P-ISSN: 2618-0723
E-ISSN: 2618-0731

Extension Journal

NAAS Rating: 5.04
www.extensionjournal.com

International Journal of Agriculture Extension and Social Development

Volume 7; Issue 1; Jan 2024; Page No. 454-464

Received: 10-11-2023
Accepted: 07-01-2023

Indexed Journal
Peer Reviewed Journal

The impact of environment on heterosis and combining ability in sunflower (*Helianthus annuus* L.) and breeding research

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DOI: https://doi.org/10.33545/26180723.2024.v7.i1f.255

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Abstract

The present investigation comprised seventy-five hybrids developed by making crosses between fifteen female parents (lines) and five male parents (testers) in line x testers mating design along with one standard check (HSFH 848). Researchers made the crosses at the research area of the Oilseed Section, Department of Genetics and Plant Breeding, CCS HAU, Hisar for the time of spring season of 2014. They assess the value of the hybrids and parents under four contrasting environments i.e. Summer 2014, the last week of August (E1) and the First week of Sept. (E2), and for the time of spring 2015, i.e. first week of February (E3) and the last week of February (E4). They set down the data on five willy-nilly selected plants from each genotype in each replication on different quantitative characters *viz*. plant height (cm), head diameter (cm), stem diameter (cm) days to 50% flowering, days to maturity, hundred seed weight (g), seed yield per plant (g), oil content (%), hull content (%), percent seed filling, germination (%), electrical conductivity (µScm-1g-1), viability (%), vigor index I, vigor index II, palmitic acid (%), stearic acid (%), oleic acid (%) and linoleic acid (%) in all the test environments. The study found Hybrids CMS 207 A x HRHA 5-3, CMS 852 A x RHA 271, CMS 207 A x RHA 297, CMS 234 A x 6D-1, and CMS 207 A x 6D-1 better and superior for combining ability and heterosis studies for seed yield and its contributing trait and also for oil content. The combining ability analysis divulges the non-additive variance in the expression of all the traits. Among lines, CMS 207 A, CMS 148 A, CMSH 91 A, CMS 17A, and testers RHA 271 and HRHA 5-3 demonstrated the qualities of good general combiners. The hybrids with good heterotic value, good GCA, SCA, and better value of stability can be directly used for heterosis breeding because of their dominant nature. The use of genotypes in hybridization from these results is likely to produce more heterotic combinations in the future.

Keywords: Sunflower, heterosis, combining ability, GCA, SCA

Introduction

The high-quality edible oil derived from sunflower is widely adopted and accepted as an important oilseed crop. It has been grown over 23.28 million hectares in the world with 39.42 million tons of production and 1690 kg per hectare productivity. Its basic chromosome number is n = 17. The genus 'Helianthus' includes diploid, tetraploid and hexaploid species. The name Helianthus derived from the Greek word "helios" meaning sun, and "anthos" meaning flower.

"Heterosis can be ideally exploited in sunflower, as it is a highly cross-pollinated crop. This is the only crop that has more than 80% sunflower growing area under the hybrids. In India, the hybrid breeding program has been quite successful, and 29 productive hybrids were developed by both the public [18] and private sectors [11]. Despite these successes, problems in the form of stagnating and unstable yields, genetic vulnerability, and susceptibility to various diseases are threatening sunflower productivity in India. The favorable characteristics of sunflower hybrids like production stability, response to high input agriculture, self-fertility, uniform growth, and maturity shifted the focus towards heterosis breeding, leading to the release of the first ever sunflower hybrid BSH-1 in India (Seetharam, 1981) [20], which provided a required fillip to expand sunflower cultivation in the country. Since then, many hybrids have been released for commercial cultivation based on cytoplasmic genetic male sterility and fertility restoration systems. Cytoplasmic male sterility (CMS) is the central component of sunflower hybrid development. Leclercq (1968) [14] discovered the first CMS source for the synthesis of hybrids with high heterotic effect and Kinman (1970) [10] detected the fertility restoration genes that gave the required impetus to commercial hybrid seed production. Several hybrids have been released for commercial cultivation by both public and private sectors after utilizing diversified parental lines. Consequently, there have been relatively fewer efforts to diversify the inbreds to get better heterosis over check hybrids.

Several biometrical techniques have been developed to generate information on gene action and mode of inheritance of various characters, among which line × tester analysis (Kempthorne, 1957) [11] has been widely used for genetic analysis in a large number of crop plants. It is a very efficient technique for evaluating a large number of inbreds for their combining ability besides, this technique also provides information on general combining ability (GCA) and specific combining ability (SCA), which are useful to judge gene action controlling various characters to adopt the appropriate breeding strategy.

Materials and Methods

The present investigation was carried out at the experimental area and laboratories of the Oilseed Section, Department of Plant Breeding and Genetics, Chaudhary Charan Singh Haryana Agricultural University, Hisar. The experimental material consisted of 15 CMS (cytoplasmic male sterile) lines used as seed parents and five restorers (R line) used as a pollen parent which was grown in paired rows and crossed in Line X Tester design to obtain 75 F1 hybrids, and there is a commercial check hybrid HSFH 848. Each CMS and restorer lines were grown in 2 rows of 4-meter length with a spacing of 45cm x 30 cm. The evaluation of 75 hybrids and a check of HSFH 848 was conducted over 4 environments during 2014 -2015. Heterosis is the relative performance of an F1 hybrid over either of its parents in a negative or positive direction.

$$H\ (BP)\% = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

Heterosis over standard check was also calculated for all the characters as:

$$H\ (SC)\% = \frac{\overline{F}_1 - \overline{SC}}{\overline{SC}} \times 100$$

Where,
H (BP)% = Heterosis is per cent over better parent
H (SC)% = Heterosis is per cent over standard check

$\overline{F}_1$ = Mean of F_1

$\overline{BP}$ = Mean of better parent

$\overline{SC}$ = Mean of standard check

The critical difference (CD) was calculated for comparing the heterosis and standard heterosis over standard check as:
CD = S.E. (d) x t value
Where,

$$SE\ (d) = \text{Standard Error of difference of mean} = \frac{\sqrt{2EMS}}{r}$$

t = tabulated value of ‘t’ at error degree freedom at 5% and 1% level of significance.
The level of significance was given to the corresponding values of heterosis by comparing CD values with difference (F_1 –BP) and (F_1 – SC)

Results

Heterosis of hybrids (F1) over their respective better parents and standard check HSFH 848 was calculated for seed yield and its component traits and expressed in percentage.

1. Plant height (cm)

The results indicated that the extent of heterosis over better parents ranged from (-0.29%) CMS 44A X RHA 271 to (35.9%) CMSH 91A X HRHA 5-3. The promising hybrids for short stature were CMS 11A X HRHA 5-3 (18.03%), ARG 3A X RHA 297 (17.42%), and ARG 2A X HRHA 5-3 (16.69%). Almost all the hybrids showed positive and significant heterosis over check for plant height. The range of heterosis was recorded from (4.95%) CMS 234A X HRHA 4-2 to (32.88%) CMS 607A X HRHA 5-3. The prominent hybrids for plant height were CMS 17A X HRHA 5-3 (23.51%), ARG 2A X RHA 271 (21.61%), ARG 3A X RHA 297(17.35%), CMS 207A X 6D -1 (16.14%) and CMS 148A X HRHA 5-3(13.07%) and DV -10 X RHA 297 (9.20%).

2. Head diameter (cm)

The magnitude of the heterotic effect over better parents ranged from (7.36%) CMS 852A X HRHA 5-3 to (63.54%) CMS 44A X RHA 297. The heterotic values over better parents in the majority of hybrids were positive and highly significant for this trait.
The extent of heterosis over HSFH 848 was positive and significant for almost all hybrids ranging from -2.99% (CMS 852A x HRHA 5-3) to 37.98% (CMS 17A X HRHA 5-3). The prominent hybrids over standard check were CMS 148A XHRHA 4-2 (30.97%) followed by CMS 207A X RHA 297 (29.72%), CMS 44A X HRHA 5-3 (28.63%), CMS 17-A X 6D-1 (28.37%), CMSH 91A X 6D-1 (26.94%) and CMS 207A X HRHA 5-3 (25.90%).

3. Stem diameter (cm)

Positive heterosis is desirable for this character. The hybrids showed high significance over better parents which ranged from 17.6% (DV 10 X HRHA 5-3) to 94.26% (CMS 148A X HRHA 4-2). Among the heterosis over standard check ranged from (-0.90%) CMS 11A X RHA 271 to (23.65%) CMS 44A X RHA 297 showed positive and significant heterosis. Other promising hybrids for these traits were CMS 17A X HRHA 5-3 (23.15%), CMS 234A X RHA 271 (21.77%), CMSH 91A X HRHA 4-2 (19.77%), CMS 207A X RHA 297 (18.14%), CMS 607A X 6D-1 (18.27%) and CMS 44A X HRHA 4-2 (18.14%).

4. Days to flowering

The results indicated the extent of negative and significant heterosis for all the hybrids over better parents which ranged from -0.02% (CMS 207A X HRHA 5-3) to -9.36% (CMS 302A X 6D-1) Heterosis over standard check was negative and highly significant for days to flowering ranging from (-0.42%) CMS 234A X RHA 297 to (-10.30%) DV 10 X HRHA 4-2. The promising hybrid CMS 103A X HRHA 5-3 (-9.16%), CMS 207A X HRHA 5-3 (-8.38%), ARG 6A X RHA 271 (-8.25%), ARG 3A X HRHA 5-3 (-8.14%), ARG 6A X HRHA 5-3 (-7.93%) and CMS 103A X RHA 271 (-7.14%) exhibited better heterosis for early flowering.

5. Days to maturity

Negative Heterosis was desirable for days to maturity indicating earliness in maturity. The magnitude of heterosis displayed by the hybrids over better parents ranged from -0.07% (ARG 3A X 6D -1) to 5.33% (CMS 302A X HRHA 5-3) indicating the extreme earliness and extreme delay in maturity. Almost all the hybrids showed negative significant heterotic effect over their respective better parents and the promising among them were CMS 607A X HRHA 5-3 (-6.09%), CMS 234A X HRHA 5-3 (-5.28%), CMS 148A X

RHA 297 (-3.46%) CMS 234A X RHA 271 (-3.35%) and CMS 234A X 6D-1 (-3.06%). Hybrids over standard check were also negatively significant for this trait which ranged from -0.96% (CMS 11A X RHA 271) to 5.55% (CMS 103A X RHA 297).The promising hybrid for early maturity were CMS 302A X HRHA 5-3(-7.50%), CMS 852A X 6D-1 (-6.70%), CMS 607A X HRHA 5-3 (-6.17), DV 10 X 6D -1(-5.75%), CMS 234A X HRHA 5-3(-5.74%), CMS 234A X HRHA 4-2 (-5.61%) and CMS 607A X 6D-1(-5.06%).

