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Study of Combining Ability and Heterosis in Sunflower (*Helianthus Annuus* L.) Using Line × Tester Method

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ABSTRACT

This experiment was designed to study the heterosis and combining ability through line × tester method in sunflower at the experimental site of Rajawala farm, University of Agriculture, Faisalabad during spring and autumn 2019. In the spring season, five lines and three testers were crossed by line × tester method to create fifteen crosses. Seeds of lines, testers, and crosses were collected at the end of the spring season. While in the autumn season crosses, lines, and testers were grown according to RCBD by using three replications to check their performance for yield-related traits. Collected data was analyzed through line × tester to identify the gene action that control the yield-related parameters. Analysis of variance was used to check significant and non-significant differences. Various lines and testers showed positive GCA for various traits. Among lines, ACC No. 252 showed significant positive GCA for all traits except days to flower initiation and head angle. ACC No. 254 also showed positive GCA for achenes yield per plant. While among testers, ACC No. 257 showed positive GCA for achenes yield per plant. ACC No. 252, ACC No. 254, and ACC No. 257 were found as good general combiners. Among crosses, ACC No. 254 × ACC No. 256 showed the highest positive SCA for achenes yield per plant, cross ACC No. 251 × ACC No. 256 expressed significant positive SCA for plant height, number of leaves, and leaf area. Cross ACC No. 253 × ACC No. 257 expressed significant positive SCA for head angle. All crosses also expressed significant positive heterosis for various traits but none of the crosses showed significant positive heterosis for all the traits. The crosses ACC No. 252 × ACC No. 257 and ACC No. 253 × ACC No. 257 expressed significant positive heterosis for achenes yield per plant. So these parental combinations can be used in future breeding programs to develop commercial hybrids with higher achenes yield.

Keywords: Tester, general and specific combinability, heterosis, *Helianthus annuus* L.), Achene.

1. Introduction

Oilseed crops are essential crops for human beings after cereals and sugars in daily life. Sunflower is a very important oilseed producer which is cultivated throughout the world for oilseed purposes. Sunflower belongs to the Asteraceae family. Sunflower is the world's 4th recorded essential oilseed crop after palm, soybean, and rapeseeds, and also as second oilseed crop in Europe, after rapeseed (Arshad and Amjad, 2012). According to Shah *et al.,* (2013), cottonseeds share 56%, sunflower 30%, canola 7%, rapeseed 6 %, and mustard plants 1% individually in the household creation of eatable oil. Pakistan is facing a deficiency (>65%) of edible oil. Oil yield from all resources is increasing 2.56% per year but our consumption is also increasing 8% per year. Pakistan obtains 76.74 oil from cotton, 13% from mustard, 8% from sunflower, and the remaining from canola and brassica (Pakistan Economic Survey 2017-18).

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Specific and General combinability as well as Heterosis play a crucial role in developing hybrids. The GCA among them is significant and it refers to the additive gene effect. However, if the CSA is significant, it points to the dominance gene effect, which plays a vital role in developing hybrids. When GCA and CSA both are insignificant, it indicates the prevalence of epistasis. The inbreds for mixed development can be assessed by significant or non-significant effects of GCA and SCA. Line x tester is the best crossover program for inbred lines to evaluate genotypes of sunflower for high yield and oil content. Hence, heterosis and combining abilities of various genotypes was estimated employing line into tester method for high oil content and high yield related attributes because it is a cross-pollination crop. These methods help in selecting better parents who have enhanced protection against biotic and abiotic factors causing stress. Apart fron stress tolerance, these parents also have high yielding capacity when locally cultivated in hybrid development.

