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GENOTYPE × ENVIRONMENT INTERACTION AND HERITABILITY ESTIMATES FOR SOME AGRONOMIC CHARACTERS IN SUNFLOWER

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ABSTRACT

This study was conducted at two locations over two years to determine the extent of genotype by environment (GE) interaction and heritability estimates for 35 sunflower genotypes including 10 parents (five each cytoplasmic male sterile lines and restorers/male and their 25 crosses). The traits studied were plant height, leaf area, stem girth, head diameter, seed and oil yield. The combined analysis of variance across years and locations revealed highly significant differences among the genotypes for all traits. A significant GLY interaction was observed for all traits except plant height. The GL interaction was also significant for all traits except stem girth. The GY interaction was found non-significant for all six traits. GY (σ^2_{GY}) variance was found largest for plant height (678.27) and leaf area (2483.86). Variance due to genotypes (σ^2_{G}) was found largest for stem girth (0.19), head diameter (6.60), seed yield (199303.97) and oil yield (46621.56). GLY (σ^2_{GLY}) variance was largest for stem girth. On entry mean basis very high estimates of heritability were observed for head diameter and oil yield (0.86±0.22) followed by seed yield and leaf area (0.85±0.24) and stem girth (0.84±0.22). Plant height was found to be a low heritable trait (0.30±0.10). Plant height was greatly influenced by the diversity in both locations and therefore, testing of genotypes over a wide range of locations is suggested to increase heritability.

Key words: Genotype, environment, heritability, sunflower.

INTRODUCTION

The production of sunflower is expected to increase rapidly during the next few years in Pakistan. Newly developed hybrids and cultivars of sunflower require testing at many sites and for several years before being recommended for a given site. Estimates of genetic variation, genotypes × environmental interaction and heritability determine the value of a source population and the appropriate procedure to use in a breeding program. Variability among plant characters is particularly useful as these variations allow for the development of cultivars adapted to specific environment and agro-climatic regimes (Fick and Miller, 1997).

The main environmental effects (E) and genotype by environment interaction (GE) have been reported as the most important sources of variation for the measured yield of crops (Dehghani *et al.,* 2006; Yan *et al.,* 2007; Sabaghnia *et al.,* 2008). For this reason, multi-environmental trials (METs) are conducted throughout the world for major crops every year. Although the measured yield is a combined result of the effects of the genotype (G), E and GE interaction, only G and GE are relevant to cultivar evaluation and mega-environment identification. Typically, E explains most (80% or higher) of the total yield variation, while G and GE are usually small (Yan and Kang, 2003). However, effective interpretation and utilization of MET data in making selection decisions remain a major challenge to researchers. Some important concepts such as mega-environment, specific adaptation, and stability all originate from the GE interaction. A significant GE interaction for grain yield can reduce the usefulness of subsequent analysis and limit the feasibility of selecting superior cultivars (Flores *et al*., 1998). A significant GE interaction for a quantitative trait such as seed yield can seriously limit efforts in selecting superior genotype for both new crop introduction and improved cultivar development. Laishram and Singh (1997), Prusti *et al.* (1999), Schoeman (2003) and Chandra *et al.* (2011) observed significant differences in the performance of genotypes between environments and genotype × environment interaction for plant height, days to 50% flowering, maturity, head diameter, seed yield per plant, and oil content while Ashok *et al.* (2000). Khurana and Nischint (1996) with the exception of stem thickness observed highly significant variance for all these characters in sunflower in their respective studies. Goksoy *et al*. (1999) determined that synthetic varieties were superior to standard varieties.

The extent to which a phenotype is determined by its genetic makeup (genotype) is called heritability in the broad sense. At gene level, broad sense heritability is the proportion of the total variance that is attributable to the average effects of genes and this is what determines the degree of resemblance between relatives. Heritability of a trait does not depend only on genetic factor, it also depends on the environmental circumstances to which an individual is subjected (Saravanan *et al*., 1996; Leon *et al.*, 2003). Gill *et al*. (1997) and Wang *et al*. (1997) observed highest estimates of heritability for stem thickness, leaf area, capitulum size, plant height, seed and oil yield.