6. Hundred seed weight (g)

A majority of hybrids displayed significant heterosis over their better parents and it ranged from 9.28% (CMS 852A X RHA 297) to 77.88% (CMS 44A X HRHA 4-2) for the test weight. A highly significant positive heterotic effect over standard check was recorded for almost all the hybrids ranging from (-2.42%) DV 10 X HRHA 4-2 to. (34.16%) CMS 17A X RHA 271. The superior heterotic hybrids CMS 44A X 6D-1 (31.12%), ARG 2A X HRHA 5-3 (29.94%), ARG 3A X RHA 271 (28.48%), CMS 852A X HRHA 4-2 (27.69%), CMS 148A X HRHA 5-3 (28.48%) and CMS 44A X RHA 297 (25.31%).

7. Seed yield per plant (g)

Most of the hybrids manifested positive and significant heterosis over their respective better parents for this trait ranging from 9.13% (CMS ARG 2A X RHA 271) to 137.7% (CMS 44A X HRHA 4-2). The magnitude of the heterotic effect over HSFH 848 observed a highly significant positive direction for all the studied hybrids ranging from CMS 17A X 6D-1 (5.97%) to CMS 207A X HRHA 5-3 (38.55%). The prominent hybrids for seed yield per plant was CMS 148A X HRHA 5-3 (32.74%) followed by the hybrids CMSH 91A X HRHA 5-3 (31.43%), CMS 44 A X HRHA 4-2 (30.45%), CMS 17A X RHA 271 (29.74%), CMSH 91A X RHA 297 (26.23%), ARG 2A X RHA 297 (25.99%), ARG 6A X 6D-1 (25.35%) and ARG 6A X RHA 297 (25.33%).

8. Oil content (%)

Heterosis for oil content over the better parents ranged from 9.52%, (CMS 207 A X 6D -1) to 27.11% (CMS 302 X 6D-1), followed by ARG 6A X RHA 271 (26.76%), CMS 302 X HRHA 5-3 (26.54%), ARG 6 A X RHA 297 (26.42%) and CMS 302 X RHA 297 (26.27%) showing the positive and significant effect for the trait.

Heterosis over standard check ranged from (-0.09%) CMS 103A X 6D-1 to (6.63%) CMS 207A X 6D -1 which exhibited positive and significant effect followed by hybrids CMS 207 A X RHA 297 (6.52%), CMS 17A X 6D-1 (5.28%), ARG 6A X HRHA 4-2 (4.99%), CMSH 91 A X 6D-1(4.82%), CMS 103A X RHA 271 (4.09%), DV -10 X RHA 297 (4.04%),), CMS 207A X HRHA 5-3 (4.02%) and ARG 6A X HRHA 5-3(3.98%).

The magnitude of negative heterosis over better parents was observed significant for the hybrids which ranged from (-3.91%) CMS 148A X RHA 271 to (-12.53%) CMS 148A X HRHA 5-3, CMS 17A x RHA 271 (-7.93%), CMS 17A X HRHA 5-3 (-5.85%), CMS 17A X HRHA 4-2 (-4.88) and CMS 148A X RHA 297 (-3.96%) except these hybrids all the crosses manifested positive significant heterosis for hull content. Negative heterotic magnitude over standard check extended from (-0.23%) CMS 11A X HRHA 5-3 to (-6.22%) CMS 207 A X 6D-1 followed by CMS 44A X HRHA 5-3 (-4.30%) and CMS 148A X HRHA 5-3 (-2.99%)) other than these crosses all the hybrids showed positive significant for heterosis hull content which ranged from 0.89% (CMSH 91A X 6D-1) to 33.52% (DV 10 X HRHA 4-2) followed by hybrids CMS 302A X HRHA 4-2 (29.03%), DV 10 X 6D -1 (28.41%), ARG 6A X 6D-1 (27.21%), and ARG 6A X RHA 271 (27.69%).

10. Seed percent filling (%)

The cross combinations showed positive and significant heterosis over the better parents varied from (11.05%) CMS 17A X HRHA 4-2 to (145.6%) CMS 44A X RHA 271, chased by hybrids CMS 44A X 6D-1 (139.4%), CMS 44A X RHA 297 (131.2%), CMS 44A X HRHA 4-2 (123.5%) ARG 6A X RHA 271 (109.87%), ARG 6A X RHA 297 (107.45%) and ARG 6A X 6D-1 (101.148%) for filled percent filling.

The heterosis over the standard check (HSFH 848) vary from (23.45%) CMS 607A X RHA 297 to (61.69%) ARG 6 A X RHA 297 followed by the hybrids ARG 2A X 6D-1 (60.55%), CMS 44A X RHA 297 (58.32%), CMS 207A X HRHA 5-3 (57.34%) CMS 607A X RHA 297 (56.08%), CMS 234A X HRHA 4-2 (54.61%), CMS 607A X HRHA 4-2 (54.48%) and DV -10 X RHA 297 (51.52%) were positive and highly significant heterotic effect for seed percent filling.

11. Germination (%)

The majority of hybrids showed negative significance for the standard germination which varied from CMS 302A X HRHA 4-2 (-30.42%) to (-0.28%) CMS 234A X HRHA 5-3, followed by the prominent hybrids CMS 148A X RHA 297 (-29.91%), CMS 103A X HRHA 5-3 (-29.89%) and CMS 17A X RHA 271 (-27.18%) exhibited heterosis for the trait. While some of the hybrids recorded positive and significant heterotic effects over better parent confines from (0.04%) CMS 234A X HRHA 4-2 to CMS 234A X RHA 297 (54.72%) chased by hybrids CMS 852A X RHA 297 (20.46%), CMS 207A X RHA 297 (13%), ARG 2A X RHA 297 (12.15%) and CMS 17A X RHA 297 (8.33%).

The magnitude of heterosis over Standard check was positively significant which ranges from (-0.42%) CMS 148A X RHA 297 to CMS 852A X 6D -1 (40.45%) followed by the hybrids CMS 148A X HRHA 4-2 (39.90%), CMS 607A X HRHA 4-2 (39.66%), CMS 17A X 6D-1 (39.32%), CMS 44A X 6D-1 (39.27%), ARG 6A X RHA 297 (39.12%), CMS 148A X 6D-1 (38.94%), CMS 17A X HRHA 5-3 and ARG 6A X HRHA 5-3 (38.75%) for standard seed germination.

12. Electrical conductivity (μScm-1 g^{-1})

Negative and significant heterosis over better parents was observed which confines from (-0.15%) CMS 234A X 6D-1 to (-69.34%) CMS 17A XRHA 297, chased by hybrids CMS 234A X RHA 297 (-67.16%), CMS 11A X RHA 297 (-67.04%), ARG 3A X RHA 297 (-66.11%), ARG 6A X RHA 297 (-63.37%), CMS 852A X 6D -1 (-61.57%) and CMS 852A X 6D -1 (-61.57%).

Almost all the hybrids out of 75 showed negative significance over the standard check ranges from (-5.00%) CMS 148A X RHA 297 to (-56.71%) CMS 148A X RHA 271 followed by hybrids CMS 11A X HRHA 5-3 (-56.12%), CMS 11A X RHA 271 (-55.04%), CMS 17A X 6D-1(-54.65%), ARG 3A X HRHA 4-2(-52.30%) and DV 10 X HRHA 4-2 (-52.50%) for this trait. The negative heterosis for electrical conductivity of seed leachates manifested higher viability of seeds.

13. Viability (%)

Viability of crosses was found positive and significant over the better parents varying from (-0.18%) CMS 302A X 6D-1 to (79.83%) CMS 234A X RHA 297 followed by ARG 2A X RHA 297 (36.7%), CMS 852A X RHA 297 (34.26%), CMS 234A X HRHA 5-3 (33.02%) and CMS 17A X RHA 297 (32.83%). Magnitude of heterosis over standard check was found positive significant which ranged from CMS 103A X HRHA 5-3 (5.02%) to (55.65%) CMS 148A X 6D-1 followed by the hybrid CMS 17A X 6D-1 (54.38%), ARG 2A X 6D-1 (54.23%), CMS 607A X HRHA 4-2 (54.04%), CMS 11A X RHA 271 (53.55%), CMS 207A X RHA 297 (52.6%), CMS 103A X 6D-1(52.01%) showed good viability of seed.

14. Vigour index I

The magnitude of the heterotic effect was significant for the hybrids over the better parents which confines from (-19.08%) CMS 148A X RHA 297 to (30.01) CMS 44A X HRHA 4-2 followed by hybrids CMS 11A X RHA 297 (26.02%), CMS 234A X HRHA 4-2 (24.02%), CMS 17A X 6D-1 (23.78%), ARG 2A X HRHA 4-2 (22.84%), and CMS 17A X RHA 297 (22.73%) manifested positive heterosis for seedling vigor index I.

Among all the hybrids heterosis over HSFH 848 was highly significant vary from (-0.56%) CMS 148A X RHA 297 to (41.12%) CMS 17A X HRHA 5-3 accompanied by the hybrids CMS 302A X RHA 297 (37.84%), CMS 17A X 6D-1 (36.75%), CMS 11A X 6D-1 (34.16%), CMS 11A X RHA 297 (36.10%), CMS 17A X RHA 271 (34.02%) and CMS 207 A X HRHA 5-3 (32.55%) flourishing positive effect for seedling vigor index I.

15. Vigour Index II

The heterotic effect was positive and significant for all the crosses over better parents which ranged from (-0.51%) ARG 2A X RHA 271 to (145.54%) CMS 234A X RHA 297 followed by the hybrids CMS 234A X HRHA 4-2 (118.04%), CMS 207A X RHA 297 (107.26%), CMS 852A X HRHA 4-2 (106.65%), CMS 17A X RHA 297 (105.74%) and CMS 852 A X RHA 297 (100.26%) for this seed quality trait.