The yield obtained by hybrid cultivation is far greater than that from normal varieties which comes as a result of heterosis. Hybrids of sunflower have a high heterotic effect because they are obtained through cross-pollination as compared to common varieties with no hybridization (Karasu *et al*., 2010). Hybrids are more stable and their survival rate is high because they are developed given all kinds of environmental and stress factors and they have disease tolerance as well as higher yield (Andarkhor *et al.,* 2012). Inadequate genetic bases of sunflower allow the supreme hybrids with higher yield. Therefore, the heterotic effect helps to develop sunflower hybrids with higher oil content. Hence this study uses genetic differences among varieties to develop the best combining abilities to get heterosis for best hybrids. The main purpose of conducting experiments was to evaluate a large number of inbred lines. Sunflower hybrids were suggested to be developed having properties observed under the study including plant height, leaf area, Internodal length, Head angle, Achene per plant, etc.

The aim of this work was the development of superior and high-yielding F1 hybrids.

2. Material and methods

Experimental material

The Research material consisted of five lines (ACC No.251, ACC No.252, ACC No.253, ACC No.254, and ACC No.255), and three testers (ACC No.256, ACC No.257, and ACC No.258) were crossed through line x tester design to develop fifteen crosses. These lines and testers were obtained from the PBG Department, University of Agriculture, Faisalabad, Pakistan. Lines were based on their diverse origin. Controlled pollination was practiced to cross Lines and testers design during spring 2019. The seeds from each cross was harvested separately.

The studied traits were

1- Days taken to initiation of flowering (D.I.F).
2-Plant Height (P.H).
3-Number of leaves/Plant (N.L/P).
4-Leaf Area (L.A).
5-Internodal length (I.L).
6-Head angle (H.A).
7-Hundred achenes weight (H.A.W).
8- Achenes yield per plant (A.Y/P).

Breeding procedure

Sunflower is a cross-pollinated crop, crossing through insects mainly and a limited degree of wind. Flowering starts from the outside of the head and moves toward the center. Depending on the size of the head and season, the head takes 5-10 days to fully flower. The flowering time is 5 to 8 o'clock. The pollen survives for another twelve hours depending on plant conditions and environmental conditions.

Selfing

Before any small flowers begin to open, protect the flower head with a suitable covering and retain the covering until fertilization is completed in all the small flowers.

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Crossing

Emasculation

The emasculation is carried out in the early morning by removing the anthers of the disc-shaped florets. Removed the spiral with tweezers in 2-3 heads. At about 9-10 AM, pollen from the male parents was taken out and sprinkled on the emasculated plant's head. This process remained for 2-3 days.

Pollination

Pollination was carried out by collecting pollen from the tester's head that had been covered with envelopes before flowering. Pollen was collected from the flowering head into a paper bag. In the morning, at about 9-10 AM, pollination was carried out by applying naturally gathered pollens on the emasculated head.

Biometrical approach

The recorded data were examined by analysis of variance as procedure given by Steel *et al.* (1997) to interpret the level of importance between F_1 hybrids.

2.5. Estimation of combining abilities and genetic effects

2.5.1. Estimation of GCA effects

$$\text{Lines } gi = \{(xj../tr) - (x.../ltr)\}$$

$$\text{Testers } gt = \{(x.j./lr) - (x.../ltr)\}$$

Where "l" stands for the number of lines; "t" for the number of testers; "r" for the number of replications; "xi.." for the Total F1 number resulting from ith lines crossed with all the testers; and "x…" for Total of all crosses.

Estimation of SCA effect

$$Si = \{(xij.)/r\} - (xi../tr) - (x.j./lr) + x.../ltr$$

Where "xij" stands for Total F1 resulting from ith lines crossed with jth tester; "xi" for a total of all ith lines crossed with all testers; "xj" for a total of all jth tester crossed with all lines.

