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COMBINING ABILITY AND HETEROSIS ANALYSIS FOR QUALITY AND YIELD TRAITS IN SUNFLOWER

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ABSTRACT

Sunflower is an important oil seed crop that has the potential to boost Pakistan's economy. The major goal of this work was to estimate heterosis and heritability estimates for agronomic traits. Within three replications, four lines GH-1, GH-2, GH-3, and GH-4, as well as three testers B-4, B-6, and B-8, were sowed in a Randomized complete block design (RCBD). In the spring of 2022, the performance of parents and crosses was evaluated at the University of Agriculture, Faisalabad. Data were recorded for number of leaves, leaf area, plant height, internodal length, head diameter, number of whorls of achene per head, 100-seed weight, and seed yield per plant. For a number of leaves, the line GH-3 and tester B-4 showed significant desired values. Line GH-1 had highly significant GCA for leaf area and tester B-6 had also desired GCA for leaf area. For plant height, line GH-4 had significant GCA for Plant height and tester B-4 also desired GCA for plant height. For internodal length, the line GH-2 and tester B-6 had significant GCA. For head diameter, line GH-1 and tester B-8 showed the highest value of GCA. The line GH-4 and tester B-8 revealed the highest GCA values for a number of whorl/achenes per head. The line GH-3 and tester B-6 exhibited the highest GCA values for 100-seed weight. The line GH-4 and tester B-8 recorded the highest GCA for seed yield/plant. The cross GH-1 × B-6 had significant SCA values for all studied agronomic traits. The cross combination of GH-2 × B-8 showed negatively non-significant SCA results for plant height trait. For the number of leaves, the cross GH-1 × B-6 showed positive and highly significant heterotic effects over the mid and better parent. For the leaf area, the cross GH-2 × B-6 exhibited a positive and highly significant heterotic effect. For head diameter, the cross GH-1 × B-8 showed positive and highly significant heterotic effects over the mid and better parent. For the number of whorls of achene per head, the cross GH-2×B-6 exhibits maximum positive heterotic effects. For 100-seed weight, the cross GH-1×B-4 exhibited significantly positive heterotic effects over the better parent. For seed yield per plant, the cross GH-2×B-6 has maximum heterotic effects.

Keywords: Genetic variability, Oil seed crops, Sunflower, Germplasm

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1. INTRODUCTION

Sunflower is a non-conventional oilseed crop which has potential to increase the production of edible oil in Pakistan. It is a short duration crop which can be grown in rain fed as well as irrigated conditions. Sunflower seed contains 35-45% oil contents (Tahir et al. 2002) and 20-24% proteins (Imran et al. 2015). Quality of oil is good because it has great percentage of linoleic acid (64%), oleic acid (25-35%) and low percentage of linoleic acid (Patil et al. 2017) Oil content standards are directly influenced by the genotype, soil nature, weather and cultural executions (Marinkovic et al. 2003). Owing to the high ratio of unsaturated fatty acids of about 90% and a very low percentage of cholesterol, sunflower oil is considered good to be used in the diet of heart patients (Oshundiya et al. 2014) Its oil is easy to refine, palatable and is a good source of vitamins, namely A, B, E, and K that are fat-soluble. This crop widely used as livestock feed, human food and various other products (Iqbal et al. 2018).

The area under sunflower cultivation in Pakistan is 101172 hectares with the seed production of 14600 metric tons and oil production of 5500 metric tons (Rana et al. 2022). Production of superior hybrids with increased yield, more oil content and disease resistance are important objectives in sunflower breeding programs (Khan et al. 2009). Furthermore, through heterosis, sunflower breeders achieve the highest seed yield. Genetic variability is required

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for the selection of superior varieties/hybrids (Hilli et al. 2020; Zafar et al. 2022). The wild species provide genetic diversity to abiotic and biotic traits which are the source of germplasm for traditional and molecular breeding (Seiler et al. 2017; Zafar et al. 2021). In an efficient breeding program selection of superior parents through careful and critical evaluation for hybridization and crosses is necessary (Azad et al. 2016). To select the best lines for production of hybrids, GCA and SCA are calculated (Zafar et al. 2020). It helps to discover the type of gene action controlling the traits of interest and development of suitable breeding strategies (Manan et al. 2022). With this background, the present study was carried out with the following objectives.

- Identification of best performing genotypes as well as different cross combinations.
- Development of selection criteria for morphological and yield related traits based on type of association among traits.

2. MATERIALS AND METHODS

2.1. Experimental Conditions

The research was conducted at the Raja Wala Farm, University of Agriculture Faisalabad, Pakistan during 2021-22. Faisalabad is located between coordinates 30°-31.5° North and 73°-74° East.

2.2. Experimental Material

Seven parental genotypes of sunflower (*Helianthus annuus* L.) consisting of 4 lines (GH-1, GH-2, GH-3 and GH-4) and 3 testers (B-4, B-6 and B-8) were collected from the department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. Lines and testers were pollinated after hand emasculation in line tester mating design during 2021. Hand emasculation was done early in the morning from 7 am to 9 am by removing anthers from florets with the help of forceps. Ovary remains receptive for 2-3 days. The pollens from testers were collected in petri dish and dusted on the emasculated head. Flowers take 5-10 days to bloom completely depending on the season and head size. Anthesis mostly occurs between 5-8 A.M.