The present study of Genotype by environment interaction is an attempt to develop sunflower hybrids with diverse genetic background for their potential in varying cross combinations for different plant characters. The main objectives of the study were to evaluate sunflower lines, tester and their crosses over two environments for wide adaptability and to determine the heritability estimates for different plant traits in sunflower hybrids.

MATERIALS AND METHODS

The present study was carried out at the Agricultural Research Institute (ARI) Tarnab Peshawar KPK and Agricultural Research Station (ARS) Baffa, Mansehra KPK. The experimental material comprised five cytoplasmic male sterile lines (CMS) of sunflower namely TS-4, TS-11, TS-17, TS-18 and TS-335, five testers/restorers (male parents) namely TR-3, TR-5, TR-6, TR-13 and TR-6023 and their 25 crosses, The parents of the developed CMS lines and restorers were selected for their desirable characters including head size, plant height, early maturity, high seed and oil yield and oil content. The five CMS lines were crossed with the five restorers/testers in a field experiment in a line x tester fashion during spring 2001 and 2002. These 25 crosses (line x tester) along with 10 parents (5 CMS lines and 5 testers) were tested at two locations i.e. ARI, Tarnab, Peshawar and ARS, Baffa, Mansehra for two consecutive years i.e. spring 2002 and 2003. The two locations were chosen to provide differences in soil type, temperature and rainfall. The altitude of Tarnab is 358 m above sea level. The soil type is clay-loam with pH of 8.4. The altitude of Baffa is 950 m above sea level. The soil type is clay-loam with a pH of 7.2. Soil organic matter at Baffa is 0.5% while at Tarnab 0.8%.

Experiments at both locations were arranged in accordance with a randomized complete-block design with 3 replicates. The experimental plots consisted of 2 rows, each 5 m in length with 75-cm row to row and 25-cm plant to plant spacing. Sowing was done by dibbling three seeds hill^{-1} to ensure uniform stand and was later thinned to one plant per hill at v2 stage as explained by Schneiter and Miller (1981). Trial plots at both locations were fertilized with NPK at the rate of 90: 58: 38kg ha^{-1}, respectively. Weeding at different stages was done manually. Rainfall at Mansehra was high and no irrigation was needed. However, at Peshawar flood irrigation was applied at three to four leaf, flowering and seed filling stages.

Data were recorded on 10 randomly selected plants of each entry from each replication. For Plant height (cm) distance from soil surface to the base of capitulum was measured in centimeter with a measuring tape at physiological maturity (R9 stage, as explained by Schneiter and Miller 1981). Leaf area was recorded on three leaves one each from top, mid and bottom at physiological maturity using the formula proposed by Schneiter (1978).

Leaf area = [(maximum leaf width × length) × 0.6683] - 2.45

The stem girth of 10 randomly selected plants plot^{-1} was measured with the help of vernier caliper at physiological maturity (R9 stage) and the computed average was used in data analysis. The head diameter of 10 randomly selected plants in each plot was measured at maturity with a measuring tape. Seed yield in kg ha^{-1} was calculated and converted from seed yield head^{-1} (plant). Oil yield ha^{-1} was calculated by the formula of Habib and Mehdi (2002).

$$\text{Oil yield ha}^{-1} = \frac{\text{Seed yield (kg ha}^{-1}) \times \text{oil content (\%)}}{100}$$

Statistical Analysis: The data recorded on the aforementioned parameters across locations and years were analyzed using the following linear additive model as outlined by Snedecor and Cochran (1980).

Format of combined analysis of variance across location and year is given in Table 1. Data from each location across 2 years was also analyzed for each trait according to Steel *et al*., (1997).