Genetic components

$$\text{Cov H.S. (line)} = \frac{Ml \times t}{rt}$$

$$\text{Cov H.S. (tester)} = \frac{Mt - Ml \times t}{rl}$$

$$\text{Cov H.S.} = [l/r(2lt-l-t][(\{(l-l)(Ml)+(t-l)(Mt)\}/(l+t-2))-Mlt]$$

Proportional contribution (PC) of lines, testers, and their total variance interaction

$$\text{Line Contribution} = \frac{SS\,(1)}{SS\,(Crosses)} \times 100$$

$$\text{Testers Contribution} = \frac{SS\,(t)}{SS\,(Crosses)} \times 100$$

$$\text{1xt's Contribution} = \frac{SS\,(lxt)}{SS\,(Crosses)} \times 100$$

Heterosis

Heterosis percentage over mid-parent and better-parent (Heterobeltiosis) was observed after calculating heterosis on respective parents. This calculation was based on the heterosis amount expressed as the difference between mid-parent values and F1 values (Falconer & Mackay 1996) presented as follows:

$$MPH = 100 \times \frac{(F1-MP)}{MP}$$

$$BPH = 100 \times \frac{(F1-BP)}{BP}$$

Where MPH stands for heterosis by mid-parent and BPH stands for heterosis by better-parent. Later on, a t-test was implemented to check the significance of heterosis among mid and better parents as given below:

$$MP\ heterosis = \frac{(F1 - MP)}{(\frac{3}{8}\sigma 2e)^{1/2}}$$

$$BP\ heterosis = \frac{(F1 - BP)}{(\frac{1}{2}\sigma 2e)^{1/2}}$$

Statistical analysis

Observed data was statistically analyzed using IBM SPSS Statistics 20 and Microsoft Excel was used to manage data.

3. Results

Analysis of variance

Analysis of Mean square values for all traits showed significant variation among all genotypes (Table 1). The interactive effect of L × T was observed to be significant for all traits under study. Parental lines with crosses were significant for all traits except for intermodal length and plant height and similar results were reported by Rauf *et al*. (2008), Aleem *et al.,* (2015), and Lakshman *et al.,* (2019).

Table 1: Mean squares from analysis of variance for plant-related traits.

SOV	DF	D.I.F	P.H	N.L/P	L.A	I.L	H.A	H.A.W	A.Y/P
Replication	2	0.3123	1.8582	0.4199	1.2783	0.0428	1.4693	0.0033	3.4795
Genotype	22	18.7727**	86.3312**	18.1157**	103.1295**	1.3186**	806.6910**	0.5063**	32.2905**
Cross	14	22.4967**	129.6151**	27.0141**	120.3623**	1.7474**	856.7335**	0.5215**	33.4162**
Line (c)	4	61.5371**	233.9773**	42.2983**	116.8008**	4.6310**	2278.327**	0.8822**	57.1160**
Tester (c)	2	4.2821*	67.9096**	4.1446**	185.3143**	1.3562**	827.4195**	0.4864**	30.5054**
LXT (c)	8	7.5302**	92.8604**	25.0894**	105.9050**	0.4033**	153.2655**	0.3499**	22.2940**
Parent	7	8.0450**	12.0305**	2.1634**	66.8688**	0.6346**	779.0775**	0.4652**	29.4801**
Line (p)	4	9.0258**	10.6587**	2.1656**	82.7249**	0.9081**	852.1460**	0.6784**	42.9739**
Tester (p)	2	4.9296*	12.8008**	2.9274**	24.8669**	0.4046**	228.5741**	0.2613**	16.5911**
L(P) v T(P)	1	10.3531**	15.9770**	0.6267	87.4483**	0.0002	1587.810**	0.0198	1.2828
Cross vs parent	1	41.7295**	0.4619	5.2040**	115.6947**	0.1035	299.3908**	0.5812**	36.2038**
Error	44	0.9664	1.2738	0.5324	1.3558	0.0264	3.4562	0.0212	0.6972

*= Significant (P≤ 0.05) **= highly Significant P≤ 0.01%, SOV= Source of variance, D.F= Degree of freedom, D.I.F= Days taken to initiation of flowering, P.H= Plant Height, N.L/P = Number of leaves/Plant, L.A = Leaf Area, I.L= Internodal length, H.A= Head angle, H.A.W = Hundred achenes weight, A.Y/P= Achenes yield per plant.