2.3. Experimental Layout

Seven parental genotypes were planted in crossing block under RCBD during autumn 2021. These genotypes were crossed in line × tester fashion. The seeds of parents and 12 crosses were sown in spring 2022, following randomized complete block design with three replications. The seeds were planted in rows maintaining 30cm plant to plant and 75cm row to row distance.

2.4. Data Recording

Data on the following pre-harvest and post-harvest plant traits were collected from four plants of each entry per replication.

- Plant Height
- Leaf Area (cm)
- Head Diameter (cm)
- Seed Yield/Plant (g)
- Number of Leaves / Plant
- Internodal Length (cm)
- Number of Whorl of Achene/Head
- 100-Seed weight (g)

2.5. Biometrical Approach

After recording the data on morphological traits according to Steel et al. (1997), Analysis of Variance was used to study the level of significance among parents and F1 hybrids, which was further subjected to combining ability analysis (Kempthrone 1957).

3. RESULTS AND DISCUSSION

Selecting genetically superior parents and making choices within segregating populations constitutes a task of utmost significance and challenge. Equally vital is for breeders to possess a comprehensive understanding of inheritance patterns and be well-versed in the transmission process through which parents transfer their alleles to offspring, thereby influencing desired traits (Bhoite et al. 2018). Breeders assume a pivotal role in enhancing plants and establishing an elevated genetic capacity for both yield and yield-contributing traits.

3.1. Mean Performance of Lines, Testers, and Crosses of Sunflower

For plant height, among lines GH-1 (142.66cm) showed maximum mean performance followed by GH-2 (133.13cm), and the lowest value in lines was observed in GH-3 (112.26cm). Among testers, B-6 (144cm) had the highest value while the lowest value was exhibited in B-4 (112.56cm) (Fig. 1). For crosses, the highest value was observed in GH-2 x B-6 (113.37cm) while the lowest value was observed in GH-1 x B-8 (111.7cm). Among lines, the maximum mean performance for the number of leaves was exhibited by GH-4 (32.53) Followed by GH-3 (32.4) and GH-2 (28.93) while among testers maximum mean value was observed in B-4 (28.76) Followed

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by B-8 (28.56) and B-6 (23.3). Among crosses maximum mean value was observed in GH-3×B4 (34.13), Followed by GH-3×B-8 (34.8) and GH-1×B-8 (33.47) exhibited high mean performance while GH-1×B-6 (32.8) showed minimum values among all crosses (Fig. 2).

For leaf area, among lines GH-1 (161.06cm^2) showed maximum mean performance followed by GH-2 (154.23cm^2) and the lowest value in lines was observed in GH-4 (135.36cm^2). Among testers, B-6 (161.36cm^2) had the highest value while lowest value was exhibited in B-4 (148.5cm^2). For crosses, the highest value was observed in GH-2 x B-8 (140.63cm^2) while lowest value was observed in GH-3 x B-4 (133.67cm^2) (Fig. 3). For internodal length, among lines GH-3 (12.66cm) showed maximum mean performance followed by GH-1 (12.26) and lowest value in lines was observed in GH-4 (11.73cm). Among testers, B-4 (12.93cm) had the highest value while lowest value was exhibited in B-6 (11.96cm). For crosses, the highest value was observed in GH-1 x B-8 (14.3cm), while lowest value was observed in GH-2 x B-4 (11.2cm) (Fig. 4).

For head diameter, among lines maximum mean performance was exhibited by GH-1 (15.23cm) followed by GH-2 (14.43cm) while among testers maximum mean value was observed in B-6 (15.33cm) followed by B-8 (15.5cm). Among crosses, GH-1 x B-8 (14.8cm) and GH-1 x B-8 (14.8cm) exhibited maximum mean value followed by GH-4 x B-6 (13.51) while GH-4 x B-8 (11.3) showed minimum values among all crosses (Fig. 5). For number of whorls of achene per head, among lines maximum mean performance was exhibited by GH-1 (17.33) followed by GH-2 (16.5) while among testers maximum mean value was observed in B-8 (18) followed by B-6 (17.66). Among crosses, GH-1 x B-4 (14.67) exhibited the maximum mean value followed by GH-3 x B-4 (14.17) while GH-2 x B-4 (11.9) showed minimum values among all crosses (Fig. 6).

For seed yield per plant, among lines maximum mean performance was exhibited by GH-2 (63.5) followed by GH-4 (59.86) while among testers maximum mean value was observed in B-8 (62.86) followed by B-4 (61.36). Among crosses, GH-1 x B-6 (63.83) exhibited high mean performance while GH-3 x B-4 (57.97) showed minimum values among all crosses (Fig. 7). Among lines, the maximum mean performance for 100 seed weight was exhibited by G-2 (6.66 g) followed by GH-1 (6.6 g) while among testers maximum mean value was observed in B-4 (6.76 g) followed by B-6 (6.5 g). Among crosses, GH-2 x B-8 (7.97g), exhibited high mean performance while GH-2 x B-6 (5.17 g) showed minimum values among all crosses (Fig. 8).

3.2. Line x Tester Analysis

Combining ability analysis is the most effective approach across different biometric techniques for the selection of F1 hybrids and their parents. Result of simple ANOVA revealed that genotypes were highly significant for all the traits but Line into tester analysis revealed that the non-significant results were due to the crosses while all parents were highly significant for plant height, number of leaves per plant, head diameter and number of whorls of achene per head (Table 2). Similar results were observed by Machikowa et al. (2011) and Saleem et al. (2014). For leaf area trait Line × tester analysis revealed that the significant results were due to the crosses as well as parents. Similar results were observed by Azad et al. (2016). For internodal length, seed yield and 100-seed weight, highly significant results were found for crosses while all parents were non-significant (Table 2). Similar results were also observed by Kanwal et al. (2015).

