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Combining ability and correlation studies in 6×6 diallel crosses of sunflower (*Helianthus annuus* L.)

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Abstract

The current studies was carried out to determine combining ability and correlation in 6×6 diallel crosses of sunflower genotypes for some physiological traits at Khyber Pakhtunkhwa Agricultural University Peshawar during 2009-10.The planted materials consisted of parental lines and their F1 hybrids using randomized complete block design with three replications. Data were recorded on yield and other important agronomic characters. General combining ability (GCA) and specific combining ability (SCA) were significant for all parameters except, seeds head^{-1}. GCA effects for head size, stem thickness were greater than SCA showing contribution of additive gene effects. For flowering and 100 grain weight SCA effects were of greater magnitude than GCA and showing contribution of non-additive gene effects. Plant height exhibited significant (P@ 0.01) positive correlation with flowering and 100 grain weight. Seed head^{-1} and head size exhibited significant positive correlation with 100 grains weight. Among parental genotypes Rising Sun, US-444 and HS-K6 were the best general combiners for all the traits. Cross combinations Rising Sun × HS-K6, Ausigold-7 × US-444, Ausigold-7 × SMH-0917, Hysun-33 × HS-K6, and Ausigold-7 × HS-K6 showed promising results for majority of the traits, hence could be used in future breeding programs.

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Introduction

Edible oil is major constituent of our diet but Pakistan is chronically deficient in its production, and large quantity of the country's edible oil requirements are met through imports. Oilseed sector, due to ever increasing consumption of edible oil, has attained critical importance in the economy of Pakistan. Total availability of edible oil during 2011-2012 was 1749 million tons, whereas local production stood at 0.680 million tons which accounted for 24% of the total availability while the remaining 1246 million tons was made available through imports (Economic Survey of Pakistan, 2011-2012). This gap in the consumption and production can be filled by introducing cultivars with high edible oil contents, lodging resistance, high seed yield, drought tolerance and early maturity. Domestic production of edible oil can be increased by increasing the area and per acre yield of conventional and non-conventional oilseed crops. The area under oilseed crops cannot be increased as land resources are limited therefore, the only way left is the improvement of gentic potential of existing oilseed crops and introduction of new crops. Sunflower (*Helianthus annuus* L. 2n = 34) belongs to the family Compositae. It is one of the three crop species along with soybean and rapeseed which account for approximately 78% of the world vegetable oil (Miller, 1988). Sunflower appears to be the only crop which can play a vital role in supplementing our local oil production due to its high yield potential, drought resistance, salt tolerance and adjustment in the present cropping pattern. Being a short duration crop, it can be grown successfully twice a year under irrigated as well as rain fed conditions (Pascale and Damario, 1997). Sunflower seed contain essential amino acids and proteins. In addition, its oil contains high levels of unsaturated fatty acids (linoleic acid; 70% and oleic acids; 20%) and low levels of saturated fatty acids (palmitic acid and stearic acids) which make this oil as a premium commodity as cooking oil. It is also a good source of calcium, phosphorus, nicotinic acid and vitamin E (Khalifa *et al*., 2000). Combining ability is the ability of two parents to transmit favorable or unfavorable traits to their progeny. Through the availability of this information, sunflower improvement program can be improved considerably. The current research aims to produce such varieties and inbreed line of sunflower, having high yielding potential.

Materials and methods

This research work was carried out at Khyber Pakhtunkhwa Agricultural University, Peshawar during 2009-2010. Six different sunflower lines (Rising Sun, Ausigold-7, US-444, Hysun-33, SMH-0917 and HS-K6) were planted in field with a row length of 2 m, with plant to plant distance of 12 cm and row-to-row distance of 0.75 m. During spring 2009, the parental lines were crossed in 6×6-diallel fashion. In spring 2010, all the F1 crosses (direct and reciprocal) along with parental lines were grown in RCB Design with three replications to record data on the different morphological and yield parameters. All the agronomic practices like thinning, hoeing, weeding, fertilizer application and irrigation were carried out whenever needed. The data were recorded on the following parameters.

Plant height (cm): Plant height was measured in cm from the soil surface to the base of capitulum at physiological maturity.

Days to flowering: For 50% flowering, data were recorded in number of days taken from the sowing date in each genotype at a stage when 50% plants flowered.