Proportional contribution

Lines gave a much higher proportional contribution as compared to testers and crosses for all traits except for leaf area and number of leaves per plant (Table 2) and similar results were reported by Hladni *et al.,* (2011) and Kanwal *et al.,* (2019). While for the number of leaves per plant and leaf area, the proportional contribution of crosses was higher as compared to lines and testers (Tyagi *et al.,* 2018).

Table 2: Proportion contribution of crosses, lines, and testers

Trait	Lines	Testers	Lines × Testers
D.I.F	78.15	2.72	19.13
P.H	51.58	7.48	40.94
N.L/P	44.74	2.19	53.07
L.A	27.73	21.99	50.28
I.L	75.72	11.09	13.19
H.A	75.98	13.80	10.22
H.A.W	48.34	13.32	38.34
A.Y/P	48.84	13.04	38.12

D.I.F= Days taken to initiation of flowering, P.H= Plant height, N.L/P = Number of leaves/plant, L.A = Leaf area, I.L= Internodal length, H.A= Head angle, H.A.W = Hundred achenes weight, A.Y/P= Achenes yield per plant.

Combining ability

The concept of GCA and SCA has gained prodigious importance among plant breeders because of their wide use in producing hybrids in many crops. Table 3 showed that among parents, ACC No. 251, ACC No. 252, and ACC No. 256 showed desirable significant negative GCA for days taken to initiation of flowering (Depar *et al.,* 2018). GCA in a negative direction has greater importance for short plant stature. ACC No. 254 and ACC No. 255 showed significant negative GCA for plant height (Imran *et al.,* 2014). ACC No. 252 and ACC No. 253 expressed significant positive GCA for the number of leaves and leaf area (Hladni *et al.,* 2011). ACC No. 254, ACC No. 255, and ACC No. 257 showed desirable significant negative GCA for intermodal length (Rehman *et al.,* 2020). GCA for head angle in a positive direction has greater importance to avoid the birds' attack. ACC No. 251, ACC No. 253, and ACC No. 256 showed significant positive GCA for head angle. ACC No. 252 and ACC No. 257 expressed significant positive GCA for achenes yield per plant (Lakshman *et al.,* 2019).

Table 3: GCA effects of lines and testers for yield and its related traits:

	D.I.F	P.H	N.L/P	L.A	I.L	H.A	H.A.W	A.Y/P
				Lines				
ACC No. 251	-2.77**	2.06**	-2.33**	-0.02 ns	0.69**	20.65**	-0.01ns	-0.13 ns
ACC No. 252	-2.29**	4.05**	0.67*	4.13**	0.60**	-0.55 ns	0.43**	3.50**
ACC No. 253	-0.14 ns	4.68**	2.93**	3.02**	0.14*	10.58**	-0.1ns	-0.87**
ACC No. 254	1.93**	-4.14**	-1.96**	-3.93**	-0.41**	-13.98**	0.11*	0.90**
ACC No. 255	3.27**	-6.65**	0.70*	-3.20**	-1.02**	-16.69**	-0.43**	-3.40**
				Traits				
ACC No. 256	-0.62*	-0.05 ns	-0.59**	2.14**	0.30**	7.47**	-0.21**	-1.64**
ACC No. 257	0.27 ns	-2.10**	0.41 ns	-4.06**	-0.30**	-0.09 ns	0.12**	0.96**
ACC No. 258	0.34 ns	2.15**	0.18 ns	1.92**	-0.00 ns	-7.38**	0.09*	0.68**

D.I.F= Days taken to Initiation of Flowering, P.H= Plant Height, N.L/P = Number of leaves/Plant, L.A= Leaf Area, I.L= Internodal Length, H.A= Head Angle, H.A.W= Hundred Achenes Weight, A.Y/P = Achenes Yield per Plant