3.3. General Combining Ability Effects

The approach for selection on the basis of combining ability effects is comprised of growing and analyzing a population's progeny. The Line × tester analysis reveals significant differences for genotypes, parents and crosses for most of studied traits (Table 1). Assessment of male and female parents for GCA is important for development of hybrids (Golabadi et al. 2015). Six lines as a female parent and four testers were tested in this study to determine best parents for hybrid development for eight characters linked to yield. Results of GCA of line and testers are presented in Table 2.

For number of leaves per plant, only GH-3 line showed significant result while all other lines exhibited non-significant result. Among testers, B-4 and B-8 showed significant results while B-6 tester showed non-significant results similar findings were reported by (Hosni et al. 2023; Mustafa et al. 2023). For leaf area GH-2 showed significantly positive GCA effects and GH-4 showed positive non-significant effects while GH-1 and GH-3 showed negative non-significant values. For testers B-6 showed significant result while B-4 and B-8 showed a non-significant value. Jondhale et al. (2012), and Memon and Jurial (2015) also observed similar results. For plant height, GH-4 exhibited a significant positive GCA value among lines while other lines showed a non-significant value. Among testers B-4 showed significant positive GCA values, while other testers showed a non-significant value. For internodal length, GH-2 showed a significant GCA value among lines while other lines showed a non-significant value. Among testers, B-4 and B-6 exhibited positive CCA values while B-8 showed a non-significant result for internodal length. Patil et al. (2012) and Andarkhor et al. (2013) also observed similar results. For head diameter, GH-1 showed a significant positive GCA values among lines while all other lines showed a non-significant results, among testers, B-6 and B-8 exhibited positive GCA values while B-4 showed a non-significant

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value. For number of Whorl of achene/head all lines exhibited highly positive significant GCA values, while among testers B-4 and B-8 showed a significant value while B-6 showed a non-significant value. Memon and Jurial (2015) also observed similar results. For 100 seed weight, GH-1, GH-3, and GH-4 exhibited significant positive GCA values among lines, while among testers B-4 and B-6 showed a significant result while B-8 showed a non-significant result. For seed yield per plant GH-2, GH-3, and GH-4 all three lines exhibited positive significant GCA values while GH-1 showed a non-significant result, among testers B-6 and B-8 exhibited positive significant GCA values while B-4 showed a non-significant result.

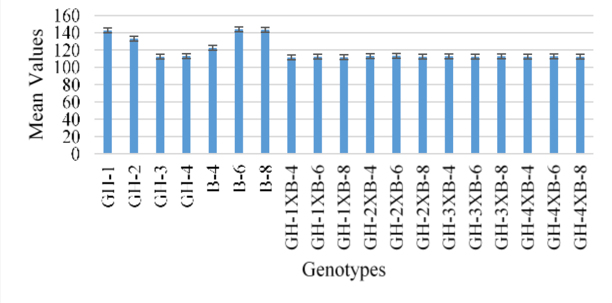

Fig. 1: Mean comparison graph for plant height.

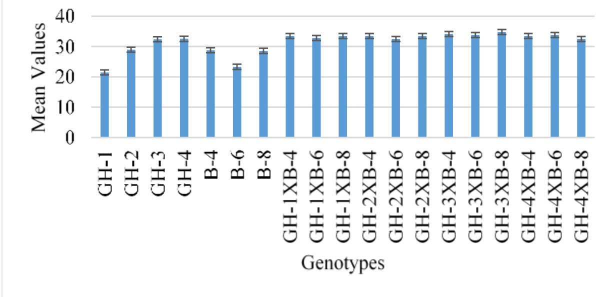

Fig. 2: Mean comparison graph for number of leaves per plant.

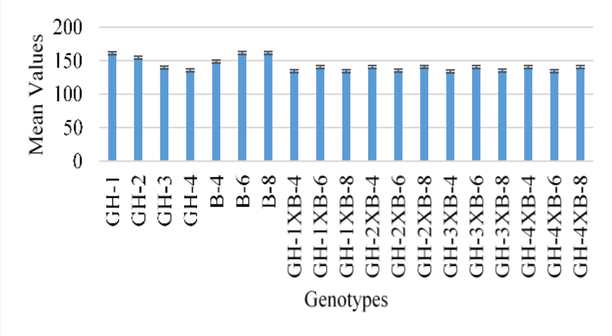

Fig. 3: Mean comparison graph for Leaf Area.

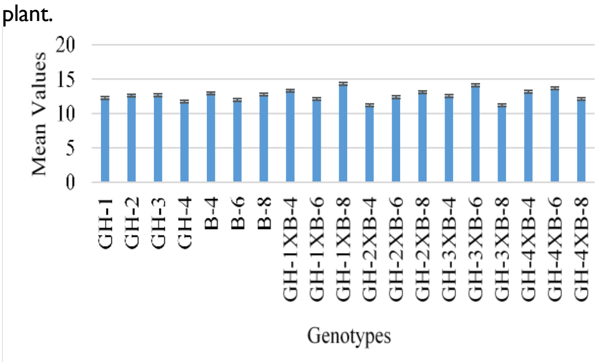

Fig. 4: Mean comparison graph for Internodal Length.

