiveness' as a measure of gene mutations in relation to dose and 'efficiency' as an estimate of mutation rate in relation to other biological effects such as lethality, injury and sterility. To obtain high efficiency, the mutagenic effect must greatly surpass other damaging effects in the cells such as chromosomal aberrations and toxic effects. Gaul and Frimmel (1972) was of the opinion that the

effectiveness of a mutagen is of theoretical importance, but does not have any immediate practical implication while for practical purposes the aim is to get high efficiency. In the present study revealed the effectiveness of chemical mutagen over physical mutagen, which both mutagens recorded difference in degree of efficiency which applied to OS-2 and Thilak. The usefulness of any mutagen depends on its mutagenic effectiveness and efficiency. The most effective mutagen need not be the most efficient one (Konzak *et al.*, 1965).

The use of genetic male sterility for production of hybrid seed is not as efficient as the use of cytoplasmic male sterility coupled with the use of fertility restorer genes. The latter is not available yet in sesame. Thus genetic male sterility could provide the initial, practical approach for the production of hybrid sesame seed until better methods are developed. Moreover, a breeder could develop F_1 lines heterozygous at the male sterility locus but behave as male fertile. These lines produce F_2 seed which when planted would give rise to F_2 plant populations segregating in a 1:2:1 ratio. Those 25 per cent male sterile plants in turn will be available for used as female parent in the crossing blocks.

5.3.2. Interspecific hybridization

The present investigation also has shown the feasibility for generation of cms line in sesame through interspecific hybridization between *Sesamum indicum* and *Sesamum malabarium,* as *S. malabaricum* was found to be more cross compatible compared to other wild specis of sesame with *S. indicum.* F_1, BC_1 and BC_2 generations were examined.

The interspecific hybrids both direct and reciprocals resulted in successful capsule and seed set indicating cross compatability between the species. The hybrids with *S.malabaricum* parent as ovule parent resulted in male sterility while the reciprocals were fertile. This pointed out the cytoplasmic difference of the crosses which resulted in male sterility.

Cytoplasmic-genetic male sterility (cms) results from nuclear-cytoplasm interaction in which higher plants fail to produce functional pollen, but maintain female fertility. In several species, cms is associated with rearrangements in the mitochondrial DNA (mt.DNA). These rearrangements result in the expression of gene(s) whose protein products are considered to interfere, by unknown mechanism (s), with normal pollen development (Newton, 1988). CMS has been commercially exploited for the production of F_1 hybrid seed in a number of crops such as maize, sorghum, sunflower and sugarbeet. The yield superiority of these hybrids over inbred cultivars or open pollinated varieties has been an important factor in the adoption and cultivation of hybrid varieties.

Major progress has been made recently in developing high yielding hybrid rice based on the cms system, occupying over 18 million ha. in China. About 95 per cent of the total area of hybrid rice in China and in the tropics, thus has wild abortive (WA) type cytoplasm derived from *Oryza sativa f. spontanea* (Yuan, 1993). Here in the present investigation, cytoplasm of *S. malabaricum* may be the factor, which induced the sterility system in the cross. It was evident from the studies conducted that F_1 hybrids exhibited the dominance of the wild parent characters of having stem colour, branching pattern, leaf shape,

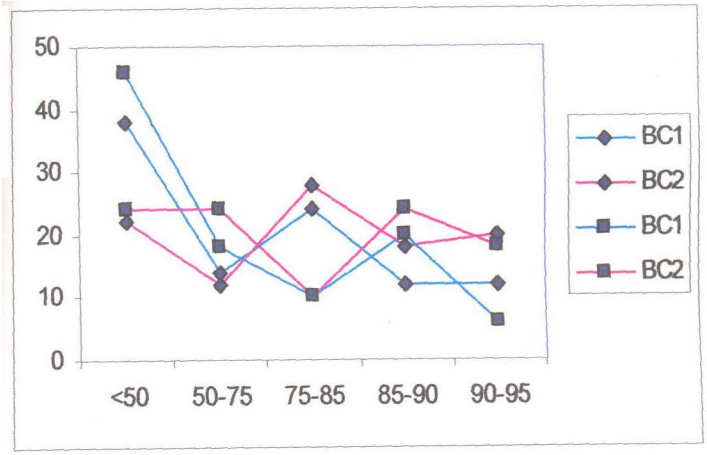
corolla colour, seed texture etc. Both direct and reciprocals resembled each other in almost all characters. However, when fertility status was examined, *Sesamum indicum* cultivar x *Sesamum malabaricum* showed high percentage of pollen fertility resulting in fairly good capsule set on selfing where as reciprocals, *Sesamum malabaricum* x *S. indicum* cultivar showed very high percentage of sterility leading to very few or no capsule set on selfing. The result indicated the cytoplasmic difference between these two species resulting in sterility. Though F_1 was similar to wild parent, in the progenies of back crosses, there was an increased resemblance to the qualitative characters of *S.indicum* cultivar parent which indicates the accumulation of cultivar genome in the progeny along with the sterility factor from the donor wild parent.

Pollen sterility was determined in the F_1 and backcross generations. F_1 hybrids showing 75 per cent and more pollen sterility were backcrossed with the respective cultivar parents. Back crossing of the plants was continued in subsequent generations in BC_1 and BC_2. With the each back crossing the sterility increased considerably by BC_2 itself the sterility has reached to a considerably higher range of 90 to 95 percent (Table 48 and Fig 10). Further continuation of backcrossing till BC_6 or BC_7 could result in stable cms lines.

In further generations intensified efforts should be made to isolate highly pollen sterile but female fertile lines in each generation and backcrossing them to *Sesamum indicum* parent as was done in BC_1 and BC_2. Moreover, this would enable to find out suitable maintainers at the end of BC_6 or BC_7, which will maintain cent per cent sterility. For the successful utilization of cms plants good restorers with high combining ability were also to be identified to produce promising hybrids of economic use in sesame.

Fig. 10

Pollen sterility observed in BC_1 and BC_2 generations



SUMMARY

SUMMARY

The present investigations on "Exploitation of male sterility in sesame *(S indicum L)"* was conducted in the Department of Plant Breeding and Genetics, College of Hortticulture, Kerala Agricultural University during 1996-1999. Field trials were laid out at the Onattukkara Regional Agricultural Research Station, Kayamkulam of the Kerala Agricultural University.

The investigation was carried out with the objectives to assess the variability and to estimate the combining ability of selected lines. Exploitation of male sterility in sesame through induced mutagenesis and wide hybridization for future development of hybrid sesame was also aimed at.

Initially 60 genotypes were evaluated during September '97 to December '97 and they were grouped into eight genetically distant clusters using Mahalanobis D^2 analysis. Observations were recorded on important yield characters like plant height, number of days to 50 per cent flowering, number of branches per plant, number of capsules per main stem, number of capsules per plant, capsule length, 1000 seed weight, seed yield per capsule, seed yield per plant and oil content. Eight genotypes representing the eight clusters were selected as parents for and 8x8 Diallel analysis. All hybrids and reciprocals were produced during January-April '98 and observations on the F_1 generations were recorded on ten characters during September-December '98. From the eight parents, two best general combiners were selected based on highly correlated yield components and used them for the exploitation of male

sterility through mutagenesis using EMS and gamma radiation and wide hybridization with *S. malabaricum* for the induction of male sterility. F_1s were screened for male sterility and sterile plants of the wide crosses obtained were backcrossed with *S. indicum* to accumulate desirable attributes from the donor parent.

Salient findings from the investigations conducted are summarised and presented below.

1. Analysis of variance showed highly significant differences among the genotypes indicating the presence of substantial genetic variability for all the characters studied.

2. The characters namely, number of branches per plant, capsules per mainstem and seed yield per plant exihibited high broad sense heritability coupled with high expected genetic advance. Number of capsules per main stem recorded high **GCV** too, while the other characters had moderate **GCV**. Plant height was found to have high **GCV** and heritability coupled with moderate expected genetic advance and capsule length had low **GCV**, high heritability and moderate expected genetic advance. Low margin of difference between **PCV** and **GCV** all the characters indicated that these characters are relatively less influenced by the environment and are comparatively more stable.

3. The principal yield determining components identified were capsules per main stem and capsules per plant.

4. Inter correlation between number of branches and number of capsules per plant revealed the importance of these characters

in improving the seed yield. The absence of significant correlation between 1000 seed weight and seed yield per plant suggests that these characters can be recombined is hybridization programmes.

5. The sixty genotypes representing different ecogeographical regions were grouped into eight clusters based on genetic distance. Clustering pattern shown that each cluster contained genotypes representing diverse ecogeographical regions whereas varieities developed at one location went to different clusters. There was no parallelism between geographical distribution and genetic diversity.

6. Highly significant mean squares due to general, specific and reciprocal combining ability analysis clearly brought out the importance of additive, non-additive and maternal effects in the expression of all the characters studied. Hence any approach facilitates simultaneous exploitation of there would be most desirable for the crop improvement programme. Low values of **GCA/SCA** ratio indicated the predominant role of non-additive gene effects in the expression of characters namely, capsules per mainstem, capsules per plant, 1000 seed weight and seed yield per plant.

7. Varieties, Thilak and OS-2 were identified as the best general combiners for five and four characters respectively and are suggested to be used as base parent in crossing programme for improving seed yield per plant, along with other component traits.

8. In breeding programme for combining dwarfness and earliness, the varieties Thilothamma, OS-2 and VS-350 can be utilized. Similarly the cultures IC 204156 and NIC 17925A can be recommended for incorporating both tallness and late maturity together.

9. Significant **sca** effects for yield and yield components were observed for the crosses from all kinds of parental combinations, namely, high x high, high x medium, medium x medium, high x low, and low x low general combiners.

10. Estimation of components of variation and genetic parameters using Hayman's approach revealed the presence of both additive and non-additive gene effects in the inheritance of all the characters with the predomionance of non-additive gene action, except for number of days to 50 per cent flowering.

11. Array means of the progenies with parents of these crosses as common male and female parents showed that the performance was high when Thilak and IC 204156 were used as female parent with consistent maximum effect for Thilak.

12. Heterosis analysis revealed that the extent of heterosis in sesame was significant enough to explore the prospects of commercial exploitation in our condition. Seventeen direct crosses and 12 reciprocals out yielded the standard check variety, by more than 50 per cent.