Table 4 shows that the magnitude of the SCA effect among crosses varies for all traits. Cross ACC No. 251 × ACC No. 258 showed the highest desirable significant negative SCA (-2.12 **) for days taken to initiation of flowering (Imran *et al.,* 2014). While cross ACC No. 251 × ACC No. 257 showed the highest significant negative SCA (-7.71 **) for plant height (Depar *et al.,* 2018). Negative SCA for days taken to initiation of flowering is very important to develop short-stature plants. Number of leaves and leaf area are also very important and related to photosynthesis. Cross ACC No. 251 × ACC No. 256 showed the highest desirable significant positive SCA (3.78 **) for number of leaves (Hladni *et al.,* 2008). While cross ACC No. 251 × ACC No. 256 showed the highest significant positive SCA (6.10 **) for the leaf area (Hladni *et al.,* 2008).

Cross ACC No. 251 × ACC No. 257 showed the highest significant negative SCA (-0.54 **) for intermodal length (Ahmad *et al.,* 2012). Head angle is a very important trait. Highly significant positive SCA for head angle helps to avoid bird attacks. Cross ACC No. 253 × ACC No. 257 showed the highest desirable significant positive SCA (7.06 **) for head angle (Rauf *et al.,* 2008). Table 4 shows that the magnitude of the SCA effect among crosses varies for achenes yield/ plant. Four crosses showed desirable significant positive SCA. Cross ACC No. 254 × ACC No. 256 showed the highest significant positive SCA (0.52**) for achenes yield per plant followed by ACC No. 251 × ACC No. 258 (0.42**).

Table 4: (SCA) effects of crosses for yield related traits

Crosses	D.I.F	P.H	N.L/P	L.A	I.L	H.A	H.A.W	A.Y/P
ACC No. 251 × ACC No. 256	1.39*	6.39**	3.78**	6.10**	0.33**	0.74 ns	-0.12ns	-0.96ns
ACC No. 251 × ACC No. 257	0.73ns	-7.71**	-1.44**	-5.82**	-0.54**	-6.02**	-0.3**	-2.46**
ACC No. 251 × ACC No. 258	-2.12**	1.33*	-2.33**	-0.28ns	0.20*	5.28**	0.42**	3.42**
ACC No. 252 × ACC No. 256	1.25ns	-6.49**	-3.67**	-1.34ns	-0.30**	-6.05**	-0.21*	-1.70**
ACC No. 252 × ACC No. 257	-1.98**	6.25**	2.56**	5.24**	0.28**	5.62**	0.28**	2.21**
ACC No. 252 × ACC No. 258	0.73ns	0.24ns	1.11*	-3.90**	0.02ns	0.43ns	-0.07ns	-0.51ns
ACC No. 253 × ACC No. 256	-2.02**	0.77ns	0.07ns	-4.46**	-0.07ns	5.27**	-0.11ns	-0.82ns
ACC No. 253 × ACC No. 257	0.54ns	-1.19*	-1.70**	2.23**	0.15ns	7.06**	0.24*	1.99**
ACC No. 253 × ACC No. 258	1.47*	0.42ns	1.63 **	2.23**	-0.08ns	-12.33**	-0.14ns	-1.17*
ACC No. 254 × ACC No. 256	-0.20ns	-1.96**	-1.48**	-5.15**	-0.31**	0.05ns	0.52**	4.07**
ACC No. 254 × ACC No. 257	0.13ns	5.62**	2.74**	5.51**	0.37**	-4.06**	-0.19*	-1.46**
ACC No. 254 × ACC No. 258	0.07ns	-3.66**	-1.26**	-0.36ns	-0.06ns	4.01**	-0.32**	-2.62**
ACC No. 255 × ACC No. 256	-0.42ns	1.30*	1.30**	4.85**	0.34**	-0.01ns	-0.08ns	-0.59ns
ACC No. 255 × ACC No. 257	0.58ns	-2.97**	-2.15**	-7.15**	-0.27**	-2.60*	-0.03ns	-0.29ns
ACC No. 255 × ACC No. 258	-0.16ns	1.67**	0.85ns	2.30**	-0.07ns	2.62*	0.11ns	0.88ns

P.H= Plant height, D.I.F= Days taken to initiation of flowering, N.L/P = Number of leaves/plant, L.A= Leaf area, I.L= Internodal length, H.A= Head angle, H.A.W= Hundred achenes weight, A.Y/P = Achenes yield per plant.