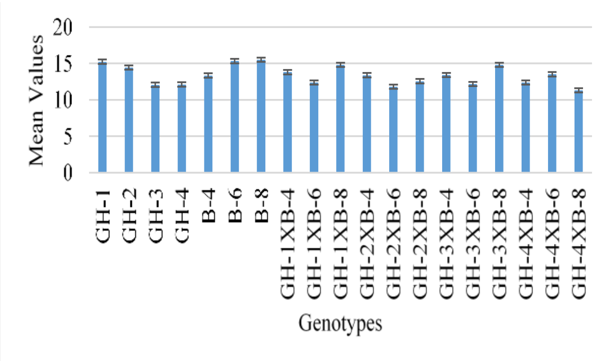

Fig. 5: Mean comparison graph for Head Diameter.

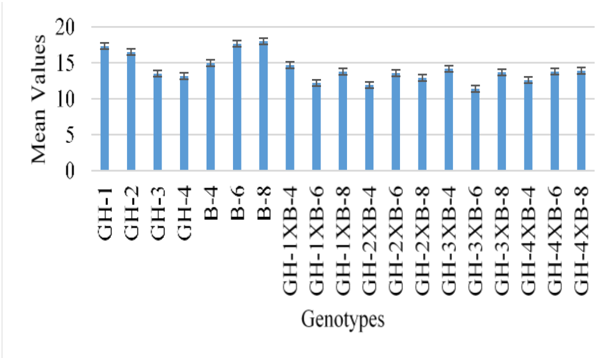

Fig. 6: Mean comparison graph for Number of Whorl of Achene / Head.

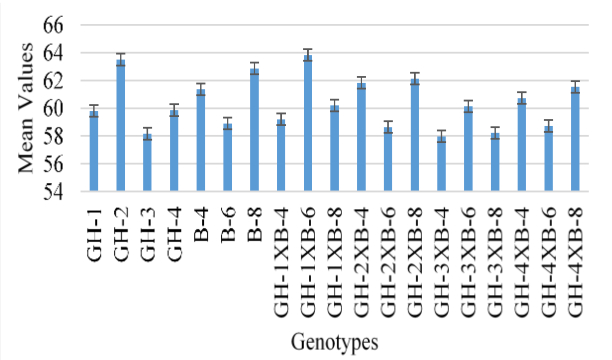

Fig. 7: Mean comparison graph for Seed Yield per Plant.

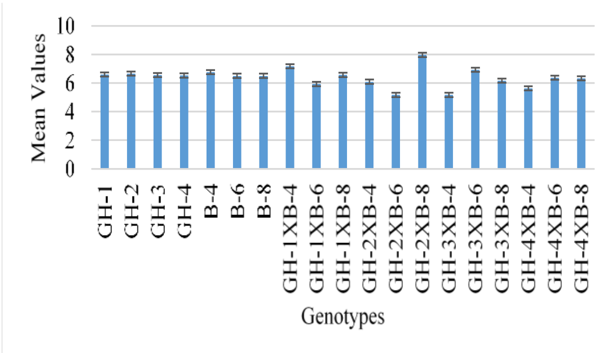

Fig. 8: Mean comparison graph for 100-Seed Weight.

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Table 1: Line × tester analysis ANOVA

Source	DF	PH	NL	LA	INL	HD	NW	SY	AW
Replications	2	4.18	1.38	10.98	0.22	0.34	0.83	30.82	0.02
Genotypes	18	432.77**	40.61**	284.78**	1.85**	5.12**	9.41**	52.86**	0.30**
Cross	11	0.85	1.33	28.95**	2.65**	0.26	1.05	75.92**	0.48**
Lines (c)	3	1.89	2.44	14.11	1.08	0.11	0.43	30.93	0.20
Testers (c)	2	0.58	0.58	0.58	0.59	0.38	0.18	12.05	0.16
Line × Tester (C)	6	0.43	1.03	45.84	4.32	0.43	1.71	123.73	0.78
Parents	6	601.05**	53.23**	352.54**	0.59	6.76**	12.02**	15.45	0.03
Lines (p)	3	682.48	80.69	439.00	0.55	7.88	13.24	20.36	0.01
Testers (p)	2	446.89	28.83	165.98	0.80	4.36	8.30	12.03	0.07
L(p) v T(P)	1	665.11	19.67	466.32	0.29	8.22	15.80	7.54	1.39
Crosses vs Parents	1	4174.24	397.05	2692.35	0.64	48.72	85.76	23.66	0.02
Error	36	31.58	5.58	18.20	0.57	0.39	0.61	16.65	0.06

NL=Number of leaves per plant, LA=Leaf area, PH=Plant height, INL=Internodal length, HD=Head diameter, NW=Number of whorls of achene/ head, AW=100-Achenes weight (g), SY=Seed yield/plant, *=Significant, **=Highly significant, ns=non-significant.

Table 2: GCA for lines and testers

Lines	NL	LA	PH	INL	HD	NW	AW	SY
GH-1	-0.22 ns	1.08 **	-0.63 *	-0.30 ns	1.09 *	1.19 **	1.13 *	-1.61 ns
GH-2	-0.33 ns	1.42 *	0.46 ns	1.02 *	0.09 ns	1.00 **	-0.22 ns	1.61 *
GH-3	1.22*	-1.08 ns	0.15 ns	-0.30 ns	1.02 ns	0.29 **	1.17*	1.11 *
GH-4	-0.22 ns	0.91 ns	1.02 *	0.30 ns	-0.09 ns	1.23 **	1.00 *	1.23 *
Standard Error	0.4420	0.5862	0.2476	0.1977	0.0611	0.0201	0.0503	1.2386
Testers	NL	LA	PH	INL	HD	NW	AW	SY
B-4	1.17 *	-0.25 ns	1.02 *	1.00 *	0.07 ns	1.04 *	1.00 *	0.06 ns
B-6	-0.25 ns	1.18 *	0.25 ns	1.12 *	1.03 *	0.02 ns	1.07 *	1.02 *
B-8	1.08 *	0.17 ns	-0.17 ns	0.05 ns	1.09 *	1.10 *	0.03 ns	1.03 *
Standard Error	0.3828	0.5077	0.2144	0.1712	0.0529	0.0174	0.0435	1.0726

*=Significant, **=Highly significant, ns=Non-significant.