The different variance components and heritability estimates from the expected mean squares of the pooled ANOVA across years × locations were estimated as under:

$$\sigma^2_E = M1$$
$$\sigma^2_{GLY} = M2 – M1/r$$
$$\sigma^2_{GY} = M3 – M2/rl$$
$$\sigma^2_{GL} = M4 – M2/ry$$
$$\sigma^2_G = M5 - (M4 + M3 – M2)/rly$$

h²(entry mean basis)

$$=\sigma^2_G/[(\sigma^2_G)+(\sigma^2_{GL}/l)+(\sigma^2_{GY}/y)+(\sigma^2_{GLY}/ly)+(\sigma^2_E/lry)]$$

h² (plot mean basis) $=\sigma^2_G/(\sigma^2_G+\sigma^2_{GL}+\sigma^2_{GY}+\sigma^2_{GLY}+\sigma^2_E)$

Standard error of heritability was calculated as (Lothrop *et al*., 1985)

SE(h^2_{BS}) = (entry mean basis) =SE $\sigma^2_G/[(\sigma^2_G)+(\sigma^2_{GL}/l)+(\sigma^2_{GY}/y)+(\sigma^2_{GLY}/ly)+(\sigma^2_E/lry)$

= (plot mean basis) =SE $\sigma^2_G/(\sigma^2_G+\sigma^2_{GL}+\sigma^2_{GY}+\sigma^2_{GLY}+\sigma^2_E)$

Where SE (h^2_{BS}) is the standard error of broad sense heritability; and SE (σ^2_G) is the standard error of the genetic variance.

Standard error of genetic variance was calculated by using the formula given by Lothrop *et al.* (1985).

$$SE(\sigma^2_G) = [2/C^2 \{\Sigma M.S._i{}^2/(df_i+2)\}]^{½}$$

where C = Coefficient of the component in the expected mean squares;
M. $S_{.i}$ = mean square for the i^{th} trait and d.f_i = degrees of freedom for the i^{th} trait.

RESULTS AND DISCUSSION

The combined analysis of variance across years and locations revealed highly significant differences among the genotypes for all traits (Table 2). A significant GLY interaction was also observed for all traits except plant height. This significant interaction indicated that the genotypes were inconsistent in their performance when tested across locations and years. The GL interaction was also significant ($p<0.05$) for all traits except stem girth. Significant GL interaction suggested fluctuations in genotypic ranking and requires testing of genotypes over a range of locations. The GY interaction was found non-significant for all six sunflower traits. This indicated that the genotypes were consistent in their performance when tested across years. These results are supported by Laishram and Singh (1997) who found significant GE interaction for plant height, head diameter, leaves plant^{-1}, and seed yield, while Prutsi *et al.* (1999) observed significant GE interaction for head diameter, plant height, oil content, seed and oil yield in sunflower genotypes.

Genotypes (σ^2_G), genotype × location (σ^2_{GL}), genotype × year (σ^2_{GY}) and genotype × location × year (δ^2_{GLY}) variances were found highly significant for the traits showing absolute values of variance higher than double of their respective standard error as indicated in Table 3. GY (σ^2_{GY}) variance was found largest for seed yield (1589.38) followed by leaf area (286.93). Variance due to genotypes (σ^2_G) was found largest for seed yield (199303.97) and oil yield (46621.56) followed by leaf area (16194). All the traits showed highly significant variance due to genotype except plant height. GLY (σ^2_{GLY}) variance was also found largest for seed yield (18632.60) and oil yield (3097.34) followed by leaf area (1424.34) Matzinger (1963) reviewed GE effects for several crops. He found that GLY was a prominent source of GE variation and could be interpreted as differing patterns of GY variation across locations. To diminish variation due to GL, GY, and GLY effects maximum number of location over multiple years is recommended for evaluating sunflower cultivars.Highly significant interaction of genotype × location (Table 2) permitted to perform independent analysis of data for each location (Peshawar and Mansehra).