Heterosis studies

Days taken to initiation of flowering

Good parents in crosses were supposed to be utilized in better hybrid development. The heterotic effects in Table 5 showed that seven F1 hybrids had desirable high negative heterosis and heterobeltiosis. Cross ACC No. 251 × ACC No. 258 showed the highest significant negative heterosis (-12.37 **) and heterobeltiosis (-14.28 **). Negative heterosis and heterobeltiosis in F1 hybrids showed that the mentioned hybrids possess dominant genes which can affect in negative directions (Kanwal *et al.*, 2019).

Plant height

Plant height is one of the important traits of sunflower because higher the plants, greater are the crop yield losses. Therefore, negative heterosis is required for plant height of sunflowers. Table 5 showed that, seven crosses showed desirable negative heterosis and heterobeltiosis. Cross ACC No. 255 × ACC No. 257 showed the highest significant negative heterosis (-21.10 **) and heterobeltiosis (Zia *et al.*, 2016; Kanwal *et al.*, 2019).

No. of leaves/ plant

Table 5 shows that the magnitude of the heterosis among crosses varies for number of leaves per plant which is related to achenes yield. Cross ACC No. 253 × ACC No. 258 showed the highest desirable significantly positive heterosis (18.56 **) and heterobeltiosis (17.24 **) for number of leaves per plant followed by ACC No. 252 × ACC No. 257. ACC No. 251 × ACC No. 256, ACC No. 252 × ACC No. 258, ACC No. 253 × ACC No. 256, ACC No. 253 × ACC No. 257, ACC No. 254 × ACC No. 257, ACC No. 255 × ACC No. 256 and ACC No. 255 × ACC No. 258 also showed significantly positive heterosis and heterobeltiosis for number of leaves per plant (Ahmad *et al.*, 2005).

Leaf area

Table 5 shows that the magnitude of the heterosis among crosses varies for leaf area. Cross ACC No. 253 × ACC No. 258 showed the highest significant positive heterosis (21.88 **) and heterobeltiosis (13.27 **) for leaf area followed by ACC No. 253 × ACC No. 257. ACC No. 251 × ACC No. 256 also showed significant positive heterosis and heterobeltiosis for leaf area. Nine other crosses showed negative heterosis and heterobeltiosis for leaf area (Ahmad *et al.,* 2005; Hladni *et al*., 2011; Nasreen *et al.*, 2011).

Table 5: Heterosis in hybrids for FlowerInitiation, Plant height, Number of leaves and Leaf area.