The magnitude of heterosis over standard check confines from (-34.82%) ARG 2A X HRHA 5-3 to (34.06%) CMS 103A X 6D-1, followed by hybrids CMS 103A X RHA 271 (31.10%), CMS 148 A X 6D-1 (29.05%), CMSH 91A X HRHA 5-3 (22.78%) and CMS 207 A X HRHA 5-3(16.96%) for seedling vigor index II.

16.1 Palmitic acid (%)

Palmitic acid exhibited significant negative heterosis over the better parents for 40 hybrids, however, 35 hybrids were positive significant which varied from (-23.70%) CMS 11A X RHA 297 to (70.43%) CMS 207A X HRHA 4-2 accompanied by hybrids DV 10 X RHA 271 (34.49%), CMS 207A X RHA 297 (28.7%), CMS 234A X HRHA 5-3 (24.79%) CMS 234A X HRHA 4-2 (23.40%) and ARG 6A X RHA 271 (20.69%).

The heterotic effect over standard check was positively significant for this trait varied from (-12.45%) CMS 44A X RHA 297 to (82.15%) CMS 207A X HRHA 4-2 followed by hybrids ARG 6A X RHA 271 (39.91%), DV 10 X RHA 271(38.53%), CMS 207A X RHA 297 (37.56%), ARG 6A X HRHA 5-3 (34.14%) and (31.60%) ARG 3A X RHA 271 for palmitic acid.

16.2 Stearic acid (%)

Significant and positive heterotic performance was observed for hybrids over their respective better parents which ranged from (-46.68%) CMS 207A X HRHA 4-2 to (107.64%) CMS 234 A X RHA 297 followed by hybrids CMS 103A X RHA 297 (102.92%), ARG 2A X RHA 271, (95.68%), ARG 2A X RHA 297 (90.22%), CMS 607A X RHA 297 (83.47%), ARG 3A X RHA 297 (79.49%), CMSH 91 A X 6D-1 (74.54%) and CMS 852A X RHA 297 (73.45%) for stearic acid.

The magnitude of the heterotic effect over standard check was significant for the hybrid which confined from -12.47% (CMS 207A X HRHA 4-2) to CMS 234 A X RHA 297 (84.22%) accompanied by hybrids CMS 302A X RHA 271 (79.67%), CMS 607A X 6D-1 (74.50%), CMS 302 A X 6D-1 (63.93%), CMS 103A X RHA 297 (61.14%) and CMS 234A X 6D-1 (61.07%) manifested positive effect for stearic acid.

16.3 Oleic acid (%)

The heterotic effect of hybrids was observed negative and significant for most of the crosses over the better parents for the fatty acids. But, 12 hybrids out of 75 were positively significant and they vary from (-0.23%) CMS 302A X RHA 297 to (12.13%) CMS 234A X HRHA 5- 3, hereafter the hybrids CMS 234A X HRHA 4-2 (12.13%), ARG 2A X 6D-1 (10.39%), CMSH 91A X HRHA 4-2 (7.57%) and CMS 852A X HRHA 5-3 (6.85%).

While the heterosis over standard check was positive significant extended from (7.81%) CMS 148A X HRHA 4-2 to (69.16%) CMS 234A X HRHA 4-2 followed by the prominent hybrids CMSH 91A X HRHA 4-2 (62.28%), ARG 2A X 6D-1(61.64%), CMS 234 A X RHA 297 (59.32%), CMS 607A X RHA 297 (56.6%), ARG 2A X HRHA 4-2 (55.34%) and CMS 852A X HRHA 5-3(52.96%) exhibited positive effect for oleic acid.

16.4 Linoleic acid (%)

Heterosis for linoleic acid was highly significant over their respective better parents which ranged from (-1.66%) CMS 148A X RHA 271 to (50.47%) ARG 2A X HRHA 5-3 and after CMS 17A X HRHA 5-3 (48.35%), CMS 207A X HRHA 5-3(45.66%), CMSH 91A X HRHA 5-3 (43.14%), ARG 3A X RHA 297 (42.01%) and CMS 302A X 6D-1 (41.44%) flourishing the positive effect for this trait.

The extent of heterotic effect was highly significant and positive over the standard check (HSFH 848%) confines from (-1.81%) CMSH 91A X HRHA 4-2 to (61.78%) ARG 2A X HRHA 5-3 accompanied by CMSH 91A X HRHA 5-

3 (59.28%), DV -10 X RHA 297 (58.66%), CMS 17A X HRHA 5-3 (57.83%), ARG 3A X RHA 297 (55.37%), CMS 44A X HRHA 5-3 (55.17%), CMS 302A X 6D-1 (54.86%), CMS 11A X HRHA 4-2 (53.36%) for this fatty acid.

Approximately all the hybrids were significant for studied traits, though some of the hybrids showed higher and positive heterosis for seed yield and oil content. These cross-combination CMS 44A X HRHA 4-2, CMS 148A X HRHA 4-2, CMS 103A X HRHA 4-2, CMS 302A X HRHA 4-2, CMS 234A X HRHA 4-2, CMS 17A X HRHA 4-2 and CMS 44A X 6D-1 were significant exhibited higher heterosis that have been used for further breeding programs.

Table 1: Estimation of heterotic effects of hybrids for morphological traits and 100 seed weight in sunflower over the environments