Evaluation of sunflower genotypes at two locations: The data were analyzed independently according to Steel and Torrie (1997) statistical model to confirm the differences among sunflower genotypes. Highly significant differences ($p<0.01$) existed among sunflower genotypes for all phenological traits as presented in Table 4. The sum of squares of genotypes for these traits were further partitioned into sum of squares pertaining to parents, crosses and parents vs. crosses. There were highly significant ($p<0.01$) differences among parents, crosses and parents vs. crosses at each location except head diameter for lines at Mansehra. These results are in confirmation with Ashok *et al.* (2000). Khurana *et al.* (1996) with the exception of stem thickness also observed highly significant variance for all these characters in sunflower.

Performance of parents (lines and testers): The cytoplasmic male sterile (CMS) lines and tester used in the present study provided a wide range of expression for various characters at both locations as evident from Table 5 and 6. Parental lines and testers exhibited higher mean values for leaf area, stem girth, head diameter, seed and oil yield ha^{-1} at Peshawar than at Mansehra which may be due to high organic matter at Peshawar. Heavy rains at Mansehra also delayed cultural practices like weeding which may have resulted in low values for the above traits at Mansehra.

Performance of hybrids: Average plant height at Peshawar was found to be 136.3 cm while at Mansehra the same set of hybrids revealed average plant height of 122.6 cm as indicated in Table 7. Out of top five dwarf hybrids only TS-4×TR-3 and TS-17×TR-5 were found consistent in their performance across both locations. Goksoy *et al*., (1999) observed plant height in sunflower ranging from 154.5 to 169.6 cm. Higher average mean value (501.5 cm^2) for leaf area was recorded at Peshawar than (469 cm^2) Mansehra. Out of top five hybrids demonstrating largest leaf area at each location, three (TS-11×TR-5, TS-11×TR6023 and TS-335×TR-5) were found consistent in performance at both locations. Average stem girth at Peshawar was 3.25 cm vs. 2.42 cm at Mansehra. Out of top five hybrids demonstrating thickest stem girth at each location only three (TS-4×TR-6023, TS-11×TR-6023 and TS-335×TR-5) were common at both locations. Smaller leaf area and lesser stem girth at Mansehra may be due to low organic matter and high weed infestation due to torrential rains.

Variation in head diameter ranged from 10.8 in TS-18×TR-6 to 20.2 cm (TS-11×TR-6023) with a mean of 15.75 cm at Peshawar, whereas the range for the same set of hybrids at Mansehra was from 11.0 in TS-11×TR-6 to 18.33 cm (TS-4×TR-6023). Out of five hybrids demonstrating largest head diameter at each location only TS-4xTR-6023 was common at both locations. These results are in agreement with the findings of Ashok *et al.* (2000) who observed significant variations in stem girth and head diameter in sunflower hybrids, while Goksoy *et al.* (1999) observed head diameter ranging from 17.7 to 20.3 cm in sunflower.

Highest seed yield of 3081.33 and 2833.7 kg ha^{-1} was observed in the cross TS-11×TR-6023 at Peshawar and Mansehra, respectively. However, the highest oil yield of 1349.67 and 1253.3 kg ha^{-1} was observed in the cross TS-4×TR-5 at Peshawar and (TS-335×TR-5) at Mansehra. Out of top five hybrids for seed yield at each location only three (TS-11×TR-5, TS-11×TR6023 andTS-333×TR-5) were found consistent in performance and remained in the top rank of five at both locations. Similarly, hybrid TS-335xTR-5 was found consistent in performance for high oil yield at both locations. The finding of Goksoy *et al*. (1999) corresponds with the present study.

Heritability: Estimates of broad sense heritability across two locations and both years on entry mean basis were very high than plot mean basis for all the six sunflower traits (Table 5). Highest heritability estimates on plot mean basis were recorded for oil yield (0.72±0.20), seed yield (0.69±0.19), leaf area (0.68±0.19) and head diameter (0.63±0.16). Stem girth exhibited heritability estimate of (0.58±0.19) on plot mean basis. The low heritable character was plant height (0.17±0.06). Plant height was greatly influenced by the diversity in both locations and testing of genotypes for the above traits over a wide range of locations is suggested to increase heritability. Vol`f and Dumacheva (1973) also reported heritability for seed yield and its components in sunflower ranging from 32 to 94%. Similarly, Saravanan *et al*. (1996) observed high heritability estimates for head diameter, plant height, leaves $plant^{-1}$, stem girth and seed yield $plant^{-1}$ in sunflower genotypes.