3.4. Specific Combining Ability Effects

The impacts of crosses on the SCA exhibited a diverse range of values, encompassing both positive and negative outcomes in terms of the number of leaves per plant (Table 3). Highest and significantly positive SCA effects were observed for GH-4×B-8 (0.86) followed by GH-4×B-6 (0.81). The significant negative SCA effects were observed for GH-2×B-6 (-0.42) followed by GH-3×B-4 (-0.28). So, this is the best specific combiner for number of leaves per plant. The highest SCA effects were observed for GH-1×B-6 (3.89) followed by GH-3×B-6 (3.89) and GH-4×B-4 (2.24) for leaf area. The negative SCA effects were observed for GH-4×B-6 (-4.06) followed by GH-2×B-6 (-3.73). So, this is the best specific combiner for leaf area.

Table 3: Specific combining ability effects of crosses

Crosses	NL	LA	PH	INL	HD	NW	AW	SY
GH-1×B-4	0.06 ns	-1.74 ns	0.34 *	0.60 *	-0.19 ns	-0.38**	-0.26**	-3.21 ns
GH-1×B-6	0.19 *	3.89**	0.26 *	1.20**	0.38**	0.76**	0.51**	6.42**
GH-1×B-8	0.14 ns	-2.16*	0.08 ns	-0.60 ns	-0.19 ns	-0.38**	-0.26**	-3.21 ns
GH-2×B-4	0.17 ns	1.91 ns	0.17 ns	0.60 ns	0.19 ns	0.38**	0.26**	3.21*
GH-2×B-6	-0.42 ns	-3.73**	0.24 ns	-0.20 ns	-0.31**	-0.76**	-0.51**	-6.42**
GH-2×B-8	0.25 ns	1.82 ns	-0.41 ns	0.60 ns	0.19 ns	0.38**	0.26**	3.21*
GH-3×B-4	-0.28 ns	-2.41*	0.22 ns	-0.60 ns	-0.19 ns	-0.38**	0-26**	-3.21 ns
GH-3×B-6	-0.19 ns	3.89**	0.52 *	1.20**	0.38**	0.76**	0.51**	6.42 **
GH-3×B-8	0.47 ns	-1.49 ns	0.30 ns	-0.60 ns	-0.19 ns	-0.38**	-0.26**	-3.21 ns
GH-4×B-4	0.06 ns	2.24*	-0.05 ns	0.60 ns	0.19 ns	0.38**	0.26**	3.21 ns
GH-4×B-6	0.81 *	-4.06**	0.02 ns	-1.20**	-0.38**	-0.76**	-0.51**	-6.42**
GH-4×B-8	0.86*	1.82 ns	0.03 ns	0.60 ns	0.19 ns	0.38**	0.26**	3.21 ns

*=Significant, **=Highly significant, ns=Non-significant.

The positive SCA effects were observed for GH-3×B-6 (0.52) followed by GH-1×B-4 (0.34) and GH-1×B-6 (0.26) for plant height. The negative SCA effects were observed for GH-2×B-8 (-0.41) followed by GH-4×B-4 (-0.05) had negative SCA effects. The highest SCA effects were observed for GH-1×B-6 (1.20) followed by GH-3×B-6 (1.20) and GH-1×B-4 (0.60) for internodal length. The negative SCA effects were observed for GH-4×B-6 (-1.20) followed by GH-1×B-8 (-0.60) and GH-3×B-4 (-0.60). So, this is the best specific combiner for internodal length. For head diameter, GH-1×B-6 (0.38) Followed by GH-3×B-6 (0.38) and GH-2×B-4 (0.19) showed positive SCA effects. While GH-4×B-6 (-0.38) followed by GH-2×B-6 (-0.31) and GH-1×B-8 (-0.19) showed negative SCA effects. For number of whorls of achene per head, GH-1×B-6 (0.76) followed by GH-3×B-6 (0.76) and GH-2×B-4 (0.38) showed positive SCA effects. While GH-2×B-6 (-0.76) followed by GH-1×B-4 (-0.38) and GH-1×B-8 (-0.38) showed negative SCA effects. The best specific combiner for 100-seed weight was GH-1×B-6 (0.51) followed by GH-2×B-4 (0.26) and GH-2×B-8 (0.26) exhibited positive SCA effects. While GH-2×B-6 (-0.51) followed by GH-1×B-4 (-0.26) and GH-1×B-8 (-0.26) had negative SCA effects. For seed yield per plant GH-1×B-6 (6.42) showed highly significant SCA values followed by GH-2×B-4 (3.21) and GH-2×B-8 (3.21) showed positive SCA effects. While GH-2×B-6 (-6.42) followed by GH-1×B-4 (-3.21) and GH-1×B-8 (-3.21) showed a negative SCA effect.