13. On the basis of **gca** effects of parents and **sca** effects of crosses, the parents VS - 350, IC 204156 and SI 1225 were identified as suitable for recombination breeding.

14. On the basis of *per se* performance, **sca** effect and heterosis, the crosses Thilothamma x VS- 350, Thilothamma x IC 204126, Thilak x Thilothamma, Thilak x OS-2, Thilak x NIC 17925 A, Thilak x SI 1225, OS-2 x Thilak, OS-2 x IC 204126, VS-350x IC 204126, IC 204156 x VS- 350, NIC 17925 A x Thilak, NIC 17925 A x OS-2 and SI 1225 x IC 204126 were identified for heterosis breeding.

15. There was no definite relationship between genetic diversity and heterosis. It was observed that hybrids can be formed from parents belonging to all divergent groups, namely high divergence, intermediate divergence and low divergence. It was worthy to note that the maximum number of superior hybrids were derived from parents of intermediate divergent group. Thus while selecting parents for recombination breeding stress should be given on parents with intermediate genetic divergence. Parents for heterosis breeding however, can be selected from all the divergent groups.

16. Physical as well as chemical mutagens reduced the germination, survival and fertility in the M_1 population with increase in doses. A linear increase in the sterility with increase in the doses of the mutagens was noted. Chemical mutagens were found to induce more number of steriles than the physical mutagens. Relative efficiency of mutations differed with genotypes.

17. Male sterile types isolated among mutants did not differ in habit from the normal plant. Shrunken anthers, green anthers and reduction in the size of the anthers were associated characters. Crossing success on male sterile plants was normal indicating female fertility.

18. Inheritance studies in M_2 and M_3 generations indicated that the present case of male sterility in the mutants was governed by a single recessive allele.

19. In wide hybridization F_1s of both direct and reciprocal crosses exhibited dominance of the morphological characters of the wild parent having stem colour, branching pattern, leaf shape, corolla colour, seed texture, etc. typical of *S.malabaricum* .

20. *Sesamum indicum* x *S. malabaricum* showed high percentage of pollen fertility with fairly good capsule set on selfing where as reciprocals showed very high percentage of pollen sterility with very few or no capsule set on selfing. This suggested a positive role of the cytoplasmic differences between these two species in the expresssion of sterility of hybrids with *S. malabaricum* as female parent.

21. In the progenies of back crosses, there was an increase resemblance to the qualitative characters of *S.indicum* cultivars, which indicates the accumulation of desirable attributes of the same in the progenies along with different degrees of sterility.

The present studies thus revealed that there is ample scope for yield improvement in sesame both through recombination breeding and heterosis breeding. As yield and yield components were found to be under the control of all the three types of gene actions, namely additive, dominance and epistasis, a breeding method that could combine both fixable and non-fixable types of gene actions would be more desirable for yield improvement in sesame.

The F_2 seeds of all cross combinations from diallel analysis were retained at the Onattukara Regional Agricultural Research Station for further evaluation of segregants and for screening out of elite types with high yield potential. The back cross seeds of sterile crosses (inter specific crosses) and *S. malabaricum* seeds were also retained at the station for further studies in the direction of development of cms lines.

Future line of studies suggested

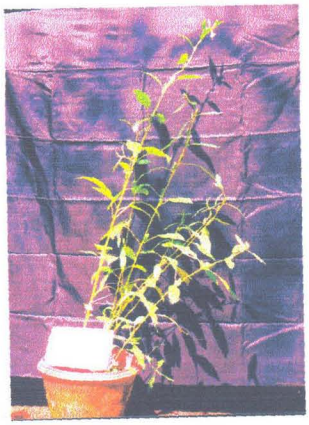
Efforts should be directed for the following future studies

1. continuation of further backcrossing with the respective recurrent parent for the development of stable cytoplasmic male sterile lines.
2. screening from the backcross progenies for 100 per cent cytoplasmic male sterile lines.
3. identification of appropriate maintainer lines for cms.
4. identification of restorer lines with fertility restoration genes.
5. evaluation of segregants for elite types with high yield.

Genotype selected for Diallel Analysis

THILOTHAMMA

THILAK



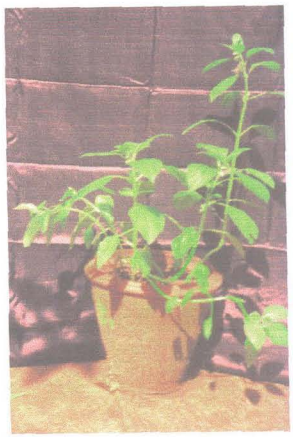
OS-2

VS-350

Plate 1

Genotype selected for Diallel Analysis

IC 204126



IC 204156

NIC 17925A

SI 1225

Plate 2

Seeds of 8 genotypes selected for Diallel Analysis

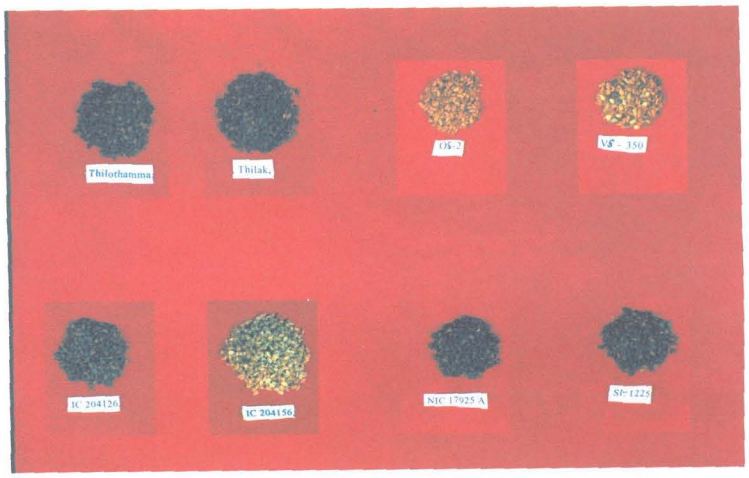
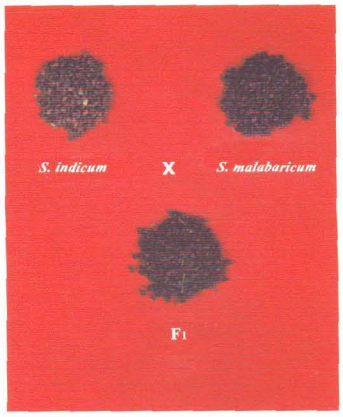
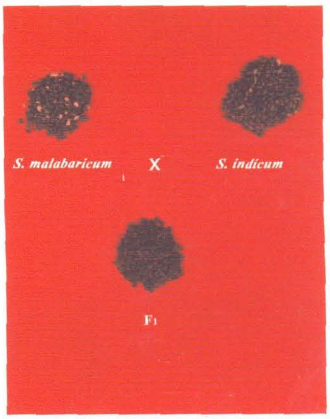


Plate 3

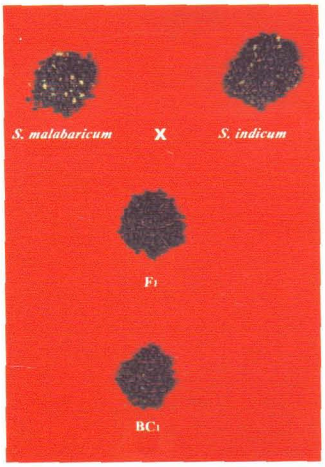
Interspecific Cross - Appearance of Seed Coat



DIRECT CROSS



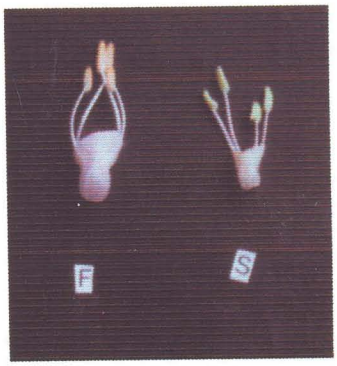
RECIPROCAL CROSS



INTERSPECIFIC CROSS F_1 AND BC_1

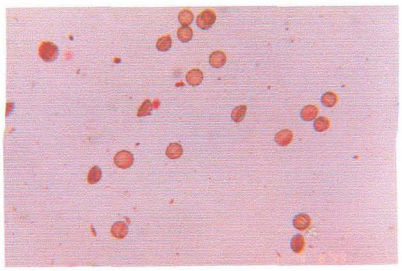
Plate 4

Anthers - Fertile and Sterile

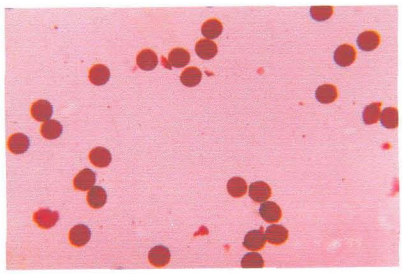


Pla

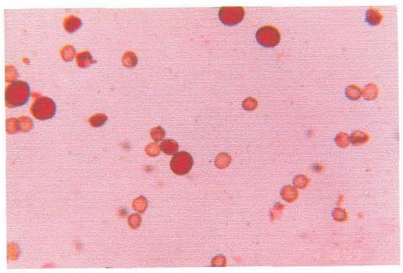
Pollen Grains on Microscopic View



STERILE



FERTILE



PARTIALLY STERILE

Plate 6

REFERENCES

REFERENCES

Achuthan, M. 1981. Studies on genetic diversity in Soybean. MSc (Ag) thesis, TNAU, Comibatore.

Adeyemo, M.O. and Ojo, A.A. 1993. Evaluation of Germplasm of sesame (*Sesamum indicum*) at Markurdi, Nigeria. *Tropical Oilseeds J.* **1** : 1-8.

Anandakumar, C. R. and Subramanian, M. 1989. Genetic divergence in upland rice. *Int. Rice Res. Newsl.* **14**: 6-7.

Angadi, S. P. 1976. Correlation Studies and D^2 analysis in cowpea, (*Vigna sinensis* L. Savi). M.Sc (Ag) thesis, Tamil Nadu Agricultural University Coimbatore.

Angarita, F.J. 1962. Path coefficient analysis in sesame. *Agron. Trop. Venezuela* **12** : 201.

Anitha, N. 1988. Studies on genetic divergence, heterosis and combining ability in *Sesamum indicum* L. MSc (Ag) Thesis, TNAU, Coimbatore.