Table 1. Format of combined analysis of variance across years x locations used in the present study.

Source of variation	d.f.	Mean squares	Expected mean squares
Location (L)	(l-1)	-	-
Year (Y)	(y-1)	-	-
L × Y	(l-1)(y-1)	-	-
Replication (LY)	(r-1)ly	-	-
Genotypes (G)	(g-1)	M5	$\sigma^2_E+r\sigma^2_{GLY}+ry\sigma^2_{GL}+rl\sigma^2_{GY}+rly\sigma^2_G$
G × L	(g-1)(l-1)	M4	$\sigma^2_E+r\sigma^2_{GLY}+ry\sigma^2_{GL}$
G × Y	(g-1)(y-1)	M3	$\sigma^2_E+r\sigma^2_{GLY}+rl\sigma^2_{GY}$
G × L × Y	(g-1)(l-1)(y-1)	M2	$\sigma^2_E+r\sigma^2_{GLY}$
Error	(g-1)((r-1)ly	M1	

Where l, y, r, g are locations, years, replications and genotypes respectively.

Table 2. Mean squares in the combined analysis of variance for indicated plant traits of 35 sunflower genotypes evaluated at 2 locations and 2 years.

Source of variation	d.f	Plant height	Leaf area	Stem girth	Head diameter	Seed yield kg ha^{-1}	Oil yield kg ha^{-1}
Year (Y)	1	2457.75**	3234.26NS	0.67**	65.61**	6616.40NS	17589.34NS
Location(L)	1	1802.14**	242308.96**	16.72**	148.81**	17009851.26**	1672276.2**
L × Y	1	590.49**	16151.00**	0.01NS	7.47*	251370.54**	33268.2NS
REP/LXY	8	3.38NS	2449.08NS	0.10**	0.57NS	15612.96*	26885.55*
Genotype(G)	34	2359.49**	227543.63**	2.40**	86.07**	2825009.69**	651015.99**
G × Y	34	23.17NS	7504.73NS	0.10NS	2.31NS	73159.83NS	11734.88NS
G × L	34	4091.58**	31486.29**	0.28**	9.97**	423827.89**	90317.73**
G × L × Y	34	21.98NS	5783.15**	0.26**	5.39**	63623.55**	10495.36**
Error	272	17.78	1510.12	0.03	1.27	7725.74	1203.33
Mean		128.34	464.28	2.98	14.92	2058.99	782.88
C.V %		3.29	8.37	6.05	7.62	4.27	4.04

*,**, NS = Significant at 0.05, 0.01 probability level and non significant, respectively.

Table 3. Variance components due to genotypes (σ^2_G), genotypes × locations (σ^2_{GL}), genotypes × years (σ^2_{GY}), g Genotypes × locations × years (σ^2_{GLY}), error (σ^2_E) variance and heritability estimates on plot (h^2_1) and e Entry (h^2_2) mean basis along with standard errors (SE) for six sunflower traits.

