GENETIC DISTANCE IN RELATION TO HETEROSIS AND COMBINING ABILITY IN SUNFLOWER (*Helianthus annuus* L.)

By

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DEDICATED

TO

MY PARENTS

CERTIFICATE-I

This is to certify that this thesis entitled : "Genetic distance in relation to heterosis and combining ability in sunflower (Helianthus annuus L.)" submitted for the degree of M.Sc. in the subject of Plant Breeding of the Chaudhary Charan Singh Haryana Agricultural University, is a *bonafide research work carried out* by Shri Sukhvinder Singh Kandhola under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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Major Advisor
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CERTIFICATE-II

This is to certify that this thesis entitled : "Genetic distance in relation to heterosis and combining ability in sunflower (*Helianthus annuus* L.)" submitted by Shri Sukhvinder Singh Kandhola to the Chaudhary Charan Singh Haryana Agricultural University in partial fulfilment of the requirements for the degree of M.Sc., in the subject of Plant Breeding, has been approved by the Student's Advisory Committee after an oral examination on the same, in collaboration with an External Examiner.

MAJOR ADVISOR **EXTERNAL EXAMINER**

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CONTENTS

INTRODUCTION

Sunflower (Helianthus annuus L.) is among the most important oil crops in the world. The major sunflower producing countries in the world are the Soviet Union, Argentina, China, USA, France, Spain, Romania, Turkey and Hungary. Sunflower became an oil crop around the end of the 19th century, when 'popular selection' was practiced in several parts of Russia to improve sunflower populations grown at that time.

The cultivated sunflower (Helianthus annuus L.) is a member of the family compositae. The genus Helianthus has a basic chromosome number of X=17, and contains diploid, tetraploid and hexaploid species. Helianthus annuus L. is a diploid species (2n = 2x = 34) and is highly cross-pollinated crop. Heiser et al. (1969), reported 67 species in the genus Helianthus.

The oil of sunflower possesses good odour which can be used for a variety of cooking purposes like any other edible oil. Sunflower oil is a rich source of linoleic acid (64%) which helps in washing out cholestrol deposition in the coronary arteries of the

the heart. Oil is also used in the manufacture of soaps and cosmetics. The sunflower meal, obtained after the oil extraction from seed, has a high protein percentage and is used primarily in food rations for livestock and poultry. Certain cultivars are grown for non oilseed or confectionery purposes, especially in the USA. Its seed oil can be used as a raw material for oleochemistry and as substitute for mineral oil in various applications, such as fuel, lubricant or an oil for hydraulic systems.

Breeding and selection work to improve sunflower at experimental stations was initiated in 1910 in the USSR (Pustovoit, 1964), where mass selection was commonly used during the early stages of cultivar improvement (Gunadaev, 1971). Hybrids were first obtained through mechanical or chemical emasculation, the discovery of genetic male sterility (Gunadaev, 1966) and the linkage of male sterility to genetic markers (Leclercq, 1966) allowed the production of the first commercial hybrids in 1970 in Romania (Vranceanu *et al.*, 1974). The discovery of cytoplasmic male sterility (Leclercq, 1969 in France) and fertility restoring genes (Kinman, 1970 in USA) lead to the phenomenal rise in sunflower production in USA and European countries. The first hybrid seed from this system became available in 1972 in USA and virtually 100 per cent of oilseed sunflower production is under hybrids in USA, Western Europe, Argentina and Australia.

Unrau and White (1944), Unrau (1947) and Putt (1966) conducted some of the earliest studies designed specifically to evaluate inbred lines in hybrid combinations. They observed marked differences among lines for combining ability. Putt (1966) reported that specific combining ability was more important than general combining ability for seed yield, suggesting that non-additive genetic variance was more important than additive in influencing yield. Assuming a relatively large, non-additive genetic component, breeding procedures that involve some form of test cross evaluation and ensure adequate genetic divergence among parents entering crosses might be most effective.

Ever since the introduction of sunflower to India from former USSR in 1965, it remained almost confined to institutions for academic studies and due to inherent problems it did not find favour with farmers. Of late, many potential hybrids are available for commercial cultivation with increased yields, disease resistance, high self-incompatability and uniformity of plant height and maturity (Gill, 1993). Consequently, farmers have shown great interest in this economically viable, profitable crop. It is evident from the fact that area under sunflower in Haryana increased to 1 lakh hectares with a production of 1.5 lakh tonnes during 1991-92.

Major goals in sunflower breeding include improved seed yield, earlier maturity, shorter plant height, uniformity of plant type, disease and insect resistance, and, in oilseed types, high oil percentage.

Most of the germplasm of sunflower has been introduced and represent, rather a narrow gene pool. Despite considerably high yield potential, sunflower hybrids are also impregnated with potential risk associated with monoculture and narrow gene pool, as most of the cultivated hybrids are based on single cytoplasmic male sterility source, Helianthus petiolaris, (Leclercq, 1969; Arnaud, 1986). Any improvement programme in sunflower therefore should precede with infusion of more genetic variability in breeding populations.

Keeping this information in view, the present studies were planned with following objectives :

i) To classify the elite sunflower inbreds on the basis of genetic divergence/distance, among parents entering crosses (18).

ii) To assess the extent of heterosis.

iii) To determine combining ability effects (GCA/SCA).

iv) To determine relationship between genetic divergence, heterosis and combining ability.

REVIEW OF LITERATURE

The relevant literature on different aspects of the present study has been reviewed as under :

Genetic divergence

In sunflower, sporadic reports are available on this aspect. Ming (1987) identified three basic groups, on the basis of an analysis of genetic divergence in 8 varieties. This allowed useful parents to be identified for crossing to produce heterotic hybrids.

Yadava et al. (1988) classified 36 genotypes obtained from 10 countries belonging to different continents into 9 clusters. No relationship was observed between genotypic and geographic diversity. Based on genotypic divergence, performance and geographic origin, EC 27290, EC 68415, EC 85815, EC 97916, EC 101492 and Sunrise were useful for further exploitation.

Combining ability

Some parents combine well and produce promising hybirds, whereas, certain others produce very poor hybrids in cross combinations. The most valuable parents for the breeder are those which combine well with other parents. It is, therefore, essential to identify the parents having desirable combining ability. So combining ability studies are of major interest where a breeding programme aims at the production of hybrid progenies and their derivatives.

Davis (1927) suggested the use of top crosses for the estimation of general combining ability of corn inbreds. Jenkins and Brunson (1932) studied the top cross progenies in corn and were of the view that inbred lines in corn could be evaluated from their combining ability rapidly by top cross method.

Sprague and Tatum (1942) defined general combining ability as the average performance of a line in hybrid combinations, while specific combining ability refers to those cases in which certain combinations do relatively better or worse than that could be expected on the basis of average performance of the lines involved. General combining ability (gca) accounts for additive gene action, whereas, specific combining ability accounts for dominance and epistatic interactions. Most efficient means of testing specific combining ability (sca) is single tester, while more than one tester is required for the estimation of general combining ability.

Federer and Sprague (1947) and Nakamura (1956) suggested general combining ability as an index of effective genes, whereas, specific combining ability was found to be index of common genes and interaction between alleles.

Kovacik and Skaloud (1972) studied combining ability in F_1 hybrids of sunflower obtained from diallel crosses of four lines. The greatest differences in gca were found for plant height and yield of seeds per head. The high sca effects for seed yield per head and oil content were shown by combinations of lines derived from Ruzyne 9 and Slovenska siva (Slovakian Ash-grey). The ratio of the variability components of general and specific combining ability was 1:9.64 for seed weight per head, indicating that suitable hybrids rather than parental lines should be selected for this character.

Anaschenko and Rozhkova (1974) studied combining ability for seed yield in 39 forms of sunflower and observed that best gca was shown by K 2140 from Australia. Polycross, diallel cross and top cross method were used to study the gca of 30 Soviet varieties and good gca was shown by Voronezh 151, Chakinskii 269, Chernyanka 66 and Enisel, while medium gca was shown by Peredovik, Armavir 3497, VNIIMK 6540 and VNIIMK 1646 (Klimov, 1974).

Alba and Porceddu (1974) observed good gca effects for height, stem diameter, yield per plant, head diameter and flowering date in male sterile lines BA 001 (Enisel), BA 004 (Kenia), BA 005 (Peredovik) and BA 007S (VNIIMK 8931) and normal lines BA 020 (Chernyanka), BA 027 (Mayak), BA 034A (Ireg early striped), BA 079 (Kenia) and BA 007F (VNIIMK 8931).

In an analysis of line x tester, involving 10 inbred lines and 2 open pollinated sunflower varieties, it was observed that the nature of gene action for flowering, head diameter, seed filling, husk content and seed yield was predominantly non-additive but was additive for maturity and plant height. Among females CM 365 and CM 379 were good combiners for yield and yield components and CM 323 was good combiner for plant height and maturity (Shetty and Singh, 1977).

Rozhkova (1978) determined gca effects of 64 varieties and various inbred lines by means of top crosses using 4 testers. A line from the variety Sputnik showed high gca, as did 18 other forms, including Peredovik uluchshennyi (Improved vanguard) and a line from variety G 22. Some reciprocal differences in gca were found; when used as female; eg. the line ZhS 17 gave more heterotic progeny than when used as male.

Rozhkova (1979) while studying the gca for yield in 43 varieties observed that the use of two testers was sufficient to give a reliable evaluation of gca in 80% of the varieities, while three testers were needed to give a reliable evaluation for 95% of the varieties. The best individual tester was ZhS 17.

Burlov and Buntovskii (1979) identified 2 inbred lines namely Od 2586 and K 395 which had high gca effects for most characters. These were the most promising for further breeding work. The gca of short stemmed inbreds were determined by top crosses with tall Mayak and Zenit and the short Donskoinizkoroslyi

47 and the Chernyanka 66. High gca for seed yield was shown by inbreds 3/95, 3/102, 4/13 and 3/11 and also by Chernyanka 66. Intervarietal hybrids between the short and the tall testers also proved promising. Of these, Doskoinizkoroslyi x Chernyanka 66 was best for seed yield. In respect of oil yield the best hybrids were 4/8 x Mayak, 4/13 x Chernyanka 66 and 3/45 x Chernyanka 66 (Alekseev et al., 1979).

Sindagi et al. (1979) carried out line x tester analysis to study combining ability of the material comprising of 11 selfed lines and three open pollinated varieties. Among the lines, S_2RR 234 and $S_3$69874-91 had good gca for yield and yield components, and $S_2$161 had the best gca for oil content, husk percentage and test weight. The best sca for the number of achenes, yield, capitulum diameter, oil content and test weight was observed in $S_2$415-1/64 x Morden, $S_2$69874-91 x Ramson Record and $S_2$415-2/151 x EC 68415.

The gca in I_6-I_9 lines was evaluated indicating that a single assessment, using the top cross method is sufficient to determine gca for 1000-seed weight, husk percentage and oil content (Buntovskii, 1979).

Furedi and Frank (1981) in 10 x 10 diallel experiment reported that lines 195, 196 and 273 were significantly superior in gca for seed yield/10 plants. GCA effects were higher than sca or reciprocal effects. Lines 195, 196 and 137 were significantly superior in GCA for oil percentage of the seed. Four lines were superior as seed parents and five as pollen parents.

Tuberosa et al. (1982) reported that gca effects in the seed parents were significant for all characters except oil and seed yield, whereas gca effects in pollen parents were significant for all characters studied. SCA effects were significant for all the characters except oil content and plant height. SCA effects for seed yield and oil yield were greater than gca effects.

Shankara (1983) evaluated sunflower inbreds for their combining ability by line x tester analysis. Data on yield and yield related traits were analysed from crosses involving 22 foreign inbreds and the testers Morden, EC 68415 and Genepool. Inbreds 275, 276, 284, 289, 263A and 256 showed good gca for most important yield related traits.

Dua and Yadava (1983) observed highly significant general and specific combining ability variances for yield and yield components over 7 environments.

Alba et al. (1985) reported good gca for seed yield and oil content in a restorer line MGBHR3 and CMS lines MGBHS04 and and MGBHS06. The crosses MGBHS04 x MGBHRI and MGBHS06 x MGBHR3 were promising for seed yield and the former also for the early flowering.

The highest gca effects were found in lines 3 and 7 for capitulum diameter. The crosses 7 x Armavirskii 14, 8 x Armavirets, 9 x Armavirets, 1 x Armavirskii 3497, 10 x Sputnik, 9 x Armavirskii 14, 1 x Armavirskii 15, 5 x Armavirskii 15, and

10 x VNIIMK1646 showed high sca effects for capitulum diameter (Cherzhentseva, 1985).

In combining ability studies Pathak et al. (1985) observed PIL 2965 as one of the best general combiner for yield and yield components. Seven cross combinations were identified showing positive sca efffects for yield and seeds/plant.