Anitha, N. and Dorairaj, M. S. 1990. Genetic divergence and hybrid performance in sesame. *J. Oilseeds Res.* **7** : 63-71.

Anitha, N. and Dorairaj, M.S. 1991. Heterosis in *Sesamum indicum Indian J. Genet.* **51** : 270-271.

Ansari, A.H., Choudhry, N. A., Qayyum, S.M., Rajput, M.A. and Khan, W.A. 1988. Correlation and regression analysis between yield and yield contributing characters in sesame (*Sesamum indicum* L.). *Oil crops Newsl.* **5** : 71-73.

Ariyanayagam, R.P., Rao, A.N. and Zaveri, P.P. 1995. Cytoplasmic gene male-sterility in interspecific matings of *Cajanus*. *Crop Sci.* **35** : 981-985.

Arunachalam, V. 1989. Genetic basis of plant Breeding. *Plant Breeding Theory and Practice* (Ed. Chopra, V. L). Oxford and IBH Publishing Co. Ltd. New Delhi. p. 324.

Asthana, K.S. and Rai, O.K. 1970. Correlation studies in til (*Sesamum indicum* L.) *Allahabad Fmr.* **44** : 385-386.

Ayyaswamy, M.K., Dhamu, K.P., Murugesan, M. and Subramanian, A.S. 1987. Comparison of D^2 analysis and canonical vector analysis in sesame. *Madras agric. J.* **74** : 322-325.

Babu, C. and Sivasubramanian, V. 1992/1993. Studies on genetic divergence and association of characters in three maturity groups of sesame (*Sesamum indicum* L.) *Plant Breeding Newsl.* **2** : 2

Backiyarani, S., Devarathinam, A.A., Rajendran. C. and Santhi, S. 1998. Diallel analysis of sesame (*Sesamum indicum* L.) for physiological traits. *Crop Res.* **15** : 85-90.

Backiyarani, S., Devarathinam, A.A. and Santhi, S. 1997. Combining ability studies on economic traits in sesame. (*Sesamum indicum* L.) *Crop Res.* **13** : 121-125.

Bakheit, B.R. and Mahdy, E.E. 1988. Genetic variability and correlations in a world collection of sesame (*Sesamum indicum* L.) *Assiut J. agric. Sci.* **19** (3) : 228-240.

Baruah, D.P. and Goud, J.V. 1993. Variability studies in hybrid and segregating populations of sesame. *Madras agric.* J. **80** : 210-214.

Bateson, W. and Gairdner, A.E. 1921. Male sterility in flax subject to two types of segregation. *J. Genet.* **11** : 269-275.

Bender, K. and Gaul, H. 1966. Nachwasche, Rucktrocknungund Lagarung bei AMS - behandeltan Gerstensamen. *Radiat. Bot.* **6:** 505-518.

Bender, K. and Gaul, H. 1967. Veriierung der AMS - Wirkung bei Gerste durch. Amundung vrschienderer Behandleings und Nachwascht - Speraturen. *Radiat. Bot.* **7:** 289-301.

Bhargava, B.D. and Saxena, N.G. 1964. Phenotypic variations and its heritable component in some important quantitative characters contributing towards yield in til. *Ann. Aridzone* **3** : 85-90.

Bhele, O.S., Khorgade, P.W. and Narkhede, M.N. 1987. Estimates of genetic parameters, correlation coefficients and path analysis in sesame (*Sesamum indicum* L.) *PKV Res. J.* **11** : 118-122.

Bhombe, A. D., Dawande, V.B., Jayade, V.S. and Mundafale, V.S. 1994. Genetic variability studies in sesamum. *J. Soils and Crops.* **4** : 54-57.

Biswas, K.P. and Akbar, M.A. 1995. Genetic variability, correlation and path analysis in sesame (*Sesamum indicum* L.). *Bangladesh of Scient. and Ind. Res.* **30** :71-79.

Brar, G.S. 1982. Male sterility in sesame. *Indian J. Genet.* **42** : 23-27.

Breese, E.L. and Haywards, M.D. 1972. The genetic basis of present breeding methods in forage crops. *Euphytica* **21** ; 324-330.a

Brindha, N. and Sivasubramanian, V. 1992/'93. Studies on combining ability and reciprocal differences through diallel analysis in sesame (*S. indicum L.*) *Plant Breeding News.* **2**:2

Burton, G.W. 1952. Quantitative inheritance in grasses. *Proc.6th Int. Grassland Congr.***1** : 277-283

Burton, G.W. 1965. Pearl millet Tift 23 A released. *Crops and Soils* **17** : 19

Casarett, A. P. 1968. Effects of radiation on higher plants and plant communties. *Radiation Biology.* United States, Atomic Energy Commission, Washington, D. C. pp: 284-309.

Caspari, E., Watson, G.S. and Smith, W. 1966. THe influence of cytoplasmic pollen sterility on gene exchange between populations. *Genetics* **53** : 741-746.

Chakraborti, P. and Basu, A.K. 1998. Combining ability in sesame in stress situation with special reference to earliness. *Ann. agric. Res.* **19** : 9-14.

Chandramony, D. and Nair, N.K. 1985. Cytogenetic studies on intervarietal hybrids of sesamum (*S. indicum* L.) Ph.D. thesis, KAU, Trichur.

Chandramony, D. and Nayar, N.K. 1988. Diallel analysis in Sesamum (*S. indicum* L.). *Agric. Sci. Digest* **8** : 193-198

Chandraprakash, J. 1987. Gene action and combining ability for oil content, yield and yield components in Sesamum (*S. indicum* L.) *Mysore J. agric. Sci.* **21** :91.

Chandrasekaraiah, S. R., Murthy, B.R. and Arunachalam, V. 1969. Genetic divergence and phenotypic stability in some interspecific hybrids of Eusorghum. *Indian J. Genet.* **34** : 294-299.

Chandrasekhara, B. and Reddy, C. R. 1993a. Association analysis for oil yield and dry matter production in sesame (*Sesamum indicum* L.) *Ann. agric. Res.* **14** : 40-44.

Chandrasekhara, B. and Reddy, C.R. 1993b. Correlation and path coefficient analysis in sesame (*Sesamum indicum* L.). *Ann.* Agric *Res.* **14** : 178-184.

Charlesworth, D. 1981. A further study of the problem of the maintenance of females in gynodioecious species. *Heredity* **46**: 27-39.

Charlesworth, D. and Ganders, F.R. 1979. The population genetics of gynodioecy with cytoplasmic genic male sterility. *Heredity* **43** : 213-218.

Chaudhari, F.P., Shah, R.M. and Patel, I. D. 1984. Heterosis and combining ability in sesamum. I*ndian J. agric. Sci.* **54** : 962-966.

Chaudhari, K. S. and Das, A. 1956. Effeccts of X-rays on the fertility of pollen grain in *Sesamum orientale. Sci.Cult.* **21**: 550-555.

Chaudhari, P.N., Zope, R.E., Deokar, A. B. and Patil, N.Y. 1979. Heterosis in sesame. *J. Maharashtra agric. Univ.* **4** : 125-126.

Chaudhari, P.N., Zope, R.E., Patel, D.M. and Joshi, B.P. 1984. Combining ability in sesame. *J. Maharashtra agric. Univ.* **9** : 270-271.

Chaudhary, S. K. 1992. Variability in finger millet grown on acidic soil under mid atitude conditions. *Agric. Sci. Digest.* **12** : 203-206.

Chauhan, S.V.S. and Kinoshita,T. 1980. Pollen abortion in *Sesamum indicum* L. plants treated with gametocide. *J. Faculty of Agri. Hokkaido Univ.* **60** : 42-46.

Chauhan, S. V. S. and Singh, B. B. 1982. Heterosis and genetic variability in relation to genetic divergence in soyabean. *Indian J. Genet.* **42**: 324-328.

Chauhan, S.V.S. and Singh, S.P. 1971. Induction of male sterility in sesame (*Sesamum indicum* L.) *Indian J.agric Sci.* **41**: 725-729.

Chavan, G.V. and Chopde, D. R. 1982. Polygenic variability, heritability and genetic advance in irradiated sesame.*J. Maharashtra agric. Univ.* 7 : 17-19.

Chavan, S.V. and Chopde, P.R. 1981. Correlation and path analysis of seed yield and the components in sesame. *Indian J. agric. Sci.* **51** : 627-630.

Childers, W.R. and Mc Lennan, H.A. 1960. Inheritance studies of a completely male sterile character in *Medicago sativa* (L). *Can. J. Genet/Cytol.* **2** : 57-65.

Dabral, K.C. 1967. Variability and correlation studies in sesame. *JNKVV Res.J.* **1** : 136-139.

Dabral, K.C. 1968. Sterility in *Sesamum indicum* L. *JNKVV Re. J.* **2** : 73.

Dabral, K.C. and Holker, A.S. 1971. Variability in sesame with special reference to capsule characters. *JNKVV Res.J.* **5** : 45-50.

Dabral, K.C. and Mandoli, K.C. 1974. A peculiar sterility in sesame (*Sesamum indicum* L.). *JNKVV Res.J.* **8** : 54-56.

Dalmacio, R., Brar, D.S., Ishii, T., Sitch, L.A., Virmani, S.S. and Khush, G.S. 1995. Identification and transfer of a new cytoplasmic male sterility source from *Oryza perennis* into indica rice (*O. sativa*). *Euphytica* **82** : 221-225.

Das, A. and Samanta, S.K. 1998. Genetic analysis of oil content and fatty acids in sesame (*Sesamum indicum* L.). *Crop Res.***15** : 199-205.

Datta, D.K. and Biswas, A.K. 1987. Gamma ray induced meiotic abnormalities and pollen sterility in sesame. *Chromosome Inf. Service*. **42** : 26-28.

De, R. N. and Rao, A. V. S. 1987. Genetic divergence in rice under lowland situation. *Crop Improv.* **14**: 128-131.

De, R.N., Reddy, J. N., Rao, A.V.S. and Mohanty, K. K. 1992. Genetic divergence in early rice under two situations. *Indian J. Genet.* **52**: 225-229.

De, R. N., Seetharaman, R., Sinha, M. K. and Banerjee, S.P. 1988. Genetic divergence in rice. *Indian J. Genet.* **48**: 189-194.

