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GENETIC ASSESSMENT AND COMBINING ABILITY ANALYSES OF ACHENE YIELD AND OIL QUALITY TRAITS IN *Helianthus annuus* L. HYBRIDS

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Combining ability analyses were estimated for 20 lines (females), three restorers (testers) and their 60 hybrids using Line × Tester mating design to assess the breeding potentiality of sunflower breeding material. Analysis of variance for all the studied traits showed significant differences among genotypes. The data were recorded on quantitative and quality parameters viz., head diameter, 100 achene weight, achene yield per plant, oil contents, palmitic acid, stearic acid, oleic acid and linoleic acid compositions. Based upon significant and positive GCA effects, the lines L6 and L11 showed the highest effects for achene yield per plant, oil contents and oleic acid while L6 and L7 showed the highest GCA effects for 100 achene weight but negative GCA effects for linoleic acid. The highest positive SCA effects for traits head diameter and achene yield per plant were shown by cross L11 × T2 while the crosses L17 × T1, L6 × T1, L20 × T3 and L5 × T3 showed the highest positive SCA effects for 100 achene weight, oil contents, oleic acid and linoleic acid respectively. The crosses L19 × T2 and L10 × T2 showed the highest negative SCA effects for palmitic acid and stearic acid respectively. All the traits in the experiment showed dominant type of gene action due to preponderance of higher SCA than GCA variances emphasizing the vitality of heterosis breeding. Therefore, these results are valuable for improvement of quantitative as well as qualitative traits in sunflower breeding material to fulfill the edible oil requirements and ensure food security for mounting population of the globe.
Keywords: Sunflower, gene action, heterosis, genetic variances

INTRODUCTION

Helianthus annuus L. is cultivated sunflower important for its edible oil. Its seed contains, on a dry weight basis, 48-58% oil contents (Neto *et al.*, 2016; Scharlack *et al.*, 2017). On a quality basis, the oil contains up to 88% mono-unsaturated fatty acids and poly-unsaturated fatty acids including oleic acid (35.2, 60 and 85 percent for low, mid and high oleic sunflowers) and linoleic acid (55-69%) (Rauf *et al.*, 2017). In 2017-18, the area of Pakistan under sunflower cultivation was 203 thousand ha with 104.01thousand tons seed yield and 40 thousand tons oil yield. Total availability from all sources was 2.45 million tons with 1.44 million tons imported spending an import bill of US$ 1.453 billion (Anonymous, 2017-18).

Achene yield and oil quality attributes are complex traits controlled by different kinds of additive and non-additive types of gene actions. These genetic components governing genes and gene actions are explored by using the combining ability analysis. The choice of parents based upon general combining ability (GCA) and specific combining ability (SCA) effects and understanding of their genetic makeup through gene actions are key factors for successful crop improvement in any breeding program (Mohanasundaram *et al.*, 2010). The GCA estimates are fixable while SCA estimates are non-fixable resulting from additive and dominant gene actions, respectively (Fasahat *et al.*, 2016). Non-additive gene action leads towards heterosis breeding, while additive gene action leads towards varietal development (Tavade *et al.*, 2009). Line × Tester Mating Design, proposed by Kempthorne (1957), is one of the most efficient designs to compute dominant and additive gene actions (Fasahat *et al.*, 2016).

Predominant role of SCA has been determined for yield and other yield contributing components in sunflower (Ahmad *et al.*, 2012; Aleem *et al.*, 2015; Tavade *et al.*, 2009), while others explained the superior effect of GCA effects over SCA for various traits contributing towards yield (Machikowa *et al.*, 2011). Higher SCA variances as compared to GCA variances were also reported for head diameter, 100 achene weight, achene yield per plant, oil contents (Aleem *et al.*, 2015; Andarkhor *et al.*, 2011; Dhillon and Tyagi, 2016), palmitic acid, stearic acid, oleic acid and linoleic acid (Baldini *et al.*, 1991; Joksimović *et al.*, 2006). Higher GCA variances as compared to SCA variances were also reported for head diameter (Hladni *et al.*, 2014; Kholghi *et al.*, 2014), 100 achene weight (Hakim *et al.*, 2008), achene yield per plant (Kholghi *et al.*, 2014), oil contents (Chandra *et al.*, 2011;

Machikowa *et al.*, 2011), palmitic acid, stearic acid and oleic acid (Joksimović *et al.*, 2006).

Keeping in view, the present investigation was carried out to understand the inheritance pattern of seed yield and oil contributing traits and to find better combining lines for future breeding programs in sunflower. Moreover, these experiments were conducted to better orient the direction of breeding material suitable for either hybrid development or varietal developmental via exploring the type of gene actions.

MATERIALS AND METHODS

***Breeding material*:** In this study, 83 sunflower genotypes including 20 females (lines), three males (testers) and their 60 hybrids were used. The female lines used in the experiment were cytoplasmic male sterile lines (CMS) as A lines with their maintainer lines (B lines) and males were restorers (R lines). The list of genotypes is given in Table 1.

Table 1. List of female parents, male parents and their hybrids.