Traits	(σ^2_G)	(σ^2_{GY})	(σ^2_{GL})	(σ^2_{GLY})	σ^2_E	h^2_1	h^2_2
Plant height (cm)	144.44±46.34^{ns}	0.20±0.91^{ns}	678.27±160.73*	1.40±1.73^{ns}	17.78±1.52*	0.17±0.06*	0.30±0.10*
Leaf area (cm²)	16194.65±4469.38*	286.93±294.81^{ns}	4283.86±1236.90*	1424.34±454.37*	1510.12±129.02*	0.68±0.19*	0.85±0.24*
Stem girth (cm)	0.19±0.05*	-0.03±0.003*	0.001±0.004*	0.08±0.02*	0.03±0.003*	0.58±0.15*	0.84±3.22^{ns}
Head diameter (cm)	6.60±1.69*	-0.51±0.09*	0.76±0.39^{ns}	1.37±0.42*	1.27±0.11*	0.63±0.16*	0.86±0.22*
Seeds head^{-1}	23722.09±7286.41*	435.95±633.41^{ns}	11695.72±3287.37*	3857.99±1061.32*	1934.37±165.26*	0.57±0.17*	0.77±0.24*
Seed Yield (kg ha^{-1})	199303.79±55488.43*	1589.38±2873.99^{ns}	60034.06±16649.53*	18632.60±4998.74*	7725.74±660.05*	0.69±0.19*	0.85±0.24*
Oil yield (kg ha^{-1})	46621.56±12787.16*	206.59±460.99^{ns}	13303.73±3548.02*	3097.34±824.59*	1203.33±102.81*	0.72±0.20*	0.86±0.24*

Table 4. Mean squares from analysis of variance for indicated plant traits of five sunflower lines and five testers evaluated at two locations (P=Peshawar and M=Mansehra).

Source of variation	d.f	Plant height (cm)		Leaf area (cm²)		Stem girth (cm)		Head diameter		Yield (kg ha^{-1})		Oil yield (kg ha^{-1})	
		P	M	P	M	P	M	P	M	P	M	P	M
Replication	2	1.72^{NS}	2.26^{NS}	2371.02^{NS}	2894.10^{NS}	0.17**	0.001^{NS}	0.43^{NS}	0.02^{NS}	1449.98^{NS}	14723.41^{NS}	297.41^{NS}	6915.80^{NS}
Genotypes (G)	34	1939.40**	1308.01**	67230.66**	62288.18**	0.68**	0.68**	28.27**	19.75**	1011768.2**	612698.16**	237051.98**	136460.54**
Parents (P)	9	2449.32**	102.42**	43269.58**	53066.10**	0.52**	0.68**	43.22**	39.87**	261426.99**	161014.43**	112256.53**	65338.70**
P vs. crosses	1	10314.44**	14529.2**	45583.74**	54735.38**	0.68**	0.44**	48.04**	22.51**	8174359.2**	5751280.3**	1736303.7**	1465632.8**
Crosses	24	1399.22**	1209.22**	77118.02**	66061.16**	0.74**	0.69**	21.84**	12.09**	994704.89**	567971.97**	221381.45**	107749.05**
Lines(L)	4	2592.43**	695.50**	10132.85**	23987.16**	0.54**	0.26**	2.14*	3.06^{NS}	44655.33**	122970.43**	15868.40**	24204.17**
Testers(T)	4	1650.90**	671.93**	10336.99**	7720.14**	0.09**	0.02^{NS}	7.56**	14.58**	42900.90**	2784.83^{NS}	3331.60**	1903.90**
L×T	16	1038.00**	1471.97**	110559.57**	91164.92**	0.95**	0.97**	30.34**	13.73**	1470168.3**	820519.14**	327272.1**	155096.56**
Error	68	5.78	12.63	496.56	1061.68	0.01	0.02	0.54	0.73	2514.92	5441.23	355.41	1616.28

*, **, NS = Significant at 0.05 and 0.01 probability level, non significant respectively.

Table 5. Mean values for plant height, leaf area, stem girth, head head diameter, seed and oil yield of five sunflower lines (female parents) evaluated at two locations used in the line x tester analysis (P=Peshawar and M=Mansehra).