Head size (cm^2): Head size was measured from one edge of the head to the other.

Stem thickness (cm): The stem thickness of randomly selected plants was measured at the middle of stem with the help of Vernearcaleper.

Seeds $head^{-1}$: Total number of seeds in each head was counted from the selected plants.

100-grain weight: Random sample of 100-grain was drawn from selected plants. These grains were sun dried for two days and weighed in grams by electrical balance.

Seed yield plant^{-1}: The total seeds harvested from a plant were sun dried and weighted in grams.

Statistical analysis: Data were subjected to analysis of variance following the method of (Steel and Torrie,1980).

Genetic variance = Vg = (M1 – M2)/ r

Environmental variance = Ve = M2

Heritability = h^2BS = Vg/ Vp

Combining ability analysis:For traits showing significant differences, data were further subjected to Combining Ability Analysis according to (Griffing, 1956)Method-I based on Eisenhart's Model-II given in "Biometrical Methods in Quantitative Genetic Analysis" by (Singh and Chaudhery) as under:

General combining ability (GCA)

$$g_i = \frac{1}{2n}(Y_i. + Y_.i) - \frac{1}{n^2}Y..$$

Where:

gi=General combining ability effects for line i.

n=Number of parents/varieties.

Yi. = Total of mean values of F_1's resulting from crossing jth lines with ith lines.

Y.i = Total of mean values of F_1'sresulting from crossing ith lines with jth lines.

Y. = Grand total of all the mean values in the table.

Specific combining ability (SCA)

$$s_{ij} = \frac{1}{2}(Y_{ij}+Y_{ji}) - \frac{1}{2n}(Y_i.+Y_.i+Y_j.+Y_.j) + \frac{1}{n^2}Y..$$

Where:

Sij = Specific combining ability between ith and jth lines.

Yij = Mean value of the F_1 resulting from crossing the ith and jth lines.

Yji = Mean value for F_1 resulting from crossing the jth and ith varieties

Yi. = Total of mean values of F_1's resulting from crossing jth line with ith varieties.

Y.i = Reciprocal values of Yi.

Y.j = Total values for F_1's resulting from crossing the ith line with jth line.

Yj. = Values of reciprocal F_1's of Y.j

Y. = Grand total of the observations.

Phenotypic correlation: The phenotypic correlation (rp) between two traits, X1 and X2, were calculated in F1 generation using the formula described by (Kwon and Torrie, 1964).

rp = COVP (X1, X2) / √QVP (X1). VP (X2)

Where,

CovP (X1, X2) = Phenotypic covariance for traits X1 and X2 in F1 generation.

VP (X1) & VP (X2) = Phenotypic variance for traits X1 and X2 in F1 generation.

Results and discussion

Plant height

Plant height is a function of both genetic constitution of a plant and the environmental conditions under which it is grown (Skoric, 1992). All sunflower genotypes showed significant differences regarding plant height (Table 1).

Table 1. Mean squares for ANOVA and combining ability in 6x6 diallel crosses of sunflower.

Parameters	ANOVA			Combining ability		
	Replication Mean Squares (Df = 2)	Genotype Mean Squares (Df = 35)	Error Mean Squares (Df = 70)	General Combing Ability (Df = 5)	Specific Combining Ability (Df =15)	Error (D f=70)
Plant height	128.12	2071.04**	179.0	296.80**	1062.42**	59.67
Days to flowering	2 1.583	52.49**	8.28	15.76**	28.04**	2.76
Leaves per plant	8.065	43.85**	10.29	20.60**	10.78**	3.43
Head size(cm)	4.194	36.92**	12.35	17.37**	9.72**	4.12
Stem thickness	4.33 8	0.48**	0.02	0.29**	0.14**	0.01
Seeds per head	60725.6	87266.99*	43066.1	30180.57^{ns}	19614.81^{ns}	14355.35
100-grain weight	0.271	2.03**	0.44	0.27ns	0.88**	0.14
Seed yield plant^{-1}	116.766	499.327**	187.090	104.26ns	171.33**	62.36
Oil %	8.569	21.02**	0.04	4.17**	5.77**	0.01

** Highly significant at 0.01 level, * Significant at 0.05 level, DF = Degree of freedom.

For plant height genotype, Rising Sun elucidated highest positive general combining ability followed by genotype SMH-0917. The highest negative desirable general combining ability for plant height was displayed by genotype US-444 (Table 2).