Deenamoni, I.E.S.K. and Dorairaj, M.S. 1994. Genetics of quantitative characters associated with capsules in *Sesamum indicum* L. *Madras agric. J.* **81** : 241-243.

Delgado, M. and Yermanos, D.M. 1975. Yield components of sesame under different population densities. *Econ. Bot.* **29** : 69-78.

Delgado, M.A. 1972. Yield components of sesame (*Sesamum indicum* L.) under different population densities. M.Sc. Thesis, University of California, Riverside, U.S.A.

Delgado, N. and Layrisse, A. 1992. Diallel cross analysis of six indehiscent and two dehiscent varieties of sesame (*Sesamum indicum* L.) *Agronomia Tropical* (*Maracay*) **42** : 191-210.

Desai, N.M., Shah, R.M. and Kukadia, M.U. 1982. Genetic parameters inter-relationship and path-coefficient analysis in sesamum. *Oilseeds J.* **12** : 33-38.

Desai, N.M., Shah, R.M. and Kukadia, M.U. 1984. Hybrid vigour in sesame. *Gujarat. agric. Univ. Res.J.* **9** : 69-71.

Deshmukh, V.A. and Chavan, D.A. 1990. Correlation and regression studies in sesamum. *J. Maharashtra agric. Univ.* **15** : 256-257.

Dharmalingam, V. and Ramanathan, T. 1993. Combining ability for yield and its components in sesame. *Oleagineux*, **48** : 421-424.

Diagma, A. 1984. Genetic conditioning of characters linked to yield in sesame. *Oleagineux* **39** : 217-225.

Ding, F.Y., Jiang, J.P. and Zhang, D.X. 1987. Study of F_1 and F_2 heterosis and correlation between parents and hybrids in sesame *Scientia Agricultura sinica* **20** : 70-76.

Ding, F.Y., Jiang, J.P., Zhang, D.X. and Li, G.S. 1991. A study on relationship between heterosis and effects of combining ability in sesame. *Acta Agriculture Boreali-Sinica* **6** : 44-46.

Dixit, R.K. 1976a. Heterosis and inbreeding depression in sesame. *Indian J. agric. Sci.* **46** ; 514-517.

Dixit, R.K. 1976b. Inheritance of yield and its components in sesame. *Indian J. agric. Sci.* **46** : 187-191.

Dixit, R.K. 1978. Combining ability analysis for protein content and test weight in sesame. *Indian J.agric. Sci.* **48**: 362-364.

Dixit, R.K. 1995. Path analysis for some quantitative traits in sesame (*Sesamum orientale* L.). *Plant Sci.* 9-12.

Dora, K.B. and Kamala, T. 1986. Heterosis and gene action in sesamum. *Indian J. agric. Sci.* **56** ; 690-694.

Dora, K.B. and Kamala, T. 1987. Combining ability in sesame (*Sesamum indicum L.*) . *Indian J.agric.Sci.* **57** : 774-778.

Dorsey, M.J. 1914. Pollen development in the grape with special reference to sterility. *Minn. Agric. Exp. Stat. Bull.* **144**:60.

Dubey, R.S. and Singh, S.P. 1968. Gametocidal properties of certain plant growth regulators. *Indian J. agric. Sci.* **38**: 208-215.

Durga, K.K., Raghunathan, G., Ranganatha. A.R.G. and Sharma. P.S. 1994. Studies on the combining ability for morpho physiological, reproductive and yield attributes is sesame. *Int. J. Trop. Agric.* **12** : 248-254.

Edwardson, J.R. 1970. Cytoplasmic male sterility. *Bot. Rev.* **36**: 341-429.

Ehrenberg, L., Gustafsson, A., Osterman, S. and Sparrow, B. 1966. The mutagenic action of alkane sulphonic esters in barley. *Hereditas.* **52**: 277-305.

El Hifny, M.Z., Mahdy, E.E., Bakheit, B.R., Guirguis, N.R. and El Shimy, A. 1988. Evaluation of some cultivars and promising strains of sesame (*Sesamum indicum* L.). *Assiut. J. agric. Sci.* **19** :35-50.

Fatteh, U.G., Patel, N.A., Chaudhari, F.P., Dangaria, C.J. and Patel, P.G. 1995. Heterosis and combining ability in sesame. *J. Oilseeds Res.* **12** :184-190.

Fatteh, V.G., Shah, R.M. and Bodar, D.G. 1982. Studies on combining ability in sesame. *Madras agric. J.* **69** : 145-150.

Fendel, A.J.E., Monteverde-Penso, E.J. 1994. Heritability estimates of six characteristics and their phenotypic correlations from a factorial cross design in sesame. *Agronomia Tropical* (*Maracay*) **44** :529-540.

Fishbein, L., Flamme, W. G. and Falk, H. L. 1970. Chemical mutagens. *Environmental effects of biologicalsystems.* Academic Press, New York. p: 305.

Frank, S.A. 1989. The evolutionary dynamics of cytoplasmic male sterility, *Am.Nat.* **133** : 345-376.

Frankel, R. and Galum, E. 1977. *Pollination mechanisms, reproduction and plant breeding.* Springer verlag, Berlin, Heidelberg, New York. P. 281.

Freese-Gertzen, E. E., Konzak, C. F., Nilan, R. A. and Heiner, R. E. 1964. The effect of ethyl methane sulphonate on the growth response, chromosome structure and mutation rate in barley. *Radiat. Bot.* **4**: 61-69.

Ganesan, J. 1995. Induction of genic male sterility system in sesame. *Crop Improv.* **22** ;167-169.

Ganesh, S.K. and Thangavelu, S. 1995. Genetic divergence in sesame (*Sesamum indicum*). *Madras agric. J.* **82**: 263-265.

Gaul, H. 1970. Mutagen effects observable in the first generation. I. Plant injury and lethality. II. Cytological effects. III. Sterility. *Manual on Mutation Breeding (Tech. Rep. Series No. 119).* IAEA, Vienna, 85-90; 90-95; 95-99.

Gaul, H. and Frimmel, G. 1972. *Proc. of a study group meeting* on *"Efficiency of mutagenesis"* Buenos Aires, 16-20 (1970). IAEA. Vienna.

Ghorai, D. P. and Pande, K. 1982. Inheritance of yield and yield components and their association in a rice cross AC 1063 x AC 27. *Oryza* **19**: 185-187.

Gilbert, N.E.C. 1958. Diallel cross in plant breeding. *Heredity* **12** : 477 - 492

Godawat, S.L. and Gupta, S.C. 1985. Inheritance of grain yield and its components in sesamum. *J. Oil seeds Res.* **2**: 260 - 267.

Gottschalk, W. and Kaul, M.L.H. 1974. The genetic control of microsporogenesis in higher plants. *Nucleus (Calcutta)* **17**:133-166.

Govindarasu, R., Subramanian, M., Natarajan, M. and Ramamoorthi, N. 1998. Selection criteria for yield improvement in sesame. *Ann. agric. Res.* **19** : 433-436.

Goyal, S.N. and Kumar, S. 1988. Heterosis in relation to general and specific combining ability in sesame. *Indian J. Genet.* **48** : 251-253.

Goyal, S.N. and Kumar, S. 1991. Combining ability for yield components and oil content in sesame. *Indian J. Genet.* **51** :311-314.

Grafius, J. E. 1959. Heterosis in barley. *Agron. J.* **51**: 551-554.

Griffing, B. 1956. Concepts of general and specific combining ability in relation to diallel crossing systems. *Aus. J. Biol. Sci.* **9** :463-493.

Gupta, B.S. and Chopra, D.P. 1984. Genetic variability and path coefficient analysis in sesamum. *Indian J. Genet.* **36** : 118-124.

Gupta, T.R. 1975. Estimates of genotypic and environmental variability in sesame. *Oilseeds J.* **5** :31-32.

Gupta, T.R. 1981. Combining ability analysis of yield components in sesamum (*Sesamum indicum* L.) *Madras agric. J.* **68** ;281-288.

Gupta, V.K. and Gupta, Y.K. 1977. Variability inter-relationships and path coefficients analysis for some quantitative characters in sesamum (*Sesamum indicum* L.) *Indian J. Heredity.* **9** :31-37.

Hanson, C. H., Robinson, H. F. and Comstock, R. E. 1956. Biometrical studies of yield in segregating populations of Korean Lespedeza. *Agron. J.* **48**: 268-272.

Hanson, M.R. and Conde, M.F. 1985. Functioning and variation of cytoplasmic genomes : Lessons from cytoplasmic nuclear interactions affecting male fertility in plants. *Int. Rev. Cytol.* **94** : 214-245

Hayman, B.I. 1954. The theory and analysis of diallel crosses. *Genetics* **39** : 789-809

Heslop-Harrison, J. 1971. Differentiation. *Ann. Rev. Pl. Physiol.* **18** : 325-345

Hu, T.K. 1985a. Studies on inheritance and breeding in sesame II. A diallel analysis of yield components in F1 progeny. *J. agric. Assoc. China.* **131** : 24-34.

Hu, T.K. 1985b. Studies on the inheritance and breeding in sesame. IV. Genetic analysis of quantitative characters in the F_2 of different crosses. *J. Agri. Forestery.* **34** : 27-35.

Ibrahim, A.F. and Ragab, A.I. 1991. Variability in 1000 seed weight, oil content and fatty acid composition of sesame (*Sesamum indicum* L.) as influenced by capsule position on the plant. *Oil Crops Newsl.* **8**:27

Jadan, B.S. and Mehrotra, H.N. 1988. Heterosis in sesame. *Indian J. Genet.* **48** :241-245.

Jinks, J.L. and Hayman, B.I. 1953. The analysis of diallel crosses. *Maize Genetics Coop. News.* **27** : 48-54

Joel, A.J. and Thangavelu, S. 1997. Variability, heritability and Genetic advance in sesame. *Madras agric.J.* **84** :156-158

John, S. and Nair, V.G. 1993. Genetic variability, heritability and genetic advance in sesame. *J. Trop. Agri.* **31** : 143-146.

Johns, C.W., Delannay, X. and Palmer, R.G. 1981a. Structural sterility controlled by nuclear mutations in angiosperms. *Nucleus* **24** :97-105.

Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955a. Estimates of genetic and environmental variability in soyabean. *Agron. J.* **47** : 314:318.

Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955b. Genotypic and phenotypic correlations in soybean and their implications in selections. *Agron. J.* **47** : 477-483.

