GENETIC ANALYSIS OF YIELD AND CERTAIN PHYSIOLOGICAL PARAMETERS IN SUNFLOWER (*Helianthus annuus* L.)

BY

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CERTIFICATE

Ms.P.RADHIKA has satisfactorily prosecuted the course of research and that the thesis entitled **GENETIC ANALYSIS OF YIELD AND CERTAIN PHYSIOLOGICAL PARAMETERS IN SUNFLOWER (Helianthus annuus L.)** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by her for a degree of any University.

Date: 16.8.94

(Dr.K. JAGADEESHWAR)
Major Advisor

CERTIFICATE

This is to certify that the thesis entitled, **GENETIC ANALYSIS OF YIELD AND CERTAIN PHYSIOLOGICAL PARAMETERS IN SUNFLOWER (Helianthus annuus L.)** submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by **Ms.P.RADHIKA** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. All the assistance and help received during the course of investigation have been duly acknowledged by the author of the thesis.

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CONTENTS

LIST OF ABBREVIATIONS

cm	:	centimeters
CGR	:	Crop Growth Rate
DAS	:	Days after sowing
g	:	grams
gca	:	general combining ability
$g\ g^{-1} day^{-1}$	:	grams per gram per day
$g\ m^{-2} day^{-1}$	:	grams per meter square per day
LAI	:	Leaf Area Index
m	:	meters
NAR	:	Net Assimilation Rate
No.	:	Number
%	:	per cent
RGR	:	Relative Growth Rate
sca	:	specific combining ability

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(P. RADHIKA)

DECLARATION

I, P. RADHIKA hereby declare that the thesis entitled, **GENETIC ANALYSIS OF YIELD AND CERTAIN PHYSIOLOGICAL PARAMETERS IN SUNFLOWER (*Helianthus annuus* L.)** submitted to Andhra Pradesh Agricultural University for the Degree of **MASTER OF SCIENCE IN AGRICULTURE** is a result of original research work done by me. It is further declared that the thesis or any part thereof has not been published earlier in any manner.

P. Radhika

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ABSTRACT

To estimate the heterosis, combining ability and nature of gene action Line x Tester analysis involving four cytoplasmic male sterile lines and ten restorer lines was carried out in sunflower (*Helianthus annuus* L.) for seed yield and yield contributing characters and certain physiological parameters. The experimental material comprising of fourteen parents and forty hybrids along with three checks viz., APSH-11, MSFH-17 and Adarsh 3425 was evaluated in a Randomized Block Design with three replications. Analysis of the mean performance of parental lines and crosses for yield and yield attributes revealed the superiority of the lines CMS 7-1 and CMS 302, the restorer 111-R and the crosses CMS 7-1 x RHA 271 and CMS 302 x RHA 586. However, when evaluated for the physiological parameters, the line CMS 302, the tester MRHA-1 and the cross CMS 300 x 111-R were found superior. The magnitude of heterosis over better parent was -10.11 per cent for days to 50 per cent flowering, 75.34 per cent for plant height, 74.70 per cent for capitulum diameter, 37.13 per cent for 100 seed weight, 26.85 per cent for oil per cent, 75.08 per cent for seed yield per plant, 196.28 per cent for LAI, 209.28 per cent for CGR, 82.09 per cent for RGR and 126.84 per cent for NAR. The cross CMS7-1 x RHA 298 recorded maximum heterosis for seed yield over better parent while the cross CMS 302 x bD-1 exhibited maximum heterobeltiosis for 100 seed weight and oil per cent. The cross CMS 302 x RHA 272 expressed maximum positive heterobeltiosis for LAI and CGR, Whereas the crosses CMS 302 x RHA 297 and CMS 7-1 x RHA 271 expressed maximum heterobeltiosis for RGR and NAR respectively.

The combining ability analysis revealed that sca variance component is more than that of gca, indicating predominance of non additive gene action for all the characters. The estimates of gca effects indicated the lines CMS 302 and CMS 7-1 as superior combiners for yield and yield contributing and physiological parameters, while the restorers RHA 271 and RHA 586 found to be good combiners for seed yield and yield contributing characters. Further the restorers 111-R and MRHA-1 were good combiners for physiological parameters. The estimates of sca effects indicated the superiority of the cross CMS 7-1 x 111-R for yield and yield contributing characters whereas CMS 7-1 x RHA 271 and CMS7-1 x RHA 859 for physiological parameters.

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INTRODUCTION

CHAPTER I

INTRODUCTION

Oilseeds occupy a pride of place in the Indian economy, next to food grains and they constitute the most important farm commodity group. The availability of oils and fats in our country is only 12 g per day per head as against a minimum requirement of 18 g recommended by FAO. Just to meet the minimum nutritional requirements the production be doubled.

Sunflower (*Helianthus annuus* L.) forms a potential source of low cost vegetable oil and protein. Among oil seeds, sunflower crop which once ranked very low in the world, now occupies second place (after soybean) as a source of edible oil (Jones, 1984). Sunflower was originated in North America and has been introduced into India in the year 1969 from Russia. The Russian cultivars viz., VNNIMK 8931 (EC 68413), Peredovick (EC 68414), Armavirskij 3497 (EC 68415), Armarerts (EC 69874) along with the cultivar Sunrise, a selection from Canada were also introduced into India and tested in different parts of the country and were found suitable.

Sunflower was introduced as a supplement to traditional oil seed crop to bridge the gap of recurring edible oil shortage in the country. It was taken up in view of its obvious advantage in terms of short duration, high yield, photoinsensitivity and better quality of oil with low cholesterol content. Sunflower until mid seventies was less known to Indian farmers. After two decades of its chequered growth and development, today occupies a prominent place in the country's vegetable oilseed scenario, with an area of 20.38 lakh hectares, 11.4 lakh tonnes of seed production and the productivity is 559 kg per hectare (Agricultural Situation in India, 1993).

Although the sunflower crop displayed impressive and positive growth rates in its total output (2.3 lakh tonnes in 1974-75, 11.4 lakh tonnes in 1992-93), much of the additional output was brought about through expansion in acreage rather than any worthwhile improvement in its productivity per se. In general, per hectare yields which have been stagnating around 400 to 500 kg per hectare are not only one of the lowest in the world 1339 kg per hectare, (France 2250 kg per ha; USSR and Argentina 1460 kg per ha), but less than 40 to 50 per cent of their proven genetic potentials on the experimental farms in the country.

Though sunflower has many desirable agronomic attributes the yield of the crop is low, unstable in India which necessitates the genetic improvement of this crop by adopting suitable plant breeding methods. The reasons for low production are mainly due to several genetical, agronomical and physiological causes. So productivity of this important oilseed crop has to be stepped-up by evolving high yielding varieties involving multidisciplinary approach. For this purpose, selection based on the yield and yield components coupled with physiological parameters is gaining importance. Though growth analysis studies were reported in this crop, the heterosis, combining ability and gene action of yield dependent growth parameters like Leaf Area Index (LAI), Crop Growth Rate (CGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) are less understood. Identification of growth parameters influencing yield and their genetic control will make it possible to plan crosses to get transgressive segregants possessing physiological complementation for predictable yield improvement (Wallace *et al*, 1973).

The breeding of hybrid sunflower has been greatly assisted by the discovery of cytoplasmic male sterility (Leclercq, 1969) and restoration of fertility genes. Therefore, current emphasis in sunflower breeding is laid on the utilisation of heterosis.

The magnitude of heterosis provides a basis for genetic diversity and a guide to the choice of desirable parents for developing superior F_1 hybrids so as to exploit hybrid vigour. Further, the breeding method to be adopted for improvement of crop depends on the nature of gene action included in the expression of quantitative traits of economic importance. The combining ability analysis helps to identify the parents with good general combining ability (gca) and crosses with good specific combining ability (sca) effects. Combining ability analysis helps the plant breeder to select the parents, crosses and the appropriate breeding methodology to achieve the objectives quickly and reliably.

Keeping these points in view, in the present investigation it is planned to study heterotic and genetic system of seed yield and its component characters and certain physiological parameters by taking four male sterile lines and ten restorers with the following objectives.

1. To study the mean performance of parental lines and crosses for yield, yield attributes and certain physiological parameters like LAI, CGR, RGR and NAR.

2. To assess the magnitude of heterosis for seed yield, yield contributing characters and physiological parameters.

3. To investigate the nature of gene action for seed yield, yield contributing characters and physiological parameters.

4. To identify better parental lines in respect of seed yield, oil yield, yield contributing characters and certain physiological parameters.

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REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

A brief review of work done by earlier research workers in sunflower (*Helianthus annuus* L.) in respect of heterosis, nature of gene action, combining ability for seed yield, yield components with special reference to some of the physiological parameters, is given hereunder.

2.1 HETEROSIS

2.1.1 Seed Yield and Yield Contributing Characters

Heterosis may be defined as the superiority of an F_1 hybrid over mid parental value or over better parent (heterobeltiosis). In terms of yield or some other characters heterosis is manifested as an increase in vigour, size, growth rate, yield or some other characteristics. Among different methods adpoted for crop improvement, the exploitation of heterosis was originally employed to cross pollinated crops. The magnitude of heterosis is generally more in the case of cross pollinated species when compared to self pollinated crops.

In sunflower, heterosis has been reported and commercially utilised by several researchers (Putt, 1964; Grebenjuk, 1968; Shchori and Pinthus, 1969). Kurnik and Zeller (1962) reported heterosis for plant height, 1000-seed weight and seed yield in hybrid progenies involving two sets (A&B) of sunflower clones. Grozev (1963) reported

12 to 17.8 per cent heterosis for seed yield. In another study Putt (1964) observed a very highly significant heterosis among a set of 10 x 10 diallel for days to flowering, plant height, head diameter and seed yield. Similarly Vulpe (1966) reported that some of the hybrids produced by utilising male sterility and restorer lines gave-higher seed yield, oil yield and oil content. Positive heterosis was identified for number of leaves per plant, stem diameter, 100 seed weight and oil content.

Vranceanu and Stoenescu (1969) found heterosis in seven most successful hybrids to an extent of 78 and 13 per cent for seed yield and oil content respectively. Neagu (1970) studied F_1 hybrids and observed significant heterosis for plant height, capitulum diameter and seed yield in addition to the identification of early flowering hybrids corresponding to their earliest parent.

Kloczowskii (1971) reported heterosis for plant height, seed yield and an improvement in oil content ranging from 13 to 58 per cent.

Stoyanova et al. (1971) in a study involving 192 stabilised inbred lines and 140 F_1 hybrids reported high heterosis for plant height and very low heterosis for oil content. Heterosis of 12 to 40 per cent for seed yield over the standard variety was reported by Leclercq (1971). Kovacik and Skaloud (1972) found marked heterosis for plant height, head diameter and seed yield per head in certain diallel crosses involving four inbred lines. Shuravina (1972) reported high heterosis for 100-seed weight and low heterosis for oil content.

Considerable hybrid vigour was reported by Pogorletskii (1973) for number of filled seeds per head, capitulum diameter, test weight and for seed yield in a study of F_1 hybrids obtained from a full diallel involving eight inbred lines. In another study Vranceanu *et al.* (1973) observed heterosis of 8 to 44 per cent for seed yield over the standard variety. Shcherbak *et al.* (1975) stated that marked heterosis in sunflower for seed yield and oil content is due to the genetic diversity of the variety differing in physiological character. Similarly, Stoyanova *et al.* (1975) reported heterosis for oil content in 90 per cent of the interline hybrids.

Voskoboinik and Soldatov (1975) investigated hybrid vigour in several promising hybrids and reported 18 to 30 per cent heterosis for seed yield and 13 per cent for oil yield over standard variety. Sindagi (1976) measured heterosis for earliness and found that some of the F_1 hybrids developed from cytoplasmic male sterile lines were 8 to 10 days earlier. In certain F_1 hybrids derived from cytoplasmically male sterile and restorer lines, Seetharam *et al.* (1977) recorded very high and significant heterosis for days to flowering, plant height, 100-seed weight, oil content and seed yield in desirable direction.

Singh et al. (1978) reported heterotic response for seed yield, number of filled seeds and 100-seed weight in ten intervarietal hybrids. Similarly Rozhkova (1978a) reported significant effects of seed yield on the expression of heterosis in sunflower. Heterosis of 13.52 per cent for number of filled seeds per head was observed by Venkateswarlu (1978).

Sudhakar (1979) analysed data from 27 crosses involving nine inbreds and three testers and found heterosis over the mid-parental value ranged upto 41 per cent for seed yield and 32 per cent for oil content. Positive heterosis for plant height, seed weight and number of filled seeds per capitulum and negative heterosis for days to 50 per cent flowering was reported by Reddy (1980). Increased hybrid vigour for seed yield and oil content over the mid parental value in certain hybrids was observed by Nuthan (1980).

Ge (1981) observed significant heterosis for seed yield, head diameter and stem diameter, where as Vranceanu (1981) reported hybrid vigour for oil content in 172 F_1 cross combinations. Heterosis in sunflower was also studied by Shrinivasa (1982) in nine crosses and noticed superiority of the F_1s over the better parent in plant height, stem girth, head diameter and yield per plant. Further heterosis for oil content was found to be significant only over the mid-parental value and negative for 100-achene weight. Contrary to the above, Dedio (1982) reported very high heterosis for oil content over better parent. Mohammad (1983) in his diallel study involving six inbred lines reported heterosis in both positive and negative direction for plant height and stem diameter.

Pathak et al. (1983) reported heterobeltiosis from 20.5 to 28.7 per cent for head diameter, 22.6 to 70.1 per cent for 100-seed weight, 4.0 to 6.5 per cent for oil content and 15.22 to 147.99 per cent for seed yield.

Chaudhary and Anand (1984) studied 100 F_1 hybrids and measured the value of heterosis over the better parent which was found to be very high for 1000-seed weight, seed yield, head diameter and low for oil content, number of leaves and days to flowering. Kadkol et al. (1984) analysed data from a line x tester analysis of 14 sunflower inbred lines and found heterosis for earliness. Both positive and negative heterosis for plant height, number of leaves per plant and only positive heterosis for stem and head diameter was observed by Sailaja (1984). In another study, Chaudhary and Anand (1985) reported negative heterosis for days to flowering, plant height, capitulum diameter and negative heterosis for 1000-seed weight.

Anashchenko et al. (1985) reported highest oil yield of 9.0 to 40.0 per cent in some single cross hybrids, while Reddy et al. (1985) observed heterobeltiosis corresponding to their better parent when exceeded 100 per cent and 10 per cent for seed yield and oil content respectively. Sheriff et al. (1985) noticed both positive and negative heterosis over better parent for number of filled seeds per capitulum and seed yield.

Giriraj et al. (1986) in their study consisting of 10 hybrids observed average heterosis ranged from -7.7 per cent for days to 50 per cent flowering to 192.4 per cent for achene yield per plant. These authors found that the characters viz., number of filled achenes, head diameter and 100-achene weight contributed 37.7, 15.2 and 9.7 per cent respectively towards heterosis for achene yield. Lawrence (1986) reported positive heterosis for days to 50 per cent flowering, number of filled seeds per head and number of unfilled seeds per head where as for plant height and 100-seed weight it was found to be both positive and negative. A positive heterosis was also observed for head diameter, 1000-seed weight and yield per plant by Cruz (1986). On evaluation of certain cross combinations, Sharma et al. (1987) recorded heterosis for days to maturity, oil content and seed yield per plant.

Vanisree (1987) recorded both positive and negative heterosis for days to 50 per cent flowering, number of leaves per plant, stem diameter and 100-seed weight, Where as Vagvolgyi (1987) reported heterosis for 1000-achene weight especially oil content. Naik *et al*. (1988) studied seed yield and eleven yield components in 36 F_1 hybrids derived from crosses between three cytoplasmically male sterile lines and twelve restorers. Appreciable heterosis was observed for all characters. Heterosis for yield per plant was chiefly attributable to heterosis for percentage filled seeds per head and head diameter.

Sreedhar (1989) observed positive heterosis for plant height and head diameter, while positive and negative heterosis for days to 50 per cent flowering, stem diameter, number of leaves per plant, number of filled seeds per head, number of unfilled seeds, 100-seed weight, oil content and yield per plant.

Laxmi Kumari (1990) reported both positive and negative heterosis for days to 50 per cent flowering, number of leaves, stem diameter and 100-seed weight, while positive heterosis for plant height, head diameter, number of filled seeds per head, oil content and seed yield per plant. In other study, Chidambaram and Sundaram (1990) recorded significant effects in desirable direction for days to 50 per cent flowering on the expression of heterosis for earliness and significant positive heterosis for plant height, head diameter, number of leaves, 100-seed weight and seed yield per plant.

Sudharani (1992) recorded positive heterosis for characters days to 50 per cent flowering, plant height, head diameter, 100-seed weight and seed yield per plant in 28 hybrids of sunflower derived from four cytoplasmic male sterile lines and seven restorer lines

Shashikala (1992) recorded a high degree of heterosis for all the ten biometrical characters viz., days to 50 per cent flowering, plant height, stem diameter, number of leaves per plant, head diameter, number of filled seeds per capitulum, number of unfilled seeds per capitulum, 100-seed weight, oil content and seed yield per plant.

2.1.2 Physiological Parameters

The growth analysis (technique) helps in understanding the growth pattern and also contribution of various plant components to economic yield. It also aids in finding-out the growth and yield characters directly relevant to the productivity of crops and thus forms the basis for manipulation of productivity. A knowledge of physiological variations of the cultivars may be helpful in manipulating for seed yield and oil yield. The understanding of physiological parameters and source-sink relationship appears necessary to assess the pattern of partitioning of the assimilates which largely decides the yield potential.

Whaley (1952) studied the physiological basis for heterosis, and concluded that heterosis arises vice numerous physiological mechanisms and frequently including the inheritance of the Relative Growth Rate (RGR) of the faster growing parent and sometimes overdominance for RGR.

Kheiralla and Willington (1962) and Peat and Willington (1965) in tomato observed that heterosis for RGR was apparent only during initial and final growth, the latter resulted in slower decline of RGR on approaching maturity. In a study with six parents and seven hybrids by Sarathe and Dabral (1969), noted heterosis for leaf area in sesame. Allison (1971) found that both Net Assimilation Rate (NAR) and Relative Growth Rate (RGR) of the corn hybrids to be heterosis, exceeding values of the parents by 15 per cent.

Deshmukh and Bhapkar (1979) reported heterosis for early growth, Leaf Area Index (LAI) and Net Assimilation Rate (NAR) during pod formation and seed filling stages in chick pea and indicated that rapid early growth and maintenance of LAI at a high level with higher NAR during pod formation and filling stage has great influence on the heterosis for grain yield.