Crosses	Flower Initiation		Plant height		Number of leaves		Leaf area	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
ACC No. 251 × ACC No. 256	-5.51 **	-6.45 **	15.04 **	13.70 **	7.71 **	5.49 *	11.89 **	8.10 **
ACC No. 251 × ACC No. 257	-3.44 *	-4.05 *	-15.08 **	-16.66 **	-12.73 **	-13.51 **	-27.94 **	-34.61 **
ACC No. 251 × ACC No. 258	-12.37 **	-14.28 **	8.17 **	5.90 **	-18.03 **	-19.48 **	-4.23 *	-7.47 **
ACC No. 252 × ACC No. 256	-6.06 **	-6.41 **	-5.85 **	-8.08 **	-11.84 **	-14.42 **	-3.61 ns	-12.72 **
ACC No. 252 × ACC No. 257	-9.80 **	-11.58 **	19.69 **	18.91 **	14.86 **	14.86 **	3.09 ns	-11.92 **
ACC No. 252 × ACC No. 258	-6.23 **	-7.03 **	11.32 **	7.67 **	7.12 **	6.17 *	-9.89 **	-18.40 **
ACC No. 253 × ACC No. 256	-9.10 **	-9.98 **	7.60 **	7.48 **	13.48 **	10.40 **	4.28 ns	-3.07 ns
ACC No. 253 × ACC No. 257	0.12 ns	-2.44 ns	2.63 ns	-0.53 ns	7.00 **	6.76 **	13.30 **	12.33 **
ACC No. 253 × ACC No. 258	-0.49 ns	-0.73 ns	10.21 **	9.26 **	18.56 **	17.24 **	21.88 **	13.27 **
ACC No. 254 × ACC No. 256	-2.06 ns	-4.49 *	-11.48 **	-15.40 **	-9.73 **	-11.02 **	-24.59 **	-26.67 **
ACC No. 254 × ACC No. 257	2.21 ns	-1.89 ns	3.32 ns	1.73 ns	9.65 **	4.96 *	-7.99 **	-16.00 **
ACC No. 254 × ACC No. 258	-0.60 ns	-1.89 ns	-11.33 **	-16.04 **	-9.10 **	-13.72 **	-13.35 **	-15.73 **
ACC No. 255 × ACC No. 256	-0.96 ns	-4.60 **	-10.39 **	-13.89 **	10.58 **	8.79 **	1.39 ns	-1.75 ns
ACC No. 255 × ACC No. 257	4.73 **	-0.68 ns	-21.10 **	-21.88 **	-2.75 ns	-4.07 ns	-39.47 **	-44.92 **
ACC No. 255 × ACC No. 258	0.47 ns	-2.07 ns	-6.01 **	-10.52 **	7.68 **	5.30 *	-5.39 *	-8.30 **

Internodal length

Table 6 shows that the magnitude of the heterosis among crosses varies for internodal length. Cross ACC No. 255 × ACC No. 257 showed the highest desirable significant negative heterosis (-23.55 **) over heterobeltiosis (-26.81 **). Five other crosses also showed significant negative heterosis and heterobeltiosis for internodal length. While other crosses showed positive or non-significant heterosis and heterobeltiosis for internodal length (Manzoor, 2015; Saba, 2016).

Head angle

Table 6 shows that the magnitude of the heterosis among crosses varies for head angle. Cross ACC No. 253 × ACC No. 256 showed the highest desirable significant positive heterosis (17.50 **) and heterobeltiosis (7.20 **) for head angle. Crosses ACC No. 251 × ACC No. 256 and ACC No. 253 × ACC No. 257 also showed positive heterosis and heterobeltiosis for head angle. While nine other crosses showed significant negative heterosis and heterobeltiosis for head angle. Rauf *et al.* (2008) also reported positive heterosis for head angle.

Hundred achenes weight

Table 6 shows the desirable positive mid-parent heterosis for eight crosses. Cross ACC No. 252 × ACC No. 257 showed the highest significant positive heterosis and heterobeltiosis for hundred achenes weight plant followed by ACC No. 253 × ACC No. 257. ACC No. 251 × ACC No. 257, ACC No. 251 × ACC No. 258, ACC No. 252 × ACC No. 258, ACC No. 254 × ACC No. 256, and ACC No. 254 × ACC No. 257 also showed significant positive heterosis and heterobeltiosis (Hladni *et al.,* 2003; Abdullah *et al.*, 2010; Manzoor *et al.*, 2016; Zia *et al.*, 2016).

Achenes yield/ plant

The positive MPH was observed in nine crosses (Table 6). The superiority of F1 progenies observed over open-pollinated populations, in terms of seed yield was well established in sunflower. Cross ACC No. 252 × ACC No. 257 showed the highest significant positive heterosis (28.19 **) and heterobeltiosis (23.59 **) for achenes yield per plant followed by ACC No. 253 × ACC No. 257. ACC No. 251 × ACC No. 257, ACC No. 251 × ACC No. 258, ACC No. 252 × ACC No. 258, ACC No. 254 × ACC No. 256, and ACC No. 254 × ACC No. 257 also showed significant positive heterosis and heterobeltiosis. This showed that achene yield was better-underperformed progenies due to a higher magnitude of fixable genes (Gowtham, 2006; Abdullah *et al*., 2010; Manzoor *et al.*, 2016; Lakshman *et al.,* 2019; Telangre *et al.*, 2019).