Sr. No.	Code	Female parents	Origin/ Source	Sr. No.	Code	Female parents	Origin/ Source
1	L1	17576	NARC	11	L11	17596	NARC
2	L2	17578	NARC	12	L12	17598	NARC
3	L3	17580	NARC	13	L13	17600	NARC
4	L4	17582	NARC	14	L14	CMS HA65	USDA
5	L5	17584	NARC	15	L15	CMS HA112	USDA
6	L6	17586	NARC	16	L16	CMS HA116	USDA
7	L7	17588	NARC	17	L17	CMS HA207	USDA
8	L8	17590	NARC	18	L18	CMS HA243	USDA
9	L9	17592	NARC	19	L19	CMS HA259	USDA
10	L10	17594	NARC	20	L20	CMS HA292	USDA
	Code	**Male Parents**					
21	T1	17601	NARC	23	T3	17603	NARC
22	T2	17602	NARC				
	Codes	**Crosses**				**Crosses**	
24	L1 × T1	017576 ×R-017601		54	L11× T2	017596× R-017602	
25	L2 × T1	017578 ×R-017601		55	L12× T2	017598× R-017602	
26	L3 × T1	017580× R-017601		56	L13 × T2	017600× R-017602	
27	L4 × T1	017582× R-017601		57	L14 × T2	CMS HA65× R-017602	
28	L5 × T1	017584× R-017601		58	L15 × T2	CMS HA112× R-017602	
29	L6 × T1	017586× R-017601		59	L16 × T2	CMS HA116× R-017602	
30	L7 × T1	017588× R-017601		60	L17 × T2	CMS HA207× R-017602	
31	L8 × T1	017590× R-017601		61	L18 × T2	CMS HA243× R-017602	
32	L9 × T1	017592× R-017601		62	L19 × T2	CMS HA259× R-017602	
33	L10 × T1	017594× R-017601		63	L20 × T2	CMS HA292× R-017602	
34	L11× T1	017596× R-017601		64	L1 × T3	017576× R-017603	
35	L12× T1	017598× R-017601		65	L2 × T3	017578× R-017603	
36	L13 × T1	017600× R-017601		66	L3 × T3	017580× R-017603	
37	L14 × T1	CMS HA65× R017601		67	L4 × T3	017582× R-017603	
38	L15 × T1	CMS HA112× R017601		68	L5 × T3	017584× R-017603	
39	L16 × T1	CMS HA116 × R017601		69	L6 × T3	017586× R-017603	
40	L17 × T1	CMS HA207× R-017601		70	L7 × T3	017588× R-017603	
41	L18 × T1	CMS HA243× R-017601		71	L8 × T3	017590× R-017603	
42	L19 × T1	CMS HA259× R-017601		72	L9 × T3	017592× R-017603	
43	L20 × T1	CMS HA292× R-017601		73	L10 × T3	017594× R-017603	
44	L1 × T2	017576× R-017602		74	L11× T3	017596× R-017603	
45	L2 × T2	017578× R-017602		75	L12× T3	017598× R-017603	
46	L3 × T2	017580× R-017602		76	L13 × T3	017600× R-017603	
47	L4 × T2	017582× R-017602		77	L14 × T3	CMS HA65× R-017603	
48	L5 × T2	017584× R-017602		78	L15 × T3	CMS HA112× R-017603	
49	L6 × T2	017586× R-017602		79	L16 × T3	CMS HA116× R-017603	
50	L7 × T2	017588× R-017602		80	L17 × T3	CMS HA207× R-017603	
51	L8 × T2	017590× R-017602		81	L18 × T3	CMS HA243× R-017603	
52	L9 × T2	017592× R-017602		82	L19 × T3	CMS HA259× R-017603	
53	L10 × T2	017594× R-017602		83	L20 × T3	CMS HA292× R-017603	

NARC- National Agriculture Research Centre, Islamabad; USDA- United States Department of Agriculture, U.S.A.

***Field layout*:** The developed 60 hybrids, along with their parents, were grown in a triplicated Randomized Complete Block Design (RCBD) in the research area of Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan in two seasons, spring and autumn. Single rows of 4 m having inter- and intra-row spacing as 75 cm and 25 cm respectively, were used for each entry. Dibbler was used for the sowing; three seeds were sown one inch deep in each hole which were thinned at four leaf stage to one plant per hole. Each row comprised of 16 plants. All standard cultural and agronomic practices were performed. At maturity, sunflower heads were harvested when their backs turned brown/yellow. The heads were cut, dried and threshed separately and used for further data analysis.

***Collection of data*:** In each replication, 10 well-guarded plants were randomly selected and tagged for each entry in both seasons. The data for 100-achene weight (g) and achene yield per plant (g) were measured using electrical balance while head diameters (cm) were taken using measuring tape at physiological maturity as described by Rameeh and Andarkhor (2017). The oil contents and fatty acids; palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1) and linoleic acid (C18:2), were measured using Nuclear Magnetic Resonance Spectroscopy as described by Madson (1976).

***Statistical analysis*:** Means of the data taken from ten plants were subjected to statistical analyses. Genetic variability was estimated using analysis of variance technique (Steel *et al.*, 1997). Gene action and combining ability analysis were performed using Line × Tester analysis reported by Kempthorne (1957).

RESULTS AND DISCUSSION

Analysis of variance showed significant genotypic variations for the traits under study as given in the Table 2. Highly significant differences were found for male parents for all the studied traits except 100 achene weight, stearic acid and palmitic acid under both seasons, whereas significant variations were observed in females for all the studied traits. Significant results were found for line × tester interactions for all the studied traits (Table 2). These differences indicate that enough variation is present in the breeding material under investigation. The results were in accordance with the findings of Adare (2014), Baloch *et al.* (2016), Golabadi *et al.* (2015) and Supriya *et al.* (2017).

***Combining ability studies*:** Combining ability is the measure of performance of any genotype in a specific cross combination or in a series of crosses. The measurement of genotypic performance in a series of crosses is termed as general combining ability (GCA) whereas the performance of genotypes in a specific cross combination is termed as specific combining ability (SCA) effects.