3.5. Heterosis Manifestation

Heterosis also known as hybrid vigor is the better performance of crosses over their parents for different traits. Heterosis for several morphological traits is given below. All the crosses showed variable heterosis for plant height in sunflowers. Four crosses showed highly positive significant mid-parent heterosis (MPH) as presented in Table 4 whereas six crosses showed highly negative significant results and five crosses showed highly significant better parent heterosis (BPH) whereas five crosses showed highly negative significant results (Table 5). All the crosses showed variable heterosis for the number of leaves in sunflowers. Seven crosses showed highly significant MPH whereas three crosses showed significant results while one cross showed highly significant BPH whereas four crosses showed significant results. Ahmed et al. (2005) reported similar results for number of leaves per plant.

Table 4: Mid-parent heterosis of crosses for studied traits

Crosses	PH	NL	LA	INL	HD	NW	SY	AW
GH-1×B-4	16.02**	33.24**	13.21**	10.32**	17.39**	20.95**	9.03 ns	7.73**
GH-1×B-6	21.65**	46.54**	12.97**	8.12 ns	19.08**	20.57**	9.40 ns	5.85**
GH-1×B-8	21.91**	33.78**	16.68**	-9.72**	23.21**	27.74**	10.17**	-5.85**
GH-2×B-4	-11.64**	16.00**	7.31**	2.61 ns	-10.92**	-11.65**	2.24 ns	3.23 ns
GH-2×B-6	-18.19**	24.31**	14.45**	8.01 ns	20.72**	25.27**	11.44**	6.33**
GH-2×B-8	-18.78**	16.41*	-10.89**	3.29 ns	17.37**	19.42**	1.03 ns	5.32**
GH-3×B-4	4.02 ns	11.61*	7.21ns	11.72**	-7.09**	-10.30**	9.31 ns	7.50**
GH-3×B-6	-12.36**	21.36**	-6.77**	6.36 ns	-9.73**	-10.80**	9.05 ns	6.12**
GH-3×B-8	-11.84**	14.16*	-10.30**	11.14**	-14.39**	18.94**	10.44**	-5.61**
GH-4×B-4	4.68 ns	9.19 ns	1.15 ns	6.22 ns	2.75 ns	1.18 ns	5.31 ns	4.26 ns
GH-4×B-6	12.32**	21.07**	-9.46**	4.64 ns	-13.97**	-17.19**	8.73 ns	-5.37**
GH-4×B-8	-12.43**	6.27 ns	5.45 ns	6.94 ns	-10.39**	-10.80**	4.02 ns	6.39**

*=Significant, **=Highly significant, ns=non-significant.

Table 5: Better parent heterosis of crosses for studied traits

Crosses	PH	NL	LA	INL	HD	NW	SY	AW
GH-1×B-4	21.94**	16.34*	16.60**	12.63**	22.54**	26.35**	11.68**	8.87**
GH-1×B-6	22.01**	40.77**	13.06**	6.79 ns	19.35**	21.32**	8.38 ns	5.05 ns
GH-1×B-8	22.11**	17.15*	16.77**	11.49**	23.87**	29.07**	13.79**	6.57**
GH-2×B-4	15.15**	15.67*	9.03**	1.29 ns	-14.32**	-15.76**	0.52 ns	2.46 ns
GH-2×B-6	-21.27**	12.21 ns	16.34**	10.32**	23.04**	27.74**	14.65**	7.50**
GH-2×B-8	-21.69**	15.67*	-12.87**	2.61 ns	20.22**	22.78**	0.52 ns	4.00 ns
GH-3×B-4	8.05 ns	5.35 ns	9.99 ns	12.63**	-11.50**	-14.70**	11.68**	8.87**
GH-3×B-6	22.01**	4.32 ns	13.06**	3.42 ns	-19.35**	21.32**	8.38 ns	5.58 ns
GH-3×B-8	-21.41**	7.41 ns	-16.36**	11.49**	23.87**	29.07**	13.79**	6.09**
GH-4×B-4	8.38 ns	2.87 ns	5.52 ns	1.29 ns	7.25 ns	7.13 ns	4.02 ns	2.46 ns
GH-4×B-6	-21.74**	3.89 ns	-16.75**	5.57 ns	23.04**	27.74**	9.47 ns	5.61 ns
GH-4×B-8	-21.69**	-0.20 ns	3.07 ns	2.61 ns	20.22**	22.78**	1.54 ns	6.12**

*=Significant, **=Highly significant, ns=non-significant.

All the crosses showed varying heterosis for leaf area in sunflower. Five crosses showed highly positive significant MPH whereas six crosses showed highly significant BPH. Ahmed et al. (2005) and Memon and Jurial (2015) had similar findings for leaf area. All the crosses showed variable heterosis for internodal length in sunflower. Three crosses showed highly positive significant MPH whereas one cross showed highly negative significant result. Five crosses showed highly significant BPH for the internodal length. Kanwal et al. (2015) had similar results for internodal length.

Five crosses showed highly positive significant MPH whereas six crosses showed highly negative significant results for head diameter, and eight crosses showed highly significant BPH whereas three crosses showed highly negative significant results. Habib et al. (2006) reported similar findings. All the crosses showed variable heterosis for a number of whorl of achene/head in sunflower. Six crosses showed highly positive significant MPH. For a number of the whorl of achene/head, nine crosses showed highly significant BPH whereas two crosses showed highly negative significant results. Imran et al. (2015) also reported similar results.