Combining ability studies were carried out by Sheriff et al. (1985) for plant height, capitulum diameter, seeds/capitulum and seed yield/capitulum in 20 hybrids obtained by crossing 5 lines and 4 testers. For seed yield, one line and 2 testers were identified as the best combiners and 3 hybrids showed significant sca effects.

Kadkol et al. (1986) through line x tester analysis reported that the inbreds EC 68415, EC 68414 and EC 68413 were best general combiners while the cross EC 68415 x ES 353 showed the highest sca effects for oil yield.

Cruz (1986) studied combining ability for yield and yield components in sunflower. Among testers, CLSUN1 was the best general combiner for plant height and Siponto was the best line. The best combinations were VNIIMK x DK Gold and Romsun HS52 x Contiflor, which were recommended for breeding for head diameter.

Naik et al. (1987) studied combining ability of 3 male sterile lines and 12 open pollinated varieties. Among females, MS40A was a good combiner for all the characters except oil content, while MS43A proved to be the best combiner for oil content. Among males, EC 42461 and EC 50277 were good combiners for yield and its components. The best specific combinations were MS40A x EC 100163 for yield/plant and 100-seed weight and MS22A x EC 93403 for oil ccontent.

Vanisree et al. (1988) studied combining ability for yield components in 10 genotypes and their F_1 hybrids. EC 68415, EC 68414 and Inbred 303 had high gca effects for most characters, whereas Karlic 11-8 x Inbred 303, EC 68415 x Irrago Export and Borowski x EC 110673 had significant positive sca effects for seed yield/plant.

Giriraj et al. (1988) reported that the CMS line F48 was a good general combiner for seed yield, 100-seed weight and oil content. Among the males PR-1 and RHA274 were good general combiners for oil content and seed yield, respectively. The cross F50 x PR-1 was the best specific combination for seed yield/plant and oil content.

Cherzhentseva (1990), while studying the combining ability for seed yield in 10 inbred lines, reported high gca effects for lines 194, 235, 237 and 255.

Rudranaik et al. (1990) evaluated 24 hybrids and the 10 parents for combining ability of yield and its attributes. GCA effects showed CMS 234 to be the most desirable female parent and PR-1 and RHA801 as most desirable among testers. SCA effects revealed

CMS308 x RHA801 and CMS234x PR-1 as the best crosses for seed yield, number of leaves, leaf area index and 100-seed weight.

Petkov (1992) studied the effect of the tester on evaluations of gca in inbred lines of sunflower and reported that in assessing the GCA of new lines, it was most promising to use oil yield/unit area as the criterion and to use a single male-sterile hybrid as the tester.

Baldini *et al*. (1992) evaluated new high oleic inbred lines and their hybrids for quantitative and qualitative yield. The best combining ability for seed yield and oil content was found in new line R66 and this, combined with HA3 female line produced the hybrid with the highest oleic acid content of 86%.

Ali *et al*. (1992) studied combining ability of yield components in a 4 x 4 diallel cross. The cross combinations of Suncom 110, KNI and Romania with Suncom 90 showed the best SCA for oil percentage, protein percentage and seed yield/plant, respectively.

Morales and Mendoza (1993) studied combining ability for seed yield and oil content from 60 hybrids derived with 5 CMS lines and 12 restorer lines. Among pollen parent lines 833R and S30R showed good gca for both traits. The maternal lines 285 and 486 showed good GCA for both traits.

Heterosis

Putt (1966) reported considerable heterosis for seed yield and plant height. Neagu (1970) studied the performance of F_1 hybrids between mutant sunflower lines. Hybrids (35) emanating from chemically and physically induced 20 mutant lines, originally from VNIIMK 8931 x Chernyanka x (T18 x Šmena), were compared with the parents. The hybrids had a faster growth rate. Of these, 28 hybrids exhibited higher yield ranging between 118 and 245% of the control values. Plant height showed the greatest heterosis. In 23 cases, the parent with the flower head of the greater diameter had the greater effect on the hybrid.

Burlov (1972) studied the possibility of using genetically controlled heterosis in sunflower breeding. Genes for male fertility and for red pigmentation were inherited independently, each being controlled by a single dominant gene. On crossing the green male sterile plants with the red cultivar Fuksinka 64, the two genes proved to be closely linked and this provides the possibility of employing the pigmentation gene as a marker in breeding sunflower hybrids with heterosis.

Volf and Dumacheva (1972) studied heterosis in interline and variety-line hybrids. Heterosis for seed yield is more strongly expressed than heterosis for oil content.

Pogorletskii (1972) studied the productiveness of sunflower hybrids. The highest yield of seeds was given by a variety-line hybrid obtained using the line MS2976/65-4; it exceeded Armavir 3497 in oil content. In the best single hybrid, obtained by crossing the lines L2658 and L2586, the oil content was 46.12% as against 44.2 in Armavir 3497.

Stoyanova et al. (1975) studied heterosis in 2500 interline hybrids and observed that 90% of the hybrids had marked heterosis, but only 3% exceeded the standard Peredovik, in oil yield/ha.

Voskoboinik and Soldatov (1975) studied heterosis and reported that hybrids MS257, MS353 and M127, exceeded the standard, VNIIMK 8931, by 18-30% in seed yield and the hybrid MML41, obtained by crossing mutant lines, exceeded VNIIMK 8931 in oil yield by 13%.

Gorbachenko (1977) studied heterosis in 520 F_1 interline, variety-line and intervarietal hybrids produced by diallel crosses between short and tall varieties. The highest yielding hybrids were obtained by crossing short lines, families and varieties with the variety Chernyanka 66. The best hybrid, 3/102, yielded upto 30.7 q/ha. The best F_1 hybrids, which had Donskoi nizkoroslyi 47 as the short parent, gave a 15-24% higher seed yield than the better parent.

Using lines derived from Bulgaria, USSR, USA, France, Romania and Argentina, 320 interline hybrids were bred, some of them outyielding the standard variety Peredovik by 10.7-33.8%. The single interline hybrid 5 (485 x 1485) out yielded the standard by 14-15% over three years of varietal trials (Voskoboinik, 1977).

Voskoboinik (1978) studied heterosis and observed that the interline hybrid ML3(NA234 x VK66), based on cytoplasmic male sterility ripened in 97 days, three days before Peredovik yielding 33.3 q/ha of seed, 16.7 q/ha of oil, respectively which was 4.4 q/ha and 2.6 q/ha more than Peredovik.

Singh et al. (1978) determined 4 yield components in ten intervarietal hybrids. The variety EC 93611-1 produced good hybrids if used as the male parent. P21ms x EC 93611-1, EC 27638 x EC 93611-1 and EC 27631 x EC 93611-1 were superior to the control variety for seed yield, number of filled seeds and 100-seed weight. The first two of these were superior in seed yield to the better parent.

Heterosis for 13 quantitative characters, including yield components, was measured in hybrids from 27 crosses involving 9 inbreds and 3 testers. Heterosis relative to the mid parental value ranged upto 41% for yield and 31% for oil content (Sudhakar, 1979).

Ge (1981) studied the utilization of hybrid vigour in sunflower. In the F_1 of 172 combinations with a common cytoplasmically male-sterile parent, there was an average increase of 75.9% in yield, 47% in seeds/head, 15.9% in head diameter and 22.4% in stem diameter.

Burlov et al. (1982) studied the possibilities of combining short growth period with high yield in sunflower. A study of hybrids from a complete 6 x 6 diallel indicated that the fertility-restoring line 40 was the most promising for use in breeding for earliness combined with heterosis for yield, leaf number and flower number.

Gupta and Khanna (1982) studied heterosis for oil yield and component characters in sunflower and observed additive, dominance and epistatic gene action in crosses involving two selections from Peredovik and a dwarf selection from Smena. Reciprocal recurrent selection is recommended as the most suitable method of improvement for Indian conditions.

Heterosis for seed yield, oil content and eight traits related to yield from 21 crosses involving seven inbreds was studied by Pathak et al. (1983).

Chaudhary and Anand (1984) studied heterosis in 100 F_1 hybrids from 77 crosses involving 20 inbred lines and 5 pollen parents in a line x tester design. The values of heterosis over the better parent were 66.23% for 1000-sed weight, 69.89% for seed yield, 64.65% for head diameter, 23.17% for oil content, 18.47% for number of leaves and -7.69% for days to flowering. By crossing selected lines having high combining ability with the best lines from the world collection of the Vavilov Institute of Plant Industry (VIR), high yielding hybrids were obtained with 10-24% higher oil yield than VNIIMK1646 (Buchuchanu et al., 1984).

Heterosis for yield and 8 related traits was studied in 66 crosses and heterosis in the F_1 was correlated with the performance of the better parent for days to maturity, head diameter and shelling percentage. The range of heterosis was 47-206% for yield and 5-55% for other traits (Singh et al., 1984).

Heterobeltiosis was observed for seed yield in 46 hybrids and for oil parentage in 41 hybrids, out of 49 hybrids derived by crossing 7 CMS lines with 7 restorer lines. In 8 hybrids, heterosis for seed yield exceeded 100% while in 10 hybrids, heterosis for oil content exceeded 10%, in each case over the respective better parents (Reddy et al., 1985).

Sheriff et al. (1985, 1986) reported that out of 20 cross combinations involving 5 female and 4 male parents, seven crosses exceeded their respective better parents in seed yield/capitulum. The best cross, EC 85820 x BSH1, did so by 147%. The following crosses viz., Morden x Col, EC 75270 x Col, EC 4428 x Morden and SUF 3 x Morden were heterotic for seed yield.

Cruz (1986) studied heterosis for yield and yield components in 24 F_1 hybrids derived from eight S_2 lines and three open-pollinated testers CLSUN1, VNIIMK and Romsun HS52. Average heterosis for yield/plant was highest in crosses involving Sigco 37, Contiflor and Cross 5. Most of the heterotic effects for head diameter were positive, while significant heterosis for 1000-seed weight was exhibited only by Romsun HS52 x Contiflor. The greatest negative heterotic effect for plant height was observed in Hysun 31 x CLSUN1.

Heterosis for yield and 5 components was studied in a diallel cross involving 6 genotypes. Heterosis for yield/plant, seed oil content and 100-seed weight showed a close positive correlation with the GCA of the parents. Heterosis for various characters showed a negative correlation with heritability. Hence heterosis could be predicted from the heritability value of the trait concerned (Sun, 1986).

Giriraj et al. (1986) studied heterosis in 10 hybrids derived from crosses between 5 CMS lines and 2 restorers. Average heterosis ranged from -7.7% for days to flowering to 192.4% for seed yield/plant. The percentage contributions of number of filled seeds, leaf area, head diameter and 100-seed weight towards heterosis for seed yield were 37.7, 20.7, 15.2 and 9.7%, respectively.

Gorbachenko (1986) studied the nature of the expression of heterosis for yield components in short sunflower hybrids derived from topcrosses between the variety Mayak and short lines. Of these, 271 hybrids (88.6%) showed heterosis for seed yield relative to the short standard vaiety Chernyanka 66 and 149 hybrids exceeded the standard by > 10%. Better results in terms of yield were obtained by crossing the short lines with the standard variety. The high degree of heterosis was mainly due to an increase in seed number/capitulum.

Naik et al. (1988) studied seed yield and 11 yield components in 36 F_1 hybrids derived from 3 cms lines and 12 restorers. The highest heterosis (52.34%) was recorded for 100-seed weight in the cross MS40A x EC 75194, followed by yield/plant (34.57%) in MS22A x Morden. Heterosis for yield/plant was mainly attributable to heterosis for percentage filled seeds/head and head diameter.

Gumenyuk et al. (1989) used interspecific hybridization for heterosis breeding. A high degree of heterosis was obtained by crossing male-sterile testers with populations produced by distant hybridization. Inbred lines and hybrids bred with these populations are recommended for use in breeding.

Wang et al. (1990) reported negative heterosis for husk percentage while studying 11 parents and their 30 hybrids. Heterosis for husk percentage was highly correlated with the sca of the female parents and negatively correlated with their phenotypic values.

Deido (1993) studied heterosis for seed oil content in two sets of hybrids derived from female parents that were cms lines and male parents with or without restorer genes. A heterotic effect of 47 g/kg over the mid parental value was observed for seed oil content. For the seed oil components, heterotic effects of 44 and 24 g/kg were obtained for kernel oil content and kernel content, respectively.

CHAPTER-III

MATERIAL AND METHODS

The present investigation was carried out at the Research Farm of Department of Plant Breeding, CCS Haryana Agricultural University, Hisar, during the year 1993-94.

The experimental material consisted of 30 genotypes involving 18 F_1 hybrids, 9 parents and 3 checks. The 18 F_1 hybrids were developed by crossing 6 elite inbred lines IB 2, IB 4, IB 14, IB 28, IB 28-1 and IB 43 with 3 testers EC 68415B, EC 68415C and Morden in Line x Tester fashion. Nine parents alongwith their 18 F_1's and 3 checks (Table 1) were grown in randomised block design with 3 replications. Each genotype was accomodated in two rows plot of 4.2 m length with plant to plant and row to row distances being 30 cm and 60 cm, respectively. All the recommended package of practices were followed to raise the crop.