***Head diameter (cm)*:** Head diameter is one of the most important traits contributing towards the achene yield directly (Memon *et al.*, 2014) and indirectly (Adare, 2014). The highest general combining ability effects were shown by L1 with the values of 3.46 and 4.17 for head diameter in spring and autumn seasons respectively followed by L2 as 3.06 and 3.28 (Table 3). These results were in accordance with Hladni *et al*. (2014), Memon *et al*. (2015) and Rameeh and Andarkhor (2017) findings. Head diameter is required in the optimum range, because any fluctuation even above this size may cause imbalances like reduction in oil contents and achene yield per plant as stated by Rameeh and Andarkhor (2017). Results regarding specific combining ability estimates for this trait showed that the cross L4 × T1 (5.30, 5.26) was better performer followed by L7 × T3 (4.72, 4.75) and L11 × T2 (4.92, 4.85) in both seasons respectively. Hladni *et al*. (2014) and Riaz *et al.* (2017) recorded the similar results. This trait is highly influenced by vegetative period,

Table 2. Mean squares of yield and oil quality components in sunflower (*Helianthus annuus* L.)

S.O.V		Replication	Genotypes	Parents	Testers	Lines	L × T	Crosses	P×C	Error
Degrees of freedom		2	82	22	2	19	1	59	1	164
Head Diameter	**Spring**	1.37	41.35**	58.45**	17.53**	37.85**	531.50**	32.70**	175.10**	0.46
	Autumn	2.31	41.98**	56.95**	17.58**	37.40**	507.10*	33.58**	206.77**	1.33
100 Achene weight	**Spring**	0.22	5.12**	1.61**	0.09	0.88**	18.59**	1.84**	292.36**	0.12
	Autumn	2.27	5.43**	1.63**	0.10	0.91*	18.08**	1.90**	298.01*	0.25
Achene yield per plant	**Spring**	1.03	449.41**	445.56**	17.54**	467.04**	893.46**	167.85**	17146.12**	4.69
	Autumn	3.61	396.21**	435.71**	17.83**	458.46**	839.68**	168.49**	12962.58**	4.99
Oil Contents	**Spring**	0.19	41.38**	42.93**	14.89**	47.47**	12.68**	41.48**	1.66**	0.29
	Autumn	1.67	41.20**	42.20**	11.73**	47.39**	4.55**	41.48**	2.19**	0.51
Palmitic acid	**Spring**	3.78	4.71**	4.39**	0.04	3.76**	25.10**	4.09**	48.65**	0.68
	Autumn	13.70	4.24**	4.25**	0.03	3.52**	26.50**	4.07**	14.21**	0.86
Stearic Acid	**Spring**	2.44	0.95**	1.08**	0.03	1.08**	3.30**	0.74**	10.49**	0.19
	Autumn	3.71.	0.93**	1.17**	0.14	1.09**	4.75**	0.71**	8.71**	0.23
Oleic Acid	**Spring**	0.51	23.14**	14.04	2.86**	13.76**	41.88**	23.36**	210.56**	7.21
	Autumn	1.84	34.38**	20.37**	1.33*	17.55**	112.02**	27.82**	729.77**	4.74
Linoleic acid	**Spring**	2.10	30.29**	27.04**	15.16**	29.61**	1.98*	28.64**	198.49**	1.73
	Autumn	9.39	22.87**	17.18**	0.07	9.85*	11.81*	9.12*	9.37*	8.56

* = Significant at 5 % probability level; ** = Significant at 1 % probability level

Table 3. GCA effects of yield and oil contributing traits of sunflower.