S. No.	Hybrids	PH (cm)		HD (cm)		SD (cm)		DF		DM		100 SW (g)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	CMS 11A X 6D-1	5.82**	17.14**	12.36**	11.25**	52.64**	5.86**	-5.43**	-1.80**	-1.24**	-1.15**	32.34**	15.41**
2	CMS 11A X RHA 271	9.66**	20.06**	12.71**	10.20**	32.01**	-0.90	-4.24**	-2.39**	-1.43**	-0.96**	29.95**	19.50**
3	CMS 11A X HRHA 4-2	7.05**	18.36**	10.9**	12.75**	60.59**	3.73**	-5.72**	-2.12**	-0.26**	3.24	48.9**	18.05**
4	CMS 11A X HRHA 5-3	18.03**	23.51**	24.34**	24.73**	48.02**	16.01**	-2.38**	-2.71**	0.17	2.06	38.4**	20.69**
5	CMS 11 A X RHA 297	13.47**	19.27**	22.3**	10.31**	54.84**	7.12**	-1.8**	-5.71**	-0.78**	-3.05**	31.74**	14.88**
6	CMS 17-A X 6D-1	11.19**	27.34**	48.04**	28.37**	64.1**	12.25**	-4.89**	-3.52**	2.07	3.81	43.5**	13.69**
7	CMS 17-A X RHA 271	5.9**	19.99**	43.64**	22.78**	53.48**	13.76**	-1.24**	-6.78**	0.66	2.38	59.75**	34.16**
8	CMS 17 -A X HRHA 4-2	7.68**	23.18**	26.91**	13.43**	66.93**	6.24**	-4.4**	4.71	-0.72**	-2.04**	74.07**	24.13**
9	CMS 17 -A X HRHA 5-3	10.79**	20.17**	56.75**	37.98**	59.06**	23.15**	-4.31**	-1.84**	0.27	1.43	45.17**	15.01**
10	CMS 17 A X RHA 297	7.34**	16.94**	51.27**	17.85**	74.44**	19.02**	-5.72**	2.64	-0.92**	-2.20**	29.5**	2.60**
11	CMS 44 A X 6D-1	4.16**	19.58**	47.72**	23.56**	53.91**	13.38**	-5.33**	-2.11**	2.01	2.83	71.21**	31.12**
12	CMS 44 A X RHA 271	-0.29	13.26**	34.16**	10.57**	26.1**	0.10	-4.25**	2.59	1.3	2.11	40.58**	14.35**
13	CMS 44 A X HRHA 4-2	-2.31	12.02**	29.97**	12.18**	35.45**	-6.66	-4.36**	3.80	1.04	2.94	77.88**	22.14**
14	CMS 44 A X HRHA 5-3	10.58**	20.26**	51.4**	28.63**	42.88**	18.14**	-3.36**	-1.90**	1.17	1.43	61.9**	23.99**
15	CMS 44 A X RHA 297	10.42**	20.61**	63.54**	22.39**	68.26**	23.65**	-4.21**	-3.33**	0.04	-2.28**	63.62**	25.31**
16	CMS 148 A X 6D-1	2.61**	13.31**	27.52**	7.58**	65.76**	6.99**	-7.35**	=2.09**	0.48	3.64	36.27**	16.60**
17	CMS 148 A X RHA 271	4.01**	13.59**	43.47**	19.26**	62.8**	14.38**	-6.58**	-2.26	-0.42**	-2.71**	31.73**	18.98**
18	CMS 148 A X HRHA 4-2	9.8**	21.10**	50.49**	30.97**	94.26**	16.14**	-9.31**	0.55	0.07	4.30	60.03**	24.26**
19	CMS 148 A X HRHA 5-3	8.33**	13.07**	34.52**	15.25**	57.53**	15.89**	-1.56**	-6.09**	0.4	-3.02**	50.15**	28.48**
20	CMS 148 A X RHA 297	11.7**	17.11**	57.87**	19.27**	79.06**	15.26**	-6.58**	-2.96**	-3.46**	-0.97**	44.6**	23.73**
21	CMSH 91 A X 6D-1	27.19**	21.02**	32.98**	26.94**	52.5**	14.63**	-4.87**	-3.28**	2.69	-3.33**	32.65**	19.11**
22	CMSH 91 A X RHA 271	25.97**	18.32**	24.24**	17.07**	45.6**	17.76**	-3.71**	-3.85**	5.25	-5.90**	25.14**	18.32**
23	CMSH 91 A X HRHA 4-2	28.01**	21.62**	27.52**	25.12**	70.11**	19.77**	-4.59**	-4.23**	1.68	-3.41**	49.84**	22.67**
24	CMSH 91 A X HRHA 5-3	35.9**	21.07**	20.44**	16.55**	34.67**	13.38**	-0.95**	-5.13**	4.26	4.34**	34.71**	20.96**
25	CMSH 91 X RHA 297	23.39**	10.51**	39.15**	20.57**	52.69**	14.51**	-5.35**	-2.77**	0.26	-2.32**	33.82**	20.16**
26	CMS 103 A X 6D-1	10.36**	17.88**	36.96**	15.12**	58.42**	15.51**	0.19	8.56	1.3	-4.30**	65**	30.73**
27	CMS 103 A X RHA 271	11.78**	18.04**	34.3**	11.22**	37.19**	7.87**	-0.47**	-7.14**	-1.9**	-1.01**	36.4**	14.62**
28	CMS 103A X HRHA 4-2	12.6**	20.13**	37.1**	18.89**	58.64**	8.12**	-2.77**	-6.01**	-1.89**	-2.08**	71.48**	22.28**
29	CMS 103A X HRHA 5-3	21.39**	22.32**	27.85**	9.14**	25.54**	2.86**	3.04	-9.16**	0.37	-2.80**	63**	29.14**
30	CMS 103 A X RHA 297	15.45**	16.88**	30.37**	-1.90	33.14**	-3.16	-4.28**	-3.74**	-1.04**	5.50	57**	24.39**
31	CMS 234 A X 6D-1	10.95**	23.81**	40.33**	19.40**	46.68**	5.74**	-5.38**	-1.55**	-3.06**	4.07	44.5**	14.49**
32	CMS 234A X RHA 271	8.87**	20.16**	35.26**	13.43**	56.52**	21.77**	-1.17**	-5.37**	-3.35**	-4.36**	35.85**	14.09**
33	CMS 234 A X HRHA 4-2	-5.84	4.95**	21.11**	6.28**	59.84**	7.62**	-3.48**	4.25	3.48	-5.61**	63.52**	16.60**
34	CMS 234 A X HRHA 5-3	11.13**	17.29**	25.63**	8.55**	34.07**	8.74**	-1.95**	-2.86**	-5.28**	-5.74**	54.17**	22.14**
35	CMS 234 A X RHA 297	10.92**	17.59**	50.4**	14.73**	47.21**	5.86**	-6.46**	-0.42**	1.92	-4.39**	37**	8.54**
36	CMS 302A X 6D-1	5.37**	14.10**	23.71**	13.30**	37.27**	12.13**	-9.36**	-1.45**	1.73	-4.38**	33.33**	5.64**
37	CMS 302 A X RHA 271	16.61**	24.84**	30.28**	17.72**	28.01**	11.88**	-6.91**	-0.54**	-0.3**	-2.30**	44.18**	21.09**
38	CMS 302 A X HRHA 4-2	7.53**	16.29**	29.45**	22.00*8	49.67**	15.13**	-6.76**	-2.00**	-0.98**	-2.67**	59.44**	13.69**
39	CMS 302 A X HRHA 5-3	22.47**	25.19**	29.37**	20.18**	25.55**	13.88**	0.45	6.77	5.33	-7.50**	40.83**	11.58**
40	CMS 302 A X RHA 297	22.8**	26.12**	39.85**	15.77**	38.64**	13.00**	-2.73**	-5.77**	-0.68**	-3.34**	44.17**	14.22**
41	CMS 607 A X 6D-1	3.48**	18.19**	33.98**	17.72**	45.19**	18.27**	3.14	9.45	4.41	-5.06**	32.74**	17.7**
42	CMS 607 A X RHA 271	12.04**	26.60**	45.79**	26.29**	30.78**	14.01**	-1.76**	-3.55**	1.28	-1.90**	54.08**	24.52**
43	CMS 607 A X HRHA 4-2	5.79**	20.68**	30.19**	17.85**	36.23**	4.49**	-5.24**	-1.20**	-2.96**	-4.71**	13.54**	0.75
44	CMS 607 A X HRHA 5-3	22.85**	32.88**	26.48**	12.78**	17.7**	6.49**	-0.46**	-3.22**	-6.09**	-6.17**	36.9**	21.48**
45	CMS 607 A X RHA 297	5.17**	14.26**	30.42**	3.10**	28.55**	4.49**	-3**	-2.95**	-1.5**	-3.60**	21.19**	15.54**
46	CMS 852 A X 6D -1	6.49**	17.48**	24.03**	10.44**	45.99**	-4.16	-4.52**	1.59	-4.55**	-6.70**	22.56**	22.67**
47	CMS 852 A X RHA 271	7.13**	16.88**	34.21**	17.85**	52.91**	9.12**	-6.26**	-0.93**	0.08	2.15	46.07**	27.69**
48	CMS 852 A X HRHA 4-2	10.37**	21.61**	18.87**	9.01**	85.8**	13.13**	-6.98**	-0.41**	3.11	6.36	16.76**	11.32**
49	CMS 852A X HRHA 5-3	10.36**	15.07**	7.36**	-2.99	40.6**	4.99**	-0.03**	-3.94**	3.94	-5.52**	9.28**	4.19**
50	CMS 852 A X RHA 297	12.84**	18.19**	42.02**	13.95**	57.48**	3.11**	-1.22**	-5.11**	-1.09**	-2.37**	12.89**	15.67**
51	ARG 2A X 6D-1	11.1**	18.16**	56.74**	18.63**	42.79**	11.63**	-5.61**	-0.97**	2.77	-4.89**	15.64**	23.99**
52	ARG 2A X RHA 271	15.67**	21.61**	63.49**	21.72**	33.21**	11.75**	-0.4**	-5.83**	0.9	-2.98**	26.4**	19.50**
53	ARG 2A X HRHA 4-2	10.27**	17.13**	44.11**	12.91**	45.39**	6.74**	-0.45**	-7.17**	1.72	-4.92**	26.8**	29.94**
54	ARG 2A X HRHA 5-3	16.69**	17.04**	39.89**	7.71**	21.12**	5.61**	-0.14**	-4.40**	0.5	2.03	9.66**	12.37**
55	ARG 2A X RHA 297	17.37**	18.27**	54.07**	3.03	29.3**	0.85**	-1.79**	-5.08**	0.79	4.33	34.28**	18.45**

S. No.	Hybrids	PH (cm)		HD (cm)		SD (cm)		DF		DM		100 SW (g)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
56	ARG 3A X 6D -1	6.72**	12.60**	36.68**	12.52**	37.3**	8.37**	-4.22**	6.12	-0.07**	-4.34**	38.21**	28.48**
57	ARG 3A X RHA 271	7.63**	12.26**	41.64**	14.86**	23.74**	4.74**	-1.94**	-7.95**	-0.25**	-4.15**	33.06**	6.83**
58	ARG 3A X HRHA 4-2	7.73**	13.53**	26.89**	7.84**	34.97**	0.10	-3.84**	-7.20**	-1.15**	-4.28**	23.95**	9.34**
59	ARG 3A X HRHA 5-3	12.36**	11.76**	38.26**	15.64**	20.8**	6.24**	-0.22**	-8.14**	-0.84**	-3.00**	40.57**	23.99**
60	ARG 3A X RHA 297	17.42**	17.35**	47.23**	8.23**	34.11**	5.61**	-4.1**	6.28	-2.31**	-3.40**	65.88**	29.67**
61	ARG 6A X 6D-1	5.61**	12.20**	48.79**	16.81**	32.65**	5.36**	-7.86**	-2.37**	-0.44**	-3.05**	65.88**	29.67**
62	ARG 6A X RHA 271	7.82**	13.23**	55.37**	20.05**	23.45**	5.11**	-1.94**	-8.25**	-0.82**	4.35	43.63**	19.11**
63	ARG 6A X HRHA 4-2	9.25**	15.92**	33.02**	7.97**	46.98**	9.75**	-4.14**	-7.15**	-0.51**	-5.12**	70.68**	19.90**
64	ARG 6A X HRHA 5-3	15.23**	15.45**	37.07**	9.40**	19.55**	5.74**	-0.69**	-7.93**	1.61	-4.62**	35.3**	5.77**
65	ARG 6 A X RHA 297	11.62**	12.36**	57.53**	9.79**	41.01**	11.75**	-3.91**	-6.77**	-0.26**	-5.22**	48.99**	16.47**
66	DV 10 X 6D -1	13.92**	21.04**	42.95**	15.64**	49.34**	14.13**	-3.96**	-4.46**	3.24	-5.75**	56.94**	19.37**
67	DV 10 X RHA 271	13.12**	18.81**	38.31**	10.18**	27.82**	4.99**	-1.62**	-6.30**	-2.8**	-5.29**	53.92**	24.39**
68	DV 10 X HRHA 4-2	13.31**	20.25**	27.82**	6.80**	44.23**	3.36**	0.78	-10.30**	-0.91**	-4.45**	43.22**	-2.42
69	DV 10 X HRHA 5-3	15.24**	15.47**	24.7**	2.51**	17.6**	0.48**	-0.84**	-5.45**	-2.98**	-4.92**	34.38**	2.21**
70	DV -10 X RHA 297	8.46**	9.20**	49.6**	7.84**	31.45**	0.23	-2.27**	-6.31**	-1.93**	-5.87**	48.61**	13.03**
71	CMS 207 A X 6D -1	9.39**	16.14**	20.55**	6.93**	44.95**	1.48**	-2.63**	-7.92**	-2.25**	-5.83**	25.78**	6.30**
72	CMS 207 A X RHA 271	8.24**	13.60**	29.08**	12.91**	39.15**	5.36**	-2.55**	-7.30**	2.18	-5.76**	32.69**	18.45**
73	CMS 207 A X HRHA 4-2	11.52**	18.26**	30.55**	19.27**	74.54**	13.88**	-3.75**	7.32	-0.26**	-4.86**	47.93**	13.30**
74	CMS 207 A X HRHA 5-3	15.61**	15.75**	39.87**	25.90**	39.51**	10.25**	-0.02**	-8.38**	-0.7**	-3.68**	36.72**	15.54**
75	CMS 207 A X RHA 297	13.78**	14.46**	62.37**	29.72**	69.18**	18.14**	-4.32**	-6.06**	-1.36**	-3.52**	42.97**	20.82**
	CD at 5%	3.91		1.45		0.70		1.85		1.48		0.92	
	CD at 1%	5.16		1.91		0.93		2.44		1.95		1.21	

Table 2: Estimation of heterotic effects for seed yield, oil content, hull content, and seed germination in sunflower over the environments