All the crosses showed variable heterosis for seed yield/plant in sunflowers. Three crosses showed highly positive significant MPH for seed yield/plant, and five crosses showed highly significant BPH. Habib et al. (2006) also published similar results. All the crosses showed variable heterosis for 100-seed weight in sunflower. Five crosses showed highly positive significant MPH whereas five crosses showed highly negative significant results and six crosses showed highly significant BPH. Similar findings were also observed by Depar et al. (2017).

3.6. Genetic Components of Sunflower under Studied Characters

Genetic variance due to GCA (σ^2_{GCA}, additive type gene action) and SCA (σ^2_{SCA}, due to non-additive type gene action), additive variance (σ^2_A), dominance variance (σ^2_D), ratio of SCA to GCA variances ($\sigma^2_{SCA/}$ $\sigma^2_{GCA)}$ and degree of dominance (ratio of $\sigma^2_{D/}$ σ^2_A $)^{1/2}$ major cause for variance in the observed parameters in this trail in sunflower accessions are mentioned in Table 6 that variation due to SCA (variation due non-additive type of gene action) is of least significant then the GCA (variation due to additive type of gene action) for all studied parameters of experiment number of leaves per plant, leaf area, plant height, internodal length, number of whorls of achene/head.

Table 6: Genetic components of sunflower under studied characters

Traits	Genetic Components							
	Cov H.S Lines GCA(σ^2_{GCA})	Cov H.S Testers SCA(σ^2_{SCA})	Cov H.S Ave (σ^2_D)	Cov H.S F. S (σ^2_A)	Var of GCA (σ^2_{GCA})	Var of SCA (σ^2_{GCA})	F=1 A (σ^2_A)	F=1 D (σ^2_D)
NL	0.1574	-0.0370	0.0132	-0.1399	0.0132	0.2436	0.0264	-0.2436
LA	-3.5260	-3.7714	-0.7283	5.9373	-0.7283	14.2491	-1.4566	14.2491
PH	0.1625	0.0131	0.0184	0.1319	0.0184	1.0418	0.0369	-0.0418
INL	0.3600	-0.3600	-0.0720	0.5067	-0.0720	1.3227	-0.1440	1.3227
HD	-0.0357	-0.0357	-0.0071	0.0506	-0.0071	0.1315	-0.0143	0.1315
NW	1.1427	-0.1427	-0.0285	0.2462	-0.0285	0.5697	-0.0571	0.5697
100 AW	-0.0653	1.0653	-0.0131	0.1056	-0.0131	0.2537	-0.0261	0.2537
SY	-10.3112	-10.3112	2.0622	13.2707	-2.0622	36.6428	-4.1245	36.6428

NL=Number of leaves per plant, LA=Leaf area, PH=Plant height, INL=Internodal length, HD=Head diameter, NW=Number of whorls of achene/ head, AW=100-Achenes weight (g), SY=Seed yield/plant, *=Significant, **=Highly significant, ns=non-significant.

4. Conclusion

The investigation into combining ability and heterosis analysis for quality and yield traits in sunflower offers valuable insights into the intricate interplay of genetics that governs these essential attributes. Through meticulous evaluation of parental lines and their potential interactions, a deeper comprehension of the inherent genetic potential has been attained. This knowledge equips breeders with a strategic advantage in selecting superior parent combinations and designing effective breeding strategies. Furthermore, the synergistic effects of heterosis observed in the study underscore the significance of hybrid vigor in enhancing both quality and yield traits. This phenomenon opens doors to harnessing the benefits of genetic diversity and exploiting the inherent strengths of different parental lines. The implications of these findings extend beyond theoretical realms, carrying practical implications for agricultural practices aiming to achieve improved sunflower varieties.

REFERENCES

Ahmed S, Khan MS, Swati MS, Shah GS and Khalil IH, 2005. A study on heterosis and inbreeding depression in sunflower (*Helianthus annuus* L.). Songklanakarin Journal Science Technology 27:1-8.

Andarkhor SA, Mastibege N and Rameeh V, 2013. Combining ability of agronomic traits in Sunflower (Helianthus annuus L.) Using Line × Tester Analysis. International Journal Bol 4(1): 89.

Azad K, Shabbir G, Khan M, Mahmood T, Shah Z, Alghabari F and Daur I, 2016. Combining ability analysis and gene action studies of different quantitative traits in sunflower by line × tester. Crop Research 51(2): 1-4.

Bhoite KD, Dubey RB, Vyas M, Mundra SL and Ameta KD, 2018. Evaluation of combining ability and heterosis for seed yield in breeding lines of sunflower (*Helianthus annuus* L.) using line × tester analysis. Journal Pharmaco Phytochemistry 7(5): 1457-1464.

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Depar S, Baloch MJ and Kumbhar MB, 2017. Heterotic Performance of F1 hybrids for phenological, yield, oil and protein traits of sunflower. Journal Agriculture Research 33:12–22.

Golabadi M, Golkar P and Shahsavari MR, 2015. Genetic analysis of agro morphological traits in promising hybrids of sunflower (*Helianthus annuus* L.). Acta Agriculture Slovenica, 105(2): 249-260.

Habib H, Mehdi SS, Rashid A, Iqbal S and Anjum MA, 2006. Heterosis studies in sunflower (*Helianthus annuus* L.) crosses for agronomic traits and oil yield under Faisalabad conditions. Pakistan Journal Agriculture Science 43(3-4).

Hilli HJ, Immadi S, Soregaon CD, Hilli JS and Bankapur NS, 2020. Combining Ability Studies and the Gene Action involved in Sunflower Lines. International Journal Current Microbialogy Appl. Science 9(1): 2206-2215.