Gupta et al. (1980) observed significant heterosis for Relative Growth Rate (RGR) throughout the growth period for F_1s involving Jai and PS-10 parents of cotton.

For NAR, on the other hand more of the hybrids exhibited significant heterosis at all the stages of plant growth. They concluded that heterosis in physiological traits was low, the hybrid breeding programme could not be suggested. Hybrids which are showing heterosis have been advocated to use in the varietal breeding programme.

Gautam and Jain (1985) reported heterosis for leaf area in wheat, however concluded that it was not related to grain yield. Similar observations were made by Nijhawan and Chandra (1986) in mungbean and Singh et al. (1986) in sesame.

Anitha (1988) while studying heterotic effects in sesame revealed that most of the crosses were exhibiting heterosis and heterobeltiosis for LAI.

Madhavi (1988) reported higher levels of heterosis for different cross combination for seed yield and yield components on one hand, and physiological traits such as drymatter production, Leaf Area Index, Specific Leaf Weight and chlorophyll content on the other hand and suggested genetically divergent parents, which could be used in groundnut hybridization.

Haripriya (1989) reported that out of 36 hybrids of sesame, 23 recorded significant positive heterosis over their mid parental value and 13 hybrids recorded significant positive heterobeltiosis. The good general combiners which are involved in these crosses also could be exploited for improving LAI in sesame, being additive genetic component prevailing in these crosses.

Damodar (1992) recorded significant heterosis for LAI, CGR, RGR and NAR in 21 hybrids of sesame. Vanisree (1992) reported heterosis in desirable direction for LAI, NAR and harvest index in 15 hybrids of sesame. Kanakadurga reported positive heterosis for leaf area and harvest index in a line x tester analysis involving 28 hybrids of sesame obtained from 4 male sterile lines and 7 restorer lines.

2.2 COMBINING ABILITY

2.2.1 Seed Yield and Yield Contributing Characters

Combining ability is the ability of an inbred line to transmit desirable performance to its hybrids. It helps the plant breeders in identifying parents to be utilised in breeding programme. Thus the combining ability is frequently employed to identify desirable parents and to study the value of genetic variation. The concept of combining ability was first put forward by Sprague and Tatum (1942) using single crosses in maize. Combining ability is partitioned into general combining ability (gca) and specific combining ability (sca). They defined general combining ability (gca) as the average performance of a line over a series of crosses and specific combining ability (sca) is the deviation in performance of a cross combination predicted on the basis of gca of the parents. They attributed gca to additive effects of genes, while sca to dominant deviation is an epistatic interaction. (non - additive effects). Later Henderson (1952) defined sca as the deviation from average of an infinitely large number of progenies of two individuals. Sprague and Federer (1951) and Rojas and Sprague (1952) examined, the combining ability has not only involved dominance and epistasis but a considerable amount of genotype x environment interaction. However, Griffing (1956) expressed that general combining ability involved both additive effects as well as additive and additive interaction.

Several research workers have studied combining ability and nature of gene action in sunflower.

Putt (1964) was the first person to study the combining ability effects in sunflower. In his study involving a diallel set developed from 16 inbred lines found that the mean squares of general combining ability and specific combining ability for seed yield and oil percentage were highly significant. Mean squares of general combining ability for seed yield was 3.3 times higher than that of specific combining ability and for oil per cent the ratio was 11 times higher. In another study, Putt (1966) reported significant mean square for gca and sca for all the characters. Estimates of gca were greater than those for sca for days to flowering, maturity, bushel weight and oil per cent. Kovacik and Skaloud (1972) observed great difference in gca for plant height and seed yield per plant and a high specific combining ability for seed yield per head and oil content in F_1 hybrids developed through 4 x 4 diallel mating system. Klimov (1974) observed both low and high gca estimates for different varieties.

Anashchenko and Razhkova (1974) reported high estimates of gca for seed yield in the F_1 hybrids. Similarly, Alba and Porceddu (1975) reported the importance of high gca for plant height, yield per plant, head diameter and flowering date in 96 F_1 hybrids. Rao and Singh (1977) reported significant additive genetic variance for plant height, head diameter, 1000-seed weight and oil content, whereas dominant gene action was reported for days to flowering and number of filled seeds per plant. Rozhkova (1978b) observed the performance of additive gene action for the characters studied. Sindagi et al. (1979) observed greater magnitude of general combining ability for oil content and test weight and greater effects of specific combining ability for the number of achenes, seed yield, capitulum diameter, oil content and test weight.

According to Dua (1979) additive genetic variance was relatively more stable with respect to number of days to flowering, number of days to maturity and oil content and dominant component in case of yield per plant, plant height and 100-seed weight. Sudhakar (1979) recorded additive genetic variance for number of leaves, yield and oil content while non-additive variance for other characters.

Rao (1980) in his study involving 8 x 8 diallel excluding reciprocals realised the preponderance of dominance gene effects in the control of number of days to flowering, plant height, number of leaves and oil content. Furedi and Frank (1981) in their study involving 10 x 10 complete diallel reported the superiority of gca for achene yield and high effects of gca than sca effects. Similarly, Rozhkova (1982) also observed highly significant effects in four per cent of the total crosses.

Tuberosa et al. (1982) in their report on 24 hybrids involving 6 cytoplasmic male sterile and 4 fertile lines of sunflower observed that gca effects in the seed parents were significant for every character except oil yield and achene yield where as gca effects in the pollen parents were significant for all the characters. Further, the sca effects were significant for every character except oil content and plant height in pollen parents. However, sca for seed yield and oil content were greater than gca effects in both the seed and pollen parents. Dua and Yadav (1983) have assessed combining ability from a diallel cross of 12 diverse varieties and inferred the predominance of dominant gene action for all the characters except days to flowering and days to maturity. In another study Manjunath and Goud (1983) have estimated combining ability for several characters involving 10 x 10 diallel crosses and found that additive effects were more important than dominant effects for number of days to flowering but converse was true for number of days to maturity. In crosses involving 22 exotic inbreds and 2 testers Shankara (1983) reported high gca for most of the important yield related traits and further observed the importance of non-additive gene action for 7 traits and additive gene action for 3 traits.

In a line x tester analysis for 14 inbreds Kadkol et al. (1984) reported that all the characters, except days to flowering were controlled predominantly by non-additive gene action. Sudhakar et al. (1984) observed the phenomena of additive gene action for seed yield, hull and oil content and non-additive gene action for days to flowering, capitulum diameter, days to maturity, number of filled seeds and 100-seed weight. Pathak et al. (1985) reported the preponderance of non-additive gene action for plant height, head diameter, 1000-achene weight, yield per plant, achene filling, achenes per plant and oil content. Cruz (1986) recorded that variance due to the interaction of line x testers was significant only for head diameter indicating the predominance of non-additive gene action for this trait while additive gene action for plant height. Giriraj *et al*. (1987) reported predominance of non-additive gene action for days to flowering, plant height, 100-seed weight and seed yield and also observed that the crosses involved parents with high x low or low x low gca effects recorded high sca effects. Vanisree *et al*. (1988) reported non-additive gene action for days to 50 per cent flowering, plant height, head diameter, stem diameter, seed filling per cent, number of leaves per plant, 100-seed weight, oil per cent and seed yield per plant. Similarly Sreedhar (1989) and Kumari (1990) in their separate studies also reported non-additive gene action for several characters in sunflower.

Sudharani (1992) reported predominance of non-additive gene action for days to 50 per cent flowering, plant height, head diameter, 100-seed weight, oil content and plant yield. Shashikala (1992) reported that the parents possessed significant gca effects for several characters and the gene action was found to be predominantly non-additive for all the yield and yield contributing characters studied.

2.2.2 Physiological Parameters

Deshmukh and Bhapkar (1982) observed non-additive gene action for Leaf Area Index (LAI), Crop Growth Rate

(CGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) in chick pea and suggested progeny selection for exploiting additive genetic variance controlling the expression of characters in Phule G-S, a best general combiner. Mahon (1983) also observed predominance of non-additive gene action for the physiological attributes viz., LAI, CGR, RGR and NAR.

Sasi Kumar et al. (1983) observed additive gene effects for leaf area in some of the tobacco crosses, Sharma and Saxena (1983) noticed predominance of additive gene action and high narrow sense heritability for leaf area, Specific Leaf Weight (SLW), fresh leaf weight, petiole length and petiole fresh weight. They suggested that improvement for any of these traits can be achieved through simple selection procedures such as pedigree and mass selection in pigeon pea.

The combining ability analysis in mungbean studied by Nijhawan and Chandra (1985) showed the mean squares due to the gca and sca were significant for all characters. From this study, it appears that upto bud initiation stage, substantial components of genetic variance for vegetative phase T-O values (a cumulative leaf areas integrated over the growth period), were governed by additive causes. However, the non additive component became important for T-O value after the bud initiation stage (reproductive phase). The sca for leaf area was relatively quite high as compared to gca indicating predominance of non-additive gene action.

Nijhawan and Chandra (1986) studied the components of genetic variance for Leaf Area Ratio (LAR) in 10 parent half diallel crosses of mungbean. Their study revealed that sca variance exceeded gca variance by many times and it was concluded that the predominant form of gene action for LAR in the material at hand was non-additive which includes dominance and epistatic forms of genic interactions.

Mangat and Satiya (1987) recorded data on morphological and physiological traits such as Early Growth Vigour (EGV), growth rate by weight (dry weight per plant per unit time), flag leaf area (cm^2), Net Assimilation Rate (NAR) (mg/sqcm/day) and harvest index in pearlmillet. It was concluded that both additive and non-additive gene effects are important for most of the morphological and physiological traits.

Baoncelli et al. (1987) reported, in a 4 x 4 complete diallel cross estimates of general combining ability and specific combining ability for mean plant growth rates from emergence to heading and from heading to anthesis, for Leaf Area Index at three growth stages and for harvest index, and phenotypic and genotypic correlations between these characters and seed yield per plant, suggested that mean plant growth rate at both stages was useful as a selection criterion.

Yadav and Hari Singh (1987) observed that LAD, NAR and LWR were predominantly controlled by additive gene effect while LAI, CGR and LAR were largely controlled by dominant gene effects in mustard.

Combining ability studies in sesame by Anitha (1988) revealed that both additive and non-additive gene actions were predominant for Leaf Area Index and suggested biparental mating followed by pedigree method of breeding for improvement of this character.

In a 9 parental diallel cross Haripriya (1989) observed the gca: sca ratio of 1:1 indicated equal importance of both additive and non-additive gene action for Leaf Area Index at 60th day after emergence in sesame. She concluded that parents showing high gca in positive direction can be used as good donors for improvement of this characters.

Line x tester analysis in Pennisetum was done by Mungse et al. (1990) to study the combining ability for grain yield and other physiological parameters namely Average Growth Rate (AGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) in pearl millet, during

Kharif, rabi and summer seasons. Both additive and non-additive genetic variances played important role though the former was more important during all the seasons. Combining ability variances were very sensitive to seasonal changes and most of these physiological parameters recorded inconsistent combining ability variances during different seasons.

Nevado and Cross (1990) observed highly significant mean squares for gca for RGR and other yield contributing characters in maize synthetics and concluded that it should be easier to select parents of high performing progenies for kernel row number, kernel weight, Relative Growth Rate, leaf length and silking date than for kernels per row or grain yield.

Damodar (1992) reported predominance of additive gene action for LAI, CGR, RGR and NAR in 21 hybrids of sesame derived from diallel cross of seven genotypes. Vanisree (1992) reported both additive and non-additive gene action for LAI and NAR whereas non-additive gene action for harvest index in her studies with 15 hybrids of sesame. Kanakadurga (1992) recorded non-additive gene action for LAI and harvest index in 28 corsses of sesame involving 4 male sterile lines and 7 restorer lines.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The present investigation was undertaken with a view to study the heterosis, combining ability and magnitude of gene action for various growth and yield parameters in sunflower. The F_1 material was generated by effecting crosses during winter, 1993. A field trial was laid out during *rabi* summer, 1994 at Agricultural College Farm, Hyderabad, which is situated at an altitude of 542.60 metres above MSL, and geographically it lies at a latitude of $80.5^{o}N$ and a longitude of $77.53^{o}E$.

3.1 MATERIALS

Four male sterile source of sunflower (*Helianthus annuus* L.) viz., CMS 851, CMS 300, CMS 302 and CMS 7-1 were utilized for the study. The ten restorers (R) which were used as testers are as follows:

1. RHA 271
2. RHA 272
3. RHA 297
4. RHA 298
5. RHA 586
6. RHA 859
7. MRHA -1
8. bD-1
9. 111-R
10. IB-29

3.2 METHODS

The crossing block was maintained with a spacing of 45 x 30 cm in winter, 1993. Fertilizer dose of 30 kg N, 90 kg P and 30 kg K per hectare was applied as basal dose. The remaining part of the nitrogen (30 kg N) was applied at the time of flowering and seed filling stage. Weeding and intercultivation were done twice during the crop growth period i.e., at 15 and 45 days after sowing (DAS). Plant protection measures were provided against pests and diseases.

3.2.1 Crossing Technique

Each male sterile line was sown in 10 rows while each restorer was sown in 2 rows. The male sterile heads were covered with paper bags just before the emergence of stigmas from the peripheral rows of disc florets. The heads of the restorer lines were also covered with paper bags to avoid contamination. Pollen from the concerned male parent was collected on a butter paper bag during morning hours (8 am to 11 am) and applied to the stigmas of the male sterile head with a piece of sterile cotton. The paper bags were replaced after pollination. The butter paper bags and sterile cotton were changed for every cross to avoid contamination. The pollination was continued till all the disc florets had opened.

3.2.2 Field Plot Technique

The 40 F_1 s in single row plots and their parents in 3 row plots with three checks were sown during <u>rabi</u>-summer of 1994 in randomized complete block design replicated thrice with a spacing of 45 cm between rows and 30 cm between hills with a row length of 5.00 m. A fertilizer dose of 30 kg N: 90 kg P and 30 kg K per hectare was applied as a basal dose at the time of sowing. The remaining nitrogen (30 kg N) was applied at flowering and seed filling stages. Effective plant protection measures were undertaken as a preventive measure against possible infection of pests and diseases and suitable agronomic practices were followed to raise healthy crop.

3.2.3 Observations Recorded

3.2.3.1 Biometric Observations

From each entry, 5 randomly selected plants were tagged in each replication to record the following observations.

3.2.3.1.1 Days to 50 per cent flowering: Number of days taken for the completion of flowering of 50 per cent plants in each treatment was recorded.

3.2.3.1.2 Plant height: The height of a fully matured plant was measured in centimetres from the ground level to the basal surface of the capitululm.

3.2.3.1.3 Capitulum diameter: The diameter of the mature head was measured in centimetres.

3.2.3.1.4 100-seed weight: The weight of 100 seeds was recorded in grams on a digital electronic top pan balance.

3.2.3.1.5 Oil content: The oil content of seeds was determined by Nuclear Magnetic Resonance (NMR) on a random sample of approximately 12 g of seed and expressed as a per cent.

3.2.3.1.6 Seed yield per plant: The seed yield per plant was weighed and expressed in grams.

3.2.3.2 Physiological Parameters

To study some of the physological parameters, 3 randomly selected plants from the middle of the plot from each entry replication-wise were sampled at 30, 45, 60 and 75 DAS to measure the leaf area and dry matter production. The period under observation represents active stages of plant growth in sunflower. Hence, the observations were used to calculate various physiological attributes.

3.2.3.2.1 Leaf area: From the total leaves of the sample a subsample of 1/5th or 20 per cent of the total leaves of all the categories viz., young, medium and old leaves were randomly selected. These leaves were fed separately to area meter (LI-3100, Lincoln, Nebraska, USA) to obtain leaf area in square centimetres directly. The dry weight of these sampled leaves were taken and expressed in grams. From the leaf area and dry weight of the subsample, the total leaf area of the sample was computed.

3.2.3.2.2 Dry matter accumulation: After sampling all the plants were separated into the components viz., leaves, stem, flower, seed (1st component) and roots (2nd component) according to the stage of sampling. All the plant parts were dried uniformly at 70^{o}C for 72 hours and the dry weight of these two components were recorded separately and expressed in grams.

3.2.3.2.3 Growth analysis: The pattern of dry matter accumulation in different plant parts and the variation in assimilation area were studied over the growing period. All plant components excluding roots were taken into consideration. The data generated above were used for calculating Leaf Area Index (LAI), Crop Growth Rate (CGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) by following the formulae of Watson (1952), Radford (1967) and Sestak et al. (1971).

3.2.3.2.4 Leaf Area Index (LAI)

$$LAI = \frac{\text{Leaf area}}{\text{Unit land area}}$$

3.2.3.2.5 Crop Growth Rate (CGR) (g m^{-2}day^{-1})

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{p}$$

where, W_1 and W_2 are the total plant dry weights at times t_1 and t_2 respectively and 'p' is the unit land area.

3.2.3.2.6 Relative Growth Rate (RGR) ($g\ g^{-1} day^{-1}$)

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

3.2.3.2.7 Net Assimilation Rate (NAR) ($g\ m^{-2} day^{-1}$)

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e A_2 - \log_e A_1}{t_2 - t_1}$$

where A_1 and A_2 are total leaf areas at times t_1 and t_2 respectively.

3.2.4 Statistical Analysis

The recorded data were analysed for the following statistical parameters.

3.2.4.1 Analysis of variance

Analysis of variance of the randomised complete block design for parents + F_1s was carried out as per the line x tester model given by Singh and Chaudhary (1977).

Source	d.f.	M.S.
Replications	(r-1)	
Genotypes (a)	(a-1)	
Parents (p)	(p-1)	
Parents Vs. Crosses	(1)	
Crosses (c)	(c-1)	
Lines (l)	(l-1)	M1
Testers (t)	(t-1)	M2
Lines x Testers	(l-1) (t-1)	M3
Error	(r-1) (z-1)	M4

where, r,a,p,c,l and t are number of replications, genotypes, parents, crosses, lines and testers respectively, and M1, M2, M3 an M4 are the mean squares of lines, testers, lines x testers and error, respectively.

3.2.4.2 Heterosis

Heterosis was considered as the deviation of the F_1 from the better parent and was calculated as per cent using the formula given by Liang et al. (1972).

$$\text{Heterosis percentage} = \frac{\overline{F_1} - \overline{B.P.}}{\overline{B.P.}} \times 100$$

where,

$\overline{F_1}$ = Mean volume of the hybrid for the character under study.

$\overline{B.P.}$ = Better parental value, the mean of the superior parent in the respective cross combination.

Standard heterosis was calculated based on standard checks.

$$\text{Percent standard heterosis} = \frac{\overline{F}_1 - \text{Mean of check}}{\text{Mean of check}} \times 100$$

To test the significance of heterosis, the following formula as suggested by Arunachalam (1980) was utilized.

$$Fcal = \frac{\overline{F}_1 - \text{Mean of better parent or check}}{\sqrt{\dfrac{2 \times EMS}{r}}}$$

where,

r = number of replications

t – cal value was compared with the tabulated value of t at error degrees of freedom.