S. No.	Hybrids	SY (g)		OC (%)		HC (%)		Seed%		GERM. (%)		EC (µScm^{-1}g^{-1})	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	CMS 11A X 6D-1	33.81**	5.97**	14.73**	0.49	28.41**	3.36**	62.71**	46.07**	-3.33	33.51*	-49.61**	-49.07**
2	CMS 11A X RHA 271	17.18**	13.97**	17.04**	3.56**	16.04**	12.64**	67.68**	49.10**	-5.25	33.63**	-55.52**	-55.04**
3	CMS 11A X HRHA 4-2	79.72**	19.25**	23.59**	2.94**	12.57**	7.09**	59.38**	51.63**	-7.43	26.00**	-26.65**	-25.86**
4	CMS 11A X HRHA 5-3	47.5**	25.75**	10.87**	1.15**	1.02	-0.23	47.18**	44.29**	3.44**	38.75**	-56.59**	-56.12**
5	CMS 11 A X RHA 297	41.23**	23.55**	21.9**	3.62**	22.17**	16.92**	64.02**	55.72**	8.33**	36.29**	-67.04**	-48.09**
6	CMS 17-A X 6D-1	64.98**	25.23**	17.34**	5.28**	27.3**	18.43**	37.48**	49.00**	0.88	39.32**	-52.56**	-54.65**
7	CMS 17-A X RHA 271	38.07**	29.74**	20.39**	1.39**	-7.93	0.93	29.8**	39.57**	-27.18	2.70**	17.62	12.44
8	CMS 17 -A X HRHA 4-2	91.61**	20.83**	23.32**	3.31**	-4.88	2.43**	11.05**	26.31**	-7.76	25.54**	-19.77**	-23.31**
9	CMS 17 -A X HRHA 5-3	43.66**	17.74**	19.91**	2.01**	-5.85	4.81**	30.29**	51.96**	-0.39	33.60**	-44.77**	-47.21**
10	CMS 17 A X RHA 297	44.15**	21.35**	23.85**	1.04**	0.52	8.82**	29.48**	47.01**	1.69**	34.38**	-69.34**	-51.71**
11	CMS 44 A X 6D-1	80**	21.91**	24.48**	1.52**	104.21**	14.55**	139.4**	51.62**	-2.65	39.27**	-51.44**	-53.77**
12	CMS 44 A X RHA 271	22.57**	5.15**	22.61**	4.04**	46.49**	6.47**	145.6**	53.44**	-4.55	36.55**	-45.06**	-47.70**
13	CMS 44 A X HRHA 4-2	137.7**	30.45**	24.53**	1.68**	43.92**	1.81**	123.5**	53.56**	-3.68	37.80**	-34.98**	-38.10**
14	CMS 44 A X HRHA 5-3	62.78**	20.10**	23.53**	2.81**	28.67**	-4.30	91.01**	36.70**	-7.09	32.91**	-47.53**	-50.05**
15	CMS 44 A X RHA 297	62.89**	23.81**	24.05**	2.10**	48.5**	5.90**	131.2**	58.32**	-15.89	20.33**	-49.25**	-20.08**
16	CMS 148 A X 6D-1	54.86**	15.50**	23.62**	2.06**	9.23**	1.18	48.68**	42.07**	-2.2	38.94**	-48.93**	-48.58**
17	CMS 148 A X RHA 271	27.18**	17.83**	23.84**	1.77**	-3.91	4.95**	56.02**	47.76**	-13.92	22.29**	-57**	-56.71**
18	CMS 148 A X HRHA 4-2	102.16**	24.82**	24.91**	1.17**	17.52**	26.07**	50.79**	52.18**	-1.53	39.90**	-52.43**	-52.11**
19	CMS 148 A X HRHA 5-3	64.61**	32.74**	24.22**	1.26**	-12.53	-2.99	42.24**	47.66**	-11.47	25.77**	-33.46**	-33.01**
20	CMS 148 A X RHA 297	58.31**	31.18**	23.24**	2.56**	-3.96	3.58**	28.24**	29.17**	-29.91	-0.42	-39.68**	-5.00**
21	CMSH 91 A X 6D-1	55.11**	31.89**	11.05**	4.82**	20.52**	0.89	33.48**	34.30**	-2.31	34.91**	-29.38**	-39.96**
22	CMSH 91 A X RHA 271	14.03**	17.55**	17.29**	3.25**	11.7**	12.05**	44.78**	44.43**	-12.25	23.75**	-29.95**	-40.45**
23	CMSH 91 A X HRHA 4-2	59.35**	15.02**	24.27**	2.03**	21.99**	19.99**	38.44**	46.71**	-3.04	31.96**	-19.93**	-31.93**
24	CMSH 91 A X HRHA 5-3	44.3**	31.43**	13.19**	1.30**	11.31**	13.54**	41.66**	54.22**	-1.15	33.71**	-41.36**	-50.15**
25	CMSH 91 X RHA 297	35.29**	26.23**	24.96**	-0.44	13.27**	12.07**	38.03**	46.00**	-9.12	22.92**	-44.78**	-13.03**
26	CMS 103 A X 6D-1	86.84**	22.52**	25.64**	-0.09	47.37**	16.38*	40.26**	41.92**	-3.62	33.11**	-19.18**	-36.04**
27	CMS 103 A X RHA 271	41.74**	18.55**	22.53**	4.09**	28.28**	22.58**	47.82**	48.32**	-1.65	38.71**	-10.27**	-28.99**
28	CMS 103A X HRHA 4-2	126.9**	19.43**	24.27**	2.03**	26.43**	18.36**	42.17**	51.49**	-1.05	34.68**	-21.53**	-37.90
29	CMS 103A X HRHA 5-3	68.22**	20.50**	24.65**	1.24**	12.89**	9.78**	21.92**	33.43**	-29.89	-5.16	49.88**	22.14
30	CMS 103 A X RHA 297	53.03**	13.03**	24.41**	1.57**	13.52**	6.92**	16.83**	24.25**	-5.67	27.60**	-54.42**	-28.21**
31	CMS 234 A X 6D-1	79.44**	21.63**	13.72**	1.68**	56.95**	21.21**	42.16**	34.89**	-24.44	4.35**	-0.15**	27.91
32	CMS 234A X RHA 271	33.31**	14.44**	19.72**	0.22	29.3**	21.31**	40.77**	32.38**	-5.53	33.24**	-50.69**	-36.83**
33	CMS 234 A X HRHA 4-2	103.2**	11.68**	25**	1.04**	34.33**	23.42**	54.22**	54.61**	0.04	36.16**	-48.7**	-34.28**
34	CMS 234 A X HRHA 5-3	48.66**	9.77**	14.5**	0.75**	24.87**	19.27**	49.8**	54.50**	-0.28	33.75**	-44.42**	-28.80**
35	CMS 234 A X RHA 297	55.64**	18.39**	23.75**	1.17**	23.97**	14.61**	46.61**	46.69**	54.72**	33.44**	-67.16**	-48.29**
36	CMS 302A X 6D-1	76.17**	16.33**	27.11**	1.86**	69.08**	21.81**	80.81**	54.45**	-3.5	33.27**	-39.4**	-50.15**
37	CMS 302 A X RHA 271	45.61**	22.45**	25.67**	3.87**	44.44**	28.03**	67.23**	41.42**	-10.26	26.57**	-1.07**	-18.61**