GCA	Head diameter		100 Achene weight		Achene yield		Oil contents		Palmitic acid		Stearic acid		Oleic acid		Linoleic acid	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
L1	**3.46****	**4.17****	-1.40**	-1.29**	-7.84**	-6.41**	-1.46 **	-1.09**	-0.16	-0.18	0.001	-0.14	-2.11**	-3.65**	-5.62**	-1.46
L2	**3.06****	**3.28****	-0.33	-0.21	-1.03	0.40	-0.65**	-0.28	-0.56*	-0.52	-0.14	-0.25	1.90**	1.03	-0.39	-0.36
L3	0.33	0.32	-0.27	-0.15	-4.73*	-3.30*	-0.95**	-0.86**	-0.47	-0.57*	-0.26	-0.30	1.23	0.80	-0.55	1.21
L4	-1.47**	-1.43**	0.08	0.20	4.45*	5.02**	-1.46**	-1.51**	-0.26	-0.28	0.21	0.17	-0.33	-0.76	1.06**	1.33
L5	-4.44**	-4.37**	-0.52*	-0.41*	5.42**	5.99**	-3.37**	-3.42**	-0.26	-0.27	-0.12	-0.16	-1.22	-0.20	-1.77**	-1.34
L6	-1.10**	-1.10**	**1.04****	**1.16****	**9.85****	**10.42****	**7.76****	**7.71****	**1.91****	**1.90****	**1.10****	**1.06****	**4.80****	**5.49****	-0.62	-1.45
L7	-1.26**	-1.24**	**1.07****	**1.18****	**0.47**	**1.04***	**6.70****	**6.65****	**1.46****	**1.41****	**1.23****	**1.19****	**4.35****	**4.16****	2.00**	-0.69
L8	-2.07**	-2.13**	-0.42	-0.31	-0.16	0.05	0.98**	0.93**	-1.13**	-1.22**	-0.11	-0.15	2.35**	3.71**	**2.27****	1.10
L9	2.19**	2.21**	0.04	0.15	0.74	0.21	0.53 **	0.48*	-0.15	-0.14	-0.40*	-0.37*	0.11	-0.78	-0.91*	1.19
L10	0.29	0.37	0.20	0.21	-3.02*	-3.54**	-2.18**	-2.15**	1.70**	1.76**	0.13	0.16	0.77	-0.34	0.05	0.06
L11	1.33**	1.43**	**0.83****	**0.78****	**6.81****	**6.29****	**7.28****	**7.34****	**1.94****	**1.91****	**0.37***	**0.40****	**3.55****	**2.33****	-0.19	-0.12
L12	-1.27**	-1.20**	0.05	0.001	4.70*	4.17*	-2.37**	-2.30*	-1.79**	-1.82**	-0.12	-0.09	-0.46	-0.89	1.97**	0.55
L13	-0.27	-0.42	-0.35	-0.40	-6.96**	-7.48**	-1.42**	-1.35**	-0.33	-0.36	-0.26	-0.23	-1.57	-3.34**	0.49	0.59
L14	-2.97**	-3.12**	0.65*	0.61*	2.45	1.93	-1.32**	-1.43**	0.90**	0.87**	-0.13	-0.10	-0.38	-0.29	0.62	1.56
L15	2.86**	2.70**	0.56*	0.52*	2.07	1.55	-3.17**	-3.27**	0.59*	0.57*	-0.33*	-0.31	0.33	1.89*	-0.10	0.46
L16	-1.07**	-1.21**	0.05	-0.05	1.68	1.16	-1.65 **	-1.76**	-0.86**	-0.84**	-0.43**	-0.39**	-2.55**	-2.09**	0.21	0.45
L17	-0.94**	-1.10**	-1.01**	-1.19**	-2.35	-2.87	-0.26	-0.37	-0.61*	-0.52	-0.30	-0.23	-3.78**	-2.54**	0.09	-2.61**
L18	0.26	0.05	-0.01	-0.19	-5.87**	-6.40**	-0.39 *	-0.50*	-0.09	0.001	-0.23	-0.17	-2.38**	-1.96*	1.28**	0.54
L19	1.06**	0.91**	-0.31	-0.49*	0.76	0.04	-1.58**	-1.69**	-0.77**	-0.69**	-0.06	0.001	-4.28**	-3.72**	2.11**	-0.74
L20	2.03**	1.86**	0.06	-0.12	-7.43**	-8.25**	-1.02**	-1.13**	-1.05**	-1.00**	-0.16	-0.10	-0.34	1.15	-2.01**	-0.28
T1	0.003	0.04	0.15	0.16	0.02	0.05	-0.81**	-0.80**	-0.15	-0.14	-0.02	-0.02	-0.25	-0.35	-0.08	0.30
T2	0.28*	0.25*	-0.14	-0.14	0.51	0.53	1.26 **	1.26**	0.21**	0.21**	-0.02	-0.02	0.16	0.24	0.05	-0.28
T3	-0.28*	-0.29*	-0.02	-0.02	-0.54	-0.58	-0.45**	-0.45*	-0.07	-0.07	0.04	0.05	0.09	0.11	0.03	-0.02
SE Line.	0.24	0.27	0.11	0.14	0.51	0.47	0.18	0.20	0.27	0.27	0.16	0.18	0.86	0.72	0.42	0.93
SE Test.	0.08	0.09	0.03	0.04	0.17	0.15	0.06	0.07	0.09	0.08	0.05	0.04	0.28	0.24	0.14	0.30

environmental factors and plant population per unit area (Chandra *et al.*, 2011).

In the head diameter trait, GCA variances were lower than SCA variances under both seasons, which indicated the dominant type of gene action (Table 5). Dominant gene component was reported to be more responsible for this trait. So, hybrid breeding would be rewarding for the trait under investigation and selection in early generations would be useful. Higher SCA variances as compared to GCA variances also indicated involvement of non-additive gene action more than additive ones reported by some researchers such as Karasu *et al.* (2010). Many other researchers emphasized the importance of additive gene component for this trait (Machikowa *et al.*, 2011; Tabrizi *et al.*, 2012).

***100 achene weight (g)*:** The 100 achene weight trait plays a significant role in determining the yield of sunflower. In table 3, the lines L7 and L6 were the best general combiners with the values of 1.07 and 1.18 in spring season, while under autumn season showed 1.04 and 1.16 respectively. Riaz *et al.* (2017), Tavade *et al.* (2009) and Tyagi and Dhillon (2016) found the similar results while Dhillon and Tyagi (2016) and Memon *et al.* (2015) explored contrasting results regarding the GCA effects for 100 achene weight in sunflower. Specific combining ability estimates depicted that the better performer cross was L17 × T1 with the values of 1.09 in spring and 1.08 in autumn seasons followed by L18×T2 (0.87) and L16×T3 (0.72) as given in Table 4. Memon *et al*. (2015) and Dhillon *et al*. (2016) found the similar results regarding the SCA effects for 100 achene weight.

Dominance type of gene action exhibited in this trait due to more SCA variances than GCA variances (Table 5), so heterosis breeding leading towards selection of better hybrids will be rewarding in current study. Other researchers also showed supporting results with higher values of SCA than GCA variances (Biradar *et al.*, 2018) and contribution of over dominance for 100 achene weight. It shows non-additive gene action for these traits. Higher GCA than SCA variances contributing towards gene inheritance were found as well by some researchers (Mohanasundaram *et al.*, 2010). Golabadi *et al.* (2015) reported contrary results with current study and showed additive type of gene action for achene weight. So, it can be concluded that both additive and non-additive gene actions govern this trait.