3.2.4.3 Estimation of combining ability

For the estimation of combining ability of various characters, the line x tester model suggested by Kempthorne (1957) was followed. The linear mathematical model for combining ability analysis is as follows:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + r_k + e_{ijk}$$

where, Y_{ijk} = Any measurable character of the cross ixj in the k^{th} replication.

μ = population mean effect.

$g_{i.}$ = gca effect of the female parent.

$g_{.j}$ = gca effect of the male parent.

s_{ij} = sca effect of the cross (i x j)

r_k = k^{th} replication effect.

e_{ijk} = environmental effect particular to $(ijk)^{th}$ individual.

ANOVA

Source	df	MSS	EMS
Replications	(r-1)		
Females	(d-1)	M_1	E + rI + rdy
Males	(s-1)	M_2	E + rI + rsy
Females x Males	(s-1) (d-1)	M_3	E + rI
Error	(r-1) (sd-1)	M_4	E

Where,

r = number of replications.

s = number of male parents.

d = number of female parents.

y = covariance of half sibs = variance general combining ability.

I = variance specific combining ability.

E = Environmental effect.

3.2.4.4 Estimation of combining ability effects

gca effects of females (g_i) $= \frac{x_{i..}}{sr} - \frac{x_{...}}{sdr}$

gca effect of males (g_j) $= \frac{x_{.j.}}{dr} - \frac{x_{...}}{sdr}$

sca effects of crosses (s_{ij}) $= \frac{x_{ij.}}{r} - \frac{x_{i..}}{sr} - \frac{x_{.j.}}{dr} + \frac{x_{...}}{sdr}$

Variance (g_i) $= \frac{(d-1)}{sdr} \times E$

Variance (g_j) $= \frac{(s-1)}{sdr} \times E$

Variance (s_{ij}) $= \frac{(s-1)\ (d-1)}{sdr} \times E$

Variance (g_i-g_j) females $= \frac{2}{sr} \times E$

Variance (g_i-g_k) males $= \frac{2}{dr} \times E$

Variance ($s_{ij} - s_{1j}$) $= \frac{2\ (s-1)}{sr} \times E$

Variance ($s_{ij} - s_{ik}$) $= \frac{2\ (d-1)}{dr} \times E$

Variance ($s_{ij} - s_{1k}$) $= \frac{(2sd - s - d)}{rsd} \times E$

3.2.4.5 Estimation of components of variance

To calculate the gca and sca variance components, the following formula of Singh and Chaudhary (1977) was followed.

$$\text{Covariance of half sibs (lines)} = \frac{M_1 - M_3}{rs}$$

$$\text{Covariance of half sibs (testers)} = \frac{M_2 - M_3}{rd}$$

$$\text{Covariance of half sibs (average)} = \frac{1}{r(2sd-d-s)}\left[\frac{M_1(s-1)+M_2(d-1)}{s+d-2} - M_3\right]$$

$$\text{Covariance of full sibs} = \frac{(M_1-M_4) + (M_2-M_4) + (M_3-M_4)}{3r} + \frac{6r\ \text{Cov. H.S.} - r(s+d)\text{Cov.H.S}}{3r}$$

$\sigma^2 gca$ = Covariance of half sibs.

$$\sigma^2 sca = \frac{M_3 - M_4}{r}$$

Where,

M_1 = MSS due to males.

M_2 = MSS due to females.

M_3 = MSS due to females x males.

M_4 = MSS due to error.

r = number of replications.

d = number of females.

s = number of males.

gca to sca ratio was calculated to know the type of gene action involved i.e., additive or non-additive.

The gca and sca effects were tested against zero for significance by calculating t-value, by using the following formulae.

$$t\text{-cal} = \frac{\hat{g}_i - 0}{SE(g_i)} \; ; \; t\text{-cal} = \frac{\hat{g}_i - 0}{SE(g_i)}$$

$$t\text{-cal} = \frac{\hat{s}_{ij} - 0}{SE\,(s_{ij})}$$

t-cal value is compared with t-table value at error degrees of freedom.

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RESULTS

CHAPTER IV

RESULTS

The experimental material comprising of 4 male sterile lines and 10 restorers were crossed in a line x tester programme. The resulting 40 hybrids along with their 14 parents and 3 checks were sown in a randomized complete block design. The data was collected on six quantitative characters viz., days to 50 per cent flowering, plant height, capitulum diameter, 100 seed weight, oil per cent and yield per plant and on four physiological parameters viz., Leaf Area Index (LAI), Crop Growth Rate (CGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR).

The data from present experiment was statistically analysed and are presented under the following heads.

4.1 Analysis of variance

4.2 Mean performance of parents and crosses

4.2.1 Yield and yield contributing characters

4.2.2 Physiological parameters

4.3 Heterosis

4.3.1 Yield and yield contributing characters

4.3.2 Physiological parameters

4.4 Combining ability analysis

4.4.1 Estimates of gca and sca variances

4.1 ANALYSIS OF VARIANCE

The analysis of variance (Table-1) revealed that the genotypes registered highly significant differences among themselves for all the characters. The parents showed significant differences for all the characters except for oil per cent. Crosses were found to be significant for all the characters. Similar behaviour was exhibited by the mean squares of parents vs crosses for all the characters.

The effect of crosses was partitioned into lines, testers and interaction effects. The lines were found to be significant for days to 50 per cent flowering, plant height, capitulum diameter, 100 seed weight, oil per cent, Leaf Area Index (LAI) and Relative Growth Rate (RGR). With regard to testers, only the characters days to 50 per cent flowering and capitulum diameter were found to be significant. The interaction effects were found to be significant for all the characters.

Table 1: Analysis of variance for combining ability for the ten characters studied in Line x Tester (4x10) experiment in sunflower

Source	d.f.	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Yield per plant (g)	Leaf Area Index (LAI)	Crop Growth Rate (CGR)	Relative Growth Rate(RGR)	Net Assimilation Rate(NAR)
Replications	2	6.48**	0.56	0.08	0.0015	0.88**	0.51	0.0000	0.0005	0.0000**	0.10
Genotypes	53	10.85**	1151.82**	15.36**	0.8720**	40.91**	55.09**	1.9866**	164.3310**	0.0005**	41.28**
Parents	13	4.86**	145.86**	3.11**	0.5146**	24.98**	28.09**	0.7707**	42.4980**	0.0004**	25.74**
Parents vs. crosses	1	236.50**	26147.25**	643.97**	12.1052**	1019.70**	2110.07**	27.1443**	3208.4850**	0.0041**	92.76**
Crosses	39	7.06**	846.23**	3.33**	0.7031**	21.13**	11.39**	1.7468**	126.8880**	0.0004**	45.13**
Lines	3	36.73**	7265.29**	9.01**	1.8569*	63.20**	15.61	6.0080*	685.9900**	0.0019**	11.46
Testers	9	10.48**	288.65	5.01*	0.6233	23.34	10.51	0.9722	117.7100**	0.0003	28.35
Lines x Testers	27	2.63**	318.87**	2.13**	0.6016**	15.71**	11.22**	1.5315**	67.8240**	0.0003**	54.47**
Error	106	1.32	2.92	0.07	0.0192	0.13	0.38	0.0001	2.4220	0.0000	0.08

* Significant at 5 per cent level; ** Significant at 1 per cent level

4.2 MEAN PERFORMANCE OF PARENTS AND HYBRIDS

Mean performance of (14) parents and (40) hybrids in the present study for yield and yield contributing characters (Table-2) and certain physiological parameters are presented in Table-3.

4.2.1 Yield and Yield Contributing Characters

4.2.1.1 Days to 50 per cent flowering

The mean number of days to 50 per cent flowering among the female parents ranged from 55.33 (CMS 302) to 59.33 (CMS 851 and CMS 300) days. Among the male parents, the range was from 56.00 (RHA 271) to 59.67 (RHA 298) days.

The hybrids exhibited a range of 52.33 (CMS 302 x RHA 297) to 58 (CMS 851 x IB-29) days. The hybrids which flowered very early were CMS 302 x RHA 297 (52.33 days), CMS 302 x MRHA-1 (52.67 days), CMS 302 x RHA 271 (53.00 days), CMS 302 x RHA 586 (53.33 days) and CMS 300 x RHA 272 (53.33 days).

4.2.1.2 Plant height (cm)

The mean plant height of the female parents ranged between 82.80 cm (CMS 7-1, CMS 302) and 94.00 cm (CMS 300). Among the male parents the range was from 85.87 (RHA 586) to 104.60 cm (bD-1).

Table 2: Mean performance of parents and hybrids of sunflower for the yield and yield contributing characters

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Seed yield per plant (g)
Lines						
CMS 851	59.33	87.40	8.43	3.35	31.44	21.83
CMS 300	59.33	94.00	7.83	3.03	33.07	16.70
CMS 302	55.33	82.80	8.37	4.30	32.26	14.37
CMS 7-1	59.00	82.80	8.63	4.17	38.02	23.20
Testers						
RHA 298	59.67	88.67	5.53	3.30	29.45	15.17
bD-1	59.33	104.60	6.73	3.40	32.45	17.60
RHA 859	58.67	90.60	6.70	3.57	31.18	17.67
RHA 271	56.00	95.13	6.37	3.59	30.43	18.50
MRHA-1	58.33	100.47	6.60	3.52	29.58	17.53
RHA 297	57.67	99.20	6.47	3.62	36.49	17.87
111-R	57.67	88.93	7.80	4.20	35.04	23.77
IB-29	57.67	88.00	8.80	3.99	33.02	21.77
RHA 272	58.67	100.33	6.53	3.62	37.57	16.37
RHA 586	58.00	85.87	7.07	3.86	36.08	22.17
Hybrids						
CMS 851 x RHA 298	56.00	122.53	11.70	4.08	38.59	26.38
CMS 851 x bD-1	57.33	145.60	12.03	3.58	38.71	26.02
CMS 851 x RHA 859	57.33	140.73	11.87	4.20	34.82	26.94
CMS 851 x RHA 271	55.33	145.00	11.83	4.10	37.89	28.86
CMS 851 x MRHA-1	57.33	145.33	12.57	3.65	36.83	27.22
CMS 851 x RHA 297	54.67	139.53	11.20	4.23	38.69	27.94
CMS 851 x 111-R	56.67	155.93	14.73	5.02	36.85	27.08
CMS 851 x IB-29	58.00	138.47	12.47	3.89	37.48	27.08
CMS 851 x RHA 272	57.33	149.73	11.90	4.78	40.09	26.96
CMS 851 x RHA 586	57.00	129.80	11.83	4.15	34.78	26.07
CMS 300 x RHA 298	55.67	114.80	10.53	4.01	38.65	27.37
CMS 300 x bD-1	54.33	110.20	11.30	4.13	41.15	27.32
CMS 300 x RHA 859	54.67	108.07	11.30	3.95	36.45	28.12
CMS 300 x RHA 271	54.33	118.33	12.00	3.86	36.82	28.42
CMS 300 x MRHA-1	56.33	97.00	11.17	3.83	35.99	28.67
CMS 300 x RHA 297	54.00	87.88	9.63	3.79	36.59	24.42
CMS 300 x 111-R	55.33	85.80	11.27	3.72	39.47	21.86
CMS 300 x IB-29	55.00	99.47	10.30	4.29	39.78	25.35
CMS 300 x RHA 272	53.33	106.73	11.00	4.19	42.93	25.80
CMS 300 x RHA 586	54.00	109.73	11.67	4.58	44.87	27.65

Contd.. Table 2

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Seed yield per plant (g)
CMS 302 x RHA 298	53.67	109.20	11.60	4.04	36.89	26.55
CMS 302 x bD-1	56.67	122.60	12.33	5.89	41.16	28.30
CMS 302 x RHA 859	56.00	107.40	11.47	4.38	37.43	25.00
CMS 302 x RHA 271	53.00	113.80	12.13	4.62	36.58	25.76
CMS 302 x MRHA-1	52.67	128.73	10.97	4.02	38.38	26.42
CMS 302 x RHA 297	52.33	118.53	11.20	3.67	37.85	24.99
CMS 302 x 111-R	54.33	101.53	12.67	3.62	39.81	26.13
CMS 302 x IB-29	56.33	137.20	13.67	4.79	34.55	28.85
CMS 302 x RHA 272	55.00	111.40	12.47	4.41	41.01	24.73
CMS 302 x RHA 586	53.33	117.07	12.47	4.89	40.56	31.33
CMS 7-1 x RHA 298	56.00	109.53	12.47	4.88	43.62	27.72
CMS 7-1 x bD-1	57.33	126.27	13.17	4.65	41.60	25.24
CMS 7-1 x RHA 859	56.33	121.93	10.23	4.48	38.88	29.67
CMS 7-1 x RHA 271	54.33	123.33	10.70	4.36	35.88	31.33
CMS 7-1 x MRHA-1	57.67	108.73	11.47	4.40	43.74	28.77
CMS 7-1 x RHA 297	54.33	112.13	11.00	4.25	44.22	24.63
CMS 7-1 x 111-R	56.33	123.20	12.50	4.73	39.95	31.30
CMS 7-1 x IB-29	57.67	135.60	14.57	4.59	41.36	27.36
CMS 7-1 x RHA 272	54.67	130.83	11.07	4.31	38.89	27.45
CMS 7-1 x RHA 586	85.33	132.20	12.60	5.18	40.80	28.08

The mean plant height of the hybrids ranged from 85.80 (CMS 300 x 111-R) to 155.93 cm (CMS 851 x 111-R). The hybrid CMS 851 x 111-R recorded higher value for mean plant height (155.93 cm).

4.2.1.3 Capitulum diameter (cm)

The mean capitulum diameter among the female parents ranged between 7.83 cm (CMS 300) and 8.63 cm (CMS 7-1). Among the male parents, the range was between 5.53 cm (RHA 298) and 8.80cm (IB-29).

The mean capitulum diameter for the hybrids ranged between 9.63 cm (CMS 300 x RHA 297) and 14.73 cm (CMS 851 x 111-R). The hybrids CMS 851 x 111-R recorded highest mean value (14.73 cm) followed by CMS 7-1 x IB-29 (14.57 cm).

4.2.1.4 100 seed weight (g)

The mean 100 seed weight among the female parents ranged from 3.03 g (CMS 300) to 4.30 g (CMS 302). Among the male parents the range was from 3.30 g (RHA 298) to 4.20 g (111-R).

Among the hybrids, the mean seed weight ranged between 3.58 g (CMS 851 x bD-1) and 5.89 g (CMS 302 x bD-1). The hybrid CMS 302 x bD-1 recorded highest mean value (5.89 g) followed by CMS 7-12 x RHA 586 (5.18 g) and CMS 851 x 111-R (5.02 g).

4.2.1.5 Oil per cent (%)

The mean oil per cent among the female parents ranged from 31.44 (CMS 851) to 38.02 per cent (CMS 7-1). Among the male parents the range was between 29.45 (RHA 298) and 37.57 per cent (RHA 272).

The hybrids recorded mean values ranging from 34.55 (CMS 302 x IB-29) to 44.87 per cent (CMS 300 x RHA 586). The hybrids which recorded high oil per cent were CMS 300 x RHA 586 (44.87%), CMS 7-1 x RHA 297 (44.22%), CMS 7-1 x MRHA-1 (43.74%), CMS 7-1 x RHA 298 (43.62%) and CMS 300 x RHA 272 (42.93%).

4.2.1.6 Yield per plant (g)

The average yield per plant among the female parents ranged from 16.70 g (CMS 300) to 23.20 g (CMS 7-1). Among the male parents, the range was between 15.17 g (RHA 298) and 23.77 g (111-R).

The mean yield per plant in the hybrids ranged between 21.86 g (CMS 300 x 111-R) and 31.33 g (CMS 7-1 x RHA 271 and CMS 302 x RHA 586). The hybrids which showed highest mean yield per plant were CMS 302 x RHA 586 and CMS 7-1 x RHA 271 (31.33 g) followed by CMS 7-1 x 111-R (31.30 g) and CMS 7-1 x RHA 859 (29.67 g).