Joshi, A.B. 1961. *Sesamum-A monograph.* Indian Central oilseeds Committee, Hyderabad.

Joshi, S.N. 1972. Variability and association of some yield components in gram (*Cicer arietinum* L.). *Indian J. agric. Sci.* **42** (5) : 397-399.

Kadu, S., Narkhede, M.N. and Khorgade, P.W. 1992. Studies on combining ability in sesamum. *J. Maharashtra agric. Univ.* **3**: 392-393.

Kamala, T. 1990. Gamma ray effects on polygenically controlled characters in sesame (*Sesamum indicum L.*) .*J. Nuclear Agric. Biol.* **19** : 179-183.

Kandasamy, M. 1985. Genetic variation and genotype-environment interaction in sesamum. *Madras agric.J.* **72** :156-161.

Kang, C.W. 1994. Sesame breeding and agronomy in Korea. p.65 -90. In :Arora, R.K. and Riley, K.W. (eds.), *Sesame biodiversity in Asia: Conservation evaluation and improvement* IPGRI, NewDelhi.

Kartha, A.R.S. and Sethi, A.S. 1957. A cold percolation method for rapid gravimetric estimation of oil in small quantities of oilseeds. *Indian j. agric. Sci.* **27** : 211-217.

Kaul, M.L.H. 1988. *Male sterility in higher plants*. Springer-Verlag, Berlin, Heidelberg. New York, p. 1005.

Kaushal, P.K., Shrivastava, P.S., Shrivas, S.R. and Goswami, U. 1974. Study on correlation and path analysis of some yield contributing characters in sesame. *JNKVV Res.J.* **8** ; 213-217.

Keneni, G., Woyessa, B., Keneni, G. and Woyessa, B. 1997. Hybrid vigor for seed yield in sesame crosses. *IAR Newsl. agric. Res.* **12**: 12-13.

Khan, W.A., Ansari, A.H., Choudhry, N.A., Rajput, M.A. and Qayyam, S.M. 1988. Inter relationships of growth attributes with seedyield in sesame (*Sesamum indicum* L.) *Oil Crops Newsl.* **5**: 73-75.

Khidir, M.O. 1972. Natural cross fertilization in sesame under Sudan conditions. *Expl. Agric.* **8** : 55-59.

Khidir, M.O. and Osman, H.E. 1970. Correlation studies of some agronomic characters in sesame. *Expl. Agric.* **6** : 27-31.

Khorgade, P.W., Deshmukh, A.V., Narkhede, M.N. and Raut, S.K. 1989. Combining ability for yield and its components in sesame. *J. Maharashtra agric. Univ.* **14** : 164-166.

Khorgade, P.W., Patil, M.M. and Narkhede, M.N. 1988. Line tester analysis for combining ability in sesame. *J. Maharashtra agric. Univ.* **13** : 67-70.

Kinnison, N.S. 1978. Heterosis for yield and yield components in sesame. M.S. Thesis, University of California, Riverside, U.S.A.

Kivi, E. T. 1962. On sterility and other injuries in dioecious *Melandrium* irradiated with X-rays and gamma rays. *Ann. Acad. Sci. Fenr.Ser.* **56**: 1-56.

Kobayashi, T. 1991. Cytogenetics of sesame (sesammum indicum). p. 581-592. In : Tsuchiya, T. and Gupta, P.K (eds), Chromosome engineering in plants : genetics, breeding, evolution B. Elsevier, Amsterdam.

Konzak, C. F., Nilan, R. A., Wagner, J. and Foster, R. J. 1965. Efficient chemical mutagenesis. The use of induced mutations in plant breeding. *Radiat. Bot.* **5**: 49-70.

Kotatah, K. C., Rao, P. C, Reddy, N. S. and Sarma, Y. R. B. 1986. Mahalanobis D^2 and metroglyph analysis in mid duration genotypes of rice *Indian J. agric. Sci.* **56**: 151-160.

Kotecha, A., and Yermanos, D.M. 1978. Combining ability of seed yield, plant height capsule number and capsule length in an 8 x 8 diallel cross of sesame. (Abstracts). in. *Agronomy Abstr.* Madison, U.S.A. *American Society of Agronomy.*

Krishnadoss, D. 1984. Studies on combining ability and heterosis in sesame (*Sesamum indicum* L.). MSc. (Ag.) Thesis, TNAU, Coimbatore.

Krishnadoss, D., Kadambavanasundaram, M., Ramalingam, R.S. and Rajasekharan, S. 1987. Combining ability in sesamum. *Indian J.agric.Sci.* **57** : 85-88.

Krishnaswami, S . and Appadurai, R. 1984. A preliminary study on heterotic potential in sesame (*Sesamum indicum* L.). *Madras agric. J.* **71** : 81-84.

Kumar, C.R.A. 1991. Association and regression analysis in sesame. *Ann. Agric. Res.* **12** : 419-421.

Kumar, C.R.A. and Rangaswamy, S.R.S. 1987. Combining ability for yield in sesame. *J. Oilseeds Res.* **4** : 238-241.

Kumar, C.R.A. and Sivasamy, N. 1995. Combining ability analysis in sesame. *Ann. agric. Res.* **16** : 468-472.

Kumar, C.R.A. and Sivasamy, N. 1996. Influence of background traits in sesame. *Madras agric J.* **83** : 619-620.

Kumar, C. R. A. and Subramanian, M. 1992. Genetic divergence studies in upland rice. *Oryza* **29**: 139-141.

Kumar, L.S.S. and Abraham, A. 1941. A cytological study of sterility in *Sesamum orientale* L. *Indian J. Genet.* **1**:41-61.

Kumar, L.S.S. and Rao, D.S.R. 1945. Inheritance of sterility in *sesamum orientale* L. *Indian J. Genet.* **5** : 58-59.

Laser, K.D. and Lersten, W.R. 1972. Anatomy and cytology of microsporogenesis of cytoplasmic male sterile angiosperms. *Bot.Rev.* **38** : 425-454.

Le, M.W. and Zhang, D.X. 1993. Studies on the relationship between yield and the main economic characters of black sesame. *Acta Agriculture Universities Jiangxiensis* **3** : 230-234.

Lee, J.I., and Choi, B.H. 1985. Progress and prospects of sesame breeding in Korea. p. 137 - 144. In Ashri. A. (ed.), *Sesame and safflower: status and potential.* FAO Plant Production and Protection Paper 66, Rome.

Lee. J.I. Kang, C.W., and Son, E.R. 1986. Studies on flowering and maturity in sesame (*Sesamum indicum* L.) VI. Grain filling rate for differently positioned capsules in different plant types. *Korean J. Crop Sci.* **31** : 214-219.

Li, M.Y. 1988. A genetic analysis of the main characters in sesame. *Oil crops in China* **4** : 33-36.

Lopez, A.M. and Mazzani, B. 1964. Character association studies of some yield contributing characters in sesame. Agron. Irop. Venezuela **14** : 133.

Mahapatra, K.C., Biswal, A.K. and Satpathy, D. 1993. Relationship of F_2 segregation pattern with genetic divergence of parents in sesame. *Indian J. Genet.* **53** : 372-380.

Malaguti, G. and Mazzani, B. 1958. Causes of sterility in sesame. *Agron. Trop. Venezuela* **8** ; 63-65.

Manivannan, N. and Nadarajan, N. 1996. Genetic divergence in sesame. *Madras agric.J.* **83** : 789-790.

Manoharan, V., Senthil, N and Dharmalingam, V. 1997. Heterosis for yield and its components in sesame. *Madras agric.J.* **84** : 39-41.

Mary, R.J. and Jayabalan, N. 1995. EMS induced variability in sesame. *Crop Improv.* **22** : 170-174.

Mather,. K. and Harrison, B.J. 1949. The manifold effects of selection. *Heredity*, **3**: 1-52.

Mather, K. and Jinks, J.L. 1971. *Biometrical genetics*. Chapman and Hall, London,. p 382.

Mazzani, B., Gonzalez, V. and Martinez, 1971. Preliminary test of gametocidal effects of chemicals in sesame, *Agron. Trop. Venezuela* **21**: 39-47.

Mc Mahan, R. J. and Gerhold, H. D. 1965. Gamma irradiation of pine seeds at various moisture contents. *The use of Induced Mutations in Plant Breeding.* (Rep. FAO/IEAE, Tech. Meeting, Rome,1964). Pergamon Press, pp: 273-281.

Mishra, A.K., Ali, S.A., Rai, H.S., Ghurayya, R.S. and Yadav, L.N. 1993. Genetic variability, correlation and path analysis in sesame. *Int. J. Trop. Agric.* **11** : 113-117.

Mishra, A.K., Raghu, J.S., Ghurayya, R.S., Ali, S.A. and Raghuwanshi, R.S. 1995. Variability and association analysis in multi-capsule types of sesame (*Sesamum indicum* L.) *Crop Res.* **9** : 317-323.

Mohanty, K. K., De, R.N. and Srivastava, D.P. 1995. Mode of gene action for some important characters in rice. *Oryza* **32**: 5-9.

Mohanty, R.N. and Sinha, S.K. 1965. Study of variation in some quantitative characters of five varieties of sesamum of Orissa. *Indian Oilseeds. J.* **9** :104-108.

Muhammed, S.V. and Dorairaj, M.S. 1964. Correlation and path analysis of seed yield and its components in sesame. *Madras agric. J.* **51**:73.

Murthy, B.R. and Arunachalam, V. 1966. The nature of divergence in relation to breeding system in some crop plants. *Indian J.Genet.* **26** : 188-198

Murthy, B. R., Arunachalam, V. and Anand, I. J. 1966. Diallel and partial diallel analysis of some yield factors in *Linum usitatissimum. Heredity* **22**: 35-41.

Murty, D.S. 1975. Heterosis, combining ability and reciprocal effects for agronomic and chemical characters in sesame. *Theor. Appl. Genet.* **45** : 294-299.

Murty, D.S. and Hashim, M. 1973. Inheritance of oil and protein content in a diallel cross of sesame. *Can J.Genet Cytol. 15*: 177-184.

Murugesan, M.K., Dhamu, K.P. and Raj, A. 1979. Genetic variability in some quantitative characters of sesamum. *Madras agric.J.* **66** : 366-369.