Recording of observations

Data were recorded on 5 randomly selected plants in each genotype per replication for the following characters.

1. Plant height (cm)

Table 1: Showing the details of parents, hybrids and checks

Parents	Hybrids	Checks
Lines	IB 2 x EC 68415B	APSH 11
IB 2	IB 2 x EC 68415C	U 5002
IB 4	IB 2 x Morden	MSFH 8
IB 14	IB 4 x EC 68415B	
IB 28	IB 4 x EC 68415C	
IB 28-1	IB 4 x Morden	
IB 43	IB 14 x EC 68415B	
	IB 14 x EC 68415C	
Testers	IB 14 x Morden	
EC 68415B	IB 28 x EC 68415B	
EC 68415C	IB 28 x EC 68415C	
Morden	IB 28 x Morden	
	IB 28-1 x EC 68415B	
	IB 28-1 x EC 68415C	
	IB 28-1 x Morden	
	IB 43 x EC 68415B	
	IB 43 x EC 68415C	
	IB 43 x Morden	

2. Days to 50 per cent flowering
3. Days to full blooming
4. Days to maturity
5. Stem girth (cm)
6. Head diameter (cm)
7. Seed yield per plant (g)
8. 100-seed weight (g)
9. Oil content (%)
10. Oil yield per plant (ml)

Description of characters

1. Plant height

The plant height was measured in centimeters from the base of the stem to the head at the time of maturity.

2. Days to 50 per cent flowering

The number of days were counted from the date of sowing to the day when 50 per cent of the plants in each genotype in each replication came to blooming.

3. Days to full blooming

The number of days were counted from the date of sowing to the day when all the plants in each genotype in each replication came to blooming.

4. Days to maturity

The number of days were calculated from the date of sowing to the day of maturity of the head i.e. when the head turned yellow and the involucral bracts began to turn brown.

5. Stem girth

The girth of the stem was measured in centimeters with the help of varnier's calliper at about one foot from the ground level.

6. Head diameter

The diameter of the head was measured in centimeters with the help of meter tape.

7. Seed yield per plant

The average yield of seeds per plant was recorded in grams after weighing the sun dried seeds of each plant.

8. 100-seed weight

100-seeds were taken from individual plant and the weight was recorded in grams.

9. Oil content

The per cent oil content of the oven dried seeds was determined by Nuclear Magnetic Resonance (NMR).

10. Oil yield per plant

The oil yield per plant was calculated as function of seed yield per plant x oil content (%) and expressed in millilitres.

Statistical methods

The mean values of each plot were used for statistical analysis. The following statistical methods were applied for the analysis of data.

1. Analysis of variance

The data for different characters were statistically analysed on the basis of following model (Panse and Sukhatme, 1967).

$$Y_{ij} = m + a_i + b_j + e_{ij}$$

Where,

Y_{ij} = any observation in i^{th} treatment and j^{th} block,

m = general mean,

a_i = i^{th} treatment (genotype) effect,

b_j = j^{th} block effect and

e_{ij} = random error associated with i^{th} treatment and j^{th} block assumed to be NID (0.02).

Table 2: Analysis of variance

Source	d.f.	Sum of squares	Mean sum of square	Expected mean sum of square	F value
Replications	(r-1)	RSS	M_r	$\sigma_e^2 + \frac{t \sum b_j^2}{r-1}$	
Treatments	(t-1)	TSS	M_t	$\sigma_e^2 + \frac{r \sum g_i^2}{t-1}$	$\frac{M_t}{M_e}$
Error	(r-1)(t-1)	ESS	M_e	σ_e^2	

Where,

t = number of treatments,

r = number of replications or blocks,

σ_e^2 = error mean squares, and

σ_t^2 = treatment mean squares

The mean squares of treatments (genotypes) were tested against corresponding error mean squares and the calculated F was compared with table value of F at 5 per cent level of significance.

2. **Statistical parameters**

i) **Mean**

The mean value of each character was worked out by dividing total sum of all the values by number of corresponding observations.

$$\bar{X} = \frac{\Sigma X_i}{n}$$

ii) **Range**

Range was calculated by taking the lowest and the highest value for each character.

iii) **Standard error**

S.E. of difference between two means were calculated with the help of error mean square from ANOVA table.

$$S.E.(d) = \sqrt{\frac{2EMS}{r}}$$

Where,

S.E.(d) = Standard error of difference between two means.

EMS = Error mean square

r = Number of replications

iv) Critical difference

Critical difference (C.D.) of all characters was calculated to compare the variation among genotypes. It was computed with the help of S.E. (d) and tabulated value of t at 5% level of significance and error degree of freedom,

$$C.D. = \sqrt{\frac{2EMS}{r}} \times t$$

In all cases C.D. is calculated at 5% level of significance.

3. Genetic parameters

i) Coefficient of variation

Genotypic and phenotypic coefficient of variations were calculated by the formula suggested by Burton and De Vane (1953).

$$\text{Genotypic coefficient of variation (GCV)} = \frac{\sigma g}{\bar{X}} \times 100$$

$$\text{Phenotypic coefficient of variation (PCV)} = \frac{\sigma p}{\bar{X}} \times 100$$

ii) Heritability (in broad sense)

The heritability in broad sense was calculated using the formula suggested by Hanson et al. (1956).

$$H (\%) = \frac{\sigma^2_g}{\sigma^2_p} \times 100$$

Where,

H = Heritability in broad sense

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

iii) Genetic advance

Genetic advance was computed by the following formula proposed by Lush (1949) and Johnson et al. (1955).

$$GA = \frac{\sigma^2_g}{\sqrt{\sigma^2_p}} \times K$$

Where,

GA = Genetic advance

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

K = Selection differential.

At 5% selection pressure the value of K is 2.06 (Lush, 1949 and Allard, 1960).

iv) Expected genetic gain

Genetic gain represents, genetic advance expressed as per cent of mean. It was calculated by the method suggested by Johnson et al. (1955).

$$\text{Expected genetic gain} = \frac{GA}{\bar{X}} \times 100$$

Where,

GA = Genetic advance

$\bar{X}$ = Mean of the character under study.

v) Correlation

Correlation coefficients among various estimates were computed using variances and covariances formula as :

$$r_{1,2} = \frac{\text{Cov. } 1.2}{\sqrt{\text{Var.1. Var.2}}}$$

The significance of correlation coefficients was tested at 5 per cent level of significance at n-2 degree of freedom, comparing them with table value (Fisher and Yates, 1949).

4. Analysis of covariance

Analysis of covariance was carried out using the following model (Ostel, 1956);

$$Y_{ijk} = u + T_i + B_j + b\ (X_{ij} - \bar{X}) + e_{ijk}$$

Where,

Y_{ijk} = effect of k^{th} observation of i^{th} treatment in j^{th} block,

u = general mean,

T_i = effect of i^{th} treatment adjusted for X,

B_j = effect of j^{th} block adjusted for X,

b = regression coefficient of Y on X, linear and additive with treatments,

X_{ij} = observation on X in i^{th} treatment from j^{th} block, and

e_{ijk} = environmental effect associated with e_{ijk}^{th} observation.

5. **Genetic divergence (Multivariate analysis of Mahalanobis, 1936)**

The variance-covariance data were subjected to multivariate analysis. The original inter-related variables (X's) were transformed into a set of mutually uncorrelated variables (Y's as linear function of X's). Pivotal condensation method was used to compute inverse matrix of the error dispersion matrix (Rao, 1952). The generalized distance function (D^2) between two genotypes is given by the simple sum of squares of differences in Y's as shown by:

$$D^2_{1.2} = \sum_{i=1} (Y_{1i} - Y_{2i})^2$$

The D^2 value between the variables on the basis of p characters is

$$D^2_p = \sum_{i=1}^{p} \sum_{r=1}^{p} (\lambda_{ij})\ d_i\ d_j$$

Where,

D^2_p = D^2 value between the variables on the basis of p characters,

λ_{ij} = inverse matrix of (X_{ij}), the pooled common dispersion obtained from error matrix, and

d = difference in mean values for the characters of respective genotypes as indicated by i and j.

The calculation of D^2 involved the following steps as described by Rao (1952) :

1. Pivotal condensation of error variance and covariance matrix to obtain inverse matrix.

2. Transformation of the original measurements to uncorrelated variables.

3. Calculation of the mean values of the transformed characters.

4. Calculation of D^2 values.

For each combination deviation between the means was computed and D^2 were computed and arranged in the form a matrix. The D^2 values presented in the matrix form were arranged in increasing order of magnitude. Genetic distance among parents entering crosses was computed as the square root of D^2 value i.e. genetic divergence.

$$\text{Genetic distance} = \sqrt{D^2}$$

6. Combining ability analysis

The combining ability analysis was carried out as per method suggested by Kempthorne (1957).

The analysis of combining ability was based on the model :

$$X_{ijk} = m + g_i + g_j + s_{ij} + b_k + e_{ijk}$$

Where,

X_{ijk} = phenotypic value of the ijk^{th} genotype in the k^{th} replication,

m	=	general mean,
g_i	=	general combining ability of i^{th} male parent,
g_j	=	general combining ability of j^{th} female parent,
s_{ij}	=	specific combining ability of cross between i^{th} male and j^{th} female,
b_k	=	k^{th} block (replication) effect, and
e_{ijk}	=	random error associated with ij^{th} genotype and k^{th} replication.

Each character was analysed for combining ability in the form given below :

Table 3: Analysis of variance for combining ability

Source	d.f.	Mean sum of squares	Expected mean sum of squares	F
Replications	(r-1)			
Hybrids	(mf-1)			
Lines	(f-1)	M_1	$\sigma^2_e + \frac{rm}{(f-1)} \sum_i fi^2$	$\frac{M_1}{M_3}$
Testers	(m-1)	M_2	$\sigma^2_e + \frac{rf}{(m-1)} \sum_j mj^2$	$\frac{M_2}{M_3}$
Lines x Testers	(m-1)(f-1)	M_3	$\sigma^2_e + \frac{r}{(f-1)(m-1)} \sum_i \sum_j fm(ij^2)$	$\frac{M_3}{M_4}$
Error	(r-1)(mf-1)	M_4	σ^2_e	

Where,

r = number of replications,

m = number of males,

f = number of females, and

σ^2_e = error variance

Mean sum of squares due to line x tester were tested against error variance, whereas the mean sum of squares due to lines as well as due to testers were tested against line x tester component. The calculated value of F was compared with F tabulated at P=0.05 for corresponding degrees of freedom.

Combining ability effects

The individual general and specific combining ability effects of parents and hybrids, respectively were calculated as follows:

$$\text{Population mean } (u) = \frac{X_{...}}{mfr}$$

Where,

$X_{...}$ = total of all observations

$$\text{GCA effects of males } (g_i) = \frac{X_{i..}}{fr} - \frac{X_{...}}{mfr}$$

Where,

$X_{i..}$ = total of i^{th} male parent over all female parents and replications.

$$\text{GCA effects of females } (g_j) = \frac{X_{.j.}}{mr} - \frac{X_{...}}{mfr}$$

Where,

$X_{.j.}$ = total of j^{th} female parent over all male parents and replications

$$\text{SCA effect of } ij^{th} \text{ cross } (s_{ij}) = \frac{X_{ij}}{r} - \frac{X_{i..}}{fr} - \frac{X_{.j.}}{mr} - \frac{X_{...}}{mfr}$$

Where,

X_{ij} = total over all replications for ij^{th} combination

For testing the general combining ability effects of individual lines and testers and specific combining effects of the crosses, their standard errors (S.E.) were calculated as follows:

S.E. (gca for females) = $\sqrt{M_4/rm}$

S.E. (gca for males) = $\sqrt{M_4/rf}$

S.E. (gca effects) = $\sqrt{M_4/r}$

S.E. $(g_{i1} - g_{i2})$ = $\sqrt{2M_4/rf}$

S.E. $(g_{j1} - g_{j2})$ = $\sqrt{2M_4/rm}$

S.E. $(s_{ij} - s_{kl})$ = $\sqrt{2M_4/r}$

The relevant critical differences (C.D.) were calculated by multiplying respective standard errors (S.E.) of differences with respective 't' value for appropriate degree of freedom at P=0.05.