Female parents	Plant height (cm)		Leaf area (cm²)		Stem girth (cm)		Head diameter (cm)		Yield (kg ha^{-1})		Oil yield (kg ha^{-1})	
	P	M	P	M	P	M	P	M	P	M	P	M
TS-4	133.7	97.7	564.93	472.13	2.90	2.93	17.00	16.17	2129.00	1762.30	704.67	635.30
TS-11	167.7	120.0	461.87	375.73	3.47	2.90	18.50	15.50	1934.00	1576.70	802.67	622.30
TS-17	152.0	125.0	563.30	339.50	3.00	3.10	17.50	16.33	2061.33	1359.00	835.00	548.30
TS-18	101.0	128.7	571.67	559.80	3.97	3.40	19.00	17.83	2009.33	1751.00	850.67	769.70
TS-335	103.3	138.7	621.37	491.67	3.37	3.57	17.33	17.67	2254.67	1878.70	900.00	736.00
Mean	131.5	122.0	556.63	447.77	3.34	3.18	17.87	16.70	2077.67	1665.53	818.60	662.33
LSD 5%	5.77	6.43	48.57	69.79	0.38	0.27	1.16	2.15	81.32	90.14	32.54	41.11
LSD 1%	8.39	9.33	70.67	101.6	0.55	0.39	1.69	3.12	118.30	131.20	47.35	59.92

Table 6. Mean values for plant height, leaf area, stem girth, head diameter, seed yield and oil yield of five testers (male parents) evaluated at two locations used in the line × tester analysis (P=Peshawar and M=Mansehra).

Male parents	P	M	P	M	P	M	P	M	P	M	P	M
(Testers)	Plant height (cm)		Leaf area (cm²)		Stem girth (cm)		Head diameter (cm)		Yield (kg ha^{-1})		Oil yield (kg ha^{-1})	
TR-3	87.3	155.0	269.90	259.70	2.63	2.23	8.83	11.83	1569.33	1306.70	431.67	384.30
TR-5	73.7	171.7	332.27	273.07	2.90	2.47	12.67	13.67	1386.33	1287.00	457.67	414.00
TR-6	135.3	145.0	349.00	316.17	2.63	2.33	10.00	9.67	1551.33	1318.30	473.00	442.00
TR-13	110.3	130.7	410.03	362.63	2.80	2.40	11.50	8.33	1723.33	1357.70	519.00	419.30
TR-6023	99.7	148.3	409.43	234.03	3.03	2.40	12.17	9.00	1574.33	1282.00	447.67	382.30
Mean	101.3	150.3	354.13	289.12	2.80	2.37	11.03	10.50	1560.93	1310.33	465.80	408.40
LSD 5%	6.49	7.15	57.00	38.34	0.17	0.19	1.47	0.90	52.11	75.14	15.94	24.51
LSD 1%	9.43	10.41	82.91	55.78	0.24	0.27	2.14	1.32	75.83	109.30	23.20	35.66

Table 7. Mean values for indicated plant traits of 25 crosses of sunflower derived from five lines and their five testers evaluated at two locations (P=Peshawar and M=Mansehra).