Nair, N.R. and Nair, V.G. 1977. Mutagenic efficiency of Gamma rays in *sesamum. Agri. Res. J. Kerala* **15** : 142-146.

Nair, N.R. and Nair, V.G. 1978 Gamma ray induced viable mutations in sesamum. *Agri. Res.J. Kerala* **16** : 274-275.

Naphade, D.S. and Kolte, N.N. 1972. Studies on genetic variability in sesamum. Phenotypic variation, genetic advance and heritability of certain quantitative characters contributing towards yield. *College of Agric. Nagpur Mag.* **45** : 63-66.

Naphade, D.S. and Kolte, N.N. 1974. Interrelationships and path analysis for some character contributing to yield of sesame (*Sesamum indicum* L.) *Nagpur agri. Coll .Mag.* **47** : 32-36.

Narasinghani, V.G. and Kanwal, K.S. 1977. Notes on yield component analysis in pea crosses. *Indian J. agric. Sci.* **47**: 60-62.

Narkhede, B.N. and Kumar, S. 1991a. Combining ability in sesame. *J. Maharashtra agric. Univ.* **16** : 190-192.

Narkhede, B.N. and Kumar, S. 1991b. Genetics of seed yield and yield components in sesame. *J. Maharashtra agric. Univ.* **16**: 193-195.

Navadiya, L.J., Godhani, P.R. and Fougat, R.S. 1995. Heterosis studies in sesamum (*Sesamum indicum* L.) *Gujarat agric. Univ. Res.J.* **20** : 73-77.

Nayar, N.M. 1995. Sesame. p. 404-407 In . Smartt, J. and Simmonds, N.W. (eds). *Evolution of crop plants*. 2nd Longman, London.

Nayar, N.M. and Mehra K.L. 1970. Sesame : its uses, botany, cytogenetics and origin. *Econ. Bot.* 24 : 20-31.

Newton, K.J. 1988. Plant mitochondrial genomes: organization, expression and variation. *Annual Rev. Plant Physiol. Plant Mol. Biol.* **39**: 503 - 532.

Osman, H.E. 1981. Genetic male sterility in sesame: Reproductive characteristics and possible use in hybrid vigour. *Dissertation Abstr. Int. B.* **41** : 3992B.

Osman, H.E. 1986. Heterosis and path coefficient analysis in sesame (*Sesamum indicum* L.). *Sesame and Safflower Newsletter* **2**:48.

Osman, H.E. 1988. Relationship between seedyield, oil content, and their components in sesame. (*Sesamum indicum* L.) *Acta Agronomica Hungarica* **37**: 287-292.

Osman, H.E. 1989. Heterosis and path coefficient analysis in sesame (*Sesamum indicum L.*) *Acta Agronomica Hungarica.* **38** : 105-112.

Osman, H.E. and Yermanos, D.M. 1982. Genetic male sterility in sesame : Reproductive characteristics and possible use in hybrid seed production. *Crop. Sci.* **22** : 492-498.

Padmavathi, N. 1987. Heterosis and combining ability analysis in sesame (*Sesamum indicum* L.). MSc. (Ag) thesis, TNAU, Coimbatore.

Pal, B.P. 1945. Studies in hybrid vigour I. Notes on the manifestation of hybrid vigour in gram, sesamum, chilli and maize. *Indian J.Genet.* **5** : 106-121.

Panse, V.G. 1957. Genetics of quantitative characters in relation to plant breeding. *Indian J. Genet.* **17**: 318-327.

Paramasivam, K. 1980. Genetic analysis of yield and yield components in F_2 and F_3 generations of sesame (*Sesamum indicum L.*) MSc. (Ag.) thesis, TNAU, Coimbatore.

Paramasivam, K. and Prasad, M.N. 1981. Study on variability and heritability in segregating population of sesamum (*Sesamum indicum L.*) Crosses. *Madras agric.J.* **68** :1-6.

Pathak, G.N. and Bajpaye, N.K. 1965. Abnormality in flower parts in *Sesamum. Indian Oilseeds J.* **9** :159.

Pathak, H.C. and Dixit, S.K. 1986. Genetic variability, correlations and path coefficient analysis for component of seed yield in single stemmed sesame (*Sesamum indicum L.*) *Gujarat Res.J* **12** :1-5.

Pathak, H.C. and Dixit, S.K. 1992. Genetic variability, interrelationship studies on black seeded sesame (*Sesamum indicum* L.). *Madras agric.J.* **79** :94-100.

Pathirana, R. and Kitto, P.H. 1991. Increased efficiency of selection for yield in gamma irradiated populations of ground nut and sesame through yield component analysis. *Plant mutation breeding for crop improvement: Proceedings of an international symposium on the contribution of plant mutation breeding to crop improvement jointly organised by IAEA and FAO*, Vienna **2**: 299-316.

Patil, R.R. and Sheriff, R.A. 1994. Genetic divergence in sesame (*Sesamum indicum* L.). *Mysore J.agric.Sci.* **28** : 106-110.

Pfahler, P.L., Pereira, M.J. and Barnett, R.D. 1996. Genetic and environmental variation in anther, pollen and pistil dimensions in sesame. *Sex plant Reprod.* **9** :228-232.

Phadnis, B.A., Ekbote, A.P. and Yayyab, M.A. 1970. Contribution of various plant characters to yield of sesame. *Nagpur agri. Coll .Mag.* **42** : 16-25.

Prabakaran, A.J. 1996. Genetic diversity of wild sesame from southern India. *Plant Genet. Resources Newsl.* **106** : 44-46.

Prabakaran, A.J., Sree Rangaswamy, S.R. and Ramalingam, R.S. 1995. Identification of cytoplasm induced male sterility in sesame through wide hybridization. *Curr. Sci.* **68** : 1044-1047.

Prasad, S. K. and Singh, T. P. 1986. Heterosis in relation to genetic divergence in maize (*Zea mays* L.) *Euphytica* **35**: 919-924.

Quijade, P. and Layrisse, A. 1995. Heterosis and combining ability in hybrids among 12 common varieties of sesame (*Sesamum indicum L.*) *Plant Breeding.* **114** : 239-242.

Rai, R.S.V., Venkateswaran, A.N., Ramachandran, T.K., Srinivasan, G.I. 1981. Genetic variability and correlation studies in sesamum- *Indian J. agric. Res.* **15** :119-122.

Ram,. T. 1995. Combining ability in sesame (*Sesamum indicum* L.) in ranifed conditions. *Ann. agric. Res.* **16** :311-316.

Ramachandran, M., Ramanathan, T. and Sridharan, C.S. 1972. Association of certain morphological characters with yield in *Sesamum indicum* L. *Madras agric.J.* **59** : 567-568.

Ramakrishnan, M. and Soundrapandian, G. 1990. Line x Jester analysis in sesame (*Sesamum indicum* L.) *Madras agric. J.* **77**: 486 - 489

Ramalingam, A., Muralidhar, V. and Sheriff, N.M. 1990. Combining ability studies in sesame. *J. Oilseeds Res.* **7** :75-77.

Ramanujam, S., Tiwari, A.S. and Mehra, R.B. 1974. Genetic divergence and hybrid performance in Mungbean. *Theoret. Appl. Genet.* **45**:211-214.

Ramesh, S., Sheriff, R.A., Ram, A.M., Savithramma, D.L. and Madhusudan, K. 1995. Generation mean analysis in sesame. *Crop Improv.* **22** : 237-240.

Rangaswamy, M. and Rathinam, M. 1982. Mutagen induced male sterile lines in sesame. *Indian J. Genet.* **42** : 142-143.

Rao, C.R. 1948. The utilization of multiple measurement in problems of biological classification. *J. Royal Stat. Soc.* **10 B** :159-203.

Rao, C.R. 1952. *Advanced statistical methods in biometric research.* John Wiley and sons, Inc., New York.

Rao, D.S.R.M., Singh, H., Singh, B., Khola, O.P.S. and Faroda. A.S. 1990. Correlation and path coefficient analysis of seed yield and its components in sesame (*Sesamum indicum* L.) *Haryana agric. Univ. J. Res.* **20** : 273-276.

Rao, G.V., Sarup, V.B., Prakash, S. and Shivanna, K.R. 1994. Development of a new cytoplasmic male-sterility system in *Brassica juneca* through wide hybridization. *Plant Breeding* **112**:171-174.

Rathinaswamy, R. 1980. Genetic analysis in *Sesamum indicum* L. Ph.D. Thesis, TNAU, Coimbatore.

Rathinaswamy. R. and Jagathesan, D. 1984. Selection of superior early generation crosses in *Sesamum indicum* L. based on combining ability study. *Zeitschrift fur pftangenzuchtung*, **93** : 184-190.

Raut, S.K., Bolke, M.N., Ingle, W.S., Khorgade, P.W. and Narkhede, M.N. 1990. Character association and path analysis in sesamum. *Ann. Plant physiol.* **4** : 221-225.

Raut, V. M., Rao, V. S. P., Patil, V. P. and Deodikar, G. B. 1985. Genetic divergence in *Triticum durum. Indian J. Genet.* **45**: 141-151.

Ray, S.D. and Sen, S. 1992. Heterosis in sesame (*Sesamum indicum L.*) *Trop. Agric. (Trinidad)* **69** : 276-278.

Reddy, C.D.R. and Haripriya, S. 1990. Genetic architecture, combining ability and heterosis for certain physiological parameters in sesame (*Sesamum indicum* L.). *Indian J. Plant Physiol.* **33**: 94-96.

Reddy, C.D.R. and Haripriya, S. 1991. Character association and path coefficient analysis in parental lines and their F_1 hybrids of sesame. *J. Oilseeds Res.* **8**: 98-104.

Reddy, C.D.R. and Haripriya, S. 1992. Genotypic character association and path coefficient analysis in parents and their F_1s in sesame. *J. Maharashtra agric. Univ.* **17** : 55-57.

Reddy, C.D.R. and Haripriya, S. 1993. Heterosis in relation to combining ability in sesame. *Indian J.Genet.* **53** : 21-27.

Reddy, C.D.R., Haripriya, S. and Ramachandraiah, D. 1993. Nature of gene action, combining ability and heterosis for seed oil content in sesame. *Madras agric.J.* **80** : 364-368.

Reddy, C.D.R. and Ramachandraiah, D. 1990. Character association and path analysis in sesamum parents and their F_1 hybrids. *Orissa. J. agric. Res.* **3**:37-44.