Table 2. General Combining Ability effects for various traits in a 6x6 diallel cross of sunflower.

Parental Lines	Plant height (cm)	Days to flowering	Stem thickness (cm)	Head size (cm)	Seed head^{-1}	100 seed weight (g)	Seed yield plant^{-1} (g)	Oil %
Rising Sun	7.59	-1.25	-0.24	1.36	45.59	0.27	-0.05	0.41
Ausigold-7	-0.03	1.06	0.07	1.11	-11.46	-0.07	0.07	-0.44
US-444	-7.09	-0.42	0.19	-0.97	-81.35	0.05	-0.48	-0.7
Hysun-33	-1.89	-0.61	-0.05	0.08	22.31	-0.16	0.56	-0.43
SMH-0917	3.09	-0.53	0.11	0.19	-25.88	-0.08	-0.05	0.71
HS-K6	-1.66	1.75	-0.09	-1.78	50.79	-0.02	-0.05	0.45

The results are in agreement with the work of (Abdullah *et al.*, 2010, Hand *et al.*, 2006, Jan *et al.*, 2003) who found high negative GCA effect for plant height. SCA effect showed significant differences for plant height (Table 1). The cross combination Ausigold-7 × HS-K6 showed high negative specific combining ability while the cross Rising Sun × HS-K6 had lowest negative specific combining ability effect for plant height (Table 3). These results are line in agreement with those of (Goksoy *et al.*, 1999, Burli *et al* 2001; Jan *et al.*, 2003) who reported significant negative SCA effect for plant height.

Table 3. Specific Combining Ability effects for various for morpho-physiological traits in a 6x6 diallel crosses of sunflower.

Specific Combining Ability	Plant Height (cm)	Days to Flowering	Stem Thickness (cm)	Head Size (cm)	Seed Head^{-1}	100 Seed Weight (g)	Seed Yield Plant^{-1} (g)	Oil%
Rising Sun × Ausigold-7	1.16	-1.47	-0.15	-0.94	-33.4	-0.04	-0.27	-1.79
Rising Sun × US-444	-1.78	-2.50	-0.19	-0.19	-78.18	-0.28	0.20	-1.61
Rising Sun × Hysun-33	-27.47	-2.47	0.01	-1.42	20.49	-0.27	0.31	-1.92
Rising Sun × SMH-0917	-9.46	-2.39	0.35	3.31	-2.48	-0.03	-0.08	-0.71
Rising Sun × HS-K6	-1.54	0.67	-0.05	0.28	50.69	0.35	-0.16	1.15
Ausigold-7 × US-444	-4.83	0.03	-0.20	4.89	199.21	0.08	0.31	-0.81
Ausigold-7 × Hysun-33	-12.19	-0.28	0.28	0.50	29.38	-0.59	-0.50	-1.17
Ausigold-7 × SMH-0917	2.16	-3.36	0.56	-1.11	-66.59	-0.63	0.16	-0.21
Ausigold-7 × HS-K6	-29.59	0.19	-0.21	-1.14	-83.93	0.17	-0.15	0.07
US-444 × Hysun-33	-12.19	-0.28	0.28	0.50	29.38	-0.59	-0.50	-1.07
US-444 × SMH-0917	-10.12	-0.72	0.05	-1.86	25.46	-0.05	-0.65	0.13
US-444 × HS-K6	-14.36	-1.00	0.01	-0.72	-56.87	-0.35	0.18	-0.66
Hysun-33 x SMH-0917	-16.98	-0.19	-0.43	-1.25	29.96	-0.32	0.34	0.1
Hysun-33 × HS-K6	-2.06	-3.64	0.19	1.06	-130.54	-0.12	0.31	-1.45
SMH-0917 × HS-K6	1.29	-0.72	-0.17	-2.39	-74.84	-0.98	-0.56	0.54