S. No.	Hybrids	SY (g)		OC (%)		HC (%)		Seed%		GERM. (%)		EC ($\mu Scm^{-1}g^{-1}$)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
38	CMS 302 A X HRHA 4-2	118.7**	16.33**	25.95**	3.47**	48.85**	29.03**	42.37**	29.25**	-30.42	-5.30	13.81	-6.37**
39	CMS 302 A X HRHA 5-3	57.12**	13.26**	26.54**	2.65**	34.76**	21.72**	37.82**	29.11**	-1.46	32.17**	-25.95**	-39.08**
40	CMS 302 A X RHA 297	61.16**	19.76**	26.27**	3.03**	47.87**	29.04**	72.41**	56.17**	0.81	35.15**	-56.41**	-31.34**
41	CMS 607 A X 6D-1	40.1**	21.68**	19.98**	1.39**	38.61**	19.94**	46.59**	38.86**	35.01**	-54.29**	-38.39**	35.01**
42	CMS 607 A X RHA 271	13.19**	18.75**	18.38**	3.43**	21.57**	25.36**	40.84**	32.22**	35.01**	-54.29**	-38.39**	35.01**
43	CMS 607 A X HRHA 4-2	60.81**	19.01**	24.15**	2.19**	17.76**	19.15**	54.33**	54.48**	2.61**	39.66**	-59.52**	-45.45**
44	CMS 607 A X HRHA 5-3	19.3**	10.84**	19.46**	2.06**	17.9**	23.57**	29.44**	33.30**	-12.93	16.79**	-40.12**	-19.29**
45	CMS 607 A X RHA 297	20.88**	15.00**	23.23**	1.86**	10.91**	12.86**	23.58**	23.45**	-14.67	-3.24	-37.31**	-1.27**
46	CMS 852 A X 6D -1	31.74**	16.66**	25.72**	1.24**	42.21**	11.18**	57.63**	29.46**	1.7**	40.45**	-61.57**	-34.97**
47	CMS 852 A X RHA 271	13.63**	21.15**	26.02**	0.82	22.46**	16.05**	91.46**	55.63**	-4.6	34.55**	-61.4**	-34.67**
48	CMS 852 A X HRHA 4-2	48.57**	12.48**	25.62**	1.37**	32.87**	23.34**	72.48**	50.92**	-1.54	34.01**	-60.82**	-33.69**
49	CMS 852A X HRHA 5-3	18.6**	12.21**	25.08**	2.10**	30.75**	26.12**	62.62**	46.99**	-4.16	28.54**	-47.28**	-10.77**
50	CMS 852 A X RHA 297	14.93**	11.30**	23.35**	4.46**	31.26**	22.59**	61.01**	40.55**	20.46**	27.17**	-47.57**	-11.26**
51	ARG 2A X 6D-1	33.09**	16.17**	21.57**	-0.09	52.04**	25.94**	80.74**	60.55**	0.68	39.05**	-40.28**	-42.21**
52	ARG 2A X RHA 271	9.13**	14.97**	19.25**	2.87**	26.99**	26.26**	51.17**	33.01**	-26.39	3.82**	12.75	9.11
53	ARG 2A X HRHA 4-2	60.28**	19.32**	22.97**	3.78**	28.53**	25.28**	35.77**	27.89**	-5.92	28.04**	-8.81**	-11.75**
54	ARG 2A X HRHA 5-3	27.39**	18.90**	19**	3.18**	24.48**	25.86**	52.52**	48.08**	-5.72	26.46**	-39.88**	-41.82**
55	ARG 2A X RHA 297	31.83**	25.99**	21.18**	4.57**	25.83**	23.37**	53.3**	44.10**	12.15**	33.86**	-62**	-40.16**
56	ARG 3A X 6D -1	54.97**	22.02**	15.69**	2.32**	52.93**	7.57**	98.84**	56.08**	-1.91	35.47**	-26.5**	-32.91**
57	ARG 3A X RHA 271	17.85**	14.08**	17.33**	3.20**	34.27**	16.72**	89.67**	47.27**	-13.65	21.79**	2.15	-6.76**
58	ARG 3A X HRHA 4-2	69.74**	11.85**	23.74**	2.74**	31.86**	12.06**	75.19**	46.92**	-5.94	28.02**	-47.75**	-52.30**
59	ARG 3A X HRHA 5-3	38.17**	17.15**	15.74**	2.25**	32.58**	17.50**	80.11**	56.26**	0.75	35.13**	-44.42**	-49.27**
60	ARG 3A X RHA 297	38.6**	20.60**	24.48**	0.20	30.35**	11.53**	89.59**	58.61**	1.09	31.63**	-66.11**	-46.62**
61	ARG 6A X 6D-1	48.49**	25.35**	25.32**	3.14**	89.94**	27.21**	101.148*	46.38**	-13.82	22.41**	-44.02**	-43.19**
62	ARG 6A X RHA 271	13.39**	16.20**	26.76**	1.15**	52.81**	27.69**	109.87**	50.95**	-3.09	37.66**	-44.5**	-43.68**
63	ARG 6A X HRHA 4-2	58.09**	13.15**	23.97**	4.99**	45.61**	18.85**	83.51**	43.40**	-9.77	28.16**	-42.86**	-42.02**
64	ARG 6A X HRHA 5-3	25.18**	13.25**	24.71**	3.98**	31.57**	12.17**	90.69**	54.53**	-2.32	38.75**	-37.64**	-36.73**
65	ARG 6 A X RHA 297	35.2**	25.33**	26.42**	1.61	51.32**	24.37**	107.45**	61.69**	-2.06	39.12**	-63.37**	-42.31**
66	DV 10 X 6D -1	50.34**	12.14**	16.17**	3.82**	56.47**	28.41**	39.13**	33.58**	-10.28	23.91**	-38.36**	-40.35**
67	DV 10 X RHA 271	22.87**	13.84**	17.89**	2.50**	26.58**	24.88**	56.23**	48.68**	-9.17	28.10**	-46.26**	-47.99**
68	DV 10 X HRHA 4-2	74.09**	7.49**	24.05**	2.32**	38.06**	33.52**	37.83**	39.73**	-5.86	28.13**	-50.91**	-52.50**
69	DV 10 X HRHA 5-3	41.38**	14.01**	17.78**	1.83	27.81**	28.25**	44.79**	50.98**	-8.4	22.87**	-26.72**	-29.09**
70	DV -10 X RHA 297	39**	15.18**	21.58**	4.04**	24.01**	20.65**	49.76**	51.52**	-11.86	17.35**	-28.05**	13.32
71	CMS 207 A X 6D -1	45.18**	18.45**	9.52**	6.63**	16.79**	-6.22	48.22**	41.46**	-4.05	32.51**	-40.32**	-34.77**
72	CMS 207 A X RHA 271	16.54**	16.14**	16.89**	3.76**	21.02**	17.24**	64.26**	55.37**	-14.35	20.79**	-24.28**	-17.24**
73	CMS 207 A X HRHA 4-2	66.86**	14.71**	23.28**	3.36**	23.14**	16.90**	48.53**	49.72**	-7.52	25.86**	-35.22**	-29.19**
74	CMS 207 A X HRHA 5-3	58.08**	38.55**	10.94**	4.02**	25.7**	23.90**	51.73**	57.34**	2.9**	38.02**	-37.37**	-31.54**
75	CMS 207 A X RHA 297	43.9**	29.33**	19.71**	6.52**	22.91**	17.39**	58**	58.96**	13**	36.22**	-44.4**	-12.44**
	CD at 5%	2.61		2.26		3.69		3.59		3.93		0.07	
	CD at 1%	3.44		2.97		4.86		4.73		5.19		0.09	

Table 3: Heterotic effects of hybrids for viability, vigor, and fatty acids in sunflower over the environments

S. No.	Hybrids	Viab. (%)		VGI		VGII		PALM.		STEAR. (%)		OLEIC (%)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	CMS 11A X 6D-1	-0.27	48.15**	20.13	34.16	55.38**	5.90**	-21.67	-9.72	13.97**	19.22**	-0.14	46.22**
2	CMS 11A X RHA 271	1.82**	53.55**	16.94	34.02	52.67**	6.29**	-13.18	0.06	-3.12	-6.45	-15.7	31.86**
3	CMS 11A X HRHA 4-2	-7.96	35.23**	21.84	26.36	44.12**	-9.02	-15.45	-2.55	32.88**	42.63**	-22.47	16.96**
4	CMS 11A X HRHA 5-3	4.94**	52.92**	21.45	41.12	47.84**	-4.70	-18.59	-6.17	-0.24	26.52**	-7.2	34.81**
5	CMS 11 A X RHA 297	26.68**	46.38**	26.02	36.10	77.14**	-1.22	-23.7	-12.06	32.5**	16.41**	-15.86	27.25**
6	CMS 17-A X 6D-1	6.57**	54.38**	23.78	36.75	43.68**	-2.91	-18.77	-10.24	28.03**	36.16**	2.95**	50.75**
7	CMS 17-A X RHA 271	-24.7	10.77**	4.27	18.24	26.31**	-12.79	-2.8	-6.43	7.73**	5.89**	-9.31	41.85**
8	CMS 17 -A X HRHA 4-2	-4.72	36.46**	13.96	16.82	54.25**	-3.52	1.1**	-2.68	30.33**	42.15**	-4.24	44.47**
9	CMS 17 -A X HRHA 5-3	1.18	43.70**	8.94	25.28	55.08**	-0.93	2.11**	-1.71	-14.25	10.24**	-7.23	26.91**
10	CMS 17 A X RHA 297	32.83**	48.58**	22.73	31.07	105.74*	13.54**	-7.05	-10.24	56.33**	40.05**	-19.68	21.47**
11	CMS 44 A X 6D-1	4.93**	51.42**	16.95	29.54	69.95**	10.57**	-13.19	-4.07	44.38**	38.97**	-3.66	48.86**
12	CMS 44 A X RHA 271	2.97**	50.90**	5.86	20.35	52.42**	1.41	-14.28	-10.66	43.89**	26.91**	-20.85	23.79**
13	CMS 44 A X HRHA 4-2	6.08**	51.34**	30.01	33.64	54.58**	-7.20	-9.02	-5.17	21.94**	20.70**	-13.15	34.19**
14	CMS 44 A X HRHA 5-3	3.94**	47.05**	14.6	32.11	42.34**	-12.65	-11.4	-7.66	7.69**	27.58**	-17.52	27.43**
15	CMS 44 A X RHA 297	21.36**	35.07**	12.04	19.98	54.65**	-18.54	-16	-12.45	54.96**	23.19**	-9.95	39.14**
16	CMS 148 A X 6D-1	4.8**	55.65**	-4.05	21.45	90.33**	29.05**	-15.45	-6.56	8.17**	16.11**	-6.07	40.60**
17	CMS 148 A X RHA 271	-10.59	34.81**	-17.13	7.31	41.96**	-1.66	-12.55	-5.29	10.4**	9.61**	-8.68	42.84**
18	CMS 148 A X HRHA 4-2	2.98**	51.26**	3.61	22.88	56.05**	-2.04	-14.72	-7.63	-3.91	5.76**	-28.54	7.81**
19	CMS 148 A X HRHA 5-3	-3.98	39.90**	-12.45	14.77	41.04**	-9.57	-8.33	-0.71	9.96**	42.46**	-18.1	22.60**