***Achene yield per plant (g)*:** Achene yield per plant is most important trait in determining the yield parameter of plant. Head diameter and 100 achene weight directly influence the achene yield per plant (Biradar *et al.*, 2018). The results regarding general combining ability effects showed that L6 (9.85 in spring, 10.42 in autumn) was the best general combiner in both seasons followed by L11 (6.81 in spring, 6.29 in autumn) and L5 (5.42 in spring, 5.99 in autumn) as given in Table 3. Similar results for this trait were studied by Machikowa *et al.* (2011), Tabrizi *et al.* (2012) and Dhillon and Tyagi (2016). Specific combining ability estimates for this trait predicted that the cross L11 × T2 (10.79, 10.78) was good specific combiner followed by L18 × T2 (8.57, 8.54) and L2 × T1 (8.13, 8.10) in spring and autumn seasons, respectively (Table 4). Similar results for this trait were studied by Rameeh and Andarkhor (2017) and Riaz *et al.* (2017).

In the current study, non-additive type of gene action was present for this trait due to SCA variances greater than GCA variances (Table 5), so early selection of hybrids would be rewarding. Dominant gene action was found for this trait as

Table 4. SCA effects of yield and oil contributing traits of sunflower.

SCA	Head diameter		100 Achene weight		Achene yield/plant		Oil Contents		Palmitic acid		Stearic acid		Oleic acid		Linoleic acid	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
L1×T1	1.97**	1.93**	-0.45*	-0.45*	3.64**	3.61**	-1.77**	-1.78**	0.01	0.02	-0.05	-0.04	0.37	-1.09	3.32**	0.59
L1×T2	2.49**	2.52**	-0.07	-0.07	-5.62**	-5.64**	2.46**	2.47**	-0.18	-0.17	0.09	0.09	-1.05	-0.34	-1.02	-0.03
L1×T3	-4.46**	-4.44**	0.52**	0.52**	1.99*	2.03**	-0.69*	-0.69*	0.17	0.17	-0.04	-0.05	0.68	1.43	-2.29**	-0.56
L2×T1	2.17**	2.57**	-0.37*	-0.38*	8.13**	8.10**	-4.06**	-4.07**	0.28	0.29	0.03	0.00	-2.64*	-3.11	0.01	1.70
L2×T2	-2.61**	-2.80**	0.10	0.10	-6.60**	-6.62**	0.42	0.43	-0.45	-0.51	0.07	0.04	0.64	0.69	4.24**	1.38
L2×T3	0.45	0.23	0.27	0.28	-1.52*	-1.48*	**3.63****	**3.64****	0.17	0.22	-0.10	-0.04	2.00	2.41	-4.25**	-3.08**
L3×T1	-0.80*	-0.84*	0.50*	0.50*	7.74**	7.72**	0.71*	0.98*	0.56	0.53	0.09	0.09	0.72	0.51	-2.42**	-1.58
L3×T2	-0.78	-0.75	-0.15	-0.15	-11.37**	-11.38**	1.57**	1.44**	-0.47	-0.51	-0.04	-0.03	1.27	1.19	0.63	-0.35
L3×T3	1.58**	1.58**	-0.35*	-0.35*	3.62**	3.67**	-2.28**	-2.41**	-0.09	-0.02	-0.05	-0.06	-1.98	-1.69	1.79**	1.93
L4×T1	5.30**	5.26**	0.58*	0.57**	-9.27**	-9.30**	-0.22	-0.23	0.38	0.37	0.12	0.12	0.94	1.40	0.78	0.55
L4×T2	0.72	0.75	0.10	0.10	2.11**	2.10**	1.66**	1.67**	-0.11	-0.10	0.06	0.06	-0.85	-1.59	0.48	-0.04
L4×T3	-6.02**	-6.01**	-0.68*	-0.67**	7.15**	7.20**	-1.45**	-1.44**	-0.27	-0.26	-0.18	-0.18	-0.09	0.20	-1.26*	-0.52
L5×T1	1.67**	1.56**	0.52*	0.51*	-1.39	-1.42*	0.10	0.09	0.01	-0.01	0.08	0.09	0.79	1.10	-5.51**	-3.60**
L5×T2	-2.11**	-2.13**	0.06	0.06	3.06**	3.05**	-0.75*	-0.74*	0.08	0.09	0.15	0.15	0.71	1.52	-1.59*	0.72
L5×T3	0.45	0.57	-0.5*	-0.57*	-1.68*	-1.64*	0.65*	0.66*	-0.09	-0.08	-0.24	-0.24	-1.50	-2.62*	7.10**	2.87*
L6×T1	3.42**	3.38**	-0.04	-0.05	7.87**	7.84**	3.37**	3.36**	-0.32	-0.34	-0.18	-0.18	-1.17	-1.52	-2.60**	-0.64
L6×T2	-2.65**	-2.62**	0.04	0.04	5.44**	5.42**	-1.28**	-1.27**	0.22	0.25	-0.07	-0.07	1.73	0.90	-0.20	-0.25
L6×T3	-0.77*	-0.76	0.01	0.01	-13.30**	-13.26**	-2.09**	-2.08**	0.10	0.09	0.25	0.25	-0.56	0.62	2.80**	0.89
L7×T1	-4.32**	-4.37**	-0.62**	-0.63**	-7.42**	-7.45**	0.83*	0.82*	0.03	0.10	-0.01	-0.01	-0.40	-0.19	-1.43*	0.20
L7×T2	-0.40	-0.38	0.49*	0.50*	5.30**	5.28**	-2.58**	-2.57**	0.76*	0.78*	0.09	0.09	0.18	0.23	0.52	-0.88
L7×T3	4.72**	4.75**	0.13	0.14	2.13**	2.17**	1.74**	1.75**	-0.79*	-0.88*	-0.08	-0.08	0.22	-0.05	0.91	0.68
L8×T1	-2.20**	-2.25**	0.48*	0.48*	-7.54**	-7.20**	2.79**	2.78**	0.04	0.08	0.29	0.29	2.56*	3.19**	-0.37	-0.54
L8×T2	-1.08*	-1.04**	-0.17	-0.17	2.67**	3.03**	-1.52**	-1.52**	-0.28	-0.37	-0.04	-0.04	-2.48*	-4.32**	-3.45**	-1.32
L8×T3	3.28**	3.29**	-0.32*	-0.31*	4.86**	4.17**	-1.26**	-1.26**	0.24	0.29	-0.24	-0.25	-0.08	1.14	3.81**	1.86