Days to flowering

Early flowering is the indication for early maturity which results in timely vacation of land for second crops or other following crops like wheat, barley etc. All sunflower genotypes under study exhibited significant difference regarding days to flowering (Table 1). The highest negative GCA effect showed by genotype Rising Sun followed by genotype Hysun-33 (Table 2). Similar results have been reported by (Arshad *et al.*, 2007, Naik *et al.*, 1999, Ashok *et al.*, 2000) who observed significant negative GCA effects for days to flowering in sunflower which confirmed our results. SCA effect showed significant differences for flowering (Table 1). The highest negative SCA effect for days to flowering showed by Hysun-33 × HS-K6 and was a good combiner for earliness (Table 3). These results are in line with the finding of (Kaya and Atakisi, 2004, Radhika *et al.*, 2001, Ashok *et al.*, 2000) who found significant difference and negative SCA effects for early flowering in sunflower hybrids.

Table 4. Correlation among various morpho-physiological traits in 6x6 diallel crosses of sunflower.

Traits	Days to Flowering	Stem Thickness	Head Size	Seed Head^{-1}	100 Seeds Weight	Seed Yield Plant^{-1}	Oil %
Plant Height	0.42**	0.02*	0.37*	0.25^{ns}	0.53**	0.44**	0.30^{ns}
Days to Flowering		-0.08^{ns}	-0.03^{ns}	0.02ns	0.30ns	0.2 1ns	0.21^{ns}
Stem Thickness			-0.09^{ns}	-0.24^{ns}	-0.13ns	0.19ns	-0.13^{ns}
Head Size				0.28^{ns}	0.43**	0.39*	-0.19^{ns}
Seed Head^{-1}					0.50**	0.83**	0.15^{ns}
100 Seeds Weight						0.85 * *	0.16^{ns}
Oil %							0.85**

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level.

Stem thickness

Stem thickness play a vital role to avoid the lodging, greater the stem thickness lesser chance of lodging. Stem thickness for all parental genotypes and their F_1 crosses were significantly different (Table 1). The maximum GCA effect for stem thickness, was demonstrated by genotype US-444 followed by genotype SMH-0917 (Table 2). Our results are in agreement with that of (Sassikumar and Gopalan, 1999, Jan *et al.*, 2003) who found maximum GCA effect for stem thickness. SCA effect for stem thickness was significantly different in all hybrids (Table 1). The cross combination Ausigold-7 × SMH-0917 showed highest positive specific combining ability while the hybrid Rising Sun × Hysun-33 and US-444 × HS-K6 showed lowest positive specific combining ability (Table 3). Our findings are in agreement with those of (Jan *et al.*, 2003, Radhika *et al.*, 2001) who reported high SCA effect for stem thickness.

Head size

The size of head contributes substantially to final seed yield of sunflower as it influences both the number of seed head^{-1} and seed yield. Head sizes for parental genotypes and F_1 hybrids were significantly different (Table 1). Genotype Rising Sun showed maximum GCA effect for head size followed by genotype Ausigold-7 (Table 2). Abdullah *et al.*, (2010), who observed significant GCA effects for head size which confirmed our results. The cross combination Ausigold-7 × US-444 showed the highest positive SCA effect while Ausigold-7 × Hysun-33 and US-444 × Hysun-33 showed the lowest positive SCA effect (Table 3). Goksoy *et al.*, (1999) reported that non-additive effect were predominant in the control of head size.

Seed head^{-1}

The number of seed head^{-1} is an important yield component of sunflower that plays a remarkable role in determining the grain yield. All genotype explicated non-significant GCA effect for seed head^{-1} (Table 1). Genotype HS-K6 showed highest positive GCA effect followed by genotype Rising Sun (Table 2). Abdullah *et al.*, (2010) and Hand *et al.*, 2006 reported non-significant GCA effect for seeds head^{-1}. Similarly SCA effect for seeds head^{-1} were observed non-significant. The maximum positive specific combining ability effect was displayed by Ausigold-7 × US-444 (Table 3). Sassikumar and Gopalan (1999) found non-significant SCA differences for seeds head^{-1}.