S. No.	Hybrids	Viab. (%)		VGI		VGII		PALM.		STEAR. (%)		OLEIC (%)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
20	CMS 148 A X RHA 297	-4.33	10.52**	-19.08	-0.56	20.07**	-33.46	-13.55	-6.37	36.21**	23.38**	-7.53	39.86**
21	CMSH 91 A X 6D-1	-2.65	44.31**	5.92	24.93	4.45**	-25.14	-12.19	4.34**	74.54**	60.75**	-5.47	38.42**
22	CMSH 91 A X RHA 271	-11.31	33.45**	-5.4	14.35	19.28**	-12.76	-17.22	-1.63	57.91**	32.71**	-18.53	27.43**
23	CMSH 91 A X HRHA 4-2	1.08	48.17**	8.43	19.26	53.52**	2.31	-15.21	0.75**	50.43**	42.65**	-15.21	0.75**
24	CMSH 91 A X HRHA 5-3	-3.06	40.96**	-1.22	20.97	80.63**	22.78	-6.45	11.17**	12.63**	28.75**	-6.45	11.17**
25	CMSH 91 X RHA 297	16.66**	34.42**	-0.95	13.18	96.85**	16.69**	-15.16	0.82**	54.25**	16.22**	-15.16	0.82**
26	CMS 103 A X 6D-1	3.71**	52.01**	3.86	29.66	63.02**	34.06**	-5.27	4.69**	49.98**	44.23**	-5.27	4.69**
27	CMS 103 A X RHA 271	2.59**	52.67**	4.25	33.20	56.62**	31.10**	5.52**	2.54**	46.46**	29.05**	5.52**	2.54**
28	CMS 103A X HRHA 4-2	1.92**	47.72**	4.81	22.49	48.47**	14.64**	7.51**	4.48**	46.15**	44.53**	7.51**	4.48**
29	CMS 103A X HRHA 5-3	-26.94	5.02**	-10.29	16.05	35.4**	6.35**	14.06**	10.84**	13.04**	33.82**	14.06**	10.84**
30	CMS 103 A X RHA 297	24.25**	41.11**	-2.02	18.72	34.96**	-5.74	19.94**	16.56**	102.92**	61.14**	19.94**	16.56**
31	CMS 234 A X 6D-1	-2.14	12.16**	1.04	7.78	66.07**	-7.33	-10.98	-1.62	52.71**	61.07**	-10.98	-1.62
32	CMS 234A X RHA 271	24.28**	45.23**	11.65	22.36	91.03**	9.41**	18.84**	10.99**	26.69**	23.42**	18.84**	10.99**
33	CMS 234 A X HRHA 4-2	30.67**	47.63**	24.02	22.42	118.04**	10.72**	23.4**	15.26**	28.69**	39.25**	23.4**	15.26**
34	CMS 234 A X HRHA 5-3	33.02**	48.69**	4.3	15.97	84.07**	-4.07	24.79**	16.56**	-13.51	10.44**	24.79**	16.56**
35	CMS 234 A X RHA 297	79.83**	46.75**	10.89	14.21	145.54**	6.61**	16.6**	12.60**	107.64**	84.22**	16.6**	12.60**
36	CMS 302A X 6D-1	-0.18	48.00**	5.87	24.68	36.48**	-9.53	-7.08	10.89**	36.83**	63.93**	-7.08	10.89**
37	CMS 302 A X RHA 271	-9.18	36.69**	8.01	30.36	31.64**	-10.80	2.33**	22.12**	60.77**	79.67**	2.33**	22.12**
38	CMS 302 A X HRHA 4-2	-25.88	8.68**	17.06	28.53	26.96**	-22.21	-6.5	11.58**	6.63**	30.66**	-6.5	11.58**
39	CMS 302 A X HRHA 5-3	-0.53	44.67**	3.35	26.38	39.89**	-12.43	-17.16	-1.14	-13.6	22.71**	-17.16	-1.14
40	CMS 302 A X RHA 297	28.49**	48.11**	20.82	37.84	67.83**	-9.54	-4.94	13.44**	-10	-7.25	-4.94	13.44**
41	CMS 607 A X 6D-1	-13.56	12.84**	-7.61	18.40	35.43**	-25.84	7.23**	18.50**	68.48**	74.50**	7.23**	18.50**
42	CMS 607 A X RHA 271	12.11**	48.88**	-8.74	19.62	48.81**	-16.33	11.7**	13.39**	38.26**	32.06**	11.7**	13.39**
43	CMS 607 A X HRHA 4-2	19.49**	54.04**	-2.06	17.70	60.27**	-20.30	23.19**	25.06**	53.3**	23.19**	25.06**	53.3**
44	CMS 607 A X HRHA 5-3	0.52	28.38**	-15.44	12.19	56.96**	-19.84	7.44**	9.08**	-8.74	7.44**	9.08**	-8.74
45	CMS 607 A X RHA 297	8.61**	5.93**	-7.65	14.95	81.58**	-23.07	12.12**	13.83**	83.47**	12.12**	13.83**	83.47**
46	CMS 852 A X 6D -1	13.93**	51.68**	14.02	25.17	49.41**	-9.31	-4.76	8.36**	55.86**	-4.76	8.36**	55.86**
47	CMS 852 A X RHA 271	9.28**	47.93**	5.86	19.31	56.38**	-2.78	13.39**	29.01**	31.33**	13.39**	29.01**	31.33**
48	CMS 852 A X HRHA 4-2	9.86**	44.46**	18.44	20.58	106.65**	15.04**	-4.32	8.86**	7.92**	-4.32	8.86**	7.92**
49	CMS 852A X HRHA 5-3	8.51**	41.40**	-1.35	12.75	82.76**	4.18**	-2.36	11.09**	15.27**	-2.36	11.09**	15.27**
50	CMS 852 A X RHA 297	34.26**	34.43**	13.3	20.21	100.26**	-3.26	-8.8	3.77**	73.45**	-8.8	3.77**	73.45**
51	ARG 2A X 6D-1	13.23**	54.23**	18.27	27.69	17.48**	-24.26	-2.36	7.90**	53.56**	-2.36	7.90**	53.56**
52	ARG 2A X RHA 271	-17.42	14.34**	1.71	12.79	-0.51	-34.40	5.75**	13.72**	95.68**	5.75**	13.72**	95.68**
53	ARG 2A X HRHA 4-2	4.84**	41.09**	22.84	22.83	35.88**	-19.23	-0.57	6.93**	5.34**	-0.57	6.93**	5.34**
54	ARG 2A X HRHA 5-3	5.21**	40.33**	0.08	12.57	7.25**	-34.82	5.34**	13.29**	-9.08	5.34**	13.29**	-9.08
55	ARG 2A X RHA 297	36.7**	41.08**	19.82	24.95	52.27**	-20.69	19.41**	28.42**	90.22**	19.41**	28.42**	90.22**
56	ARG 3A X 6D -1	0.17	46.29**	0.91	24.83	15.97**	-14.47	-3.21	15.06**	14.74**	-3.21	15.06**	14.74**
57	ARG 3A X RHA 271	-11.28	31.56**	-11.1	12.58	16.51**	-12.36	10.7**	31.60**	56.12**	10.7**	31.60**	56.12**
58	ARG 3A X HRHA 4-2	-5.23	36.84**	3.32	19.58	13.63**	-21.91	5.85**	25.84**	25.29**	5.85**	25.84**	25.29**
59	ARG 3A X HRHA 5-3	1.73**	45.69**	6.49	36.55	21.89**	-14.60	-9.5	7.58**	24.93**	-9.5	7.58**	24.93**
60	ARG 3A X RHA 297	24.45**	40.66**	3.45	24.16	43.28**	-12.08	-0.15	18.70**	79.49**	-0.15	18.70**	79.49**
61	ARG 6A X 6D-1	-13.77	29.28**	-9.89	12.81	21.82**	0.13	-1.94	13.67**	13.41**	-1.94	13.67**	13.41**
62	ARG 6A X RHA 271	-5.65	43.57**	-6.19	20.18	8.86**	-8.92	20.69**	39.91**	30.64**	20.69**	39.91**	30.64**
63	ARG 6A X HRHA 4-2	-7.01	37.90**	9.52	28.38	25.38**	-3.24	-2.16	13.42**	-11.14	13.62**	-2.16	13.42**
64	ARG 6A X HRHA 5-3	2.32**	50.51**	-6.19	21.68	46.47**	14.99**	15.72**	34.14**	-4.45	40.79**	15.72**	34.14**
65	ARG 6 A X RHA 297	27.84**	49.47**	-4.94	15.51	59.34**	11.23**	-13.08	0.75**	1.58**	10.09**	-13.08	0.75**
66	DV 10 X 6D -1	-10.59	31.53**	-0.03	20.46	41.81**	-5.24	-0.51	9.95**	17.64**	12.77**	-0.51	9.95**
67	DV 10 X RHA 271	-7.63	37.96**	0.9	24.52	20.85**	-17.46	34.49**	38.53**	25.79**	10.46**	34.49**	38.53**
68	DV 10 X HRHA 4-2	-4.81	38.48**	3.09	16.00	57.09**	-2.92	21.12**	24.75**	46.05**	43.99**	21.12**	24.75**
69	DV 10 X HRHA 5-3	-8.63	31.84**	-9.34	13.34	32.98**	-16.04	8.09**	11.34**	17.86**	39.16**	8.09**	11.34**
70	DV -10 X RHA 297	11.85**	27.62**	-5.61	10.26	44.54**	-21.31	14.95**	18.40**	41.9**	12.25**	14.95**	18.40**
71	CMS 207 A X 6D -1	1.03	39.24**	1.52	16.96	29**	-18.92	16**	28.19**	-32.69	8.66**	16**	28.19**
72	CMS 207 A X RHA 271	-4.63	33.59**	-9.49	6.92	60.75**	3.40**	16.88**	24.92**	-41.77	-10.69	16.88**	24.92**
73	CMS 207 A X HRHA 4-2	0.79	37.26**	4.7	12.27	69.86**	-1.77	70.43**	82.15**	-46.68	-12.47	70.43**	82.15**
74	CMS 207 A X HRHA 5-3	9.58**	47.93**	10.71	32.55	97.7**	16.96**	-6.75	-0.33	-40.97	8.40**	-6.75	-0.33
75	CMS 207 A X RHA 297	45.6**	52.61**	19.26	33.00	107.26**	4.59**	28.7**	37.56**	-16.94	20.16**	28.7**	37.56**
	CD at 5%	2.84		293.57		3.53		0.58		0.47		1.07	
	CD at 1%	3.74		387.24		4.66		0.76		0.62		1.41	

PH –Plant height, HD -Head diameter, SD- Stem diameter, DF- days to flowering, DM- days to maturity,100 Seed weight, SY- Seed yield per plant, OC- Oil content, HC- Hull content, Seed%- Seed percent filling, GERMN.- Germination, EC- Electrical conductivity, VIAB. –Viability, VI 1 -Vigour index 1, VI 2 – Vigour index 2, PALM.- Palmitic acid, STEAR. – Stearic acid, OLEIC- Oleic acid, LINO. -Linolenic acid. * at 5% level of significance, ** at 1% level of significance

Table 4: Estimation of the Heterotic effect of hybrids for linoleic acid over the environments in sunflower