L9×T1	-1.77**	-1.82**	0.01	0.00	0.24	0.22	0.14	0.13	-0.20	-0.14	0.28	0.28	0.13	-0.32	1.08	0.42
L9×T2	1.56**	1.61**	-0.66**	-0.66**	5.62**	5.61**	0.09	0.10	-0.11	-0.13	-0.26	-0.20	0.06	0.43	2.42**	1.28
L9×T3	0.21	0.21	0.65**	0.66**	-5.87**	-5.83**	-0.24	-0.23	0.31	0.26	-0.02	-0.03	-0.20	-0.11	-3.50**	-1.70
L10×TI	-2.57**	-2.46**	0.06	0.16	-0.80	-0.83	0.56*	0.48	-0.83*	-0.76*	-0.18	-0.18	-0.20	-0.77	2.00**	0.84
L10×T2	-1.14*	-1.19*	0.32*	0.27	-0.88	-0.89	-1.37**	-1.33**	0.33	0.35	-0.58**	-0.58**	-0.95	-0.35	-0.92	0.18
L10×T3	3.71**	3.65**	-0.38*	-0.43*	1.68*	1.72*	0.81*	0.85*	0.51	0.42	0.77**	0.76**	1.14	1.11	-1.08	-1.02
L11×TI	-0.60	-0.44	0.06	0.06	-8.78**	-8.81**	0.73*	0.72*	0.05	0.04	-0.15	-0.15	-1.31	0.24	0.32	-0.59
L11×T2	**4.92****	**4.85****	0.22	0.22	**10.79****	**10.78****	-2.20**	-2.20**	0.09	0.09	0.25	0.25	0.96	0.32	0.55	1.03
L11×T3	-4.32**	-4.41**	-0.28	-0.27	-2.01*	-1.97*	1.47**	1.47**	-0.13	-0.12	-0.10	-0.10	0.35	-0.56	-0.87	-0.44
L12×TI	-3.00**	-2.85**	0.35*	0.34*	-1.64*	-1.67*	1.07**	1.06**	0.91*	0.89*	0.22	0.22	-1.30	-0.21	-0.64	-0.24
L12×T2	1.72**	1.78**	-0.53**	-0.53**	-2.18**	-2.20**	-0.70*	-0.70*	-0.14	-0.13	-0.08	-0.08	0.95	1.21	-0.14	-0.79
L12×T3	1.28*	1.07*	0.18	0.19	3.83**	3.87**	-0.37	-0.36	-0.77*	-0.76*	-0.14	-0.15	0.35	-1.00	0.78	1.02
L13×TI	3.90**	3.85**	-1.01**	-1.02**	3.97**	3.94**	-0.98*	-0.99*	-0.95*	-0.96*	-0.10	-0.10	1.48	1.57	3.89**	2.40
L13×T2	0.62	0.66	0.56**	0.56**	-5.74**	-5.75**	-0.59*	-0.58*	0.28	0.29	-0.13	-0.13	-0.61	-0.35	-2.02**	-1.32
L13×T3	-4.52**	-4.51**	0.46*	0.46*	1.77*	1.81*	1.56**	1.57**	0.67	0.67	0.23	0.23	-0.87	-1.22	-1.87*	-1.08
L14×TI	0.70*	0.65	-0.23	-0.24	-0.43	-0.46	-1.66**	-1.67**	-0.40	-0.40	-0.20	-0.20	-0.72	-1.81	-4.13**	-2.12
L14×T2	1.62**	1.65**	0.26	0.26	-1.97*	-1.98*	1.98**	1.98**	0.46	0.46	0.07	0.07	1.24	1.35	-1.08	-0.54
L14×T3	-2.32**	-2.30**	-0.02	-0.02	2.40**	2.44**	-0.32	-0.31	-0.06	-0.06	0.13	0.13	-0.52	0.47	5.21**	2.66**
L15×TI	-1.24**	-1.29**	-0.03	-0.04	3.93**	3.90**	0.09	0.08	0.43	0.42	-0.19	-0.18	-0.74	-1.65	0.75	1.23
L15×T2	-0.61	-0.58	-0.10	-0.10	-5.51**	-5.52**	-0.40	-0.40	0.31	0.33	0.18	0.18	1.16	1.10	1.99**	1.14
L15×T3	1.85**	1.87**	0.13	0.14	1.58*	1.62*	0.32	0.32	-0.74	-0.75*	0.01	0.00	-0.42	0.56	-2.74**	-2.37
L16×TI	-1.60**	-1.65**	0.09	0.13	3.31**	3.28**	-0.77*	-0.78*	0.89*	0.84*	0.53**	0.52**	3.13**	4.99**	0.58	-0.05
L16×T2	-1.48**	-1.43**	-0.81**	-0.76**	-0.86	-0.87	-0.70*	-0.69*	-0.85*	-0.89*	-0.50**	-0.51**	-1.24	-1.85	-1.70	-0.24
L16×T3	3.08**	3.07**	0.72**	0.64*	-2.45**	-2.41**	1.46**	1.47**	-0.04	0.05	-0.03	-0.02	-1.89	-3.14**	1.12	0.29
L17×TI	-1.44**	-1.49**	1.09**	1.08**	6.04**	6.01**	1.80**	1.79**	0.49	0.47	-0.13	-0.13	0.02	-0.23	0.57	0.34
L17×T2	0.29	0.33	-0.15	-0.15	-5.95**	-5.96**	-0.17	-0.17	-0.27	-0.25	0.23	0.24	-0.69	-0.41	0.81	1.08
L17×T3	1.15**	1.17**	-0.94**	-0.94**	-0.09	-0.05	-1.63**	-1.63**	-0.22	-0.22	-0.10	-0.10	0.68	0.64	-1.38*	-1.42
L18×TI	-3.64**	-3.62**	-0.97**	-0.98**	-14.95**	-14.98**	0.84*	0.83*	-0.46	-0.47	-0.47**	-0.47**	1.30	1.22	-0.91	-0.45
L18×T2	0.09	0.01	0.87**	0.87**	8.57**	8.55**	0.42	0.43	0.45	0.45	0.23	0.24	0.08	0.35	-1.95*	-0.65
L18×T3	3.55**	3.62**	0.10	0.11	6.39**	6.43**	-1.26**	-1.25**	0.01	0.01	0.23	0.23	-1.38	-1.57	2.86**	1.11
L19×TI	3.37**	3.22**	-0.48*	-0.49*	3.24**	3.41**	-1.63**	-1.64**	-0.21	-0.22	0.18	0.18	-0.47	0.28	3.04**	-0.31
L19×T2	-1.41**	-1.38**	-0.03	-0.03	-0.01	-0.12	2.95**	2.95**	-0.97*	-0.96*	0.34	0.35	0.17	-0.30	-1.23*	-0.66
L19×T3	-1.96**	-1.84**	0.51**	0.52**	-3.23**	-3.29**	-1.31**	-1.31**	1.18**	1.18**	-0.52**	-0.53**	0.29	0.02	-1.81**	0.97
L20×TI	0.70	0.67	0.46*	0.46*	4.11**	4.08**	-1.95**	-1.96**	-0.71	-0.69	-0.16	-0.15	-2.49*	-3.59**	1.66**	1.84
L20×T2	0.22	0.13	-0.34*	-0.34*	3.13**	3.12**	0.71*	0.71*	0.86*	0.91*	-0.06	-0.05	-1.29	0.23	3.66**	0.26
L20×T3	-0.92	-0.80*	-0.12	-0.12	-7.24**	-7.20**	1.25**	1.25**	-0.15	-0.22	0.21	0.21	3.77**	3.36**	-5.32**	-2.09
SE SCA	0.34	0.39	0.15	0.16	0.73	0.67	0.25	0.28	0.38	0.37	0.23	0.22	1.22	1.02	0.6	1.32