Table 3: Mean performance of sunflower parents and hybrids for certain physiological parameters : LAI, CGR, RGR and NAR at various growth stages

Source	Leaf Area Index				Crop Growth Rate ($g\ m^{-2}\ day^{-1}$)			Relative Growth Rate ($g\ g^{-1}\ day^{-1}$)			Net Assimilation Rate ($g\ m^{-2}\ day^{-1}$)		
	30 DAS	45 DAS	60 DAS	75 DAS	30-45 DAS	45-60 DAS	60-75 DAS	30-45 DAS	45-60 DAS	60-75 DAS	30-45 DAS	45-60 DAS	60-75 DAS
Lines													
CMS 851	0.0876	1.2787	1.2788	1.1793	12.55	13.18	4.88	0.1214	0.0417	0.0116	40.74	13.82	3.96
CMS 300	0.1355	0.5466	1.2075	1.1428	10.83	9.97	9.42	0.1224	0.0365	0.0227	38.55	12.81	7.89
CMS 302	0.1524	0.5249	1.0463	0.9885	12.04	10.46	8.98	0.1278	0.0379	0.0208	40.14	20.11	8.76
CMS 7-1	0.0922	0.4562	1.3628	0.8462	14.41	5.53	6.32	0.1886	0.0217	0.0178	42.75	17.49	2.26
Testers													
RHA 298	0.1525	0.4633	2.0475	1.6945	8.88	13.42	12.84	0.1186	0.0545	0.0275	31.76	12.31	6.93
bD-1	0.1634	0.4618	2.0471	1.9117	9.88	14.09	8.78	0.1224	0.0527	0.0198	34.41	16.54	9.77
RHA 859	0.1031	0.5584	2.9605	2.5813	7.94	17.15	8.07	0.1225	0.0685	0.0176	29.40	14.42	8.88
RHA 271	0.1304	0.6574	1.9637	1.7850	10.54	17.95	15.32	0.1172	0.0552	0.0271	32.32	19.65	4.08
MRHA-1	0.1469	0.6288	1.9739	1.7845	10.51	19.35	16.01	0.1228	0.0634	0.0271	31.65	7.39	8.61
RHA 297	0.1124	0.6248	1.6501	1.5235	13.88	12.41	7.92	0.1231	0.0383	0.0164	46.57	8.69	5.01
111-R	0.0967	0.5266	1.9945	1.8560	9.68	18.05	13.46	0.1265	0.0527	0.0308	37.96	15.08	7.16
IB-29	0.1228	0.5917	1.3006	1.1379	11.75	15.99	10.00	0.1114	0.0490	0.0195	39.37	8.27	8.35
RHA 272	0.0866	0.6081	1.4479	1.1844	8.63	12.86	5.82	0.1171	0.0537	0.0148	32.43	15.67	4.39
RHA 586	0.1060	0.6082	2.0325	1.6187	11.93	11.68	7.91	0.1378	0.0419	0.0174	41.23	19.89	4.31
Hybrids													
CMS 851 x RHA 298	0.1976	1.0089	4.0680	3.7890	16.17	21.25	11.12	0.1340	0.0618	0.0144	32.76	7.66	2.84
CMS 851 x bD-1	0.1625	0.7345	1.7928	1.8980	13.22	24.55	9.52	0.1155	0.0535	0.0140	35.01	9.92	3.14
CMS 851 x RHA 859	0.1783	0.7705	2.0245	1.6409	13.88	21.89	12.70	0.1030	0.0519	0.0182	34.64	16.78	2.13
CMS 851 x RHA 271	0.2245	0.8138	2.2405	1.9758	12.81	18.87	13.61	0.1090	0.0492	0.0218	28.71	14.28	6.57
CMS 851 x MRHA-1	0.2202	0.7862	2.1774	1.9159	12.01	17.46	21.07	0.0935	0.0649	0.0356	27.51	18.60	10.27
CMS 851 x RHA 297	0.1827	0.6949	2.1071	1.9062	13.02	25.60	13.59	0.1714	0.0585	0.0201	34.11	15.58	7.08
CMS 851 x 111-R	0.2130	0.7035	2.2568	2.2405	14.32	23.38	15.04	0.1255	0.0486	0.0218	35.00	11.59	6.98
CMS 851 x IB-29	0.2535	0.7172	1.9949	1.8033	9.11	17.06	16.86	0.1084	0.0538	0.0270	24.44	13.19	8.28
CMS 851 x RHA 272	0.2166	0.9245	2.0937	1.7726	14.61	21.26	15.21	0.1192	0.0516	0.0229	23.03	6.83	7.84
CMS 851 x RHA 586	0.2128	0.7296	2.5832	2.3024	15.17	20.84	17.90	0.1266	0.0487	0.0285	35.59	15.46	7.39

Contd.. Table 3

Source	Leaf Area Index				Crop Growth Rate ($g\ m^{-2}\ day^{-1}$)			Relative Growth Rate ($g\ g^{-1}\ day^{-1}$)			Net Assimilation Rate ($g\ m^{-2}\ day^{-1}$)		
	30 DAS	45 DAS	60 DAS	75 DAS	30-45 DAS	45-60 DAS	60-75 DAS	30-45 DAS	45-60 DAS	60-75 DAS	30-45 DAS	45-60 DAS	60-75 DAS
CMS 300 x RHA 298	0.2849	0.9047	3.0691	2.5003	12.61	16.56	17.22	0.1157	0.0570	0.0255	23.76	11.59	6.26
CMS 300 x bD-1	0.2980	0.6958	2.6187	2.4364	14.43	22.78	19.02	0.1320	0.0446	0.0288	30.92	13.67	7.58
CMS 300 x RHA 859	0.1686	0.6866	2.4000	2.2606	15.54	16.06	18.19	0.1110	0.0579	0.0245	42.68	6.80	7.84
CMS 300 x RHA 271	0.1803	0.6764	2.2623	2.2331	11.97	21.09	16.26	0.1014	0.0494	0.0285	31.96	12.78	6.51
CMS 300 x MRHA-1	0.3263	0.9984	3.5280	3.2543	16.17	16.13	17.95	0.1203	0.0426	0.0265	27.98	13.43	5.24
CMS 300 x RHA 297	0.2157	0.7590	2.2694	1.9653	13.87	14.65	18.08	0.1209	0.0483	0.0313	32.54	10.87	3.59
CMS 300 x 111-R	0.1954	0.8638	2.1294	1.9011	12.42	30.63	21.25	0.1155	0.0738	0.0245	31.35	14.98	4.54
CMS 300 x IB-29	0.2379	1.0332	2.9078	2.4247	13.13	20.42	11.63	0.1260	0.0469	0.0186	24.47	16.37	4.35
CMS 300 x RHA 272	0.2504	1.0390	2.2105	1.9043	15.49	22.13	13.29	0.1215	0.0535	0.0196	27.92	11.84	6.41
CMS 300 x RHA 586	0.1829	0.6696	1.5416	1.6269	16.25	19.76	11.68	0.1191	0.0568	0.0209	37.74	11.75	8.94
CMS 302 x RHA 298	0.2180	0.7954	2.5653	2.2865	14.81	25.07	13.54	0.1274	0.0598	0.0186	28.40	17.73	5.59
CMS 302 x bD-1	0.3544	1.1749	4.1114	3.8337	12.29	24.05	13.47	0.0993	0.0614	0.0200	17.87	13.31	3.39
CMS 302 x RHA 859	0.2054	1.0178	3.1666	2.6752	13.42	23.07	12.18	0.1236	0.0582	0.0185	26.97	9.92	3.19
CMS 302 x RHA 271	0.2973	0.8459	4.0123	3.6582	13.07	32.77	13.53	0.1142	0.0743	0.0108	25.75	16.47	2.75
CMS 302 x MRHA-1	0.2262	0.8025	3.2171	2.8911	14.32	37.72	16.87	0.1153	0.0771	0.0176	31.29	15.36	5.60
CMS 302 x RHA 297	0.1754	0.7327	2.3751	2.0843	11.89	26.92	13.44	0.1101	0.0698	0.0184	30.57	16.68	5.98
CMS 302 x 111-R	0.2767	1.0142	3.9291	3.5910	11.39	42.73	13.83	0.1136	0.0953	0.0197	20.71	14.45	5.12
CMS 302 x IB-29	0.2082	0.7634	2.1186	1.8573	12.34	35.73	19.28	0.1203	0.0792	0.0172	29.59	14.94	7.55
CMS 302 x RHA 272	0.2552	0.9122	4.2897	3.9155	13.73	39.76	14.89	0.1247	0.0827	0.0162	24.82	8.23	2.73
CMS 302 x RHA 586	0.2637	1.0991	3.5158	3.1972	14.97	19.59	14.81	0.1281	0.0492	0.0211	25.64	13.78	3.49
CMS 7-1 x RHA 298	0.2074	0.6803	1.8526	1.6933	12.25	22.14	13.92	0.1202	0.0616	0.0237	30.98	8.11	4.57
CMS 7-1 x bD-1	0.2101	0.7273	1.7630	1.5127	11.54	20.92	15.16	0.1134	0.0564	0.0197	28.47	16.86	8.45
CMS 7-1 x RHA 859	0.1791	0.7714	2.4774	2.5436	15.26	20.34	12.36	0.1200	0.0629	0.0183	37.99	23.78	2.08
CMS 7-1 x RHA 271	0.3398	1.0443	3.9557	3.6192	12.15	25.69	12.31	0.1186	0.0807	0.0190	19.37	15.49	3.47
CMS 7-1 x MRHA-1	0.2183	0.7050	2.8862	2.4395	10.68	31.21	13.14	0.0800	0.0455	0.0200	25.96	12.59	5.65
CMS 7-1 x RHA 297	0.3564	0.8068	2.7954	2.4243	15.30	19.36	10.92	0.1170	0.0487	0.0167	28.49	17.77	4.18
CMS 7-1 x 111-R	0.2780	0.9992	3.3373	2.8106	17.48	22.39	11.66	0.1236	0.0582	0.0167	30.96	11.65	3.82
CMS 7-1 x IB-29	0.2258	0.7943	2.2752	1.9399	15.37	23.15	12.08	0.1269	0.0685	0.0177	34.88	10.09	5.74
CMS 7-1 x RHA 272	0.2177	0.8260	2.1896	1.8225	13.24	27.75	13.21	0.1194	0.0598	0.0174	29.84	15.45	6.63
CMS 7-1 x RHA 586	0.1805	0.8187	1.7210	1.6125	12.71	22.72	14.32	0.1105	0.0455	0.0216	30.18	15.23	8.65

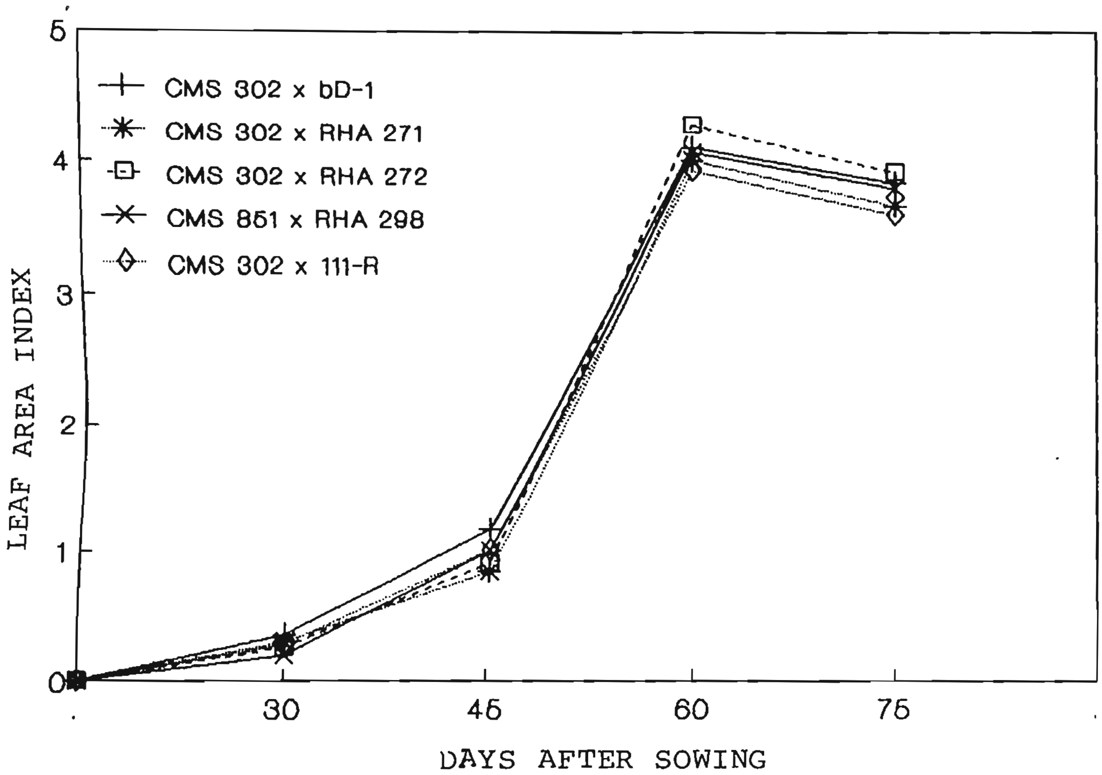

Fig.1: LEAF AREA INDEX (LAI) IN DIFFEENT HYBRIDS OF SUNFLOWER AT VARIOUS GROWTH STAGES

4.2.2 Physiological Parameters

4.2.2.1 Leaf Area Index (LAI)

The LAI showed fluctuations during the growth period. It increased slowly during the early vegetative phase and attained its maximum at the time of seed set (60 DAS) in all the genotypes. Thereafter, it slightly decreased towards maturity. All the parents and hybrids followed the same trend and is depicted in Fig.1.

Among the female parents, CMS 851 showed higher mean values for LAI at all stages except at initial stage (30 DAS).

Among the male parents, RHA 859 showed higher values for LAI at 60 DAS and 75 DAS while exhibited moderately high values at 30 DAS and 45 DAS.

Among the hybrids, CMS 302 x bD-1 showed comparatively high mean values at all stages of growth period viz., 0.3544 (30 DAS), 1.1749 (45 DAS), 4.114 (60 DAS) and 3.8337 (75 DAS).

4.2.2.2 Crop Growth Rate (CGR) in g m^{-2} day^{-1}

The data on CGR (g m^{-2} day^{-1}) recorded at different growth stages in sunflower parents and hybrids are depicted in Fig.2. In general, the mean values for CGR increased upto 45-60 DAS and declined towards maturity. Hybrids exhibited higher values than that of parents.

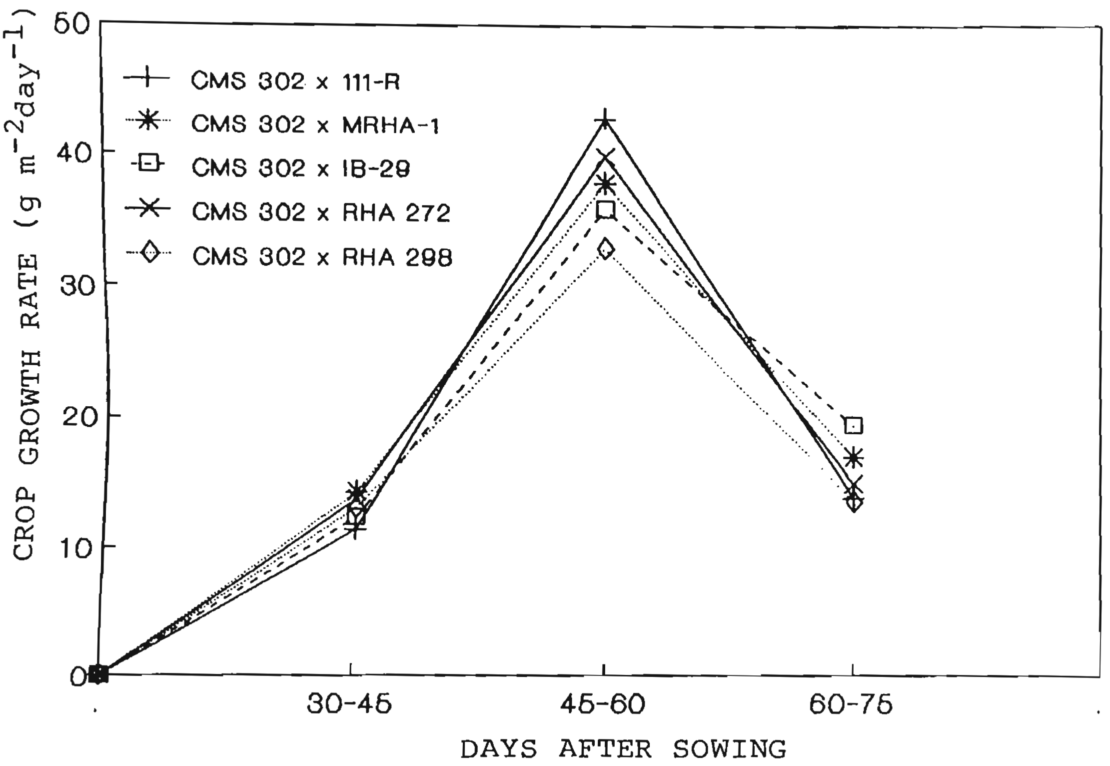

Fig.2: CROP GROWTH RATE (CGR) IN g $m^{-2}day^{-2}$ AT VARIOUS GROWTH STAGES IN DIFFERENT HYBRIDS OF SUNFLOWER

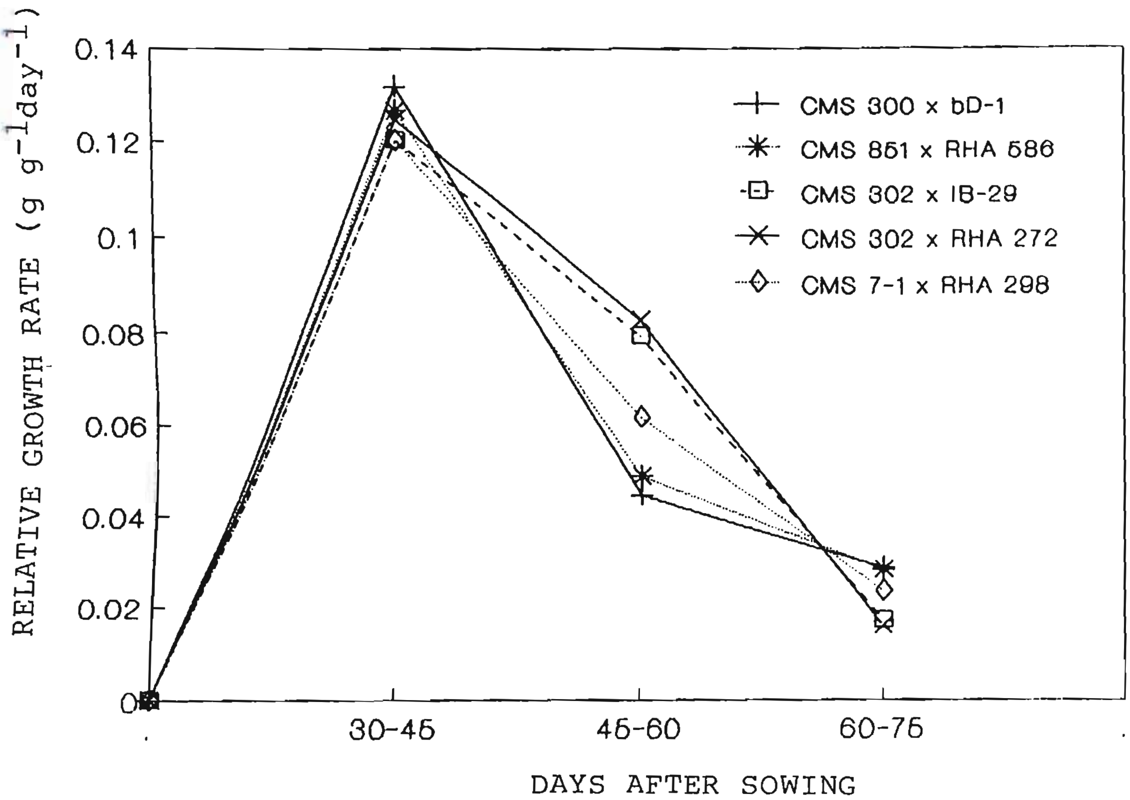

Fig.3: RELATIVE GROWTH RATE IN g $g^{-1}day^{-1}$ IN DIFFERENT HYBRIDS OF SUNFLOWER AT VARIOUS GROWTH STAGES

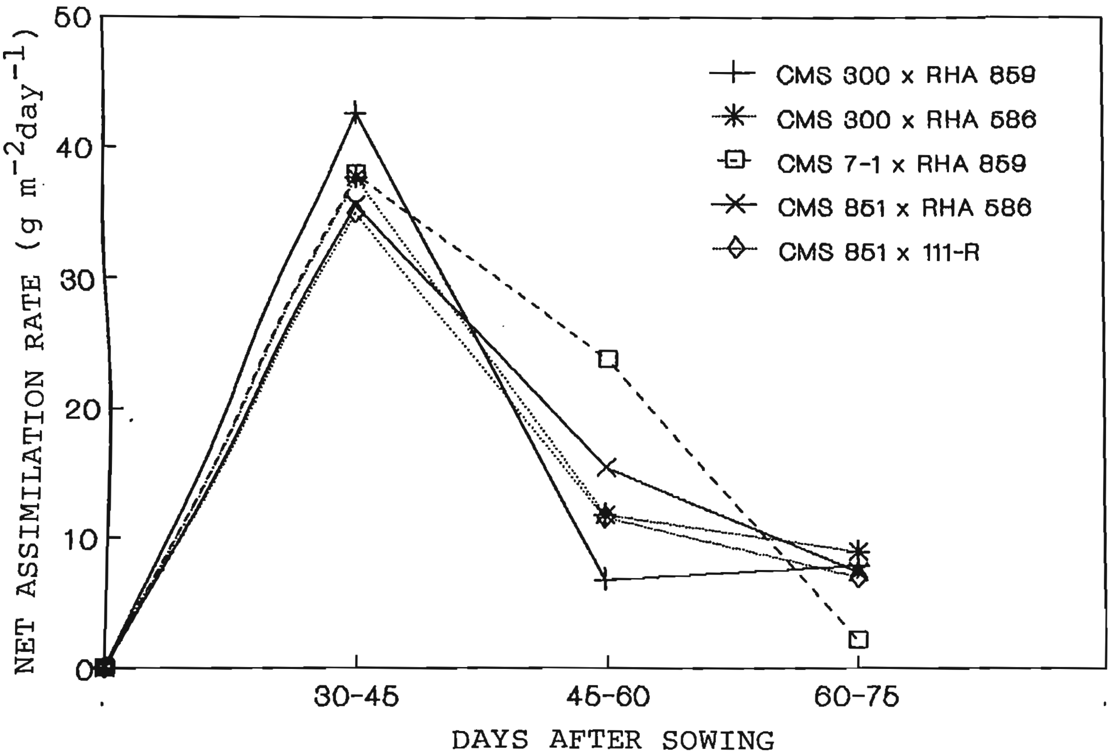

Fig.4: NET ASSIMILATION RATE IN g m^{-2} day^{-1} AT VARIOUS GROWTH STAGES IN DIFFERENT HYBRIDS OF SUNFLOWER

Among the female parents, CMS 302 performed well at all stages while among the male parents MRHA-1 exhibited comparative high mean values at all growth stages. Among the hybrids CMS 300 x 111-R showed higher mean values at all the stages.