7. **Estimation of heterosis**

Heterosis is the increase or decrease in F_1 performance from their respective mid-parent value ($MP = \frac{\bar{P}_1 + \bar{P}_2}{2}$) and expressed in per cent as :

$$\text{Per cent heterosis over mid parent (MP)} = \frac{\bar{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

In the same way heterobeltiosis/standard heterosis values were calculated as the increase or decrease of F_1 over respective better parent and best check under study as :

$$\text{Per cent heterosis over better parent (BP)} = \frac{\bar{F}_1 - \overline{BP}}{\overline{BP}} \times 100 \quad \text{and}$$

$$\text{Per cent heterosis over best check (BC)} = \frac{\bar{F}_1 - \overline{BC}}{\overline{BC}} \times 100$$

To test the significance of extent of heterosis, standard error (S.E.) and then critical difference (C.D.) were calculated as under:

C.D. = S.E. (d) x t value

Where,

S.E.(d) = standard error of difference of mean $= \sqrt{2M_e/r}$, for heterosis over BP and BC.

S.E.(d) = $\sqrt{3M_e/2r}$, for heterosis over MP

t = tabulated value of 't' at error degree of freedom at 5 per cent level of significance

The level of significance was given to the corresponding values of heterosis, by comparing C.D. values with ($\bar{F}_1 - \overline{MP}$), ($\bar{F}_1 - \overline{BP}$) and ($\bar{F}_1 - \overline{BC}$).

EXPERIMENTAL RESULTS

The results obtained from present investigations have been presented under the following sub-heads :

A. Analysis of variance for experimental layout

B. Mean performance and range for different characters

C. Components of variation

D. Genetic divergence/distance

E. Analysis of variance for combining ability

F. Estimation of gca and sca effects

G. Extent of heterosis in hybrids

A. Analysis of variance for experimental layout

Mean sum of squares due to replication, genotypes and error for different characters have been presented in Table 4. The mean square values due to genotypes were found to be significant for all the characters, except for stem girth. This indicated that the genotypic differences existed in respect of different progenies including parents and F_1 hybrids for all the characters except for stem girth. No further genetic analysis with respect to stem girth was carried out as mean square value due to genotypes for this trait was non-significant.

Table 4: Analysis of variance for various characters in sunflower

Source	d.f.	Mean square value									
		Plant height (cm)	50% flowering (days)	Full blooming (days)	Maturity (days)	Head diameter (cm)	Stem girth (cm)	Seed yield/ plant (g)	100-seed weight (g)	Oil content (%)	Oil yield/ plant (ml)
Replications	2	169.46	2.47*	0.31	2.41	5.50	0.06	134.27	0.36	4.41	12.76
Genotypes	29	1048.14*	9.69*	11.02*	8.04*	7.46*	0.06	1339.04*	2.50*	63.91*	252.97*
Error	58	109.19	0.36	0.74	0.98	3.04	0.04	70.81	0.22	2.61	9.23

* Significant at 5 per cent

B. **Mean performance and range**

Mean values of parents and F_1 hybrids in respect of various plant characters were studied and presented in Table 5. The comparative performance of nine parents, 18 F_1 hybrids and three standard checks for various characters has been discussed characterwise as under:

1. **Plant height**

The hybrid IB 4 x Morden (113.05 cm) attained the minimum plant height, while the parent IB 28-1 (195.53 cm) was observed to be tallest. The standard checks APSH 11, U 5002 and MSFH 8 attained the plant height of 166.38 cm, 166.35 cm and 173.87 cm, respectively. The hybrid IB 4 x Morden was found to be significantly superior over its better parent and best check U 5002 for dwarfness.

2. **Days to 50 per cent flowering**

The maximum number of days for 50 per cent flowering were taken by hybrid IB 28 x Morden (72.67 days) and the minimum by the hybrid IB 28-1 x EC 68415C (66.67 days) compared to checks APSH 11 (71.67 days), U 5002 (71.67 days) and MSFH 8 (72.67 days). The hybrids IB 4 x Morden, IB 14 x Morden and IB 43 x Morden were found to be significantly superior over their respective better parent for earliness to 50 per cent flowering.

3. **Days to full blooming**

The maximum number of days for full blooming were taken by the hybrid IB 28 x Morden (77.67 days), while the minimum

Table 5: Mean values, range, S.E.(d) and C.D. for various characters in sunflower

Genotypes	Plant height (cm)	50% flowering (days)	Full blooming (days)	Maturity (days)	Head diameter (cm)	Seed yield/ plant (g)	100-seed weight (g)	Oil content (%)	Oil yield/ plant (ml)
Hybrids									
IB 2 x EC 68415B	131.69	67.33	72.33	94.33	14.83	63.00	4.96	25.20	15.87
IB 2 x EC 68415C	134.38	67.00	72.00	96.00	17.43	59.13	5.63	23.73	14.04
IB 2 x Morden	142.10	70.67	76.67	93.00	15.87	59.13	5.64*	31.70	18.80
IB 4 x EC 68415B	135.24	67.33	72.33	92.00	15.87	120.00*	5.74	34.40	41.23
IB 4 x EC 68415C	146.04	67.33	72.33	90.67	18.60	100.67	4.36	21.97	22.16
IB 4 x Morden	113.05*	67.00*	72.00*	91.00	13.39	123.00*	6.55*	33.83	41.68*
IB 14 x EC 68415B	154.43	71.33	76.33	92.33	18.05	100.33	6.08	38.63	38.76
IB 14 x EC 68415C	157.53	71.33	77.33	92.33	18.58	96.33	5.63	37.97*	36.57
IB 14 x Morden	160.33	68.33*	73.33*	93.33	17.37	120.67*	3.09	30.10	36.23*
IB 28 x EC 68415B	145.10	70.33	73.67	94.00	16.83	70.53	5.71	32.53	23.01
IB 28 x EC 68415C	149.67	70.33	76.33	94.33	15.97	109.00	5.47	32.60	36.29
IB 28 x Morden	194.90	72.67	77.67	93.33	18.07	120.00*	6.21	29.53	34.31
IB 28-1 x EC 68415B	150.80	67.33	72.67	93.67	15.13	104.87	4.41	31.00	32.59
IB 28-1 x EC 68415C	166.42	66.67	71.67	91.67	16.73	87.40	5.05	28.00	24.46
IB 28-1 x Morden	166.87	68.67	73.67	92.67	15.85	108.40*	4.80	30.67	33.32
IB 43 x EC 68415B	161.13	68.67	74.67	92.67	17.17	76.33	5.08	29.57	22.56
IB 43 x EC 68415C	179.30	68.00	74.00	93.00	17.33	111.87	6.40	33.67	37.65
IB 43 x Morden	160.42	68.67*	73.67	93.33	20.73	122.00*	5.71	33.03	40.38*
Parents									
IB 2	144.24	71.00	76.00	93.67	15.43	76.47	3.24	28.53	21.81
IB 4	145.17	71.00	76.00	92.00	16.25	81.00	5.28	24.50	19.85
IB 14	134.90	70.67	76.67	92.33	14.40	74.67	6.76	35.00	24.33
IB 28	128.53	68.00	73.00	94.00	15.71	75.73	6.19	36.10	25.71
IB 28-1	195.53	68.00	73.00	93.33	18.22	73.33	6.01	31.73	23.28
IB 43	147.28	71.33	76.33	92.33	17.52	97.00	6.06	34.53	33.74
EC 68415B	163.43	67.67	72.67	90.00	18.75	97.47	5.68	36.73	35.48
EC 68415C	173.25	67.00	73.00	88.00*	16.42	102.67	4.95	32.50	33.33
Morden	160.37	70.00	75.00	92.00	18.47	91.50	4.15	33.10	30.87
Standard checks									
APSH 11	166.38	66.67	71.67	90.00	17.05	114.20	4.01	28.60	32.70
U 5002	166.35	66.67	71.67	94.67	17.58	116.13	6.01	40.83	47.43
MSFH 8	173.87	67.67	72.67	94.67	19.27	133.13	5.59	39.80	50.00
G.M.	154.96	68.82	74.04	92.69	16.96	96.20	5.35	32.00	30.95
Range	113.05-195.53	66.67-72.67	71.67-77.67	88.00-96.00	13.39-20.73	59.13-133.13	3.09-6.76	21.97-40.83	14.04-50.00
S.E.(d)	8.53	0.49	0.71	0.81	1.42	6.87	0.39	1.32	2.48
C.D. 5%	17.08	0.98	1.42	1.62	2.84	13.75	0.78	2.64	4.96

* Significant at 5 per cent

by the hybrid IB 28-1 x EC 68415C (71.67 days). The two checks APSH 11 and U 5002 also took minimum period (71.67 days) for full blooming. The hybrids IB 4 x Morden and IB 14 x Morden were found to be significantly superior over their respective better parent for full blooming.

4. **Days to maturity**

The hybrid IB 2 x EC 68415C took maximum days to mature (96.00 days), whereas the genotype (parent) EC 68415C, the minimum (88.00 days) period to reach maturity. Among checks, APSH 11 took minimum period of 90 days to reach maturity.

5. **Head diameter**

The largest size of head was produced by the hybrid IB 43 x Morden (20.73 cm), while the hybrid IB 4 x Morden (13.39 cm) had smallest head. Among checks MSFH 8 (19.27 cm) attained the largest head size followed by U 5002 (17.58 cm) and APSH 11 (17.05 cm).

6. **Seed yield per plant**

The highest seed yield was recorded by the check genotype MSFH 8 (133.13 g), while lowest seed yield was attained by hybrids IB 2 x EC 68415C (59.13 g) and IB 2 x Morden (59.13 g). The hybrids IB 4 x EC 68415B, IB 4 x Morden, IB 14 x Morden, IB 28 x Morden, IB 28-1 x Morden and IB 43 x Morden were found to be significantly superior to their respective better parent for seed yield per plant.

7. **100-seed weight**

The highest 100-seed weight was recorded for the genotype (parent) IB 14 (6.76 g) and the lowest for the hybrid IB 14 x Morden (3.09 g) as against 4.01 g, 6.01 g and 5.59 g of checks APSH 11, U 5002 and MSFH 8, respectively. The hybrids IB 2 x Morden and IB 4 x Morden were found to be significantly superior over their respective better parent for 100-seed weight.

8. **Oil content**

The highest oil content was recorded for check U 5002 (40.83%) and the lowest for the hybrid IB 4 x EC 68415C (21.97%). Among checks, U 5002 (40.83%) produced highest oil content followed by MSFH 8 (39.80%) and APSH 11 (28.60%). The hybrid IB 14 x EC 68415C was found to be significantly superior to its better parent for per cent oil content.

9. **Oil yield per plant**

The highest yield of oil was recorded for check MSFH 8 (50.00 ml) and the lowest for the hybrid IB 2 x EC 68415C (14.04 ml). The hybrids IB 4 x Morden, IB 14 x Morden and IB 43 x Morden were found to be significantly superior over their respective better parent for oil yield per plant.

C. **Coefficient of variation**

The estimate of components of variation for various characters have been presented in Table 6. The magnitude of phenotypic coefficient of variation was higher than the genotypic coefficient

Table 6: Coefficient of variation (Phenotypic and genotypic), heritability, genetic advance and expected genetic gain for various characters in sunflower

Characters	Genotypic coefficient of variation	Phenotypic coefficient of variation	Heritability broad sense (%)	Genetic advance (%)	Expected genetic gain (genetic advance as % of mean)
Plant height (cm)	11.42	13.26	74.14	31.38	20.25
50% flowering (days)	2.56	2.71	89.55	3.44	5.00
Full blooming (days)	2.50	2.76	82.09	3.46	4.67
Maturity (days)	1.65	1.97	70.47	2.65	2.86
Head diameter (cm)	7.16	12.53	32.64	1.43	8.42
Seed yield/plant (g)	21.37	23.09	85.65	39.20	40.75
100-seed weight (g)	16.27	18.56	76.87	1.57	29.39
Oil content (%)	14.12	15.00	88.65	8.77	27.40
Oil yield/plant (ml)	29.13	30.74	89.80	17.60	56.86

of variation for all the traits under study. The genotypic coefficient of variation ranged from 1.65 to 29.13 per cent, while the phenotypic coefficient of variation ranged from 1.97 to 30.74 per cent. The maximum phenotypic as well as genotypic coefficient of variability was observed in case of oil yield per plant (30.74 and 29.13%) followed by seed yield per plant (23.09% and 21.37%) and 100-seed weight (18.56% and 16.27%). Days to maturity recorded the least phenotypic and genotypic coefficient of variability.

The heritability estimates in broad sense ranged from 32.64 to 89.80 per cent. In general the heritability was high for all the traits except head dismeter. The highest heritability was shown by oil yield per plant (89.80%), followed by days to 50% flowering (89.55%) and oil content (88.65%), while the head diameter recorded lowest heritability (32.64%).

Maximum expected genetic gain was observed for oil yield per plant (56.86%) followed by seed yield per plant (40.75%). The lowest expected genetic gain was recorded in case of days to maturity (2.86%).

D. Genetic divergence/distance

Although, the genotypes showed genotypic variation for all the characters except for stem girth (Table 4), however, such a variation does not form the basis for measuring the extent of genetic diversity. In order to measure extent of genetic diversity and to quantify the genetic distance between two genotypes, the numerical measure of diversity was obtained with the help of D^2 statistics.