confirmed by Mohanasundaram *et al.* (2010), Aleem *et al.* (2015) and Tyagi and Dhillon (2016) revealing predominant role of SCA variances than GCA variances for the said trait. The higher GCA variance was publicized than SCA for this trait by Machikowa *et al.* (2011) indicating additive type of gene action which was contrary to the results under study. So, determination of achene yield by both additive and non-additive types of gene actions shows the complex nature of this trait.

***Oil contents (%)*: ** Sunflower oil is premium quality oil used as major cooking oil in the country. Pakistan is facing the problem of oil deficiency and huge budget is spent to meet the edible oil requirement which is met through import. In the current studies, by selecting the best parents and their hybrids will be useful to meet this requirement.

Table 5. Genetic components of yield and oil contributing traits in sunflower.

Traits	σ^2_{GCA}		σ^2_{SCA}	
	Spring	Autumn	Spring	Autumn
HD	0.02	0.03	10.11	10.03
100 AW	0.01	0.01	0.08	0.29
AYP	0.66	0.19	19.42	48.82
OC	0.28	0.29	3.91	3.74
PA	0.03	0.03	0.18	0.14
SA	0.01	0.004	0.06	0.01
OA	0.12	0.15	2.54	2.51
LinA	0.09	0.01	4.67	0.11

HD=Head diameter, 100A.W= 100 Achene weight, AYP= achene yield per plant, OC= Oil contents, PA= Palmitic acid, SA= Stearic acid, OA= Oleic acid,LinA= Linoleic acid, σ^2_{GCA}= variances due to GCA, σ^2_{SCA}= Variances due to SCA

In case of oil contents, the line L6 (7.76, 7.71) was the best general combiner followed by L11 (7.28, 7.34) and L7 (6.70, 6.65) in spring and autumn seasons respectively (Table 3). Results regarding specific combining ability estimates showed that the crosses L2 × T3 (3.63 in spring, 3.64 in autumn) followed by L6 × T1 (3.37 in spring, 3.36 in autumn) were the best performing hybrids for oil contents out of 60 sunflower hybrids under study (Table 4). The above mentioned parents and crosses would be added in sunflower breeding programs for production of high oil varieties. Many other researchers such as Rameeh and Andarkhor (2017) and Riaz *et al.* (2017) got results in accordance with the above ones. In the current study, dominant gene action was predominant for oil contents due to more SCA variances than GCA variances (Table 5), Therefore, hybrid breeding for early selection would be fruitful for this trait in the current study. Andarkhor *et al.* (2013) reported similar result with significant role of dominance gene action while Golabadi *et al.* (2015) reported additive type of gene action for oil contents.