Hosni, T., Kourda, H. C., Medimagh, S., Youssef, N., Ben, O., Abbes, Z., ... & Kharrat, M. (2023). Agro-morphological variation and genetic diversity assessment of tunisian sunflower (*Helianthus Annuus* L.) Accessions using microsatellite markers. *JOURNAL OF ANIMAL AND PLANT SCIENCES-JAPS*, *33*(2), 330-344.

Imran M, Malook S, Qasrani SA, Nawaz MA, Shabaz MK, Asif M and Ali Q, 2015. Combining ability analysis for yield related traits in sunflower (*Helianthus annuus* L.). American-Eurasian Journal Agriculture and Environment Science 15(3): 424-436.

Iqbal Q, Safdar A, Tahir MN, Shafique O, Khan BA, Ijaz A and Khan I, 2018. Assessment of different exotic sunflower hybrids for their agro-ecological adaptability. Pakistan Journal Agriculture Research 31(2): 122-132.

Jondhale AS, Goud IS and Praveenkumar B, 2012. Combining ability and gene action studies in diversecmS sources in sunflower (*Helianthus annuus* L.). International Journal Science and Research 3(12).

Kanwal N, Sadaqat HA, Ali Q, Ali F, Bibi I and Niazi NK, 2015. Role of combining ability and heterosis in improving achene yield of *Helianthus annuus* L. An overview. National Science 14(1):55-62.

Khan SA, Ahmad H, Khan A, Saeed M, Khan SM and Ahmad B, 2009. Using line × tester analysis for earliness and plant height traits in sunflower (*Helianthus annuus* L.). Journal Research Science Technology 1(5): 202-206.

Marinkovic R, Dozet B and Vasic D, 2003. Sunflower breeding (monograph). School books, Novi Sad:1-368

Manan, A., Zafar, M. M., Ren, M., Khurshid, M., Sahar, A., Rehman, A., ... & Shakeel, A. (2022). Genetic analysis of biochemical, fiber yield and quality traits of upland cotton under high-temperature. *Plant Production Science*, *25*(1), 105-119.

Memon S and Jurial M, 2015. Combining ability through line 3 tester analysis for phonological, seed yield, and oil traits in sunflower (*Helianthus annuus* L.). Euphytica 199–209.

Machikowa T, Saetang C and Funpeng K, 2011. General and specific combining ability for quantitative characters in sunflower (*Helianthus annuus* L.). Journal Agriculture Science 3(1): 91-97

Mustafa, W., Tariq, K., Zafar, H., Affan, Q., Rafiq, M., Khan, M., ... & Asghar, S. (2023). Combining ability analysis for various morphological traits in sunflower (*Helianthus Annuus* L.). *Biological and Clinical Sciences Research Journal*, *2023*(1), 183-183.

Oshundiya FV, Olowe, Sowemimo F and Odedina J, 2014, Seed yield and quality sunflower (*Helianthus annuus* L.) as influenced by staggered sowing and organic of fertilizer application in the humid tropics, Helia 37(61):237-255.

Patil TRGM, Kulkarni VV, Kenganal M, Shankergoud I and JR, 2017. Combining ability studies in restorer lines of sunflower (*Helianthus annuus* L.). Journal App. Nattional Science 9(1):603-608.

Patil R, Goud I, Kulkarni V and Banaka C, 2012. Combining ability and gene action studies for seed yield and its components in sunflower (*Helianthus annuus* L.). Elec. Journal P. Breed 3(3): 861-867

Rana, A. W., Gill, S., & Akram, I. (2022). *Promoting oil seed crops in Pakistan: Prospects and constraints*. Intl Food Policy Res Inst.

Saleem U, Khan M, Gull S, Usama K, Saleem F and Siyal O, 2014. Line × tester analysis of yield and yield related attributes in different sunflower genotypes. Pakistan Journal Botony 4(3): 131-142.

Steel, R. G. D., & Torrie, J. H. DA Dic ey (1997). Principles and procedures of statistics: A biometrical approach. *McGraw-Hill Co. Inc, New York NY.*

Seiler GJ, Qi LL and Marek LF, 2017. Utilization of sunflower crop wild relatives for cultivated sunflower improvement. Crop Science 57:1083-1101.

Tahir MNH, Imran M and Hussain MK, 2002. Evaluation of sunflower (*Helianthus annuus* L.) Inbred lines for drought tolerance. International Journal Agriculture Biology 4(3): 120-125

Zafar, M. M., Shakeel, A., Haroon, M., Manan, A., Sahar, A., Shoukat, A., ... & Ren, M. (2022). Effects of salinity stress on some growth, physiological, and biochemical parameters in cotton (Gossypium hirsutum L.) germplasm. *Journal of Natural Fibers*, *19*(14), 8854-8886.

Zafar, M. M., Manan, A., Razzaq, A., Zulfqar, M., Saeed, A., Kashif, M., ... & Ren, M. (2021). Exploiting agronomic and biochemical traits to develop heat resilient cotton cultivars under climate change scenarios. *Agronomy*, *11*(9), 1885.

Zafar, M. M., Razzaq, A., Farooq, M. A., Rehman, A., Firdous, H., Shakeel, A., ... & Youlu, Y. (2020). Genetic variation studies of ionic and within boll yield components in cotton (Gossypium Hirsutum L.) Under salt stress. *Journal of Natural Fibers*, *19*(8), 3063-3082.