4.2.2.3 Relative Growth Rate (RGR) in g $g^{-1}day^{-1}$

In general, RGR (g $g^{-1}day^{-1}$) values increased upto 30-45 DAS and showed gradual decline thereafter (Fig.3). Hybrids showed higher mean values for RGR than parents at all growth stages.

Among the female parents, CMS 302 showed better mean values while among the male parents, MRHA-1 was found to be better at all stages. The hybrid CMS 300 x 111-R showed comparatively higher mean values at all stages.

4.2.2.4 Net Assimination Rate (NAR) in g $m^{-2}day^{-1}$

The trend depicted in Fig.4 indicated that NAR increased upto 30-45 DAS and showed gradual decline towards maturity. Among the female parents, CMS 302 showed better performance for NAR at all stages while the male parent RHA 586 performed well at all stages. Among the hybrids, the performance of CMS 300 x RHA 586 was better at all stages, while some other hybrids showed highest mean values at 30-45 DAS but exhibited steep decline in values at later stages.

Plate No.1. Field lay out of the experiment.

Plate No.2. Variation in plant height between parents and hybrids of sunflower

Plate No.3. The head of sunflower hybrid CMS 851 x 111-R

Plate No.4. The head of sunflower hybrid CMS 7-1 x IB-29

4.3 HETEROSIS

Heterobeltiosis is calculated as the deviation of the hybrids from the better parental mean for the forty hybrids under study and is presented in the Table-4.

4.3.1 Yield and Yield Contributing Characters

4.3.1.1 Days to 50 per cent flowering

All the 40 hybrids recorded negative heterosis over the better parent. No positive heterosis was exhibited by any of the hybrids. Negative heterosis ranged between -2.25 (CMS 851 x RHA 586) and -10.11 per cent (CMS 300 x RHA 272). Significant negative heterosis was expressed by the hybrid CMS 300 x RHA 272 (-10.11%) followed by CMS 302 x RHA 298 (-10.06%).

4.3.1.2 Plant height

Among the forty hybrids, all the hybrids except three of them exhibited significant positive heterosis over better parent. Negative heterosis was exhibited by the hybrids CMS 300 x MRHA-1 (-3.45%), CMS 300 x 111-R (-8.72%) and CMS 300 x RHA 297 (-11.41%). In all the three crosses, the male sterile source was common (CMS 300). Positive heterosis ranged from 5.35 (CMS 300 x bD-1) to 75.34 per cent (CMS 851 x 111-R). Maximum positive heterosis was shown by the hybrid CMS 851 x 111-R (75.34%) followed by CMS 851 x IB-29 (57.35%).

Table 4: Heterobeltiosis in forty F_1 hybrids of sunflower [Line x Tester experiment involving 4 lines and 10 testers] for the ten characters studied

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Yield per plant (g)	Leaf Area Index (LAI)	Crop Growth Rate (CGR)	Relative Growth Rate(RGR)	Net Assimilation Rate(NAR)
CMS 851 x RHA 298	-6.15**	38.20**	38.74**	21.89**	22.77**	19.20**	98.68**	58.27**	13.39**	-24.56
CMS 851 x bD-1	-3.37*	39.20**	42.69**	5.32	19.29**	20.84**	-12.42**	74.11**	1.58	13.80**
CMS 851 x RHA 859	-3.37*	55.33**	40.71**	25.12**	10.76**	23.39**	-31.62**	27.67**	-24.27**	-14.57**
CMS 851 x RHA 271	-6.74**	52.42**	40.32**	14.45**	20.52**	32.21**	14.09**	5.12	-10.98**	-36.31**
CMS 851 x MRHA-1	-3.37*	44.66**	49.01**	3.67	17.17**	24.68**	10.31**	-9.78	2.37**	5.73**
CMS 851 x RHA 297	-7.87**	40.66**	32.81**	16.87**	6.05**	27.99**	27.69**	94.30**	40.10**	-1.43
CMS 851 x 111-R	-4.49**	75.34**	74.70**	19.57**	5.17**	13.93**	13.15**	29.58**	-7.84**	7.04**
CMS 851 x IB-29	-2.25	57.35**	41.67**	-2.84	13.50**	24.02**	53.39**	6.71	9.79**	-11.32**
CMS 851 x RHA 272	-3.37*	49.24**	41.11**	31.83**	6.73**	23.50**	44.60**	61.38**	-3.79**	-21.73**
CMS 851 x RHA 586	-3.93*	48.51**	40.32**	7.58*	-3.58**	17.59**	27.09**	58.18**	16.14**	29.08**
CMS 300 x RHA 298	-6.70**	22.13**	34.47**	21.41**	16.88**	63.91**	49.90**	23.34**	4.58**	13.11**
CMS 300 x bD-1	-8.43**	5.35**	44.26**	21.57**	24.44**	55.21**	27.92**	61.68**	-15.37**	6.24**
CMS 300 x RHA 859	-7.87**	14.96**	44.26**	17.83**	10.24**	59.15**	-18.93**	-6.33	-15.47**	20.97**
CMS 300 x RHA 271	-8.43**	24.39**	53.19**	7.53*	11.34**	53.62**	15.21**	17.51	-10.56**	24.42**
CMS 300 x MRHA-1	-5.06**	-3.45*	42.55**	8.92**	8.84**	63.50**	78.73**	-16.66*	-32.75**	53.82**
CMS 300 x RHA 297	-8.99**	-11.41**	22.98**	4.75	0.29	36.66**	37.53**	18.09	26.00**	-44.94**
CMS 300 x 111-R	-6.74**	-8.72**	43.83**	-11.51**	12.65**	-8.04**	6.77**	69.72**	40.01**	-25.02**
CMS 300 x IB-29	-7.30**	5.82**	17.05**	7.60**	20.29**	16.46**	123.58**	27.71**	-4.28**	0.67
CMS 300 x RHA 272	-10.11**	6.38**	40.43**	15.73**	14.28**	54.49**	52.67**	72.14**	-0.31	-49.50**
CMS 300 x RHA 586	-8.99**	16.74**	48.94**	18.64**	24.37**	24.72**	-24.15**	69.02**	35.37**	32.34**
CMS 302 x RHA 298	-10.06**	23.16**	38.65**	-6.12*	14.37**	75.08**	25.29**	86.78**	9.72**	28.68**
CMS 302 x bD-1	-4.49**	17.21**	47.41**	37.13**	26.85**	60.80**	100.84**	70.61**	16.57**	-41.91**
CMS 302 x RHA 859	-4.55**	18.54**	37.05**	1.94	16.02**	41.51**	6.96**	34.52**	-15.08**	-27.47**
CMS 302 x RHA 271	-5.36**	19.62**	45.02**	7.44**	13.39**	39.23**	104.32**	82.53**	34.46**	27.28**
CMS 302 x MRHA-1	-9.71**	28.14**	31.08**	-6.43*	18.98**	50.68**	62.98**	94.91**	21.61**	8.29**
CMS 302 x RHA 297	-9.25**	19.49**	33.86**	-14.65**	3.73**	39.85**	43.97**	116.99**	82.09**	38.53**

Contd.. Table 4

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Yield per plant (g)	Leaf Area Index (LAI)	Crop Growth Rate (CGR)	Relative Growth Rate(RGR)	Net Assimilation Rate(NAR)
CMS 302 x 111-R	-5.78**	14.17**	51.39**	-15.89**	13.62**	9.96**	97.00**	136.77**	80.66**	9.56**
CMS 302 x IB-29	-2.31	55.91**	55.30**	11.32**	4.63**	32.54**	62.90**	120.85**	61.52**	-0.31
CMS 302 x RHA 272	-6.25**	11.03**	49.00**	2.48	9.17**	51.10**	196.28**	209.28**	54.04**	-49.75**
CMS 302 x RHA 586	-8.05**	36.34**	49.00**	13.76**	12.44**	41.35**	72.98**	67.67**	17.25**	4.50*
CMS 7-1 x RHA 298	-6.15**	23.53**	44.40**	10.57**	14.71**	19.49**	-9.52**	64.91**	12.90**	-47.56**
CMS 7-1 x bD-1	-3.37*	20.71**	52.51**	5.28*	9.42**	8.79**	-13.88**	48.56**	6.96**	45.44**
CMS 7-1 x RHA 859	-4.52**	34.58**	18.53**	1.47	2.25**	27.87**	-16.32**	18.60*	-8.27**	73.94**
CMS 7-1 x RHA 271	-7.91**	29.64**	23.94**	-1.21	-5.64**	35.06**	101.44**	43.13**	46.05**	126.84**
CMS 7-1 x MRHA-1	-2.26	8.23**	32.82**	-0.30	15.03**	23.99**	46.22**	61.28**	-28.23**	-1.46
CMS 7-1 x RHA 297	-7.91**	13.04**	27.41**	-3.77	16.31**	6.15**	69.40**	56.02**	27.13**	32.37**
CMS 7-1 x 111-R	-4.52**	38.53**	44.79**	7.02**	5.07**	31.70**	67.33**	24.11**	10.43**	7.14**
CMS 7-1 x IB-29	-2.26	54.09**	65.53**	3.92	8.77**	17.95**	66.95**	44.79**	39.77**	-32.68**
CMS 7-1 x RHA 272	-7.34**	30.40**	28.19**	-2.42	2.27**	18.33**	51.23**	115.81**	11.43**	-5.62**
CMS 7-1 x RHA 586	-6.21**	53.96**	45.95**	17.40**	7.31**	21.02**	-15.33**	94.34**	8.51**	28.62**

* Significant at 5 per cent level; ** Significant at 1 per cent level

4.3.1.3 Capitulum diameter

All the hybrids exhibited positive heterosis while none recorded negative heterosis over better parent. Positive heterobeltiosis ranged from 17.05 (CMS 300 x IB-29) to 74.70 per cent (CMS 851 x 111-R). Maximum positive heterobeltiosis was exhibited by CMS 851 x 111-R (74.70%) followed by CMS 7-1 x IB-29 (65.53%).

4.3.1.4 100 seed weight

Out of forty hybrids, thirty recorded positive heterobeltiosis while ten recorded negative heterosis over better parent. Positive heterobeltiosis ranged from 1.47 to 37.13 per cent. Negative heterobeltiosis ranged from -0.3 to -15.89 per cent. Highly significant positive heterobeltiosis was exhibited by the hybrid CMS 302 x bD-1 (37.13%) followed by CMS 851 x RHA 272 (31.83%).

4.3.1.5 Oil per cent

Out of forty hybrids, all of them except two recorded positive heterosis over better parent. Positive heterobeltiosis ranged from 0.29 (CMS 300 x RHA 297) to 26.85 per cent (CMS 302 x bD-1). Highly significant positive heterobeltiosis was recorded by the hybrids CMS 302 x bD-1 (26.85%), CMS 300 x bD-1 (24.44%) and CMS 300 x RHA 586 (24.37%).

4.3.1.6 Yield per plant

All the hybrids except one hybrid recorded positive heterosis over better parent. Only one hybrid CMS 300 x 111-R (-8.04%) recorded significant negative heterosis for yield. Positive heterobeltiosis ranged from 6.15 (CMS 7-1 x RHA 297) to 75.08 per cent (CMS 302 x RHA 298). The hybrid which showed maximum positive heterobeltiosis was CMS 302 x RHA 298 (75.08%) followed by the hybrid CMS 300 x RHA 298 (63.91%) and CMS 300 x MRHA-1 (63.50%).

4.3.2 Physiological Parameters

4.3.2.1 Leaf Area Index (LAI)

All the forty hybrids exhibited significant positive and negative heterosis. Out of the forty hybrids, only eight hybrids exhibited negative heterosis and rest of them expressed significant positive heterosis over better parent. Negative heterosis ranged from -9.52 (CMS 7-1 x RHA 298) to -31.62 per cent(CMS 851 x RHA 859), whereas positive heterosis ranged between 6.77 (CMS 300 x 111-R) and 196.28 per cent (CMS 302 x RHA 272).

4.3.2.2 Crop Growth Rate (CGR)

Out of forty hybrids, 34 hybrids showed significant positive heterosis while only one hybrid showed significant negative heterosis of -16.66 per cent (CMS 300 x MRHA-1). Positive heterobeltiosis ranged from 5.12

(CMS 851 x RHA 271) to 209.28 per cent (CMS 302 x RHA 272). Highly significant positive heterosis was showed by hybrids CMS 302 x RHA 272 (209.28%) followed by CMS 302 x 111-R (136.77%) and CMS 302 x IB-29 (120.85%), all of them having common male sterile source.

4.3.2.3 Relative Growth Rate (RGR)

Out of forty hybrids, all of them except two showed significant heterobeltiosis both in positive and negative direction. Twelve hybrids showed significant negative heterosis which ranged between-3.79 (CMS 851 X RHA 272) and-32.75 per cent (CMS 300 x MRHA-1). Twenty six hybrids showed significant positive heterosis for RGR with highest positive heterosis in the hybrid CMS 302 x RHA 297 (82.09%) followed by CMS 302 x 111-R (80.66%) and the lowest significant positive heterosis in the hybrid CMS 851 X MRHA-1 (2.37%).

4.3.2.4 Net Assimilation Rate (NAR)

All the hybrids except four showed significant heterobeltiosis and fourteen hybrids showed significant negative heterosis which ranged between -5.62 (CMS 7-1 x RHA 272) and -49.75 per cent (CMS 302 x RHA 272). Significant positive heterosis exhibited by 22 hybrids, the values of which ranged between 4.50 (CMS 302 X RHA 586) and 126.84 per cent (CMS 7-1 x RHA 271).

4.4 COMBINING ABILITY ANALYSIS

4.4.1 Estimates of gca and sca Variances (Table-5)

4.4.1.1 Yield and Yield Contributing Characters

4.4.1.1.1 **Days to 50 per cent flowering:** The sca variance component (0.4347) was more than the gca variance component (0.0728) indicating the predominance of non additive gene action (gca:sca = 0.1675). The degree of dominance was 1.728.

4.4.1.1.2 **Plant height:** The variance component due to sca (105.31) was greater compared to the variance component due to gca (8.6563) indicating predominance of non additive gene action (gca:sca = 0.0822). The degree of dominance was 2.4663.

4.4.1.1.3 **Capitulum diameter:** The variance component due to sca (0.6888) was more compared to the variance component due to gca (0.0196) indicating predominance of non additive gene action (gca:sca = 0.0284). The degree of dominance was 4.1929.

4.4.1.1.4 **100 seed weight:** The variance component due to sca (0.1941) was more compared to the variance component due to gca (0.0016) indicating predominance of non-additive gene action (gca:sca = 0.0087). The degree of dominance was 7.6307.

4.4.1.1.5 **Oil per cent:** The variance component due to sca (3.6136) was more compared to the variance component due to gca (0.0028) indicating predominance of non-additive

Table 5: Combining ability variance components for the ten characters studied in sunflower

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Yield per plant (g)	Leaf Area Index (LAI)	Crop Growth Rate (CGR)	Relative Growth Rate(RGR)	Net Assimilation Rate(NAR)
σ^2 gca	0.0728	8.6563	0.0196	0.00167	0.0028	0.0888	0.0035	1.3120	0.000002	-0.3065
σ^2 sca	0.4347	105.3100	0.6888	0.1941	3.6136	5.1940	0.5105	21.8007	0.00010	18.1302
σ^2gca/ σ^2sca	0.1675	0.0822	0.0284	0.0087	0.0008	0.0171	0.0068	0.0602	0.0200	-0.1690
Degree of dominance $= \sqrt{\frac{\sigma^2 sca}{2\sigma^2 gca}}$	1.728	2.4663	4.1929	7.6307	25.2720	5.4064	8.4989	2.8824	4.9950	NE

NE - Not estimable

gene action (gca:sca = 0.0008). The degree of dominance was 25.272.

4.4.1.1.6 Yield per plant: The variance component due to sca (5.1940) was more compared to the variance component due to gca (0.0888) indicating predominance of non-additive gene action (gca:sca = 0.0171). The degree of dominance was 5.4064.

4.4.1.2 Physiological Parameters

4.4.1.2.1 Leaf Area Index (LAI): The sca variance component (0.5105) was more than gca variance component (0.0035) indicating the predominance of non-additive gene action (gca:sca = 0.0068). The degree of dominance was 8.4989.