The lowest D^2 value (32.08) was obtained between parents IB 2 and Morden, while the maximum value 129.47 was obtained between parents IB 14 and EC 68415C. The parents involved in hybridization were classified as having high, medium and low genetic distance as shown in Table 7. Low genetic distance group consisted of 8 crosses namely; IB 43 x Morden, IB 2 x Morden, IB 28-1 x EC 68415B, IB 43 x EC 68415B, IB 4 x Morden, IB 28-1 x Morden, IB 28 x EC 68415B and IB 28-1 x EC 68415C, medium group of 4 crosses namely; IB 28 x Mordeen, IB 43 x EC 68415C, IB 14 x Morden, IB 28 x EC 68415C and high group of 6 crosses namely IB 14 x EC 68415B, IB 4 x EC 68415C, IB 2 x EC 68415C, IB 2 x EC 68415B, IB 4 x EC 68415B and IB 14 x EC 68415C.

E. Analysis of variance for combining ability

All the characters except stem girth, whose mean square value for genotypes was non-significant, were subjected to combining ability analysis of line x tester design as proposed by Kempthorne (1957). The ANOVA for combining ability (Table 8) revealed that mean squares due to specific combining ability (SCA) variance were significant for all the characters. The mean squares due to combining ability for lines (females) were significant for seed yield per plant, days to maturity, days to 50 per cent flowering and oil yield per plant. Variance due to testers (males) was significant in case of 100-seed weight only.

Table 7: Genetic divergence (D^2-statistic) among parents entering crosses

Crosses	Genetic divergence (D^2 value)	Genetic distance (D value)
D^2 Low		
IB 43 x Morden	28.04	5.30
IB 2 x Morden	32.08	5.66
IB 28-1 x EC 68415B	44.35	6.66
IB 43 x EC 68415B	54.55	7.38
IB 4 x Morden	54.64	7.39
IB 28-1 x Morden	55.50	7.45
IB 28 x EC 68415B	56.35	7.51
IB 28-1 x EC 68415C	59.35	7.70
D^2 Medium		
IB 28 x Morden	65.74	8.11
IB 43 x EC 68415C	78.24	8.85
IB 14 x Morden	82.24	9.07
IB 28 x EC 68415C	89.02	9.44
D^2 High		
IB 14 x EC 68415B	104.60	10.23
IB 4 x EC 68415C	108.98	10.44
IB 2 x EC 68415C	114.71	10.71
IB 2 x EC 68415B	121.50	11.02
IB 4 x EC 68415B	123.80	11.13
IB 14 x EC 68415C	129.47	11.37

Table 8: Analysis of variance for combining ability

Source	d.f	Mean square values								
		Plant height (cm)	50% flowering (days)	Full blooming (days)	Maturity (days)	Head diameter (cm)	Seed yield/ plant (g)	100-seed weight (g)	Oil content (%)	Oil yield/ plant (ml)
Replications	2	219.50	0.72	0.35	1.91	2.55	120.25	0.82	1.52	18.42
Hybrids	17	1054.11*	9.97*	11.91*	4.88*	8.42*	1542.71*	2.13*	57.39*	253.11*
Lines	5	2051.69	21.72*	19.04	11.26*	11.00	3207.22*	1.64	74.60	501.19*
Testers	2	546.06	3.72	4.80	0.69	5.72	1891.78	0.05*	25.43	173.09
Lines x Testers	10	656.93*	5.34*	9.77*	2.53*	7.66*	640.64*	2.78*	55.17*	145.08*
Error	34	81.15	0.37	0.92	1.18	2.42	62.61	0.25	2.74	9.37

* Significant at 5 per cent

F. Estimation of gca and sca effects

The characterwise estimates of general combining ability (gca) effects and specific combining ability (sca) effects presented in Table 9 & 10, respectively are discussed as follows:

1. Plant height

A perusal of the results presented in Table 9 indicated significant negative gca effects for IB 2 (-16.69) and IB 4 (-21.30) among females and EC 68415B (-6.35) among males. These parents were considered as good combiners for dwarfness.

The hybrids showing significant negative sca effects were IB 4 x Morden (-21.92) and IB 28 x EC 68415C (-16.37), whereas significant positive sca effect was shown by hybrid IB 28 x Morden (28.14).

2. Days to 50 per cent flowering

Significant negative gca effects were shown by females IB 4 (-1.61) and IB 28-1 (-1.28), which indicated their suitability as source material for earliness. On the contrary, significant positive gca effects were observed in case of IB 14 (1.50) and IB 28 (2.28). These parents were categorized as poor general combiners for this trait. Among males, none of the parent showed significant negative gca effects. However, significant positive gca effects were recorded for Morden (0.50) indicating its suitability for developing late maturing material.

Table 9: Analysis for general combining ability effects of the parents for various characters in sunflower

Parents	Plant height (cm)	50% flowering (days)	Full blooming (days)	Maturity (days)	Head diameter (cm)	Seed yield/ plant (g)	100-seed weight (g)	Oil content (%)	Oil yield/ plant (ml)
Females									
IB 2	-16.69*	-0.50	-0.43	1.46*	-0.83	-36.95*	0.05	-4.13*	-14.31*
IB 4	-21.30*	-1.61*	-1.87*	-1.76*	-0.93	17.19*	0.19	-0.94	4.47*
IB 14	4.69	1.50*	1.57*	-0.32	1.12	8.41*	-0.43	4.56*	6.64*
IB 28	10.48*	2.28*	1.80*	0.91	0.08	2.47	0.43	0.55	0.65
IB 28-1	8.62	-1.28*	-1.09*	-0.32	-0.97	2.85	-0.61*	-1.12	-0.43
IB 43	14.20*	-0.39	0.02	0.02	1.53*	6.03	0.37	1.08	2.98*
C.D. at 5%	8.64	0.59	0.91	1.04	1.48	7.58	0.49	1.59	2.93
Males									
EC 68415B	-6.35*	-0.11	-0.43	0.19	-0.56	-8.19*	-0.03	0.88	-1.55
EC 68415C	2.81	-0.39	-0.15	0.02	0.56	-3.30	0.06	-1.35*	-2.02
Morden	3.53	0.50*	0.57	-0.20	0.00	11.50*	-0.03	0.47	3.57*
C.D. at 5%	6.10	0.41	0.65	0.73	1.06	5.37	0.35	1.12	1.02
r(gca Vs. *per se*)	0.13	-0.13	0.01	0.24	-0.24	0.06	-0.17	0.60	0.12

* Significant at 5 per cent

Table 10: Estimation of specific combining ability effects of crosses for various characters in sunflower

Crosses	Plant height (cm)	50% flowering (days)	Full blooming (days)	Maturity (days)	Head diameter (cm)	Seed yield/ plant (g)	100-seed weight (g)	Oil content (%)	Oil yield/ plant (ml)
IB 2 x EC 68415B	1.98	-0.89	-0.91	-0.30	-0.65	10.77	-0.42	-2.56	1.18
IB 2 x EC 68415C	-4.49	-0.94	-1.52	1.54	0.83	2.02	0.16	-1.79	-0.17
IB 2 x Morden	2.51	1.83*	2.43*	-1.24	-0.18	-12.79	0.26	4.35*	-1.01
IB 4 x EC 68415B	10.14	0.22	0.54	0.59	0.48	13.64*	0.22	3.45*	7.76*
IB 4 x EC 68415C	11.78	0.50	0.26	-0.57	2.08	-10.59	-1.25*	-6.75*	-10.85*
IB 4 x Morden	-21.92*	-0.72	-0.80	-0.02	-2.56	-3.05	1.03*	3.30*	3.09
IB 14 x EC 68415B	3.34	1.11*	1.09	-0.52	0.61	2.75	1.17*	2.19	3.12
IB 14 x EC 68415C	-2.71	1.39*	1.82*	-0.35	0.02	-6.14	0.64	3.75*	1.40
IB 14 x Morden	-0.63	-2.50*	-2.91*	0.87	-0.63	3.39	-1.81*	-5.94*	-4.52
IB 28 x EC 68415B	-11.77	-0.67	-1.79*	-0.07	0.44	-21.22*	-0.05	0.10	-6.64*
IB 28 x EC 68415C	-16.37*	-0.39	0.59	0.43	-1.55	12.46	-0.39	2.40	7.11*
IB 28 x Morden	28.14*	1.06*	1.20	-0.35	1.11	8.66	0.44	-2.50	-0.47
IB 28-1 x EC 68415B	-4.21	-0.11	0.09	0.82	-0.21	12.84	-0.31	0.23	4.01
IB 28-1 x EC 68415C	2.24	-0.50	-1.18	-1.02	0.26	-9.52	0.24	-0.54	-3.64
IB 28-1 x Morden	1.97	0.61	1.09	0.20	-0.05	-3.32	0.07	0.31	-0.37
IB 43 x EC 68415B	0.53	0.33	0.98	-0.52	-0.68	-18.87*	-0.62	-3.40*	-9.42*
IB 43 x EC 68415C	9.54	-0.06	0.04	-0.02	-1.64	11.77	0.61	2.93*	6.14*
IB 43 x Morden	-10.07	-0.28	-1.02	0.54	2.32	7.10	0.01	0.47	3.28
C.D. 5%	14.96	1.02	1.59	1.81	2.58	13.13	0.83	2.74	5.08
r(sca Vs. *per se*)	0.61*	0.56*	0.69*	0.55*	0.73*	0.49*	0.88*	0.75*	0.58*
r[sca Vs. Heterosis (MP)]	0.56*	0.48*	0.64*	0.50*	0.59*	0.46	0.62*	0.83*	0.54*

* Significant at 5 per cent

Only one hybrid IB 14 x Morden (-2.50) exhibited significant negative sca effects indicating a good combination for days to 50 per cent flowering.

3. **Days to full blooming**

Significant negative gca effects were shown by the females IB 4 (-1.87) and IB 28-1 (-1.09) indicating that these parents were good general combiners for earliness to full blooming.

Two hybrids IB 14 x Morden (-2.91) and IB 28 x EC 68415B (-1.79) showed significant negative sca effects and were categorized as good specific combinations for earliness to full blooming.

4. **Days to maturity**

The parent IB 4 (-1.76) among females showed significant negative gca effects was categorized as good general combiner for earliness. Among males only Morden (-0.20) showed non-significant negative gca effect.

Among the hybrids, none showed significant negative sca effects, although the hybrid IB 2 x Morden (-1.24) showed highest negative sca effects.

5. **Head diameter**

The female parent IB 43 (1.53) was categorized as good general combiner for head diameter as it showed significant positive gca effects for this trait. Among male parents, none exhibited significant positive gca effects.

None of the hybrid combination showed significant positive sca effects for head diameter.

6. **Seed yield per plant**

It was apparent from the results that among females, IB 4 (17.19) and IB 14 (8.41) and among males, Morden (11.50) had significant positive gca effects for seed yield per plant, indicating that these were good general combiners for this character.

The hybrid IB 4 x EC 68415B (13.64) was the most desirable combination as it showed significant positive sca effects. On the other hand, hybrids IB 28 x EC 68415B (-21.22) and IB 43 x EC 68415B (-18.87) were most undesirable combinations as they exhibited significant negative sca effects.

7. **100-seed weight**

None of the parents, showed significant positive gca effect for this character. However, significant negative gca effects were observed for female IB 28 (-0.61) indicating that it is poor general combiner for 100-seed weight.

The results pertaining to sca effects indicated that hybrids IB 4 x Morden (1.03) and IB 14 x EC 68415B (1.17) were best combinations for 100-seed weight owing to thier significant positive sca effects.

8. **Per cent oil content**

For this character the female IB 14 (4.56) exhibited significant positive gca effects pointing it to be a good general combiner for per cent oil content whereas the female IB 2 (-4.13) was poor combiner for this character owing to its significant negative gca effect. None of the male parents exhibited positive gca effects but the male EC 68415C (-1.35) showed significant negative gca effect indicating it to be a poor general combiner for this character.

The maximum positive and significant sca effect for this character was recorded for the hybrid IB 2 x Morden (4.35) followed by IB 14 x EC 68415C (3.75), IB 4 x EC 68415B (3.45) IB 4 x Morden (3.30) and IB 43 x EC 68415C (2.93). These hybrids were characterized as good specific combinations for this trait.

9. Oil yield per plant

An examination of gca effects in respect of oil yield per plant revealed that females, IB 4 (4.47), IB 14 (6.64) and IB 43 (2.98) and the male, Morden (3.57) were good general combiners as these recorded significant positive gca effects.

The hybrids IB 4 x EC 68415B (7.76), IB 28 x EC 68415C (7.11) and IB 43 x EC 68415C (6.14) exhibited significant positive sca effects for oil yield per plant indicating that they are good specific combiners for this character.