***Palmitic acids (16:0)*:** One of the major factors involved to mount the cardio-vascular diseases are trans-fats. Along with percent increase in sunflower oil, the overall concentration of natural saturated fatty acids is appreciated by vegetable ghee manufacturers and margarine industry (Rauf *et al*., 2017).

The best general combining ability effects were shown by lines L6 (1.91, 1.90) and L7 (1.46, 1.41) in two seasons i.e., spring and autumn for palmitic acid (Table 3). Manzoor *et al.* (2016) reported the similar results regarding palmitic acid GCA effects. Specific combining ability estimates for palmitic acid were higher for the cross L19 × T3 (1.18, 1.19) followed by L12 × T1 (0.91, 0.89) and L16 × T1 (0.89, 0.84) in spring and autumn seasons respectively (Table 4). Skoric *et al*. (2008) and Manzoor *et al*. (2016) reported the observations for this trait as in this study. The genes showing additive behavior were comparatively lower than genes showing dominance behavior. for palmitic acid due to SCA variances greater than GCA variances in the current study as given in Table 5.

***Stearic acid (18:0)*:** Stearic acid is saturated fatty acid but has neutral impact on cholesterol level of blood and its increased level is desirable for vegetable ghee and margarine production (Rauf *et al.*, 2017).

The results regarding general combining ability estimates for stearic acid indicated that the line L7 proved to be the best general combiner with the values 1.23 and 1.19 in spring and autumn seasons followed by L6 (1.10, 1.06) in both seasons as given in Table 3. Manzoor *et al*. (2016) gave similar results for GCA effects. Results regarding specificity combining ability effects for stearic acid among 60 sunflower hybrids predicted that the crosses L10×T3 (0.77, 0.76) and L16×T1 (0.53, 0.52) were good performers in both seasons (Table 4). Skoric *et al*. (2008) and Manzoor *et al.* (2016) reported the similar results for SCA in sunflower. This study showed non-additive gene action was found higher than additive gene action for stearic acid due to higher values of SCA variances than GCA variances (Table 5), so selection for hybrid breeding of stearic acid would be useful.

***Oleic acids (18:1)*:** The high oleic sunflower types are superior over regular sunflower, soybean and peanut oils due to suitability for cooking and frying for better resistance against heat (Smith *et al*., 2007). This is an important ω-9 (omega-9) fatty acid. The lines L6 (4.80, 5.49), L7 (4.35, 4.16), L11 (3.55, 2.33) and L8 (2.35, 3.71) were good general combiners for oleic acid in spring and autumn seasons respectively (Table 3). Similar results for parents regarding GCA were reported by Aslam *et al*. (2010).

Results regarding specificity combining ability effects for oleic acid among 60 sunflower hybrids predicted that the crosses L8×T1 (2.56, 3.19) and L2×T3 (2.0, 2.41) were only good performers in both seasons (Table 4). In this genetic study, additive gene action was lower than non-additive gene action for oleic acid due to less GCA variances than SCA variances (Table 5) favouring heterosis breeding for oleic acid.

***Linoleic acids (18:2)*:** Linoleic acid is an important ω-6 (omega-6) fatty acid out of major polyunsaturated fatty acids because it has health benefits of lowering blood cholesterol levels (Orsavova *et al.*, 2015). In current breeding experiment, the line L8 with the value of 2.27, L19 with 2.11 and L12 with the value of 1.97 were good general combiners for linoleic acid in spring season whereas the line L4 (1.33) and L14 (1.56) were good combiners in autumn (Table 3). Joksimović *et al*. (2006) and Manzoor *et al*. (2016) reported similar results for linoleic acid. Specific combining ability estimates for linoleic acid were higher for the cross L5 × T2 (7.10) followed by L2 × T2 (4.24) and L13 × T1 (3.89) in spring season and L14 × T3 (2.87) and L5 × T3 (2.67) in autumn were good performers (Table 4). Skoric *et al*. (2008) reported the similar results for linoleic acid SCA effects in sunflower. The experiment showed that non-additive gene action was higher than additive gene action for linoleic acid due to SCA variances greater than GCA variances (Table 5) which favours development of hybrids using heterosis breeding for this trait.

***Conclusion*:** The present study was conducted to assess the genetic significance among the 60 sunflower hybrids and their 23 parents. The genotypes L6, L7 and L11 had the best general combining abilities for 100 achene weights, achene yield per plant, oil contents, stearic acid, palmitic acid and oleic acid except for head diameter and linoleic acid. For head diameter, L1 and L2 were the best general combiners while for linoleic acid, L8 performed the best. The best specific cross combination L11 × T2 was observed for yield contributing traits as head diameter and achene yield per plant while L2 × T3 was best specific cross for oil contents. Dominant type of gene action was predominant for all the traits which favored the authenticity of heterosis breeding. It is concluded that this breeding material may be useful for the improvement of achene yield and oil quality traits in sunflower. This breeding material showing enough genetic variation would be used in further breeding programs to combat oil requirements.

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