4.4.1.2.2 Crop Growth Rate (CGR): The sca variance component (21.8007) was greater than gca variance component (1.3120) indicating the predominance of non-additive gene action (gca:sca = 0.0602). The degree of dominance was 2.8824.

4.4.1.2.3 Relative Growth Rate (RGR): The variance component due to sca (0.00010) was greater compared to the variance component due to gca (0.000002) indicating predominance of non-additive gene action (gca:sca = 0.0200). The degree of dominance was 4.9950.

4.4.1.2.4 Net Assimilation Rate (NAR): The sca variance component (18.1302) was more than gca variance component (-0.3065) indicating predominance of non additive gene action (gca:sca = -0.1690). The degree of dominance was not estimable.

4.4.2 Estimates of General Combining Ability Effects

4.4.2.1 Yield and Yield Contributing Characters (Table 6)

4.4.2.1.1 Days to 50 per cent flowering: Estimates of gca effects for days to 50 per cent flowering varied from -1.6000 (RHA 297) to 1.3167 (IB-29).

Among the lines CMS 302 (-1.1000) and CMS 300 (-0.7333) recorded significant negative gca effects while lines CMS 851 (1.2667) and CMS 7-1 (0.5667) exhibited significant positive gca effects.

Among the testers, IB-29 (1.3167) and bD-1 (0.9833) recorded significant positive gca effects while the testers RHA 297 (-1.6000) and RHA 271 (-1.1833) recorded significant negative gca effects.

4.4.2.1.2 Plant height: All the parents recorded significant gca effects ranging from -17.247 (CMS 300) to 20.219 (CMS 851).

Among the lines CMS 851 (20.219) recorded highly significant gca effect in positive direction followed by CMS 7-1 (1.329) whereas the lines CMS 300 (-17.247) and CMS 302 (-4.3011) recorded significant gca effect in negative direction.

Significant positive gca effects were expressed by testers i.e., IB-29 (6.636), bD-1 (5.119), RHA 271 (4.069) and RHA 272 (3.627). Highly significant negative

Table 6: Estimates of general combining ability effects of fourteen parents of sunflower for the ten characters studied

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Yield per plant (g)	Leaf Area Index (LAI)	Crop Growth Rate (CGR)	Relative Growth Rate(RGR)	Net Assimilation Rate(NAR)
Lines										
CMS 851	1.2667**	20.2190**	0.3875**	-0.1365**	1.5412**	-0.0721	-0.3369**	-2.6600**	-0.0049**	0.5706**
CMS 300	-0.7333**	-17.2470**	-0.8092**	-0.2701**	0.2548**	-0.6321**	-0.1771**	-3.8550**	-0.0061**	-0.6737**
CMS 302	-1.1000**	-4.3011**	0.2708**	0.1277**	-0.5919**	-0.3221**	0.6594**	6.8240**	0.0115**	-0.3734**
CMS 7-1	0.5667**	1.3290**	0.1508**	0.2789**	1.8784**	1.0263**	-0.1454**	-0.3090	-0.0004	0.4766**
Testers										
RHA 298	-0.1000	-7.0300**	-0.2508**	-0.0529	0.4231**	-0.2105	0.2180**	-2.6210**	0.0009	0.0843
bD-1	0.9833**	5.1190**	-0.3825**	0.2598**	1.6389**	-0.3184	-0.0993**	-0.8010	-0.0052**	-0.5857**
RHA 859	0.6500*	-1.5140**	0.6092**	-0.0504	-2.1202**	0.3024	-0.1536**	-3.5360**	-0.0015*	1.6618**
RHA 271	-1.1833**	4.069**	-0.1592*	-0.0692	-2.2244**	1.4653**	0.4469**	0.7290	0.0042**	-0.0707
MRHA-1	0.5667	-1.0980*	-0.2842**	-0.3284**	-0.2794**	0.6405**	0.2814**	1.7540**	-0.0017**	1.5234**
RHA 297	-1.6000**	-6.5290**	-1.0675**	-0.3217**	0.3239**	-1.6349**	-0.2839**	-2.2435**	-0.0029**	0.5551**
111-R	0.2333	-4.4310**	0.9658**	-0.349	0.0064	-0.5368**	0.2424**	5.9065**	0.0098**	-1.3599**
IB-29	1.3167**	6.6360**	0.9242**	-0.0862*	-0.7253**	0.0318	-0.3466**	0.1115	0.0029**	-0.7449**
RHA 272	-0.3500	3.6270**	-0.2175**	0.1162**	1.7173**	-0.8918**	0.0251**	3.8490**	0.0027**	-3.0366**
RHA 586	-0.5167	1.1523*	0.3158**	0.3954**	1.2398**	1.1524**	-0.3304**	-3.1485**	-0.0092**	1.9734**
S.E(lines)	0.2101025	0.3121618	0.04762	0.02527	0.06351	0.11285	0.002008	0.28414	0.000415	0.05153
S.E(testers)	0.332313	0.4935711	0.07529	0.03995	0.10491	0.17843	0.003174	0.44926	0.000657	0.08147
S.E(gi-gj) lines	0.2971299	0.4414634	0.06734	0.03573	0.09383	0.15959	0.002839	0.40183	0.000588	0.72872
S.E(gi-gj)testers	0.4698036	0.6980149	0.10648	0.05650	0.14837	0.25334	0.004489	0.34799	0.000929	0.11522

* Significant at 5 per cent level; ** Significant at 1 per cent level

gca effects were observed in RHA-298 (-7.03) followed by RHA 297 (-6.529) and 111-R (-4.431).

4.4.2.1.3 Capitulum diameter: All the parental lines recorded significant gca effects for the capitulum diameter ranging from -1.0675 (RHA 297) to 0.9658 (111-R).

Among the lines, only one line CMS 300 (-0.8092) recorded negative gca effects whereas remaining three lines CMS 851 (0.3875), CMS 302 (0.2708) and CMS 7-1 (0.1508) recorded significant positive gca effects.

Among the testers, four recorded significant positive gca effects and six recorded significant negative gca effects. Highly significant positive gca effect was recorded by the tester 111-R (0.9658) and highly significant negative gca effect was recorded by the tester RHA 297 (-1.0675).

4.4.2.1.4 100 seed weight: The gca effects for the 100 seed weight ranged between -0.3284 (MRHA-1) and 0.3954 (RHA 586).

Among the lines, two lines CMS 7-1 (0.2789) and CMS 302 (0.1277) recorded significant positive gca effects while two lines CMS 300 (-0.2701) and CMS 851 (-0.1365) recorded significant negative gca effects.

Among the testers, three recorded significant positive gca effects while three recorded significant

Table 6: Estimates of general combining ability effects of fourteen parents of sunflower for the ten characters studied

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Yield per plant (g)	Leaf Area Index (LAI)	Crop Growth Rate (CGR)	Relative Growth Rate(RGR)	Net Assimilation Rate(NAR)
Lines										
CMS 851	1.2667**	20.2190**	0.3875**	-0.1365**	1.5412**	-0.0721	-0.3369**	-2.6600**	-0.0049**	0.5706**
CMS 300	-0.7333**	-17.2470**	-0.8092**	-0.2701**	0.2548**	-0.6321**	-0.1771**	-3.8550**	-0.0061**	-0.6737**
CMS 302	-1.1000**	-4.3011**	0.2708**	0.1277**	-0.5919**	-0.3221**	0.6594**	6.8240**	0.0115**	-0.3734**
CMS 7-1	0.5667**	1.3290**	0.1508**	0.2789**	1.8784**	1.0263**	-0.1454**	-0.3090	-0.0004	0.4766**
Testers										
RHA 298	-0.1000	-7.0300**	-0.2508**	-0.0529	0.4231**	-0.2105	0.2180**	-2.6210**	0.0009	0.0843
bD-1	0.9833**	5.1190**	-0.3825**	0.2598**	1.6389**	-0.3184	-0.0993**	-0.8010	-0.0052**	-0.5857**
RHA 859	0.6500*	-1.5140**	0.6092**	-0.0504	-2.1202**	0.3024	-0.1536**	-3.5360**	-0.0015*	1.6618**
RHA 271	-1.1833**	4.069**	-0.1592*	-0.0692	-2.2244**	1.4653**	0.4469**	0.7290	0.0042**	-0.0707
MRHA-1	0.5667	-1.0980*	-0.2842**	-0.3284**	-0.2794**	0.6405**	0.2814**	1.7540**	-0.0017**	1.5234**
RHA 297	-1.6000**	-6.5290**	-1.0675**	-0.3217**	0.3239**	-1.6349**	-0.2839**	-2.2435**	-0.0029**	0.5551**
111-R	0.2333	-4.4310**	0.9658**	-0.349	0.0064	-0.5368**	0.2424**	5.9065**	0.0098**	-1.3599**
IB-29	1.3167**	6.6360**	0.9242**	-0.0862*	-0.7253**	0.0318	-0.3466**	0.1115	0.0029**	-0.7449**
RHA 272	-0.3500	3.6270**	-0.2175**	0.1162**	1.7173**	-0.8918**	0.0251**	3.8490**	0.0027**	-3.0366**
RHA 586	-0.5167	1.1523*	0.3158**	0.3954**	1.2398**	1.1524**	-0.3304**	-3.1485**	-0.0092**	1.9734**
S.E(lines)	0.2101025	0.3121618	0.04762	0.02527	0.06351	0.11285	0.002008	0.28414	0.000415	0.05153
S.E(testers)	0.332313	0.4935711	0.07529	0.03995	0.10491	0.17843	0.003174	0.44926	0.000657	0.08147
S.E(gi-gj) lines	0.2971299	0.4414634	0.06734	0.03573	0.09383	0.15959	0.002839	0.40183	0.000588	0.72872
S.E(gi-gj)testers	0.4698036	0.6980149	0.10648	0.05650	0.14837	0.25334	0.004489	0.34799	0.000929	0.11522

* Significant at 5 per cent level; ** Significant at 1 per cent level

gca effects were observed in RHA-298 (-7.03) followed by RHA 297 (-6.529) and 111-R (-4.431).

4.4.2.1.3 Capitulum diameter: All the parental lines recorded significant gca effects for the capitulum diameter ranging from -1.0675 (RHA 297) to 0.9658 (111-R).

Among the lines, only one line CMS 300 (-0.8092) recorded negative gca effects whereas remaining three lines CMS 851 (0.3875), CMS 302 (0.2708) and CMS 7-1 (0.1508) recorded significant positive gca effects.

Among the testers, four recorded significant positive gca effects and six recorded significant negative gca effects. Highly significant positive gca effect was recorded by the tester 111-R (0.9658) and highly significant negative gca effect was recorded by the tester RHA 297 (-1.0675).

4.4.2.1.4 100 seed weight: The gca effects for the 100 seed weight ranged between -0.3284 (MRHA-1) and 0.3954 (RHA 586).

Among the lines, two lines CMS 7-1 (0.2789) and CMS 302 (0.1277) recorded significant positive gca effects while two lines CMS 300 (-0.2701) and CMS 851 (-0.1365) recorded significant negative gca effects.

Among the testers, three recorded significant positive gca effects while three recorded significant negative gca effects. Highly significant positive gca effect was showed by the tester RHA 586 (0.3954) and highly significant negative gca effect recorded by the tester MRHA-1 (-0.3284).

4.4.2.1.5 Oil per cent: All the parents except one recorded significant gca effects both in positive and negative direction. The gca effects ranged between -2.2244(RHA 271) and 1.8784 (CMS 7-1).

Among the lines, two lines CMS 7-1 (1.8784) and CMS 300 (0.2548) recorded significant positive gca effects whereas CMS 851 (-0.0721) and CMS 302 (-0.5919) recorded significant gca effects in negative direction.

Among the testers, four testers recorded significant negative gca effects while five testers recorded positive gca effects. Highly significant positive gca effect was recorded by the tester RHA-272 (1.7173) and highly significant negative gca effect was recorded by the tester RHA 271 (-2.2244).

4.4.2.1.6 Yield per plant: The gca effects for the character yield per plant ranged from -1.6349 (RHA-297) to 1.4653 (RHA 271).

Significant positive gca effect was exhibited by the line CMS 7-1 (1.0263) and significant negative gca effects exhibited by the lines CMS 300 (-0.6321) and CMS 302 (-0.3221).

Among the testers, RHA 271, RHA 586 and MRHA-1 expressed positive significant gca effect of 1.4653, 1.1524 and 0.6405 respectively. Significant negative gca effect was recorded by the testers RHA-297 (-1.6349), RHA 272 (-0.8918) and 111-R (-0.5368).

4.4.2.2 Physiological Parameters

4.4.2.2.1 Leaf Area Index (LAI): Estimates of gca effects for LAI varied from -0.3466 (IB-29) to 0.6594 (CMS 302).

Among the lines, only CMS 302 (0.6594) showed highly significant positive gca effect while CMS 851 (-0.3369) showed highly significant negative gca effect.

Among the testers, RHA 271 (0.4469) showed highly significant positive gca effect while IB-29 (-0.3466) exhibited highly significant negative gca effect.

4.4.2.2.2 Crop Growth Rate (CGR): The significant gca effects among the parents ranged from -3.855 (CMS 300) to 6.824 (CMS 302).

Among the lines CMS 300 (-3.855) recorded highest significant negative gca effect followed by CMS 851 (-2.66) whereas the line CMS 302 (6.824) recorded highest significant positive gca effect.

Among the testers, RHA 850 (-3.536) recorded highest significant negative gca effect while 111-R (5.9065) recorded highest significant positive gca effect.

4.4.2.2.3 Relative Growth Rate (RGR): Estimates of significant gca effects ranged from -0.0092 (RHA 586) to 0.0098 (111-R).

Among the lines CMS 300 (-0.0061) exhibited maximum negative gca effect followed by CMS 851 (-0.0049) while CMS 302 (0.0115) exhibited maximum positive gca effect.

Among the testers, maximum negative gca effect was showed by the tester RHA 586 (-0.0092) while maximum positive gca effect recorded in 111-R (0.0098).

4.4.2.2.4 Net Assimilation Rate (NAR): All the parents except two showed significant gca effects both in positive and negative direction which ranged between -3.0366 (RHA 272) and -1.9734 (RHA 586).

Among the lines, CMS 300 (-0.6737) and CMS 302 (-0.3734) showed significant negative gca effects while CMS 851 (0.5706) and CMS 7-1 (0.4766) exhibited significant positive gca effects.

Among the testers, RHA 272 (-3.0366) exhibited maximum negative gca effect while highest positive gca effect exhibited by CMS 586 (1.9734) followed by RHA 850 (1.6618) and MRHA-1 (1.5234).

4.4.3 Estimates of Specific Combining Ability Effects

Estimates of specific combining ability (sca) effects for all characters under study are furnished in the Table-7.

4.4.3.1 Yield and Yield Contributing Characters

4.4.3.1.1 Days to 50 per cent flowering: For days to 50 per cent flowering, the sca effects varied from -2.2333 (CMS 302 x MRHA-1) to 1.3500 (CMS 302 x RHA 298). Out of forty hybrids only one recorded significant positive sca effect while two recorded significant negative sca effects. The hybrid CMS 302 x RHA 298 (1.35) expressed highest significant positive sca effect while hybrids CMS 302 x MRHA-1 (-2.2333) and CMS 300 x RHA 851 (-1.3500) expressed significant negative sca effects.

4.4.3.1.2 Plant height: The sca effects for the trait ranged from -13.5699 (CMS 300 x 111-R) to 19.0977 (CMS 851 x 111-R). Out of forty F_1s, fifteen of them exhibited significant negative sca effects while fifteen exhibited significant positive sca effects.

Highly significant positive sca effect was recorded by the hybrid CMS 851 x 111-R (19.0977) followed by CMS 300 x RHA 298 (18.0301) whereas the hybrids CMS 300

Table 7: Estimates of specific combining ability effects of forty hybrids of sunflower for the ten characters studied

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Yield per plant (g)	Leaf Area Index (LAI)	Crop Growth Rate (CGR)	Relative Growth Rate(RGR)	Net Assimilation Rate(NAR)
CMS 851 x RHA 298	-0.6000	-11.7023**	-0.2625	-0.0327	0.6962**	-0.8208*	1.5161**	2.655**	0.0067**	-3.1273**
CMS 851 x bD-1	-0.3500	-0.7856	-0.5625**	-0.8478**	-0.4063	-0.3546	-0.4418**	4.135**	0.0045**	3.5194**
CMS 851 x RHA 859	-0.0167	0.9811	0.2625	0.0815	-0.5337*	-0.4187	-0.1558**	4.210**	-0.0009	-3.1481**
CMS 851 x RHA 271	-0.1833	-0.3356	-0.2208	0.0052	2.6371**	0.3434	-0.5404**	-3.075**	-0.0093**	-4.8023**
CMS 851 x MRHA-1	0.0667	5.1644**	0.6375**	-0.1923*	-0.3613	-0.4745	-0.4379**	-5.510**	0.0123**	0.1536
CMS 851 x RHA 297	-0.4333	4.7952**	0.0542	0.3794**	0.8954**	2.5229**	0.0571**	6.628**	0.0071**	0.0052
CMS 851 x 111-R	-0.2667	19.0977**	1.5542**	0.8880**	-0.6304**	0.5571	-0.3195**	-3.740**	-0.0154**	3.2402**
CMS 851 x IB-29	-0.0167	-9.4356**	-0.6708**	-0.3585**	0.7279**	-0.0115	0.0077	-4.267**	-0.0033*	-0.2348
CMS 851 x RHA 272	0.9833	4.8394**	-0.0958	0.4915**	0.9054**	0.7988*	-0.2653**	-3.800**	-0.0053**	1.0536**
CMS 851 x RHA 586	0.8167	-12.6189**	-0.6958*	-0.4144**	-3.9304**	-2.1421**	0.5797**	2.772**	0.0036**	3.3402**
CMS 300 x RHA 298	1.0667	18.0301**	-0.2325	0.0243	-1.0464**	1.0875**	0.3574**	-0.840	0.0031*	3.8504**
CMS 300 x bD-1	-1.3500*	1.2801	-0.0992	-0.1618*	0.2378	1.1388**	0.2243**	3.560**	-0.0033*	-0.6529**
CMS 300 x RHA 859	-0.6833	5.7801**	0.8925**	-0.0299	-0.6964**	1.3179**	0.0600**	-0.425	0.0063**	1.3262**
CMS 300 x RHA 271	0.8167	10.4634**	1.1425**	-0.1095	-0.2289	0.4584	-0.6783**	0.340	-0.0079**	0.9387**
CMS 300 x MRHA-1	1.0667	-5.7032**	0.4342**	0.1264	-3.0006**	1.5299**	0.7529**	-5.645**	-0.0088**	4.5779**
CMS 300 x RHA 297	0.9000	-9.3957**	-0.3158*	0.0747	-3.0006**	-0.4448	0.0596**	-3.127**	-0.0019	-6.7138**
CMS 300 x 111-R	0.4000	-13.5699**	-0.7158**	-0.2837**	0.1969	-4.1029**	-0.6066**	4.705**	0.0110**	-3.5021**
CMS 300 x IB-29	-1.0167	-10.9699**	-1.6408**	0.1718*	1.2319**	-1.1781**	0.7607**	0.288	-0.0091**	2.2762**
CMS 300 x RHA 272	-1.0167	-0.6949	0.2008	0.0418	1.9461**	0.1954	-0.3083**	-1.740	-0.0023	-2.2488**
CMS 300 x RHA 586	-0.1833	4.7801**	0.3342*	0.1459	4.3602**	-0.0021	-0.6217**	2.887**	0.0128**	0.1479
CMS 302 x RHA 298	-0.5667	-0.5156	-0.2458	-0.3435**	-1.9498**	0.0425	-0.9828**	-3.009**	-0.0117**	5.9567**
CMS 302 x bD-1	1.3500*	0.7344	-0.1458	1.2037**	1.0978**	1.8121**	0.8805**	-5.849**	-0.0040**	-5.6066**
CMS 302 x RHA 859	1.0167	-7.8323**	-0.0208	0.0006	1.1236**	-2.1087**	-0.0099	-4.094**	-0.0110**	-5.5974**
CMS 302 x RHA 271	-0.1500	-7.0156**	0.1958	0.2560**	0.3811	-2.5150**	0.2352**	1.341	-0.0006	3.0017**
CMS 302 x MRHA-1	-2.2333**	13.0844**	-0.8458**	-0.0815	0.2394	-1.0268**	-0.3944**	5.416**	0.0081**	-1.0958**