G. Extent of heterosis in hybrids

Heterosis over mid parent (relative heterosis), heterosis over better parent (heterobeltiosis) and heterosis over best check (standard heterosis) was calculated for various characters and expressed in percentage. The results have been presented in Table 11. A brief description of the heterotic response of the hybrids for various characters is given below :

1. **Plant height**

Negative heterosis is desirable in sunflower because it indicates reduction in plant height. Relative heterosis, heterobeltiosis and standard heterosis over best check U 5002 ranged from -26.00 to 34.93 per cent, -42.40 to 34.43 per cent and -55.58 to -7.61 per cent, respectively. The hybrid IB 4 x Morden attained highest significant negative relative heterosis (-26.00%), heterobeltiosis (-22.1%) and standard heterosis (-32.1%). The hybrids IB 2 x EC 68415B (-20.8%), IB 2 x EC 68415C (-19.2%) and IB 4 x EC 68415B (-18.7%) also showed significant negative standard heterosis over best check U 5002, while only one hybrid IB 14 x EC 68415B (-14.5%) showed significant negative heterobeltiosis.

2. **Days to 50 per cent flowering**

For days to 50 per cent flowering the range for relative heterosis, heterobeltiosis and standard heterosis over best check U 5002 varied from -4.96 to 5.32 per cent, -4.29 to 6.87 per cent and 0.00 to 9.00 per cent, respectively. The hybrid IB 4 x Morden exhibited highest significant negative heterosis (-4.96) over mid parent and heterobeltiosis (-4.30) indicating earliness for 50 per cent flowering. The hybrids IB 14 x Morden (-2.39) and IB 43 x Morden (-1.90%) also showed significant negative heterobeltiosis. Not a

Table 11: Heterosis over mid parent, better parent and best check for various characters in sunflower

Crosses	Plant height (cm)			50% flowering (days)			Full blooming (days)			Maturity (days)			Head diameter (cm)			Seed yield/ plant (g)			100-seed weight (g)			Oil content (%)			Oil yield/ plant (ml)		
	MP	BP	BC	MP	BP	BC	MP	BP	BC	MP	BP	BC	MP	BP	BC	MP	BP	BC	MP	BP	BC	MP	BP	BC	MP	BP	BC
IB 2 × EC 68415B	-14.40*	-8.70	-20.84*	-2.90*	-0.50	0.99	-2.70*	-0.47	0.92	2.71*	4.81*	4.81*	-13.22	-20.90*	-23.04*	-27.56*	-35.36*	-52.68*	11.21	-12.68	-17.47*	-22.77*	-31.39*	-38.28*	-44.60*	-55.27*	-68.26*
IB 2 × EC 68415C	-15.35*	-6.84	-19.22*	-2.90*	0.00	0.49	-3.36*	-1.37	0.46	5.68*	9.09*	6.67*	9.42	6.15	-9.55	-33.98*	-42.40*	-55.58*	37.32*	13.74	-6.32	-22.25*	-26.98*	-41.88*	-49.08*	-57.88*	-71.92*
IB 2 × Morden	-6.70	-1.48	-14.58*	0.24	0.96	6.00*	1.55	2.23*	6.98*	0.17	1.09	3.33*	-6.37	-14.08	-17.64*	-29.60*	-35.38*	-55.58*	52.43*	35.90*	-6.16	2.86	-4.23	-22.36	-28.63*	-39.10*	-62.40*
IB 4 × EC 68415B	-12.35*	-6.84	-18.70*	-2.90*	-0.50	0.99	-2.70*	-0.47	0.92	1.10	2.22*	2.22*	-9.31	-15.36*	-17.64*	34.47*	23.11*	-9.86	4.74	1.06	-4.49	12.34*	-6.34	-15.75*	49.01*	16.21*	-17.54*
IB 4 × EC 68415C	-8.27	0.60	-12.21*	-2.42*	0.49	0.99	-2.91*	-0.92	0.92	0.74	3.03*	0.74	13.83	13.28	-3.48	9.61	-1.95	-24.38*	-14.84*	-17.42*	-27.45*	-22.91*	-32.40*	-46.19*	-16.66*	-33.51*	-55.68*
IB 4 × Morden	-26.00*	-22.13*	-32.04*	-4.96*	-4.29*	0.49	-4.64*	-4.00*	0.46	-1.09	-1.09	1.11	-22.87*	-27.50*	-30.51*	42.60*	34.43*	-7.61	38.77*	24.05*	8.99	17.47*	2.21	-17.14*	64.35*	35.02*	-16.64*
IB 14 × EC 68415B	3.53	14.48*	-7.17	3.12*	5.40*	6.99*	2.22*	5.04*	6.50*	1.27	2.59*	2.59*	8.87	-3.73	-6.33	16.57*	2.93	-24.64*	-2.25	-10.06	1.16	7.69*	5.17	-5.39	29.59*	9.24	-22.48*
IB 14 × EC 68415C	2.24	16.78*	-5.30	3.62*	6.46*	6.99*	3.33*	5.93*	7.90*	2.40*	4.92*	2.59*	20.57*	13.15	-3.58	8.64	-6.18	-27.64*	-3.92	-16.72*	-6.32	12.50*	8.49*	-7.00*	26.81*	9.72	-26.86*
IB 14 × Morden	8.60	18.85*	-3.62	-2.86*	-2.39*	2.49*	-3.31*	-2.23*	2.32*	1.26	1.45	3.70*	5.66	-5.96	-9.86	45.23*	31.88*	-9.36	-43.41*	-54.29*	-48.59*	-11.60*	-14.00*	-26.28*	31.22*	17.36*	-27.54*
IB 28 × EC 68415B	-0.60	12.89	-12.77*	3.67*	3.93*	5.49*	1.14	1.38	2.79*	2.17*	4.44*	4.44*	-2.32	-10.24	-12.66	-18.56*	-27.64*	-47.02*	-3.87	-7.75	-4.99	-10.68*	-11.50*	-20.33*	-24.80*	-35.15*	-53.98*
IB 28 × EC 68415C	-0.81	16.45*	-10.03	4.19*	4.97*	5.49*	4.56*	4.56*	6.50*	3.66*	7.19*	4.81*	-0.62	-2.74	-17.13*	22.20*	6.17	-18.13*	-1.80	-11.63	-8.99	-4.96	-9.70*	-20.16*	22.93*	8.88	-27.42*
IB 28 × Morden	34.93*	51.64*	17.16*	5.32*	6.87*	9.00*	4.96*	6.40*	8.37*	0.35	1.45	3.70*	5.73	-2.17	-6.23	43.51*	31.15*	-9.86	20.12*	0.32	3.33	-14.65*	-18.20*	-27.68*	21.28*	11.14	-31.38*
IB 28-1 × EC 68415B	-15.98*	-7.73	-9.35	-0.75	-0.50	0.99	-0.23	0.00	1.40	2.18*	4.08*	4.08*	-18.17*	-19.30*	-21.48*	19.47*	7.59	-21.23*	-24.62*	-26.62*	-26.62*	-9.44*	-15.60*	-24.08*	10.93	-8.15	-34.82*
IB 28-1 × EC 68415C	-9.75*	-3.94	0.04	-1.23	-0.49	0.00	-1.82*	-1.82	0.00	1.10	4.17*	1.86*	-3.41	-8.18	-13.18	-0.68	-14.87*	-34.35*	-7.85	-15.97*	-15.97*	-12.83*	-13.85*	-31.42*	-13.60	-26.61*	-51.08*
IB 28-1 × Morden	-6.23	4.05	0.31	-0.48	0.99	3.00*	0.91	2.29*	4.19*	0.00	0.73	2.97*	-13.62*	-14.19	-17.75*	31.52*	18.47*	-18.58*	-5.51	-20.13*	-20.13*	-5.40	-7.34	-24.88*	23.04*	7.94	-33.36*
IB 43 × EC 68415B	3.71	9.40	-3.14	-1.19	1.48*	3.00*	0.23	2.75*	4.19*	1.65*	2.97*	2.97*	-5.35	-8.43	-10.90	-21.50*	-21.69*	-42.67*	-13.46*	-16.17*	-15.47*	-17.01*	-19.49*	-27.58*	-34.82*	-36.41*	-54.88*
IB 43 × EC 68415C	11.87*	21.74*	7.78	-1.69*	1.49*	1.99*	-0.90	1.37	3.25*	3.14*	5.68*	3.33*	2.12	-1.08	-10.08	12.05*	8.96	-15.97*	16.15*	5.61	6.49	0.45	-2.49	-17.54*	12.25	11.59	-24.70*
IB 43 × Morden	4.28	8.92	-3.56	-2.83*	-1.90*	3.00*	-2.64*	1.77	2.79*	1.26	1.45	3.70*	15.17*	12.24	7.58	29.44*	25.77*	-8.36	12.40	-5.78	-4.99	-2.34	-4.34	-19.10*	24.98*	19.68*	-19.24*
C.D. 5%		17.08			0.98			1.42			1.62			2.84			13.75			0.78			2.64			4.96	
C.D. 5% (Heterosis over MP)		14.79			0.84			1.22			1.40			2.46			11.91			0.66			2.28			4.30	

* Significant at 5 per cent

MP = Mid parent, BP = Better parent, BC = Best check single hybrid showed standard heterosis over best check for earliness to 50 per cent flowering.

3. Days to full blooming

For days to full blooming, the range for relative heterosis, heterobeltiosis and heterosis over best check U 5002 varied from -4.64 to 4.96 per cent, -4.00 to 6.40 per cent and 0.00 to 8.37 per cent, respectively. The hybrid IB 4 x Morden exhibited highest significant negative values for both heterosis over mid parent (-4.64) and heterobeltiosis (-4.00) indicating earliness for full blooming. The hybrid IB 14 x Morden (-2.23) also showed significant negative heterobeltiosis. None of the hybrids showed standard heterosis over best check for earliness to full blooming, owing to their positive heterosis over best check.

4. Days to maturity

Heterosis over mid parent and standard heterosis over best check for days to maturity varied from -1.09 to 5.68 per cent and -1.09 to 4.09 per cent, respectively. The hybrid IB 4 x Morden showed non-significant negative values for heterosis (-1.09) over mid parent and heterobeltiosis (-1.09). All other hybrids showed positive values for heterosis over mid parent and heterobeltiosis indicating their late maturity. The standard heterosis over best check APSH 11 ranged from 0.74 to 6.67 per cent, with the hybrid IB 2 x EC 68415C taking maximum days to mature.

5. **Head diameter**

The range for relative heterosis and heterobeltiosis for head diameter was -22.87 to 20.57 per cent and -27.50 to 13.28 per cent, respectively. The hybrids IB 14 x EC 68415C (20.57) and IB 43 x Morden (15.17) exhibited significant positive heterosis over mid parent. Out of 18 hybrids, 4 and 1 hybrid (s) displayed non-significant positive heterobeltiosis and heterosis over best check, respectively. The heterosis over best check MSFH 8 varied from -30.51 to 7.58 per cent and not even a single hybrid showed significant positive heterosis over best check.

6. **Seed yield per plant**

The range of heterosis over mid parent and better parent was -33.98 to 45.23 and -42.40 to 34.43 per cent, respectively. The highest relative heterosis (45.23%) was seen for the hybrid IB 14 x Morden, followed by hybrids IB 28 x Morden (43.51%), IB 4 x Morden (42.60%) and IB 4 x EC 68415B (34.47%). The highest heterobeltiosis (34.43%) was seen for the hybrid IB 4 x Morden followed by hybrids IB 14 x Morden (31.88%), IB 28 x Morden (31.15%) and IB 43 x Morden (25.77%). The range for heterosis over best was -55.58 to -7.61 per cent for seed yield per plant. All the hybrids showed negative heterosis over best check MSFH 8.

7. **100-seed weight**

The range for relative heterosis, heterobeltiosis and heterosis over best check was -43.41 to 52.43, -54.29 to 35.90 and -48.59 to 8.99 per cent, respectively, for 100-seed weight. The highest and significant positive relative heterosis (52.43%) and heterobeltiosis (35.90%) was observed for the hybrid IB 2 x Morden followed by hybrids IB 4 x Morden and IB 2 x EC 68415C. None of the hybrids was able to exhibit significant positive standard heterosis over best check U 5002.

8. **Per cent oil content**

The range for relative heterosis and heterobeltiosis was -22.91 to 17.47 and -31.39 to 8.49 per cent, respectively. The highest and significant positive relative heterosis (17.47%) was shown by the hybrid IB 4 x Morden, followed by the hybrids IB 14 x EC 68415C (12.50%), IB 4 x EC 68415B (12.34%) and IB 14 x EC 68415B (7.69%). Only one hybrid to show significant positive (8.49%) heterobeltiosis was IB 14 x EC 68415C. The range of heterosis over best check U 5002 was -5.39 to -46.19 per cent and none of the hybrids was able to attain positive standard heterosis over best check.