Reddy, C.D.R., Ramachandraiah, D., Haripriya, S. and Reddy, K.S. 1990. Combining ability and heterosis in sesame (*Sesamum indicum* L.) *Orissa. J. agric. Res.* **3** :181-187.

Reddy, C.D.R., Ramachandraiah, D., Haripriya, S. and Reddy, K.S. 1992. Combining ability and heterosis for seed oil and yield in sesame. *J. Maharashtra agric. Univ.* **1**:78-81.

Reddy, M.B., Reddy, M.V. and Rana. B.S. 1984a. Combining ability studies in sesame. *Indian J.Genet.* **44** : 314-318.

Reddy, M.B., Reddy, M.V. and Rana, B.S. 1984b. Character association and path coefficient analysis in parents and F_1 hybrids of sesamum (*Sesamum indicum L*). *Madras agric.J.* **71** :147-150.

Reddy, O.U.K, 1986. Studies on variability, character association and genetic divergence in *Sesamum indicum* L. Msc (Ag) thesis, TNAU, Coimbatore. p. 106.

Reddy, O.U.K. and Dorairaj, M.S. 1990. Variability, heritability and genetic advance in sesame (*Sesamum indicum* L.) *Madras agric. J.* **77**: 398-400.

Reddy, O.U.K. and Dorairaj, M.S. 1994. Path coefficient analysis in sesamum. *Madras agric.J.* **81** : 446-447.

Reddy, O.U.K., and Dorairaj, M. S. 1995. Heritability and correlation studies of various components of dry matter production in *Sesamum indicum. Madras agric.J.* **82** :11-13.

Reddy, P.G. 1984. Studies on induced mutagenesis in sesame through gamma irradiation. *Mysore J. agric. Sci.* **18** : 167-168.

Reddy, P.N. and Reddy, G.P. 1976. Heritability studies in sesamum. *Andhra agric.J.* **28**:224-227.

Renard, M., Delourme, R., Mesquida, R.R., Pelletier, G., Boulidard, L., Gore, C., Ruffio, V., Harre, Y. and Morice, J. 1992. Male sterilities and F1 hybrids in *Brassica. Reproductive Biology and Plant Breeding* (Dattif, Y., Dumus, C. and Gallais, A. (ed.). Springer Verlag, Berlin.P.P. 107-119.

Rhind, D. and Ba Thein, 1933. Contribution of various plant characters to yield of sesame (*Sesamum indicum* L) *Indian J. agric. Sci.* **3**:478.

Riccelli, M. and Mazzani, B. 1964. Manifestation of heterosis on development, earliness and yield in diallel crosses of 32 sesame cultivars. *Agron. Trop. Venezuela* **14** :101-125.

Rong, X.X. and Wu, W. 1989. Correlation and path analysis of seed yield and some important agronomic characters in sesame (*Sesamum indicum*). *Oil crops of China* **4** :30-32.

Ross, W. C. J. 1962. *Biological alkylating agents*. Butterworths, London. p: 285.

Roy, A. and Panwar, D. V. 1993. Genetic divergence in rice. *Oryza* **30**: 197-201.

Roy, S.C. 1931. A preliminary note on the occurrence of sepaloid and sterility in til, *Sesamum indicum*. *Agric. Liveslk., India***1** : 282-285.

Rudraradhya, M., Habib, A.F. and Joshi, M.S. 1984. Variability studies of some quantitative characters in sesamum. *J. Oilseeds Res.* **1**;179-182.

Sajjanar, G.M., Giriraj, K. and Nadaf, H.L. 1995. Combining ability in sesame *Crop Improv.* **22** : 250-254.

Salazar, R.., D. and Onoro, C.P.R. 1975. Determination of heritability of plant height, number of capsules and seed weight per plant in sesame. *Revista ICA* . **10** : 109-114.

Sanjeeviah, B.S. and Joshi, M. S. 1974. Correlation and genetic variability in sesamum. *Curr. Res.* **11**: 144-145.

Sarathe, M.C. and Dabral, K.C. 1969. Heterosis studies in *Sesamum orientale* L. *Sci. Cult.* **35** : 572-577.

Sarathe, M. L. and Perraju, P. 1990. Genetic divergence and hybrid performance in rice. *Oryza* **27**: 227-231.

Sasikumar, B. and Sardana, S. 1990. Heterosis for yield and yield components in sesame. *Indian J. Genet.* **50**: 45 - 49.

Sato, H. and Gaul, H. 1967. Effect of Ethyl Methane Sulphonate on the fertility of barley. *Radiat. Bot.* **7**: 7-15.

Sawant, A.R. 1971. Genetic variation and heritability of quantitative characters in some improved varieties of sesame. *Mysore J. agri. Sci.* **5** : 88-95.

Selima, A. R., Hussian, H. A. S. and Shawarf, H. S. 1974. EMS and gamma ray induced mutation in *Pisum sativum* L. II. Effects of EMS and gamma rays on M1 germination, seedling height and fertility. *Egypt. J. Genet. & Cytol.* **3**: 172-192.

Selvakumar, K. S., Soundrapandian, G. and Amrithadevarathinam, A. 1989. Genetic divergence for yield and yield components in cold tolerant rice. *Madras agric. J.* **76**: 688-694.

Sengupta, K. 1980. Combining ability in sesame. *Indian Agric* **24** : 95-100.

Shadakshari, Y.G., Virupakshappa, K. and Shivashankar, G. 1995. Genetic variability studies in the Germplasm collections of sesamum (*Sesamum indicum* L.). *Mysore J.agric. Sci.* **29**: 133-137.

Shanmugavalli, N. and Vanniarajan, C. 1998. Genetic variability studies in sesamum. *Crop Res.* **16** : 280-281.

Sharma, R.L. and Chauhan, B.P.S. 1983. Heterosis and inbreeding depression in sesame. *Madras agric. J.* **70**: 561-566.

Sharma, R.L. and Chauhan, B.P.S. 1984. Path analysis in sesame. *J. Maharashtra agric. Univ.* **9**:158-160.

Sharma, R.L. and Chauhan, B.P.S. 1985. Combining ability in sesame. *Indian J.Genet.* **45**:45-49.

Sharma, S.M. 1985. Sesamum research and its progress in India. p. 11-27. In : Omran, A. (ed.) *Oil crops: sesame and safflower.* IDRC- MR 105e, IDRC, Ottawa.

Sharma, S.M. 1994. Utilization of national collections of sesame in India. p. 135-156. In: Arora, R.K. and Riley, K.W. (eds.), *Sesame biodiversity in Asia: conservation, evaluation and improvement.* IPGRI, New Delhi.

Shinde, Y.M., Badhe, P.L., Patel, D.M., Deokar, A.B. 1991. Genetic evaluation of some lines in sesame. *J. Maharashtra agric. Univ.* **16** : 22-24.

Shivaprakash, B. 1986. Genetic analysis of yield and yield components in sesame (*Sesamum indium* L.) *Mysore J. agric. Sci.* **20** :156.

Shrivas, S.R. and Singh, S.P. 1981. Heterosis and combining ability in Sesamum. *Indian J.Genet.* **41**:1-4.

Shukla, G.P., 1983. Path coefficient analysis in sesame *Indian J. agric. Sci.* **53**: 407-08.

Shukla, G.P. and Verma, G.V. 1976. Correlation and heritability in sesame. *Indian J agric. Sci.* **46** : 283-285.

Sikka, S.M. and Gupta, N.D. 1949. Correlation studies in *Sesamum oriental* L. *Indian J.Genet.* **9**:27-32.

Singh, O., Gowda, S.C., Sethi, C.L.L., Dasgupta, T. and Smithson, J.B. 1992. Genetic analysis of agronomic characters in chickpea. I Estimates of genetic variances from diallel mating design. *Theor. Appl. Genet.* **83**: 956 - 962.

Singh, R.B. and Bains, S.S. 1968. Genetic divergence for ginning outturn and its components in upland cotton. *Indian J.Genet.* **28**: 262-269.

Singh, R.M., Singh, A.K., Kumar, P., Thakral, N.K. and Kumar, P. 1997a. Genetic divergence in sesame. *Ann Biol. Ludhiana* **13**: 41-45.

Singh, R.M., Singh, A.K., Kumar, P, Thakral, N.K, and Kumar, P. 1997b. Association of yield and its component traits in sesame. *Ann biol. Ludhiana* **13** : 47-51.

Singh, R. P. 1983. Studies on genetic variability in rice. *Madras agric. J.* **70**: 436-440.

Singh, R. S. and Richharia, A. K. 1980. Diallel analysis of grain yield and its components in rice. *Indian J. agric. Sci.* **50**: 1-5.

Singh, S. K., Singh, R. S., Maurya, D. M. and Verma, O. P. 1987. Genetic divergence among lowland rice cultivars. *Indian J. Genet.* **47**: 11-14.

Singh, S. P., Singh, H. N. and Rai, J. N. 1980. Multivariate analysis in relation to breeding systems in Okra (Abelmoschus *esculentus (L)* Moench). *Z. Pflanzonzenchtg.* **84**: 57-62.

Singh, V.K., Singh, H.G. and Chauhan, Y.S. 1986. Heterosis in sesame *Farm science J.* **1**:65-69.

Singh, Y. P ., Kumar, A. and Chauhan, B. P. S. 1981. Genetic divergence in pearl millet. *Indian J. Genet.* **41**: 186-190.

Sodani, S.N. and Bhatnagar, S.K. 1990. Heterosis and inbreeding depression in sesame. *Indian J.Genet.* **50**:87-88.

Solanki, Z.S. and Paliwal, R.V. 1981. Genetic variability and heritability studies on yield and its components in sesame. *Indian J. agric. Sci.* **51**:554-556.

Srivastava, D.P. and Singh, S.N. 1968. Heterosis in sesame. *J. Indian Bot. Soc.* **47** : 59-68.

Stephens, J.C. and Holland, R.F. 1954. Cytoplasmic male sterility for hybrid sorghum seed production. *Agron.J.* **46** : 20-23.

Subramaniam, E. 1979. Biometrical studies on variability, correlation, path analysis and genetic divergence in little millet, MSc. (Ag.) thesis, TNAU coimbatore.

Subramanian, S. and Subramanian, M. 1994. Correlation studies and path coefficient analysis in sesame (*Sesamum indicum* L). *J. Agron. & Crop. Sci.* **173** : 241-248.