Contd.. Table 7

Source	Days to 50% flowering	Plant height (cm)	Capitulum diameter (cm)	100 seed weight (g)	Oil per cent	Yield per plant (g)	Leaf Area Index (LAI)	Crop Growth Rate (CGR)	Relative Growth Rate(RGR)	Net Assimilation Rate(NAR)
CMS 302 x RHA 297	-0.4000	8.3152**	0.1708	-0.4415**	-0.9006**	-0.1848	-0.6706**	-1.536	0.0020	4.1926**
CMS 302 x 111-R	-0.2333	-10.7823**	-0.3958**	-0.7815**	1.3836**	-0.1362	0.3566**	6.126**	0.0148**	1.9542**
CMS 302 x IB-29	0.6833	13.8177**	0.6458**	0.2673**	-3.1481**	2.0119**	-0.8649**	4.509**	0.0056**	1.8293**
CMS 302 x RHA 272	1.0167	-8.9739**	0.5875**	-0.1427	0.8727**	-1.1846**	0.9344**	5.211**	0.0093**	-2.5891**
CMS 302 x RHA 586	-0.4833	-0.8323	0.0542	0.0631	0.9002**	3.3746**	0.5160**	-7.961**	-0.0124**	-2.0458**
CMS 7-1 x RHA 298	0.1000	-5.8123**	0.7408**	0.3520**	2.2999**	-0.2242	-0.8907**	1.194	0.0019	-6.6799**
CMS 7-1 x bD-1	0.3500	-1.2289	0.8075**	-0.1941*	-0.9293**	-2.5963**	-0.6630**	-1.846*	0.0028*	2.7401**
CMS 7-1 x RHA 859	-0.3167	1.0711	-1.1342**	-0.0522	0.1066	-1.2095**	0.1057**	0.309	0.0056**	7.4192**
CMS 7-1 x RHA 271	-0.4833	-3.1123**	-1.1175**	-0.1518	-2.7893**	1.7133**	0.9834**	1.394	0.0177**	0.8617**
CMS 7-1 x MRHA-1	1.1000	-12.5456**	-0.2258	0.1474	3.1224**	-0.0286	0.0794**	5.889**	-0.0116**	-3.6358**
CMS 7-1 x RHA 297	-0.0667	-3.7148**	0.0908	-0.0126	3.0057**	-1.8932**	0.5539**	-1.963*	-0.0072**	2.5159**
CMS 7-1 x 111-R	0.1000	5.2544**	-0.4425**	0.1773*	-0.9501**	3.6820**	0.5695**	-7.081**	-0.0103**	-1.6924**
CMS 7-1 x IB-29	0.3500	6.5877**	1.6658**	-0.0806	1.1883**	-0.8222*	0.0965**	-0.528	0.0068**	-3.8708**
CMS 7-1 x RHA 272	-0.9833	4.8294**	-0.6925**	-0.3906**	-3.7243**	0.1903	-0.3608**	0.334	-0.0017	3.7842**
CMS 7-1 x RHA 586	-0.1500	8.6711**	0.3075**	0.2053*	-1.3301**	-1.2305**	-0.4740**	2.301*	-0.0041**	-1.4424**
S.E(Sij)	0.664403	0.98714	0.15058	0.079903	0.20982	0.35687	0.006349	0.89852	0.0013137	0.16295
S.E(Sij-Sjk)	0.939607	1.39603	0.21296	0.1130001	0.29673	0.50495	0.008978	1.27069	0.0018579	0.23044

* Significant at 5 per cent level; ** Significant at 1 per cent level

x 111-R (-13.5699), CMS 851 x RHA 586 (-12.6189) and CMS 7-1 x MRHA-1 (-12.5456) exhibited significant negative sca effects.

4.4.3.1.3 Capitulum diameter: Estimates of sca effects ranged from -1.6408 (CMS 300 x IB-29) to 1.6658 (CMS 7-1 x RHA 586) for the trait. Out of forty hybrids, twelve of them exhibited significant positive sca effects while twelve hybrids exhibited significant negative sca effects. Highly significant sca effects in the positive direction was exhibited by the hybrids CMS 7-1 x RHA 586 (1.6658), CMS 851 x 111-R (1.5542) and CMS 300 x RHA 271 (1.1425). Highly significant sca effects in the negative direction was exhibited by the hybrids CMS 300 x IB-29 (-1.6408), CMS 7-1 x RHA 859(-1.1342) and CMS 7-1 x RHA 271 (-1.1175).

4.4.3.1.4 100 seed weight: The sca effects for the trait ranged from -0.8478 (CMS 851 x bD-1) to 1.2037 (CMS 302 x bD-1). Out of forty hybrids, ten expressed significant positive sca effects whereas eleven of them expressed significant negative sca effects. Highly significant positive sca effect was recorded by the hybrid CMS 302 x bD-1 (1.2037) followed by CMS 851 x 111-R (0.8880). Significant negative sca effect was maximum in the hybrid CMS 851 x bD-1 (-0.8478) followed by CMS 302 x 111-R (-0.7815).

4.4.3.1.5 Oil per cent: The sca effects for oil per cent ranged between -3.9304 (CMS 851 x RHA 586) and 4.3602 (CMS 300 x RHA 586). Significant sca effects in the positive direction were observed in seventeen hybrids while significant negative sca effects were observed in fifteen hybrids. The hybrid CMS 300 x RHA 586 (4.3602) followed by CMS 7-1 x RHA 271 (3.1224) exhibited significant positive sca effect. Significant negative sca effects were recorded by the hybrids CMS 851 x RHA 586 (-3.9304) and CMS 7-1 x RHA 272 (-3.7243).

4.4.3.1.6 Yield per plant: The sca effects for the trait ranged from -4.1029 (CMS 300 x 111-R) to 3.6820 (CMS 7-1 x 111-R). Among the forty hybrids, twelve of them exhibited significant positive sca effects and twelve showed significant negative sca effects. Highly significant positive sca effects were recorded by the hybrids CMS 7-1 x 111-R (3.6820), CMS 302 x RHA 586 (3.3746) and CMS 851 x RHA 297 (2.5229). Highly significant negative sca effect was recorded by the hybrid CMS 300 x 111-R (-4.1029).

4.4.3.2 Physiological Parameters

4.4.3.2.1 Leaf Area Index: All the hybrids except two exhibited significant sca effects for the LAI. The significant sca effects varied from -0.9828 (CMS 302 x RHA 298) to 1.5161 (CMS 851 x RHA 298). Out of forty hybrids, 18 recorded significant negative gca effects while 20 recorded significant positive gca effects. Highest negative sca effect expressed by the hybrid CMS 302 x RHA 298 (-0.9828) followed by CMS 7-1 x bD-1 (-0.8907), while highest positive sca effects exhibited by the hybrids CMS 851 x RHA 298 (1.5161) and CMS 7-1 x RHA 271 (0.9834).

4.4.3.2.2 **Crop Growth Rate:** The significant sca effects for this trait ranged between -7.9615 (CMS 302 x RHA 586) to 6.628 (CMS 851 x RHA 297).

Out of 40 hybrids 14 showed significant positive sca effects while 14 showed significant negative sca effects. The highest positive sca effect was observed in the hybrid CMS 851 x RHA 297 (6.628) followed by CMS 302 x 111-R (6.126). The maximum negative sca effects were observed in the hybrids CMS 302 x RHA 586 (-7.9615) and CMS 7-1 x 111-R (-7.081).

4.4.3.2.3 **Relative Growth Rate (RGR):** The significant sca effects for the RGR varied from -0.0154 (CMS 851 x 111-R) to 0.0177 (CMS 7-1 x RHA 271). Out of forty hybrids, 17 showed significant positive sca effects with maximum in the hybrid CMS 7-1 x RHA 271 (0.0177) followed by CMS 302 x 111-R (0.0148). The significant negative sca effects recorded by 16 hybrids with highest in the hybrid CMS 851 x 111-R (-0.0154) followed by CMS 302 x RHA 586 (-0.0124).

4.4.3.2.4 **Net Assimilation Rate (NAR):** The significant sca effects for the NAR ranged between -6.7138 (CMS 300 x

RHA 297) and 7.4192 (CMS 7-1 x RHA 850). Among the 40 hybrids 17 exhibited significant negative sca effects with maximum in the hybrid CMS 300 x RHA 297 (-6.7138) followed by CMS 7-1 x RHA 298 (-6.6799). Whereas 19 hybrids expressed significant positive sca effects with maximum in the hybrid CMS 7-1 x RHA 850 (7.4192) followed by CMS 302 x RHA 298 (5.9567).

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DISCUSSION

CHAPTER V

DISCUSSION

The discovery of cytoplasmic male sterility by Leclercq (1969) in sunflower and subsequent identification of gene totality restoration (Kinman, 1970 and Vranceanu and Stoenescu, 1971) have resulted in wide spread production of hybrids using cytoplasmic male sterility and fertility restoration system. Thus, amongst several oil seed crops cultivated in the country, sunflower offers scope for commercial exploitation of heterosis utilising cytorestorer system. One of the prerequisites in such a breeding programme would be the isolation of lines with good combining ability from the available genetic resources. The magnitude of heterosis depends much on the genetic diversity of the parental lines. Hence, information on the various quantitatively inherited attributes viz., the nature of gene action controlling their expression and heterosis is basic to any attempt to improve the yield. Breeding programmes based on sound knowledge of the genetic nature of the yield and yield components and physiological parameters alone can help to achieve the target quickly and reliably.

5.1 MEAN PERFORMANCE

5.1.1 Yield and Yield Contributing Characters

The success of crop breeding programme depends upon the choice of the parents possessing genetic divergence and combining ability. Parents with a good mean performance are expected to yield desirable segregants in the succeeding generations and the potentiality of such genotypes will reflect the performance of the hybrids.

The analysis of variance revealed significant genotypic differences for all the characters studied indicating that the differences existed among parents, crosses and parents vs crosses.

Mean performance of four lines and ten restorers (Table – 2) indicated that the male sterile line CMS 302 exhibited early flowering, dwarfness and higher 100 seed weight while the line CMS 7-1 exhibited dwarfness, higher mean values for capitulum diameter, oil per cent and seed yield per plant.

Among restorers, RHA 271 showed early flowering whereas the restorer RHA 586 expressed short stature. The restorers IB-29 and RHA 272 exhibited higher mean values for capitulum diameter and oil per cent respectively while the restorer 111-R recorded higher mean values for 100 seed weight and seed yield per plant.

The data on mean performance of F_1 hybrids indicated that the crosses CMS 302 x RHA 297, CMS 300 x 111-R and CMS 851 x 111-R exhibited early flowering, dwarfness and higher capitulum diameter and oil per cent respectively which is in conformity with the earlier studies of Chaudhary and Anand (1984), Kadkol et al. (1984) and Sreedhar (1989) reported early flowering while Sheriff et al. (1985) and Giriraj et al. (1986) reported a reduction in plant height in certain F_1 crosses. Higher mean values for 100 seed weight and oil per cent was observed in the hybrids CMS 302 x bD-1 and CMS 300 x RHA 586, respectively. On the other hand, higher values for seed yield per plant was noticed in CMS 7-1 x RHA 271 and CMS 302 x RHA 586. Earlier workers Putt (1964), Sheriff et al. (1986), Vanisree (1987), Rajini (1988), Sreedhar (1989) and Shashikala (1992) also observed increased mean performance for head diameter, 100 seed weight and seed yield per plant in F_1 hybrids. In the present study, it was observed that the mean performance of parents had no relation with hybrid mean performance with respect to plant height, capitulum diameter and oil per cent. For early flowering, 100 seed weight and seed yield per plant, the best performed hybrids included one best parent for that respective character. Probably this may be attributed to the dominance.

From an agronomic point of view, seed yield is an important trait based on which selection is practiced. Since, no single parent possess all desirable traits, selection should be done on the basis of yield possibly coupled with as many desirable characters as possible.

From the data, it is evident that the lines CMS 302 and CMS 7-1, which possess desirable agronomic characters can be used as potential donors in hybridisation programme for improving seed yield and other yield contributing traits. A close study of the data regarding F_1 hybrids revealed that the crosses CMS 302 x RHA 586, CMS 7-1 x RHA 271, CMS 7-1 x 111-R, CMS 7-1 x RHA 859 and CMS 851 x RHA 271 recorded more seed yields and these crosses are expected to provide better segregants in the succeeding generations.

5.1.2 Physiological Parameters

Leaf Area Index indicates the ability of plants to produce leaves per unit ground area. In general, LAI attained maximum values at 60 DAS in most of the parents and hybrids. The hybrid CMS 302 x bD-1 showed comparatively high mean values at all growth stages. But it recorded moderate yield per plant probably due to mutual shading of leaves and poor partitioning of photosynthates to seeds.

Crop Growth Rate (CGR) indicates the total dry matter production per unit land area over a certain time period. Relative Growth Rate (RGR) indicates the increase in dry weight per unit of original weight over a time interval or the plant's capacity to add to its own dry weight and is also known as Efficiency Index. Net Assimilation Rate (NAR) express the plant's capacity to increase dry weight in terms of the area of its assimilatory surface. The term therefore represents photosynthetic efficiency of the crop in conjunction with Leaf Area Ratio and Relative Growth Rate.

In general, CGR increased upto 45-60 DAS while RGR and NAR values were higher at 30-45 DAS and declined steadily thereafter and reached lowest values at the time of maturity. The hybrid CMS 300 x 111-R showed comparatively high mean values for CGR and RGR at all the growth stages. This shows that the cross CMS 300 x 111-R is a high biomass producer. Inspite of that, yield levels were very low which may be due to less partitioning of assimilates to the economic part. The hybrid CMS 300 x RHA 586 exhibited comparatively better performance at all growth stages with regard to NAR, but it showed moderate seed yield. Thus it is interesting to note that though the photosynthetic efficiency is high in this hybrid, partitioning may be poor to head.

5.2 HETEROSIS

Heterosis is defined as the increased vigour of F_1 over parental mean and is a genetic expression of beneficial effects of hybridization. Heterosis could be used as an indicative of the crosses which are likely to throw productive transgressive segregants (Singh and Jain, 1970).

Sunflower being a cross-pollinated crop offers scope for development of new and superior varieties through heterosis breeding. During the last 4-5 decades, sunflower improvement has largely been through individual plant selection followed by mass breeding of the superior germplasm. But with the discovery of cytoplasmic male sterility in 1969 by Leclercq, there has been a shift in emphasis from population breeding to development of single cross hybrids (Jensma, 1973 and Faure, 1976). Hybrid performance can be ensured in sunflower at a stable and high level in view of the fact that inbreds once stabilized donot generally show depression in the succeeding generations of inbreeding (Nikolicvig and Skoric, 1972).

5.2.1 Yield and Yield Contributing Characters

An examination of the data revealed that all the hybrids exhibited heterosis for more than one character. Heterosis, to an extent of -10.11 per cent for days to 50 per cent flowering, 75.34 per cent for plant height, 65.53 per cent for capitulum diameter, 37.13 per cent for 100 seed weight, 26.85 per cent for oil per cent and 75.08 per cent for seed yield per plant over the better parent was observed in different crosses.

The cross CMS 302 x RHA 298 which exhibited high heterosis for yield over better parent, also recorded significant positive heterosis for plant height, capitulum diameter, oil per cent and significant negative heterosis for days to 50 per cent flowering and 100 seed weight.

Thus the heterosis for seed yield can be mainly attributed to the manifestation of heterosis in component characters like plant height, capitulum diameter and oil per cent. Grafius (1959) also reported that heterosis expressed for component characters.

A positive heterosis for yield was reported by several workers like Putt (1964), Grebenjuk (1968), Vulpe (1966 and 1977), Shankara (1983), Chaudhary and Anand (1984), Sailaja (1984), Sreedhar (1989), Laxmi Kumari (1990) and Sudharani (1992). Both positive and negative heterosis ranging from -62.3 to 147 per cent over better parent was observed by Sheriff _et al_. (1985) as was observed in the present study.

Heterosis was maximum and significantly positive in the hybrid CMS 302 x bD-1 (26.85%) for oil per cent and for 100 seed weight (37.13%). The hybrid CMS 302 x bD-1 exhibited significant positive heterosis for all the characters except for days to 50 per cent flowering. When head diameter was taken into consideration maximum positive heterobeltiosis was recorded in hybrid CMS 7-1 x IB-

Table 8: Average seed yield of promising hybrids of present study in relation to their parents and checks viz., APSH-11, MSFH-17 and Adarsh 3425

S.No.	Hybrids	Average seed yield per plant (g)	Percentage increase over				
			Mid parent	Better parent	APSH-11 [28.57 g]	MSFH-17 [28.07 g]	Adarsh-3425 [28.21 g]
1.	CMS 302 x RHA 586	31.33	71.48	41.32	9.66	11.61	11.06
2.	CMS 7-1 x RHA 271	31.33	50.26	35.04	9.66	11.61	11.06
3.	CMS 7-1 x 111-4	31.30	33.30	31.68	9.55	11.51	10.95
4.	CMS 7-1 x RHA 859	29.67	45.23	27.89	3.85	5.70	5.17
5.	CMS 851 x RHA 271	28.86	43.15	32.20	1.01	2.81	2.30
6.	CMS 302 x IB-29	28.85	63.15	32.52	0.98	2.78	2.27
7.	CMS 7-1 x MRHA-1	28.77	41.31	24.01	0.70	2.49	1.98
8.	CMS 300 x MRHA-1	28.67	67.56	63.55	0.35	2.14	1.63
9.	CMS 300 x RHA 271	28.42	61.48	53.62	-	1.17	0.74
10.	CMS 302 x bD-1	28.30	77.10	60.79	-	0.82	0.32

29 (65.53%). Negative heterosis, which is a desirable trend for days to 50 per cent flowering was predominant in all hybrids and highly significant negative heterosis was exhibited by the hybrid CMS 300 x RHA 272 (-10.11%). The positive heterosis for plant height was maximum in the hybrid CMS 851 x 111-R (75.34%).