9. **Oil yield per plant**

The range for relative heterosis and heterobeltiosis was -44.60 to 64.35 and -57.88 to 35.02 per cent, respectively, for oil yield per plant. The highest and significant positive heterosis (64.35%) and heterobeltiosis (35.02%) was shown by the hybrid IB 4 x Morden. The other promising hybrids showing significant positive heterobeltiosis were IB 43 x Morden (19.68%), IB 14 x Morden (17.36%) and IB 4 x EC 68415B (16.21%). The range for standard heterosis over best check MSFH 8 was -16.64 to -71.92% and none of the hybrids was able to produce positive standard heterosis over best check.

DISCUSSION

It is only in recent years that sunflower has attained the status of farm crop in commercial sense. Most of the germplasm available at present has been introduced and represents, rather a narrow gene pool. Sunflower hybrids are impregnated with potential risk associated with monoculture and narrow gene pool, as most of the cultivated hybrids are based on single cytoplasmic male sterility source _H. petiolaris_ (Leclercq, 1969; Arnaud, 1986). Any improvement in sunflower should precede with infusion of more genetic variability in breeding population. For creating the genetic variability through hybridization, the choice of a suitable parent is a matter of great concern to the plant-breeders. The importance of genetic diversity in choosing desirable parents for hybridization has been stressed upon by many workers (Prasad and Singh, 1986; Ming, 1987; Yadava _et al._, 1988). Besides the selection of genetically diverse parents for hybridization, it is most crucial to realize high heterosis and productive recombinants in subsequent generations. Mahalanobis D^2 statistic (Mahalanobis, 1928) approach, which is based on multivariate analysis is a powerful tool for measuring genetic diversity using the concept of statistical distance utilizing multiple measurements. Further more, several genetical designs are available to study the genetic architecture and to identify desirable parents and cross combinations. The line x tester analysis proposed by Kempthorne (1957) used in the present study is one of the potent methods as it involves large number of parents compared to diallel cross technique which are generally based on fewer parents.

Keeping the above points in view, the present investigation was undertaken to study the 'Genetic distance in relation to heterosis and combining ability in sunflower (Helianthus annuus L.)'. The results obtained in the present study have been discussed in the light of latest available literature.

Mean performance and range

Sufficient amount of variability was observed among the various genotypes for all the characters except for stem girth which indicated that the material used in the study was appropriate for estimation of various genetic parameters. Maximum range was observed for plant height and seed yield per plant. On the contrary, the range was very narrow for 100-seed weight. Considering the mean performance of the parents and hybrids, for seed yield and other important traits, hybrid IB 4 x Morden (123.00 g) had the highest seed yield followed by IB 43 x Morden (122.00 g), IB 14 x Morden (120.67 g), IB 4 x EC 68415B and IB 28 x Morden (120.00 g), whereas among parents EC 68415C (102.67 g) exhibited highest seed yield compared to APSH 11 (114.20 g), U 5002 (116.13 g) and MSFH 8 (133.13 g), the standard checks. The lowest seed yield among parents and hybrids was recorded for two hybrids IB 2 x EC 68415C and IB 2 x Morden (59.13 g). It was very interesting to note that all the high yielding hybrids mentioned above had at least high mean value either for 100-seed weight or head diameter the main yield contributing traits. The hybrid IB 4 x Morden possessed the boldest seeds weighing 6.55 g/ 100 seeds followed by 6.40 g, 6.21 g and 6.08 g of IB 43 x EC 68415C, IB 28 x Morden and IB 14 x EC 68415B, respectively. Among parents IB 14 (6.76 g), IB 28 (6.19 g), IB 43 (6.06 g) and IB 28-1 (6.01 g) were characterized bold seeded. The largest head size among hybrids was attained by IB 43 x Morden (20.73 cm) compared to 19.27 cm of MSFH 8, the best check. None of the parents exhibited larger head size compared to the hybrid IB 43 x Morden and standard check MSFH 8. The standard check U 5002 (40.83%) recorded highest oil content compared to parents and hybrids. None of the parents and hybrids had higher oil yield per plant (ml) compared to best check MSFH 8 (50.00 ml). These results were in confirmation to the findings of various previous workers (Giriraj et al., 1979; Lakshmanaiah, 1980; Rao, 1980).

Components of variation

In breeding, the varietal development programme through selection is mainly dependent on the extent of genetic variability present and also the genetic architecture of yield and its components. Traits with high heritability, as it is likely to give high genetic advance provided the traits are direct components of yield are more amenable for improvement through selection. The results of present study have shown close relationship between phenotypic and genotypic coefficients of variation in all the characters studied. Further, the magnitude of phenotypic coefficient of variation was higher than their corresponding genotypic variation. These results were in close agreement with results reported by Reddy and Reddy (1979), Pathak et al. (1987) and Singh and Labana (1990).

It is a fact that genetic coefficient of variation alone is not sufficient for determination of the amount of heritable variation, which can be found out with greater accuracy when heritability in conjunction with genetic advance is studied. Estimates of heritability were observed to be high for all the traits except for head diameter. The characters oil yield per plant (89.80%), days to 50 per cent flowering (89.55%), oil content (88.65%) and seed yield per plant (85.65%) were found to be highly heritable. To a larger extent the present results were in confirmation to the finding of Volf and Dumacheva (1973), Miller et al. (1977), Fernandez et al. (1979), Reddy & Reddy (1979), Lakshmanaiah (1980), Venkateswarlu et al. (1980) and Dilruba Begum et al. (1988).

The high heritable variation coupled with high genetic gain is very useful in predicting the resultant gain from selection. Panse (1957) reported that high heritability with high genetic advance was indicative of additive gene effects and high heritability associated with low genetic advance was indicative of dominance and epistatic effects. In the present study, high heritability estimates accompanied with high genetic advances were observed for seed yield per plant, plant height and oil yield per plant indicating thereby that these characters could be improved through simple selection. Although, days to 50 per cent flowering, days to full blooming, days to maturity, head diameter, 100-seed weight and oil content exhibited high heritability estimates but the magnitude of genetic advance was low revealing thereby the presence of dominance and epistasis. Johnson *et al.* (1955) also reported that higher estimates of heritability need not to be associated with higher values of genetic advance.

Combining ability variances

The mean square values due to combining ability for lines (females) were significant for seed yield per plant, days to maturity, days to 50 per cent flowering and oil yield per plant. The variances due to testers were significant only for 100-seed weight. Further, the mean squares due to lines x testers (SCA) were significant for all the traits. Though both GCA and SCA variances played their role for the inheritance of seed yield and other component characters, but the latter being more important (Shetty and Singh, 1977; Shankara, 1983; Dua and Yadava, 1983; Sheriff *et al.*, 1985).

Genetic evaluation of parents and hybrids

Relative evaluation of the parents as genetic stocks for future population improvement is always one of the objectives and indeed an advantage in the line x tester analysis. A consideration of the general and specific combining ability effects might be of help in isolating suitable genotypes for genetic enhancement of the breeding material. Results on the combining ability effects showed that the female parent IB 4 was good combiner for 6 characters viz., plant height, days to 50 per cent flowering, days to full blooming, days to maturity, seed yield per plant and oil yield per plant. The female parent IB 14 was a good combiner for seed yield per plant, oil content and oil yield per plant but it was poor combiner for days to 50 per cent flowering and days to full blooming. The female parent IB 43 was a good general combiner for head diameter and oil yield per plant.

Among testers, Morden was a good combiner for seed yield per plant and oil yield per plant, while EC 68415B was good general combiner for dwarfness but was a poor combiner for yield and its component characters.

In order to find out some relationship between *per se* performance and general combining ability of genotypes, correlation coefficients between gca effects and *per se* performance were computed for all the characters and are presented in Table 9. Non-significant association existed between these two for all the characters studied. It is also evident from Table 12, three best

Table 12 : Best parents on the basis of gca effects and *per se* performance for oil yield and its components in sunflower

Sr. No.	Seed yield/plant (g)		100-seed weight (g)		Oil content (%)		Oil yield/plant (ml)	
	gca	*per se*	gca	*per se*	gca	*per se*	gca	*per se*
1.	IB 4 (17.19)	EC 68415C (102.67)	IB 28 (0.43)	IB 14 (6.76)	IB 14 (4.56)	EC 68415B (36.73)	IB 14 (6.64)	EC 68415B (35.48)
2.	Morden (11.50)	EC 68415B (97.47)	IB 43 (0.37)	IB 28 (6.19)	IB 43 (1.08)	IB 28 (36.10)	IB 4 (4.47)	IB 43 (33.74)
3.	IB 14 (8.41)	IB 43 (97.00)	EC 68415C (0.06)	IB 43 (6.06)	EC 68415B (0.88)	IB 14 (35.00)	Morden (3.57)	EC 68415C (33.33)

parents selected on the basis of per se and gca effects were not exactly the same. However, little agreement did exists between gca and per se performance for oil yield, 100-seed weight and oil content. The results indicated that per se performance, as such does not qualify for effective use in judging the combining ability of parents (Kumar et al., 1984; Pathak et al., 1985).

In present studies, none of the hybrids showed consistently high sca effects simultaneously for all the characters. Few crosses figured worth mentioning as they were significant for a few charactes. These were IB 4 x EC 68415B for seed yield per plant, per cent oil content and oil yield per plant; IB 4 x Morden for per cent oil content, 100-seed weight and plant height; IB 14 x Morden for days to 50 per cent flowering and days to full blooming; IB 28 x EC 68415C for plant height and oil yield per plant and IB 43 x EC 68415C for per cent oil content and oil yield per plant. Some of the above hybrids resulted from at least one good combining parent for the character with regard to which they had high sca effects. But in some cases, none of the parents involved was a good combiner for a particular character, the high sca effects might have arisen purely from genic interactions.

Correlation coefficients between sca effects and per se performance and sca effects and heterosis (mid parent) are presented in Table 10. The correlation coefficients between sca effects and per se performance were found to be significant for all the characters under study, indicating that *per se* performance of hybrids provided a fair index for isolating a good cross combination on the basis of *per se* performance. These results were in confirmation to the finding of Dua and Yadava, (1983) and Pathak *et al*. (1985).

For obtaining a comprehensive picture of sca effects viz-a-viz *per se* performance, considering oil yield and its major components simultaneously, five best hybrids were selected for seed yield per plant, 100-seed weight, per cent oil content and oil yield per plant. These have been listed in descending order of magnitude of sca effects and *per se* performance (Table 13). It appeared that hybrid IB 4 x EC 68415B expressed high sca effects and *per se* performance for seed yield per plant, whereas, in general, no agreement was found between sca effects and *per se* performance for this character in other hybrids. Out of five best hybrids, four showed high sca effects as well as *per se* performance for per cent oil content and 100-seed weight. These hybrids were IB 14 x EC 68415C, IB 4 x EC 68415B, IB 4 x Morden and IB 43 x EC 68415C for per cent oil content and IB 14 x EC 68415B, IB 4 x Morden, IB 43 x EC 68415C and IB 28 x Morden for 100-seed weight. For oil yield the hybrids; IB 4 x EC 68415B, IB 43 x EC 68415C and IB 43 x Morden exhibited high sca and *per se* performance. Thus, in general there was good agreement between sca effects and *per se* performance for these characters.

Table 13 : Five best crosses on the basis of sca effects and *per se* performance for oil yield and its components in sunflower

Sr. No.	Seed yield/plant (g)		100-seed weight (g)		Oil content (%)		Oil yield/plant (ml)	
	sca	*per se*	sca	*per se*	sca	*per se*	sca	*per se*
1.	IB 4 x EC 68415B (13.64)	IB 4 x Morden (123.00)	IB 14 x EC 68415B (1.17)	IB 4 x Morden (6.55)	IB 2 x Morden (4.35)	IB 14 x EC 68415B (38.63)	IB 4 x EC 68415B (7.76)	IB 4 x Morden (41.68)
2.	IB 28-1 x EC 68415B (12.84)	IB 43 x Morden (122.00)	IB 4 x Morden (1.03)	IB 43 x EC 68415C (6.40)	IB 14 x EC 68415C (3.75)	IB 14 x EC 68415C (37.97)	IB 28 x EC 68415C (7.11)	IB 4 x EC 68415B (41.23)
3.	IB 28 x EC 68415C (12.46)	IB 14 x Morden (120.67)	IB 14 x EC 68415C (0.64)	IB 28 x Morden (6.21)	IB 4 x EC 68415B (3.45)	IB 4 x EC 68415B (34.40)	IB 43 x EC 68415C (6.14)	IB 43 x Morden (40.38)
4.	IB 43 x EC 68415C (11.77)	IB 4 x EC 68415B (120.00)	IB 43 x EC 68415C (0.61)	IB 14 x EC 68415B (6.08)	IB 4 x Morden (3.30)	IB 4 x Morden (33.83)	IB 28-1 x EC 68415B (4.01)	IB 14 x EC 68415B (38.76)
5.	IB 2 x EC 68415B (10.77)	IB 28 x Morden (120.00)	IB 28 x Morden (0.44)	IB 4 x EC 68415B (5.74)	IB 43 x EC 68415C (2.93)	IB 43 x EC 68415C (33.67)	IB 43 x Morden (3.28)	IB 43 x EC 68415C (37.65)

Extent of heterosis in hybrids

Sunflower being a highly cross pollinated crop, offers lot of scope for developing new and superior high yielding hybrids and varieties through heterosis breeding. Studies on heterosis have revealed considerable gain for seed and oil yield (Chaudhary and Anand, 1984; Singh et al., 1984).