100 seed weight

100 seed weight is an important yield parameter in determining the yield potential of a crop as it expresses the magnitude of grain development. The data regarding 100 seed weight of sunflower showed non-significant differences (Table 1). Genotype Rising Sun showed maximum GCA effect followed by genotype US-444 (Table 2). Our results are in agreement with that (Kumar *et al.*, 1999, Hand *et al.*, 2006) who reported non-significant GCA effects for 100 grain weight. There were significant SCA differences in all genotype for 100-seed weight (Table 1). The cross combination Rising Sun × HS-K6 exhibited the highest positive specific combining ability (Table 3). Our results confirm the studies of (Goksoy *et al.*, 1999, Kannababu and Karivaratharaju 2000) who reported significant SCA effect for 100 seed weight in sunflower hybrids.

Yield plant^{-1}

Yield is an ultimate objective of sunflower breeding and hybrid development programs. Yield plant^{-1} showed non-significant GCA differences for all genotypes (Table 1). In case of yield plant^{-1} Hysun-33 showed the highest GCA effect followed by Ausigold-7 (Table 2). These results are line in agreement with those of (Kumar *et al.*, 1998). SCA effect for yield plant^{-1} showed highly significant differences for all genotype (Table 1). The cross combination Hysun-33 × SMH-0917 showed the highest SCA effect while cross combination Ausigold-7 × SMH-0917 showed the lowest SCA effect (Table 3). Our findings are in agreement with those of (Goksoy *et al.*, 1999, Kannababu and Karivaratharaju 2000).

Oil content (%)

Sunflower oil is premium oil in the market because of its high percentage of unsaturated fatty acids. The palmitic acid and stearic acid are the major saturated fatty acid whereas oleic acid and linoleic acid are the predominant unsaturated fatty acid. Higher oil content is the major objective of sunflower breeding programs around the globe. Mean values for oil content varied significantly for genotypes. Genotype SMH-0917 showed maximum GCA effect followed by genotype HS-K6. Hand *et al.*, (2006), Jan *et al.*, (2003) also reported that additive effect were predominant in the control of oil content. Our results are in agreement with the findings of Jan *et al.*, (2003) and who observed significant variations in oil content of sunflower genotypes. The hybrids Rising Sun × HS-K6 showed the highest positive SCA effect for oil content. These results are in line with the findings of (Jan *et al.*, 2005) who found significant SCA differences for oil content.

Correlation

Correlations have to be made in the light of genetic behavior, genotypic correlation values are used for further analysis. Genetic relation of traits may result from pleotropic effects of a gene, linkage of two genes, chromogema and regimental affiliation or due to the environmental influences (Sgro and Hoffmann 2004). Plant height exhibited highly significant (P@ 0.01) positive correlation with leaves plant^{-1}, flowering, 100 grain weight, while it was significantly (P@ 0.05) positive correlated with head size (Table 4). Our results are similar with that (Ozer and Oral, 1999, Ellahi, *et al.*, 2009) who found significant correlation for these traits. Days to 50 % flowering were significant (P@ 0.05) positive correlated with 100 grain weight (Table 4. These lines are in agreements with the findings of (Khan *et al.*, 2008) who found correlation for days to flowering. Head size showed highly significant (P@ 0.01) positive correlation with 100 grain weight (Table 4). Our results are in agreement with those of (Tahir *et al.*, 2004, Machikowa and Saetang, 2008) who also reported that head size^{-1} strongly correlated with 100 grain weight.

Seed head^{-1} exhibited highly significant (P@ 0.01) positive correlation with 100 grains weight (Table 4). Our results are in agreement with that (Tahir *et al.*, 2004) who reported correlation for seeds head^{-1} with 100 grain weight.

Conclusion

Rising Sun was good combiner for plant height, 100-garin weight and head size, US-444 was superior for stem thickness and HS-K6 surpassed for seed head^{-1}. Therefore, these genotypes could be used in future breeding programs. Ausigold-7 × HS-K6 and Hysun-33 × HS-K6 exhibited negative specific combining ability effect for plant height and 50 % flowering, respectively. For stem thickness better combination expressed by Ausigold-7 × SMH-0917, for head size and seed head^{-1} Ausigold-7 × US-444 was a good specific combiner. For 100-grain weight rising sun × HS-K6 was the best combiner.

All these crosses were obtained by the combinations of high × low or low × high general combiners but high SCA effect was observed in the hybrid of these crosses. This might be due to the interaction of dominant alleles from good combiner and recessive alleles from poor combiner.

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