Vranceanu (1981) and Anashchenko et al. (1985) observed heterosis for oil content while Seetharam et al. (1977) and Singh et al. (1978) reported heterosis for 100 seed weight. Vulpe (1966) and Setty and Singh (1977) observed heterosis for earliness and reduced height in F_1 hybrids.

The best performing ten hybrids for mean seed yield per plant over mid parent, better parent and standard checks were given in the Table-8. The cross CMS 302 x RHA 586 followed by CMS 7-1 x RHA 271 found to perform better over mid parent, better parent and also over standard checks viz., APSH-11, MSFH-17 and Adarsh 3425.

Heterosis is desirable for all the characters examined, except plant height. Short plants are usually considered more desirable for mechanical harvesting. Particularly encouraging is the marked heterosis exhibited for seed yield and oil per cent which are the economic characters.

5.2.2 Physiological Parameters

Higher heterobeltiosis for LAI was recorded in the cross CMS 302 x RHA 272 followed by CMS 851 x RHA 271, CMS 851 x RHA 586, CMS 300 x RHA 586 and CMS 851 x IB-29. Singh et al. (1986) reported that heterosis for leaf area is not related to seed yield. Heterosis for this character was also reported by Sarathe and Dabral (1969), Singh et al. (1986), Anitha (1988) and Haripriya (1989) in sesame, by Deshmukh and Bhapkar (1979) in chickpea and by Madhavi (1988) in groundnut. Damodar (1992) found that the crosses with high heterobeltiosis values for LAI also recorded higher *per se* performance for LAI and seed yield per plant in sesame.

Maximum positive heterobeltiosis for CGR was observed in the hybrids CMS 302 x RHA 272, CMS 302 x 111-R and CMS 302 x IB-29. Deshmukh and Bhapkar (1979) observed heterosis for CGR, and this heterosis contributing for seed yield in chickpea. Damodar (1992) also reported the similar results in case of sesame.

Heterobeltiosis for RGR was highest in the hybrid CMS 302 x RHA 297 followed by CMS 302 x 111-R. But these crosses were not better yielders indicating that heterobeltiosis for RGR does not contribute much to the seed yield. Gupta et al. (1980) reported lower magnitude of heterosis for this trait in cotton hybrids while high positive heterosis for RGR was reported by Whaley (1952), Kheiralla and Willington (1962) and Peat and Willington (1965) in tomato and Allison (1971) in corn hybrids. Damodar (1992) reported negative heterosis for RGR in the hybrids of sesame.

For NAR, the crosses CMS 7-1 x RHA 271, CMS 7-1 x RHA 859 and CMS 300 x MRHA-1 recorded high positive heterosis and were also found to record high mean yields. Thus, it indicates that heterosis for NAR significantly contributed to seed yield per plant. Heterosis for NAR was also reported by Allison (1971) in corn hybrids, Deshmukh and Bhapkar (1979) in chickpea, Gupta et al. (1980) in cotton, Niranjana Murthy et al. (1991) in rice and Damodar (1992) in sesame.

5.3 COMBINING ABILITY ANALYSIS

Combining ability analysis helps the breeder in selecting the parents and the breeding method to be employed for improving a particular trait, by providing information on the genetic nature of the characters.

General combining ability (gca) refers to the average performance of a line in a series of hybrid combinations and is attributable to additive (fixable) gene action, while the specific combining ability (sca) refers to the deviation in the performance of a cross that would be expected on the basis of the average performance of the line involved and is attributable primarily to dominant, over dominant and epistatic effects of genes (non –additive). The non-additive gene action is mostly non-fixable and often brings about the phenotypes that are not available under normal additive gene action.

The sum of the additive gene effects produced by the genes lacking dominance (additive genes) and by the additive contribution of genes along with dominance or epistatic effects is the additive components of genetic variance. Additive gene action tends to produce a normal phenotypic distribution. The non-additive gene action results from dominance, epistasis and various other interaction effects which are non-fixable. The comparison of 'gca' to 'sca' variance components provides an estimate of the predominance of additive gene effects or the non-additive gene effects.

5.3.1 Yield and Yield Contributing Characters

The analysis of variance components for combining ability (Table-5) revealed that the higher magnitude of sca variance in relation to gca variance implied that all the characters were predominantly under the control of non-additive gene action, while Putt (1966) and Kadkol et al. (1984) reported that additive gene action was important in the inheritance of days to 50 per cent flowering. The non-additive gene action obtained in the present study for other characters is in agreement with the findings of Pathak et al. (1985), Sheriff et al. (1986), Sreedhar (1989) and Sudharani (1992).

The degree of dominance was maximum for seed yield per plant (25.27) and 100 seed weight (7.631).

The gca effects of the parents (Table-6) revealed that none of the parents was superior for all the characters studied. Neverthless, line CMS 851 recorded significant positive gca effects for days to 50 per cent flowering, plant height, capitulum diameter while exhibited significant negative gca effects in case of economic traits like 100 seed weight and oil per cent. The line CMS 7-1 showed maximum positive gca effect for 100 seed weight, oil per cent and seed yield per plant. It also showed significant positive gca effects for other characters viz., plant height, days to 50 per cent flowering and capitulum diameter. This indicates that the line which is a good combiner for economic traits like capitulum diameter, 100 seed weight and oil per cent will also be good combiner for seed yield per plant.

Among the male parents, IB-29 and bD-1 were proved to be good combiners for days to 50 per cent flowering and plant height, while 111-R was found to be good combiner for capitulum diameter. For 100-seed weight and oil per cent, the testers RHA 586 and RHA 272 are the good general combiners respectively. For seed yield per plant, the tester RHA 271 followed by RHA 586 was good general combiner. RHA 271 showed negative gca effects for all the other yield contributing characters except plant height. But RHA 586 exhibited significant positive gca effects for all the characters except days to 50 per cent flowering.

Thus, in general, good general combiners for yield possessed gca effects in the desired direction for yield contributing characters. Rao and Singh (1977) observed that no parent was found to contain all favourable or unfavourable genes for all the characters as in the present study. Setty and Singh (1977) observed that gca for yield was related to gca for one or more yield components which was also proved in the present study.

The sca effects of the crosses (Table-7) revealed that twelve cross combinations had significant positive sca effects while twelve had significant negative sca effects for seed yield per plant. The crosses CMS 7-1 x 111-R (3.682), CMS 302 x RHA 586 (3.3746), CMS 851 x RHA 297 (2.5229), CMS 302 x IB-29 (2.0119) and CMS 302 x bD-1 (1.8121) were found to be best specific combiners for seed yield per plant. Among the hybrids showing significant positive sca effects, no female parent contributed more than 50 per cent of the crosses with positive sca effects.

Table 9: Top five crosses recording high sca effects for 100 seed weight, seed yield and oil per cent

Cross	100 seed weight (g)	Cross	Seed yield per plant	Cross	Oil per cent
1. CMS 302 x bD-1	1.2037	1. CMS 7-1 x 111-4	3.6820	1. CMS 300 x RHA 586	4.3602
2. CMS 851 x 111-4	0.8880	2. CMS 302 x RHA 586	3.3746	2. CMS 7-1 x RHA 271	3.1224
3. CMS 851 x RHA 272	0.4915	3. CMS 851 x RHA 297	2.5229	3. CMS 7-1 x RHA 297	3.0057
4. CMS 851 x RHA 297	0.3794	4. CMS 302 x IB-29	2.0119	4. CMS 851 x RHA 271	2.6373
5. CMS 7-1 x RHA 298	0.3520	5. CMS 302 x bD-1	1.8121	5. CMS 7-1 x RHA 298	2.2999

The sca effects of top five crosses (Table-9) revealed that none of the crosses combined high sca effect for all the economic traits viz., seed yield, 100-seed weight and oil content. In majority of the crosses high sca effect was due to low x low or low x high and high x low combining parents which further substantiated the operation of non-additive gene action for the characters studied. The crosses involving high combiners for economic traits can be exploited for breeding programme for production of hybrids.

Dua (1979) reported the non-involvement of two good combining parents for the high sca effects of the crosses, indirectly indicating the rare occurance of additive gene action which was in agreement with the present study.

Dua and Yadava (1983) found that crosses with high sca effects rarely involved two good combining ability parents.

Vanisree <u>et</u> <u>al</u>. (1988) reported that the performance order of the hybrids were high x high, high x low and low x low parents which was attributed due to the major role of non-additive gene action in determining the character expression.

Sudharani (1992) reported that the crosses with high sca effect was either due to low x low or low x high combining parents indicating the involvement of non-additive gene action for the characters studied.

5.3.2 **Physiological Parameters**

Non-additive gene action was predominant for LAI as sca variance component was more than that of gca. However, Anitha (1988) and Haripriya (1989) indicated the existance of both additive and non-additive gene action for LAI in sesame. The predominant role of non-additive gene action was reported by Deshmukh and Bhapkar (1982) in chickpea and Nijhawan and Chandra (1985) in mungbean, while Damodar (1992) reported additive gene action for LAI in sesame. Among the lines CMS 302 and among the testers RHA 271 were found to be good general combiners for this trait.

Prevalence of non-additive gene action for CGR was indicated by the higher value of sca variance component in the present study. Similarly Deshmukh and Bhapkar (1982) reported predominance of non-additivity in chickpea while Mungse et al. (1990) and Damodar (1992) observed predominance of additive gene action for this trait in pearl millet and sesame respectively. The line CMS 302 and the tester RHA 859 registered high significant positive gca effects for this character among the parents.

Non-additive gene action was predominant for RGR as the variance component due to sca was more than that of gca. Non-additive gene action for this trait was also reported by Deshmukh and Bhapkar (1982) in chickpea, whereas additive gene action was reported by Mungse et al. (1990) in pearl millet, Nevado and Cross (1990) in maize and Damodar (1992) in sesame. The line CMS 300 and the tester RHA 586 exhibited maximum positive gca effects which indicate that they are good general combiners for the trait.

Net Assimilation Rate (NAR) was observed to be governed by non-additive gene action. Similar results were also reported by Deshmukh and Bhapkar (1982) for NAR in chickpea. Additive gene action was observed by Mungse et al. (1990) in pearl millet and Damodar (1992) in sesame while Niranjana Murthy et al. (1991) observed additive as well as non-additive genetic system contributing to this trait in rice. Among the parents, the line CMS 851 and the tester RHA 586 were found to be good general combiners for NAR.

The hybrids CMS 851 x RHA 298, CMS 7-1 x RHA 271 and CMS 302 x RHA 272 recorded high positive sca effects for LAI while the hybrids CMS 851 x RHA 297 followed by CMS 302 x 111-R expressed significant positive gca effects for CGR. The hybrids CMS 7-1 x RHA 271 and CMS 302 x 111-R showed high positive sca effects for RGR whereas the hybrid CMS 7-1 x RHA 859 followed by CMS 302 x RHA 298 exhibited highest positive sca effects for the character

NAR. None of the hybrids expressed maximum positive sca effects for all the physiological parameters.

Thus from the present study, it can be concluded that all the yield components and physiological parameters were governed by non-additive gene action. The hybrids which showed high sca effects for yield and yield components involving one or both good combiners as parents can be utilised in the breeding programme to get increased yields in sunflower. The hybrids showing high sca effects involving good general combiners as parents for physiological parameters can be utilised in the breeding programmes to improve photosynthetic efficiency which might lead to high dry matter accumulation and seed yield. Thus, due to predominance of non-additive gene action and manifestation of high heterosis in the desirable direction for all the characters studied, it can be suggested that exploitation of hybrid vigour through heterosis breeding using cyto restorer system is the best method for improving the yield potential in sunflower crop.

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Table 10: Good general combiners and best specific crosses of sunflower for various characters studied

Character	Parents		Crosses
	Lines	Testers	
Days to 50 per cent flowering	CMS 302 CMS 300	RHA 297 RHA 271	CMS 302 x MRHA-1 CMS 300 x bD-1 CMS 300 x RHA 272 CMS 300 x IB-29
Plant height	CMS 851	IB-29 bD-1 RHA 271	CMS 851-111R CMS 300 x RHA 298 CMS 302 x IB-29 CMS 302 x MRHA-1
Capitulum diameter	CMS 851 CMS 302	111-R IB-29 RHA 859	CMS 7-1 x IB-29 CMS 851 x 111-R CMS 300 x RHA 271
100 Seed weight	CMS 7-1 CMS 302	RHA 586 bD-1 RHA 272	CMS 302 x bD-1 CMS 851 x 111-R CMS 851 x RHA 272 CMS 851 x RHA 297
Oil per cent	CMS 7-1 CMS 851	bD-1 RHA 272 RHA 586	CMS 300 x RHA 586 CMS 7-1 x MRHA 1 CMS 7-1 x RHA 297
Yield per plant	CMS 7-1	RHA 271 RHA 586	CMS 7-1 x 111-R CMS 302 x RHA 586 CMS 851 x RHA 297
Leaf Area Index (LAI)	CMS 302	RHA 271 MRHA-1	CMS 851 x RHA 298 CMS 7-1 Kx RHA 271 CMS 302 x RHA 272
Crop Growth Rate (CGR)	CMS 302	111-R RHA 272 MRHA-1	CMS 851 x RHA 297 CMS 302 x 111-R CMS 7-1 x MRHA-1
Relative Growth Rate (RGR)	CMS 302	111-R RHA 271	CMS 7-1 x RHA 271 CMS 302 x 111-R CMS 300 x RHA 586
Net Assimilation Rate (NAR)	CMS 851 CMS 7-1	RHA 586 RHA 859 MRHA-1	CMS 7-1 x RHA 859 CMS 302 x RHA 298 CMS 300 x MRHA-1

SUMMARY

CHAPTER VI

SUMMARY

The present investigation was taken up with a view to estimate the heterosis, combining ability and gene action in the hybrids using 4 male sterile lines and 10 restorers. The 4 male sterile lines used were viz., CMS 851, CMS 300, CMS 302 and CMS 586. The ten restorers included were RHA 271, RHA 272, RHA 297, RHA 298, RHA 586, RHA 859, MRHA-1, bD-1, 111-R and IB-29. The combining ability analysis was done adopting line x tester analysis as proposed by Kempthorne (1957). Data were collected on six quantitative characters viz., days to 50 per cent flowering, plant height, capitulum diameter, 100 seed weight, oil per cent and yield per plant and also on four physiological parameters viz., Leaf Area Index (LAI), Crop Growth Rate (CGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR). For calculating leaf area and drymatter production, distructive sampling was done on 30th, 45th, 60th and 75th days after sowing and this data were used for estimating LAI, CGR, RGR and NAR as per the methods suggested by Watson (1952), Radford (1967) and Sestak et al. (1971).

Analysis of variance for combining ability revealed significant genotypic differences for all the characters studied indicating that the differences existed among the hybrids, females, males and males x females.

Among the lines, CMS 302 registered highest mean values for 100 seed weight, CGR, NAR and recorded early flowering. CMS 7-1 recorded higher mean values for capitulum diameter, oil per cent, yield per plant and RGR. CMS 300 and CMS 851 recorded higher mean values for plant height and LAI respectively. Among the testers, MRHA-1 recorded higher mean values for CGR and RGR while 111-R exhibited superior performance for 100 seed weight and yield per plant whereas RHA 271, bD-1, IB-29, RHA 272, RHA 859 and RHA 586 recorded better performance for early flowering, plant height, capitulum diameter, oil per cent, LAI and NAR respectively. No tester was found to be superior for majority of characters.

Out of 40 hybrids studied, higher mean seed yield per plant was recorded by CMS 302 x RHA 586, CMS 7-1 x RHA 271, CMS 7-1 x 111R and CMS 7-1 x RHA 859. The hybrid CMS 300 x 111-R was the best performer for CGR and RGR, while CMS 302 x bD-1 and CMS 300 x RHA 586 recorded high mean values for LAI and NAR respectively.

Hybrids exhibited significant heterobeltiosis for all the characters in the desirable direction. Positive heterobeltiosis to an extent of 75.34 per cent for plant height, 65.53 per cent for capitulum diameter, 37.13 per cent for 100 seed weight, 26.85 per cent for oil per cent and 75.08 per cent for yield per plant while negative heterobeltiosis to an extent of -10.11 per cent for days to 50 per cent flowering over the better parent were observed in different crosses. The cross CMS 302 x RHA 298 registered maximum significant positive heterosis for yield per plant and CMS 302 x bD-1 for 100 seed weight over better parent. Heterosis for seed yield can be attributed to the heterosis in component characters such as plant height, head diameter and oil per cent. The cross CMS 302 x RHA 272 recorded maximum positive heterosis for LAI and CGR whereas the crosses CMS 302 x RHA 297 and CMS 7-1 x RHA 271 showed higher positive heterobeltiosis for RGR and NAR, respectively.

The analysis of variance components for combining ability revealed that the component due to sca was greater than the component due to gca indicating the predominance of non-additive gene action. Degree of dominance was maximum for oil per cent followed by 100 seed weight among yield components while it was maximum for LAI among physiological parameters. Among the lines (females) CMS 302 and CMS 7-1 recorded significant gca effects for seed yield, several yield components and physiological parameters. Among the testers (males) RHA 271 and RHA 586 were found to be good combiners for seed yield. MRHA-1 and 111-R were found to be good combiners for physiological parameters. The cross CMS 7-1 x 111-R showed maximum sca effect for yield while highest positive sca effects for yield components were found in different crosses.

The crosses CMS 851 x RHA 298, CMS 851 x RHA 297, CMS 7-1 x RHA 271 and CMS 7-1 x RHA 859 exhibited highest positive sca effects for physioilogical parameters viz., LAI, CGR, RGR and NAR respectively.

In the light of the above findings, it can be suggested that the crosses with maximum sca effects for yield, yield contributing characters and physiological parameters involving good general combiners as one or both the parents, can be utilised for exploitation of hybrid vigour through heterosis breeding in sunflower.

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