The highest and significant positive relative heterosis (64.35%) and heterobeltiosis (35.02%) was shown by the hybrid IB 4 x Morden indicating highest oil yield for this hybrid. The other promising hybrids showing significant positive heterobeltiosis were IB 43 x Morden (19.68%), IB 14 x Morden (17.36%) and IB 4 x EC 68415B (16.21%).

None of the hybrids was able to producee significant heterosis over best check for any character except for plant height. Highest significant negative heterosis for plant height over check was recorded for IB 4 x Morden (-32.04%) followed by IB 2 x EC 68415C (-19.22%) and IB 4 x EC 68415B (-18.70%).

It appeared that for different characters, hybrids showing significant heterosis over MP and BP were different. However, few hybrids showed significant heterosis simultaneously for more than one character, for example IB 4 x Morden for plant height, days to 50 per cent flowering, days to full blooming, seed yield per plant, 100-seed weight and oil yield per plant; IB 14 x Morden for days to 50 per cent flowering, days to full blooming, seed yield per plant and oil yield per plant; IB 43 x Morden for days to 50 per cent flowering, days to full blooming, head diameter, seed yield per plant and oil yield per plant; IB 4 x EC 68415B for plant height, days to 50 per cent flowering, days to full blooming, seed yield per plant, per cent oil content and oil yield per plant and IB 14 x EC 68415C for head diameter, per cent oil content and oil yield per plant. Use of these five hybrids in hybridization programme would facilitate synthesis of a dynamic population. Similar results were also observed by Sudhakar (1979) and Seetha Ram (1984). They reported moderate to high degree of heterosis for seed yield over the check varieties. Chaudhary and Anand (1984) reported 69.8 per cent heterosis for seed yield. Singh et al. (1978) found heterosis in intervarietal crosses of sunflower. They observed that heterosis for seed yield per plant in most of the cases was associated with main components in most of the crosses i.e. 100-seed weight, head diameter and per cent seed filling. Similar observations on heterosis were also reported by Naik et al. (1988). They observed that heterosis for percentage of filled seeds, 100-seed weight and head diameter contributed towards the yields of sunflower. Shrinivasa (1982), reported significant heterosis for plant height, head diameter and yield per plant.

Five best heterotic hybrids for oil yield and its components were selected to assess relationship, if any, between heterosis and *per se* performance. These are indexed in Table 14. It appeared that there was a fairly good agreement between *per se* performance

Table 14: Five best crosses on the basis of heterosis and *per se* performance for oil yield and its components in sunflower

Sr. No.	Seed yield/plant (g)		100-seed weight (g)		Oil content (%)		Oil yield/plant (ml)	
	Heterosis over (BP)	*per se*	Heterosis over (BP)	*per se*	Heterosis over (BP)	*per se*	Heterosis over (BP)	*per se*
1.	IB 4 x Morden (34.43)	IB 4 x Morden (123.00)	IB 2 x Morden (35.90)	IB 4 x Morden (6.55)	IB 14 x EC 68415C (8.49)	IB 14 x EC 68415B (38.63)	IB 4 x Morden (35.02)	IB 4 x Morden (41.68)
2.	IB 14 x Morden (31.88)	IB 43 x Morden (122.00)	IB 4 x Morden (24.05)	IB 43 x EC 68415C (6.40)	IB 14 x EC 68415B (5.17)	IB 14 x EC 68415C (37.97)	IB 43 x Morden (19.68)	IB 4 x EC 68415B (41.23)
3.	IB 28 x Morden (31.15)	IB 14 x Morden (120.67)	IB 2 x EC 68415C (13.74)	IB 28 x Morden (6.21)	IB 4 x Morden (2.21)	IB 4 x EC 68415B (34.40)	IB 14 x Morden (17.36)	IB 43 x Morden (40.38)
4.	IB 43 x Morden (25.77)	IB 4 x EC 68415B (120.00)	IB 43 x EC 68415C (5.61)	IB 14 x EC 68415B (6.08)		IB 4 x Morden (33.83)	IB 4 x EC 68415B (16.21)	IB 14 x EC 68415B (38.76)
5.	IB 4 x EC 68415B (23.11)	IB 28 x Morden (120.00)	IB 4 x EC 68415B (1.06)	IB 4 x EC 68415B (5.74)		IB 43 x EC 68415C (33.67)	IB 43 x EC 68415C (11.59)	IB 43 x EC 68415C (37.65)

and heterobeltiosis for per cent oil content, 100-seed weight and oil yield per plant. However, all the five hybrids revealed high *per se* performance as well as heterobeltiosis for seed yield per plant, indicating complete agreement between *per se* performance and heterobeltiosis. It was also seen that hybrids showing heterobeltiosis for oil yield, also depicted considerable heterobeltiosis for all the yield components, the most frequent being seed yield per plant and 100-seed weight.

Genetic divergence in relation to heterosis and sca effects

Genetic divergence between parent genotypes involved in crosses has been greatly emphasized. High genetic divergence has been advocated to be desirable for high heterotic effect and/or for obtaining new desired recombinants.

Accordingly, correlation coefficients of genetic divergence (D^2) value with sca effects, relative heterosis, heterobeltiosis and standard heterosis were calculated for different characters studied. Results are presented in Table 15. No clear cut association was evident between magnitude of genetic divergence/distance on one hand and relative heterosis, heterobeltiosis, standard heterosis or sca effects on the other hand. Perhaps, some specific compatible range of genetic divergence might be more important for expression of heterosis. With this view, 18 hybrids were partitioned into three categories on the basis of the magnitude of genetic divergence. Total range of D^2- value among parents involved in hybridization was

Table 15: Correlation between D^2 values and heterosis over MP, BP, BC and sca effects for various traits in sunflower

Correlation	Plant height (cm)	50% flowering (days)	Full blooming (days)	Maturity (days)	Head diameter (cm)	Seed yield/ plant (g)	100-seed weight (g)	Oil content (%)	Oil yield plant (ml)
D^2 Vs. Heterosis (MP)	-0.09	0.02	-0.05	0.43	0.33	-0.08	-0.11	-0.02	-0.02
D^2 Vs. Heterosis (BP)	-0.01	0.25	0.14	0.46	0.27	-0.16	-0.15	-0.15	-0.11
D^2 Vs. Heterosis (BC)	-0.22	-0.05	-0.05	0.05	0.05	-0.08	-0.03	-0.07	-0.06
D^2 Vs. SCA	0.21	-0.03	0.01	0.16	0.05	0.26	-0.02	-0.09	0.13

partitioned into low (28.04 to 59.35); medium (65.74 to 89.02) and high (104.60 to 129.47). Correlation coefficients of partitioned D^2 values with relative heterosis, heterobeltiosis, standard heterosis and sca effects were calculated for various characters studied (Table 16). The significant negative associations for plant height were recorded between genetic divergence (medium) and relative heterosis, standard heterosis and sca effects. All correlation coefficients among various divergence limits and heterosis were found to be non-significant for all other characters. It was also evident that correlation coefficients among genetic divergence and sca effects were non-significant for all the categories for all other characters.

On overall basis, hybrids IB 4 x Morden, IB 4 x EC 68415B and IB 43 x Morden were good for further breeding programmes including development of improved populations for selection of inbreds and development of composites.

Table 16: Correlation between classified D^2 values and heterosis over MP, BP, BC and sca effects for various traits in sunflower

Correlation	Plant height (cm)	50% flowering (days)	Full blooming (days)	Maturity (days)	Head diameter (cm)	Seed yield/ plant (g)	100-seed weight (g)	Oil content (%)	Oil yield/ plant (ml)
D^2 (Low) Vs. Heterosis (MP)	-0.26	0.13	-0.02	-0.02	-0.48	0.01	-0.44	-0.25	-0.02
D^2 (Low) Vs. Heterosis (BP)	-0.12	0.19	0.00	0.23	-0.48	-0.06	-0.37	-0.33	-0.11
D^2 (Low) Vs. Heterosis (BC)	0.01	-0.37	-0.46	-0.39	-0.48	-0.05	-0.12	-0.41	-0.14
D^2 (Low) Vs. SCA	-0.03	-0.45	-0.31	-0.13	-0.51	-0.43	0.05	-0.41	-0.49
D^2 (Med.) Vs. Heterosis (MP)	-0.99*	-0.29	-0.24	0.77	-0.70	-0.40	-0.51	0.50	0.24
D^2 (Med.) Vs. Heterosis (BP)	-0.94	-0.40	-0.40	0.65	-0.31	-0.58	-0.39	0.46	-0.01
D^2 (Med.) Vs. Heterosis (BC)	-0.97*	-0.57	-0.44	0.61	-0.90	-0.61	-0.41	0.53	0.61
D^2 (Med.) Vs. SCA	-0.99*	-0.60	-0.36	0.76	-0.84	0.15	-0.50	0.28	0.36
D^2 (High) Vs. Heterosis (MP)	-0.14	0.00	0.11	0.14	-0.18	0.01	0.10	0.32	0.17
D^2 (High) Vs. Heterosis (BP)	-0.08	0.01	0.09	0.13	-0.14	0.01	-0.03	0.22	0.17
D^2 (High) Vs. Heterosis (BC)	-0.13	0.00	0.10	0.12	-0.33	0.02	0.08	0.22	0.15
D^2 (High) Vs. SCA	-0.27	-0.02	0.16	0.14	-0.60	0.24	0.06	0.46	0.42

* Significant of 5 per cent

SUMMARY

The present investigation was carried out at the Research Farm of Department of Plant Breeding, CCS Haryana Agricultural University, Hisar, during the year 1993-94. A total of 30 genotypes involving 18 F_1 hybrids, nine parents and three standard checks, planted in randomized block design with three replications were grown.

The objectives were to classify the sunflower inbreds on the basis of genetic divergence/distance, among parents entering crosses, to assess the extent of heterosis, to determine combining ability effects and to determine relationship between genetic divergence, heterosis and combining ability.

The observations were recorded on five randomly selected plants in each genotype per replication with respect to plant height, days to 50 per cent flowering, days to full blooming, days to maturity, stem girth, head diameter, seed yield per plant, 100-seed weight, oil content and oil yield per plant. The data recorded on various characters was subjected to biometrical analyses to gather information on genetic divergence/distance, heterosis, combining

ability and the relationship of genetic divergence with heterosis and combining ability.

The analysis of variance showed presence of considerable variability for all the characters, except stem girth.

The magnitude of phenotypic coefficient of variation was higher than the genotypic coefficient of variation for all the characters. Heritability estimates (broad sense) were generally high for all the characters except head diameter. Expected genetic gain indicated that seed and oil yield can possibly be improved upto a considerable extent.

Genetic divergence among parents entering crosses was considerable. The parents involved in hybridization were classified as having high, medium and low genetic divergence.

The analysis of variance for combining ability revealed that specific combining ability variances were significant for all the characters. General combining ability variances for lines were significant for seed yield per plant, days to maturity, days to 50 per cent flowering and oil yield per plant, and variance due to testers was significant in case of 100-seed weight only.

Female parent IB 4 was good general combiner for six characters viz., plant height, days to 50 per cent flowering, days to full blooming, days to maturity, seed yield per plant and oil yield per plant. Among the testers, Morden was the best general combiner for seed yield and oil yield per plant.

Among the crosses, IB 4 x EC 68415B exhibited highest sca effects for seed yield and oil yield per plant, IB 14 x Morden for days to 50 per cent flowering and days to full blooming, and IB 2 x Morden for days to maturity and per cent oil content.

Standard heterosis was found for the character plant height only. The hybrid IB 4 x Morden recorded the highest negative standard heterosis for plant height. The hybrid IB 4 x Morden showed highest heterobeltiosis for plant height, days to 50 per cent floweing, days to full blooming, days to maturity, seed yield and oil yield per plant. The same hybrid also produced significant heterobeltiosis for 100-seed weight. The hybrid IB 14 x EC 68415C showed highest heterobeltiosis for oil content and the hybrid IB 2 x Morden produced highest heterobeltiosis for 100-seed weight.

Correlation studies revealed significant negative relationship of genetic divergence (medium) with relative heterosis, standard heterosis and sca effects for plant height. It was also evident that relationship of genetic divergence limits with heterosis and combining ability was non-significant for all other characters.

On over all basis hybrids IB 4 x Morden, IB 4 x EC 68415B IB 43 x Morden were identified to be good for further breeding programmes including development of improved populations for selection of inbreds and development of composites.

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