S. No.	Hybrids	Linoleic (%)		S. No.	Hybrids	Linoleic (%)		S. No.	Hybrids	Linoleic (%)	
		BP	SC			BP	SC			BP	SC
1	CMS 11A X 6D-1	21.52**	39.29**	31	CMS 234 A X 6D-1	7.24**	15.95**	61	ARG 6A X 6D-1	30.29**	36.40**
2	CMS 11A X RHA 271	27.56**	45.54**	32	CMS 234A X RHA 271	21.97**	31.22**	62	ARG 6A X RHA 271	36.66**	42.35**
3	CMS 11A X HRHA 4-2	38.05**	53.36**	33	CMS 234 A X HRHA 4-2	22.59**	28.21**	63	ARG 6A X HRHA 4-2	21.03**	37.53**
4	CMS 11A X HRHA 5-3	26.51**	39.06**	34	CMS 234 A X HRHA 5-3	35.38**	40.00**	64	ARG 6A X HRHA 5-3	11.67**	25.59**
5	CMS 11 A X RHA 297	27.01**	47.01**	35	CMS 234 A X RHA 297	31.17**	43.29**	65	ARG 6 A X RHA 297	22.56**	44.97**
6	CMS 17-A X 6D-1	15.27**	28.08**	36	CMS 302A X 6D-1	41.44**	54.86**	66	DV 10 X 6D -1	32.19**	46.90**
7	CMS 17-A X RHA 271	26.82**	40.23**	37	CMS 302 A X RHA 271	14.49**	24.75**	67	DV 10 X RHA 271	14.02**	26.11**
8	CMS 17 -A X HRHA 4-2	9.91**	18.22**	38	CMS 302 A X HRHA 4-2	25.31**	32.77**	68	DV 10 X HRHA 4-2	35.7**	46.00**
9	CMS 17 -A X HRHA 5-3	48.35**	57.83**	39	CMS 302 A X HRHA 5-3	36.48**	43.01**	69	DV 10 X HRHA 5-3	36.61**	45.38**
10	CMS 17 A X RHA 297	39.45**	56.49**	40	CMS 302 A X RHA 297	34.01**	48.23**	70	DV -10 X RHA 297	41.35**	58.66**
11	CMS 44 A X 6D-1	3.95**	23.11**	41	CMS 607 A X 6D-1	30.29**	36.40**	71	CMS 207 A X 6D -1	36.04**	42.71**
12	CMS 44 A X RHA 271	29.69**	52.91**	42	CMS 607 A X RHA 271	36.66**	42.35**	72	CMS 207 A X RHA 271	26.94**	32.48**
13	CMS 44 A X HRHA 4-2	12.74**	29.54**	43	CMS 607 A X HRHA 4-2	-12.68	-1.81	73	CMS 207 A X HRHA 4-2	33.11**	34.92**
14	CMS 44 A X HRHA 5-3	36.44**	55.17**	44	CMS 607 A X HRHA 5-3	43.14**	59.28**	74	CMS 207 A X HRHA 5-3	45.66**	45.93**
15	CMS 44 A X RHA 297	23.19**	47.29**	45	CMS 607 A X RHA 297	20.52**	41.13**	75	CMS 207 A X RHA 297	37.99**	46.29**
16	CMS 148 A X 6D-1	21.57**	40.23**	46	CMS 852 A X 6D -1	27.15**	45.44**		CD at 5%	0.63	
17	CMS 148 A X RHA 271	-1.66	12.90**	47	CMS 852 A X RHA 271	25.75**	43.17**		CD at 1%	0.84	
18	CMS 148 A X HRHA 4-2	31.08**	46.55**	48	CMS 852 A X HRHA 4-2	26.59**	40.32**				
19	CMS 148 A X HRHA 5-3	29.02**	42.74**	49	CMS 852A X HRHA 5-3	24.08**	36.09**				
20	CMS 148 A X RHA 297	20.07**	39.83**	50	CMS 852 A X RHA 297	-9.16	4.92**				
21	CMSH 91 A X 6D-1	24.21**	44.06**	51	ARG 2A X 6D-1	7.24**	15.95**				
22	CMSH 91 A X RHA 271	32.5**	52.98**	52	ARG 2A X RHA 271	21.97**	31.22**				
23	CMSH 91 A X HRHA 4-2	-12.68	-1.81	53	ARG 2A X HRHA 4-2	22.59**	28.21**				
24	CMSH 91 A X HRHA 5-3	43.14**	59.28**	54	ARG 2A X HRHA 5-3	35.38**	40.00**				
25	CMSH 91 X RHA 297	20.52**	41.13**	55	ARG 2A X RHA 297	31.17**	43.29**				
26	CMS 103 A X 6D-1	27.15**	45.44**	56	ARG 3A X 6D -1	41.44**	54.86**				
27	CMS 103 A X RHA 271	25.75**	43.17**	57	ARG 3A X RHA 271	14.49**	24.75**				
28	CMS 103A X HRHA 4-2	26.59**	40.32**	58	ARG 3A X HRHA 4-2	25.31**	32.77**				
29	CMS 103A X HRHA 5-3	24.08**	36.09**	59	ARG 3A X HRHA 5-3	36.48**	43.01**				
30	CMS 103 A X RHA 297	-12.68	-1.81	60	ARG 3A X RHA 297	34.01**	48.23**				

Discussion

Heterosis is the superiority of F1 over the mean of the parents or the better parent or the standard check (Hayes *et al*. 1956) [5], concerning agriculturally useful traits. The primary objective of heterosis breeding is to achieve a quantum jump in yield and quality aspects of crop plants.

Sunflower belongs to a highly cross-pollinated group of crop plants. The discovery of cytoplasmic male sterility (Leclerq, 1968) [14] and fertility restoration (Kinman, 1970) [10] has helped to revolutionize heterosis breeding in sunflowers. In India, the era of sunflower hybrids began with the production and release of the first-ever sunflower hybrid, BSH-1 in 1980 (Seetharam, 1981) [20] for commercial cultivation.

In the present study, the superiority of hybrids was estimated over better parent and standard checks for all 19 traits. Analysis of variance for parents, hybrids, location, parent vs. female, parent vs. female x location was significant for all the characters except electrical conductivity (µScm-1g^{-1}) for hybrids and stem diameter (cm) for female x male interaction. Heterosis was positively significant for plant height (cm), the suitable hybrid over the better parent and standard check were CMS 11A X HRHA 5-3, CMS 607A X HRHA 5-3, and ARG 3A x RHA 297 as they showed higher heterosis. For head diameter over better parent CMS 44 A X RHA 297 and over standard check HSFH 848 the cross-combination CMS 148A X HRHA 4-2 and CMS 207A X RHA 297 were significant and showed positive heterosis. The hybrid CMS 148A X HRHA 4-2 showed heterosis over better parent and CMS 44A X RHA 297, CMS 17A X HRHA 5-3 over HSFH 848 and showed positive heterosis for stem diameter (cm).

Hybrids CMS 302A X 6D-1, DV 10 X HRHA 4-2, CMS 103A X HRHA 5-3 showed negative and significant heterosis over better parent and standard check for days to flowering while CMS 302A X HRHA 5-3, CMS 607A X HRHA 5-3, CMS 103A X RHA 297 also showed negative heterosis and significant for early maturity.

For 100 seed weight (g) the hybrids CMS 44A X HRHA 4-2, CMS 44A X 6D-1, and CMS 17A X RHA 271 were highly significant and observed positive heterosis over better parent and standard check. Seed yield (g) for hybrids CMS 44A X HRHA 4-2, CMS 207A X HRHA 5-3, and CMS 148A X HRHA 5-3 showed positive and significant heterosis. For oil content (%) the cross combinations CMS 302A X 6D-1, ARG 6A X RHA 271, CMS 207A X 6D -1, and CMS 207A X RHA 297 were significant and illustrated positive heterotic effect over a standard check and better parent.

Heterosis for hull content (%) was negative and significant over better parent and standard check for the hybrids CMS 148A X HRHA 5-3, CMS 17A x RHA 271, CMS 207A X 6D-1, while the hybrids CMS 17A X RHA 297, CMS 234A X RHA 297, CMS 148A X RHA 271, CMS 11A X HRHA 5-3 were significant and flourished negative heterotic effect for electrical conductivity over the batter parent and HSFH 848. Heterosis for germination (%) was negative and significant for the cross combinations *viz*. CMS 234A X HRHA 5-3, CMS 148A X RHA 297, CMS 234A X RHA 297, CMS 852A X 6D -1, CMS 148A X HRHA 4-2 over the better parent and standard check.

For seed percent filling (%) the hybrids namely CMS 44A X RHA 271, CMS 44A X 6D-1, ARG 6A X RHA 297, and ARG 2A X 6D-1 and for viability (%) hybrids CMS 234A X RHA 297, CMS 103A X 6D-1, CMS 148A X 6D-1 and CMS 17A X 6D-1 were found highly significant and showed positive heterotic effect over a standard check and better parents.

Vigour index I and II were positive and significant over the standard check and better parent for the hybrids namely CMS 44A X HRHA 4-2, CMS 11A X RHA 297, CMS 11A X HRHA 5-3, CMS 17A X 6D-1, CMS 234A X RHA 297, CMS 234A X HRHA 4-2, CMS 103A X 6D-1 and CMS 103A X RHA 271.

The fatty acids; palmitic (%), stearic (%) and linoleic acid (%) were significant and observed positive heterosis for the hybrids namely CMS 207A X HRHA 4-2, DV 10 X RHA 271, ARG 6A X RHA 271, CMS 103A X RHA 297, ARG 2A X RHA 271, ARG 3A X RHA 297, CMS 17A X HRHA 5-3, ARG 2A X HRHA 5-3 and CMSH 91A X HRHA 5-3 while oleic acid (%) was negative and significant for the hybrids CMS 234A X HRHA 5- 3, CMS 234A X HRHA 4-2 and CMSH 91A X HRHA 4-2 over better parent and standard check.

A similar result was reported by Singh *et al*. (1984) [19], Pathak *et al*. (1985) [17], Giriraj *et al*. (1986) [3], Naware (1999) [16], Goksoy *et al*. (2000) [4] Nehru *et al*. (2000) [15], Radhika *et al*. (2001) [18], Joksimovic *et al*. (2006) [7], Gill and Sheoran (2002) [2], Hladni *et al*. (2003) [6], Khan *et al*. (2004) [13], Goksoy and Turan (2004) [4], Kaya (2005) [9], khan *et al*. (2008) [12], Karasu *et al*. (2010) [8] and Deshmukh *et al*. (2016) [1].

Conclusion

Based on heterosis, the mean sums of squares due to replications were found significant for four different environments which emphasizes the presence of variations in the environment. The mean sum of squares due to partitioning component-parents, males, females, hybrids, location, hybrid x location, (Parent vs. hybrid) x location were found significant for all the seed yield and its component characters except female vs. male for stem diameter (cm). Approximately, all the hybrids were significant for studied traits, though some of the hybrids showed higher and positive heterosis for seed yield and oil content. These cross combinations, *viz*., CMS 44A X HRHA 4-2, CMS 148A X HRHA 4-2, CMS 103A X HRHA 4-2, CMS 302A X HRHA 4-2, CMS 234A X HRHA 4-2, CMS 17A X HRHA 4-2 and CMS 44A X 6D-1 were significant and exhibited higher heterosis that can be used for further breeding programs.

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