Table 6: Heterosis in hybrids for internodal length, head angle, 100-achene weight, Achene yield/plant

Crosses	Internodal length		Head angle		100- achene weight		Achene yield/ plant	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
ACC No. 251 × ACC No. 256	24.12 **	21.25 **	8.49 **	6.07 **	-1.95ns	-5.59*	-2.02 ns	-5.65 **
ACC No. 251 × ACC No. 257	0.73 ns	-2.48 ns	0.73 ns	-3.36 **	7.07**	5.35ns	6.79 **	5.06 *
ACC No. 251 × ACC No. 258	14.00 **	9.98 **	-2.27 *	-3.76 **	16.06**	11.3**	16.00 **	11.32 **
ACC No. 252 × ACC No. 256	6.71 **	6.00 *	1.10 ns	-8.27 **	3.82ns	2.05ns	3.83 *	2.01 ns
ACC No. 252 × ACC No. 257	12.36 **	5.69 *	6.47 **	-1.67 ns	28.24**	23.59**	28.19 **	23.59 **
ACC No. 252 × ACC No. 258	5.52 *	4.87 ns	-9.25 **	-20.38 **	12.69**	10.32**	12.89 **	10.53 **
ACC No. 253 × ACC No. 256	-2.34 ns	-7.11 **	17.50 **	7.20 **	-0.34ns	-7.15**	-0.47 ns	-7.24 **
ACC No. 253 × ACC No. 257	-4.48 *	-13.75 **	15.56 **	7.33 **	21.88**	19.67**	21.69 **	19.53 **
ACC No. 253 × ACC No. 258	-9.36 **	-12.71 **	-10.90 **	-21.42 **	5.1*	-2.46ns	4.72 **	-2.72 ns
ACC No. 254 × ACC No. 256	-11.20 **	-12.16 **	-3.86 **	-13.32 **	9.61**	8.62**	9.46 **	8.51 **
ACC No. 254 × ACC No. 257	-4.55 ns	-8.70 **	-10.89 **	-18.23 **	7.06**	0.63ns	7.29 **	0.87 ns
ACC No. 254 × ACC No. 258	-13.57 **	-15.60 **	-15.91 **	-26.67 **	-2.3ns	-2.78ns	-2.36 ns	-2.86 ns
ACC No. 255 × ACC No. 256	-2.40 ns	-11.33 **	-15.27 **	-15.30 **	-18.74**	-23.42**	-18.59 **	-23.24 **
ACC No. 255 × ACC No. 257	-23.55 **	-26.81 **	-20.75 **	-22.29 **	-6.67**	-16.34**	-6.81 **	-16.43 **
ACC No. 255 × ACC No. 258	-18.79 **	-27.07 **	-26.61 **	-29.29 **	-9.4**	-14.28**	-9.43 **	-14.32 **

BPH= Better parent heterosis, **MPH**= Mid parent heterosis, *= Significance at 0.05% Probability level
**= Significance at 0.01% Probability level

4. Conclusion

It was concluded that ACC No. 252, ACC No. 254, and ACC No. 257 were established as good general combiners. Among crosses, ACC No. 254 × ACC No. 256 showed the highest positive SCA for achene yield per plant, and cross ACC No. 251 × ACC No. 256 expressed significant positive SCA for number of leaves, plant height, and leaf area. Cross ACC No. 253 × ACC No. 257 expressed significant positive SCA for head angle. All crosses also expressed significant positive heterosis for various traits but none of the crosses showed significant positive heterosis for all the traits. The crosses ACC No. 252 × ACC No. 257 and ACC No. 253 × ACC No. 257 expressed significant positive heterosis for achenes yield per plant. So these parental combinations can be used in future breeding programs to develop commercial hybrids with higher achenes yield.

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