Sudharani, M., Reddy, G.L.K., Reddy, C.R. and Reddy, K.S. 1996. Path coefficient analysis in biparental progenies and F_3 bulk population in sesame. *J. Res, APAU.* **34**: 9-12.

Sun, L. and Singer, B. 1975. The specificity of different classes of ethylating agents towards various sites of Hela cell DNA *in vitro* and *in vivo*. *Biochemistry* **14**: 1795-1802.

Suresh, K.M. and Unnithan, V.K.G. 1996. A computer oriented iterative algorithm for clustering. *Indian J. Genet.* **56** : 412-424.

Swain, D. and Dikshit, U.N. 1997. Genetic divergence in rabi sesame (*Sesamum indicum* L) *Indian J.Genet.* **57** : 296-300.

Swaminathan, M.S., Siddiq, E.A and Sharma, S.D. 1972. Outlook for hybrid rice in India. In: *Rice Breeding*. IRRI, Los Banos, Philippines: 609 - 613

Tak, G.M. 1997. Correlation and path coefficient analysis in sesame. *Agric. Sci. Digest.* **17** : 153-154.

Thangavelu, M.S. 1980 Studies on variability D^2 statistics and correlation in sesamum (*S. indicum* L) M.Sc. (Ag.) thesis, Tamil Nadu, Agric. Univ., Madurai.

Thangavelu, S. 1994. Diversity in wild and cultivated species of sesame and its uses p. 13-23. In Arora, R.K. and Riley, K.W. (eds) *Sesame biodiversity in Asia : conservation, evaluation and improvement*. IPGRI, New Delhi.

Thangavelu, S. and Nallathambi, G. 1982. Simple new techniques for selfing and emasculation in *Sesamum indicum* L. *Madras agric.J.* **69** : 555-556

Thangavelu, M.S. and Rajasekharan, S. 1983a. Genetic divergence in sesame (*Sesamum indicum* L.). *Madras agric.* J. *70*: 211-214.

Thangavelu, M.S. and Rajasekharan, S. 1983b Correlation and path coefficient analysis in (*Sesamum indicum* L.). *Madras agric.J.* **70**: 109-113..

Thiyagarajan, K. and Ramanathan, T. 1995a. Combining ability analysis for yield components of sesame in different environments. *Madras agric.*J. **82**: 445-449.

Thiyagarajan, K. and Ramanathan, T. 1995b, Inheritance of seed yield in sesame under different environment. *Madras agric.* J. **82**: 640-642.

Thiyagarajan, K. and Ramanthan, T. 1996. Character association and path coefficient analysis of components of seed yield in sesame. *Madras agric.* J. **83** : 683-687.

Tu, L.C., Liang, X.Y., Wang, W.Q., Zheng, Y.Z. Liu, J.R. 1995. Studies on genetic male sterility in sesame (*Sesamum indicum* L.,) *Acta Agriculture Boreai-Sinica* **10** : 34-39.

Tu, L.C. Liu, J.R. and Liang, X.Y. 1988. A study on heterosis in sesame, *Oil crops of china*. **2**: 8-12.

Tu, L.C., Wang, W.Q. and Lui. J.R. 1991. Study of heterosis, combining ability and reciprocal effects in sesame. *Acta Agriculture Boreali-sinica*. **6**: 48-53.

Tyagi, B.P. and Singh, H.G. 1981. Heterosis in sesame. *Indian J.agric. Sci*. **51**:849-852.

Uzo, J. 1976. Expression of hybrid vigour in sesame (*Sesamum indicum* L.) Ph.D. Thesis, University of California, Riverside, U.S.A.

Vadhvani, H.K., Kukadia, M.U. and Parmar, V.L. 1992. Correlation and path analysis in sesamum. *Gujarat agric. Univ. Res.J.* **18**: 31-34.

Varisai, M. and Stephen, M.P. 1964. Correlation studies in *Sesamum indicum* L., Association of yield and certain yield components in different groups of sesamum based on seed colour. *Madras agric.*J., **51**: 73-74.

Verma, A.K. and Mahto, J. 1995. D^2 analysis in sesame under rainfed environments. *J. Res. Brisa agric. Univ*. **7** : 83-84.

Verma, V.S. and Mehta, R.K. 1976. Genetic divergence in lucerne. *J Maharashtra agric. Univ*. **1**: 23-28.

Verma, Y. S., Singh, H. and Pandey, M.P. 1995. Combining ability for yield and its components in rice. *Oryza* **32**: 1-5.

Vivekanandan, P. and Giridharan, S. 1997. Combining ability for grain traits in rice. *Madras agric. J.* **84**: 129-132.

Vivekanandan, P. and Subramanian, M. 1993. Genetic divergence in rainfed rice. *Oryza* **30**: 60-62.

Wang, W.Q., Zheng, Y.Z., Liu, J.R., Tu, L.C. and Liang, X.Y. 1995. A study of the effectiveness of hybrid seed production by utilizing genic male sterility in sesame (*Sesamum indicum* L) *Oil crops in china* **17** : 12-15.

Weaver, J.B. 1968. Analysis of a genetic double recessive completely male sterile cotton. *Crop sci.* **60** : 597-600.l;

Wei, W.S., Zhang, H., Lu, F.Y and Wei, S.L. 1994. Principle component analysis and genetic distance estimation and their application in sesame breeding programme. A*cta Agriculturea Boreali-sinica* **9** : 29-33.

Xavier, G. 1979. Studies on yield and yield components and genetic divergence in ragi. Msc. (Ag) thesis, TNAU, Coimbatore.

Yadav, I.S. and Gupta, S.K. 1988. Inheritance of oil and protein content in sesame. *J. Oilseeds Res.* **5**: 80-82.

Yermanos, D.M. and Kotecha, A. 1978. Diallel analysis in sesame (*Sesamum indicum* L.) *Agron. Abstr.* p 68.

Yuan, L.P. 1993. Advantages and constraints of the use of hybrid rice varieties. In: K.J. Wilson (Ed.) *International Workshop on Apomixis in Rice*. pp. 1-4. Rockefeller Foundation. New York and China National centre for Biotechnology Development, Beijing, China.

Zhan, Y.X., Zhou, X.C. Liu. S.K. and Li, Y. R. 1990. Studies on heterosis in sesame and its utilization. Heterosis and genotypic correlation of characters. *Scientia Agricultureasinica* **23** : 27-36.

Zhan, Y.X., Zhou, X.C., Li. Y. R. and Liu.S.K. 1991. Studies on heterosis and its utilisation in sesame. The chemical induction of male sterility and its mechanism. *Scientia Agriculturae sinica* **24** : 34-41.

Zhao, Y. Z. 1994. Sesame and varietal improvement in China. p. 57-64 In: Arora, R.K. and Riley, K.W. (eds.) *Sesame biodiversity in Asia: conservation, evaluation and improvement*, IPGRI, New Delhi.

EXPLOITATION OF MALE STERILITY IN SESAME

(*Sesamum indicum L.*)

By
VEENA VIGHNESWARAN

ABSTRACT

of the Thesis submitted in partial fulfillment of the requirement for the degree of **Doctor of Philosophy in Agriculture,** Faculty of Agriculture, Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS
COLLEGE OF HORTICULTURE
KERALA AGRICULTURAL UNIVERSITY
VELLANIKARA, THRISSUR 680 656
KERALA, INDIA
2001

ABSTRACT

The research project "Exploitation of male sterility in sesame (*S.indicum* L.)" was carried out in the college of Horticulture, Kerala Agricultural University, Vellanikkara during 1996-'99. The persent investigation was carried out with a view to assess the variability and to estimate the combining ability of selected lines. Exploitation of male sterility in sesame through induced mutagenesis and wide hybridization for future development of hybrid sesame was also aimed at.

Sixty genotypes of diverse origin were evaluated during '96-'99 at Onattukara Regional Agricultural Research Station, Kayamkulam for their divergence using Mahalanobis D^2 statistics. Based on yield and attributed components, these genotypes were grouped into eight clusters. Eight genotypes representing each cluster were selected and were evaluated for their combining ability, gene action and heterosis using diallel analysis. Two best general combiners were selected and carried forward for the induction of male sterility through mutagenesis and wide hybridization.

The wide range of variation was noticed in all the ten characters among the 60 genotypes selected for divergence study indicates the presence of substantial genetic variability among the genotypes. The magnitude of heterosis was largely dependent on the degree of genetic diversity in the parental lines.

The study on genetic parameters revealed that the characters number of branches per plant, number of capsules per main

stem and seed yield per plant exhibited high broad sense heritability coupled with high expected genetic advance along with high or moderate GCV.

Correlation studies revealed that the principal yield determining components were capsules per main stem and capsules per plant. While selecting genotypes for higher yield potential, emphasis should be given for these characters. Cluster analysis revealed that there was no parallelism between geographical distribution and genetic diversity of the genotypes. The sixty genotypes representing different geographical regions were grouped into eight clusters based on genetic distances.

Combining ability studies revealed the importance of all the three additive, non-additive and maternal effects in all the characters studied. The varieties Thilak and OS-2 were identified as best general combiners.

Studies on induced mutagenesis clearly indicated that both physical as well as chemical mutagens reduced the germination, survival and fertility in the M_1 population. A linear increase in the sterility with increase in the doses of mutagens was noted. Chemical mutagens were found to induce more number of steriles than the physical mutagens. Male sterile types isolated were similar in habit as the normal plants but for their shrunken, green undersized anthers. These plants had normal female fertility and exihibited regular seed set. Inheritance studies indicated that the present case of male sterility is governed by a single recessive gene.

In the wide hybridization of *Sesamum indicum* x *S.malabaricum,* F_1s had high percentage of pollen fertility as indicated by a fairly good capsule set on selfing while reciprocals had little capsule set on selfing. This points to a positive role of the wild cytoplasm on the expression of sterility in crosses where *S. malabaricum* was used as female parent. The F_1 interspecific hybrids both direct and reciprocal, exihibited dominance of the wild parent characters in hybrids. Progenies of back crosses BC_1 and BC_2 exihibited more of the attributes of the recurrent parent indicating further improvement of hybrids for desirable attributes retaining high levels of male sterility along with. These lines offer scope for efficient utilization in future hybrid seed production programme in cultivated sesame.