Crosses	Plant height (cm)		Leaf area (cm²)		Stem girth (cm)		Head diameter (cm)		Yield (kg ha^{-1})		Oil yield (kg ha^{-1})	
	P	M	P	M	P	M	P	M	P	M	P	M
TS-4×TR-3	104.3	97.0	551.30	592.77	3.30	2.90	17.20	14.33	2650.00	2432.70	1102.67	997.30
TS-4×TR-5	172.3	123.0	658.13	481.20	4.00	2.93	18.50	15.83	3016.67	1760.30	1349.67	800.30
TS-4×TR-6	104.3	129.0	569.83	443.87	3.93	3.00	18.70	15.83	2750.00	1908.70	1289.33	837.70
TS-4×TR-13	108.7	149.0	633.50	630.43	3.77	2.97	18.00	16.17	3013.67	2291.70	1054.00	928.70
TS-4×TR-6023	152.7	138.0	638.03	570.20	4.10	3.87	18.20	18.33	2944.33	2129.00	1225.67	918.00
TS-11×TR-3	121.7	125.0	499.33	431.93	3.30	2.87	17.80	15.33	2906.33	1740.30	980.33	644.70
TS-11×TR-5	171.7	147.0	646.27	620.30	3.07	2.83	17.00	15.67	3000.00	2532.30	1114.00	927.70
TS-11×TR-6	155.0	118.0	469.67	317.40	2.87	2.10	15.80	11.00	2503.00	1618.30	1111.33	719.70
TS-11×TR-13	111.3	113.0	620.53	581.87	3.67	2.93	19.20	14.83	2920.33	2236.30	1042.33	963.00
TS-11×TR-6023	132.7	152.0	679.73	650.47	3.93	3.57	20.20	17.50	3081.33	2833.70	1141.00	1084.30
TS-17×TR-3	138.7	132.0	291.50	499.30	2.80	2.53	12.50	12.00	1629.33	1957.70	613.67	771.70
TS-17×TR-5	104.7	100.0	241.80	491.83	3.07	2.27	15.30	11.67	1789.67	1920.00	621.67	604.00
TS-17×TR-6	136.7	162.0	639.00	546.33	3.33	3.47	17.30	16.67	2509.00	2047.30	791.67	838.70
TS-17×TR-13	157.3	121.0	527.97	317.53	3.00	2.77	15.00	13.00	2226.33	1777.70	763.67	741.70
TS-17×TR-6023	145.7	110.0	351.07	237.33	2.97	2.73	14.70	13.67	1644.33	1491.70	581.00	598.00
TS-18×TR-3	134.0	121.0	252.40	325.20	2.70	2.43	12.30	13.17	1656.33	1237.00	558.67	449.00
TS-18×TR-5	156.3	99.0	686.90	596.30	3.10	3.03	17.00	16.00	2463.67	2108.70	816.67	758.00
TS-18×TR-6	108.3	104.0	448.57	352.47	2.50	2.37	10.80	11.83	1846.00	1433.00	641.33	520.70
TS-18×TR-13	124.0	100.0	235.40	263.63	2.67	2.03	11.80	12.33	1253.00	1685.70	363.67	618.00
TS-18×TR-6023	159.3	86.0	310.17	297.23	2.70	2.50	12.80	14.83	1656.00	1622.30	636.67	580.70
TS-335×TR-3	151.0	105.0	626.47	631.73	3.70	3.47	17.20	17.00	2903.67	2562.30	1142.67	886.70
TS-335×TR-5	153.7	124.0	644.63	690.50	3.77	3.13	18.30	15.67	2969.00	2815.00	1243.33	1253.30
TS-335×TR-6	148.3	149.0	496.07	309.40	3.10	2.47	13.70	13.83	1998.00	1896.70	838.00	862.30
TS-335×TR-13	136.7	120.0	225.43	233.63	2.50	2.13	11.70	12.67	2684.33	1571.00	1141.33	649.70
TS-335×TR-6023	119.0	142.0	593.77	612.47	3.53	3.30	17.70	16.33	2909.00	2540.70	1007.00	968.70
Mean	136.3	122.6	501.50	469.00	3.25	2.42	15.75	14.62	2436.93	2006.00	926.85	776.90
LSD 5%	3.25	5.94	34.11	56.20	0.16	0.23	1.26	1.32	86.73	135.2	33.23	74.00
LSD 1%	4.33	7.93	45.50	74.97	0.21	0.32	1.69	1.76	114.80	180.3	44.33	98.71

Conclusion: Genotypes by environmental interactions are highly important in evaluating the performance of sunflower cultivars. Farmers will prefer to use high yielding genotypes with consistent performance over locations and years. In the present study variance due to genotypes (δ^2_G) was found largest for seed and oil yield followed by leaf area. Genotype x locations (GL), and genotype x locations x years (GLY) interactions were found significant for all the traits except plant height. The δ^2_{GL} was largest for plant height and leaf area. The GY (σ^2_{GY}) variance was found largest for seed yield followed by leaf area. Variance due to GLY (σ^2_{GLY}) variance was also found largest for seed and oil yield followed by leaf area. Sunflower genotypes showing significantly high and consistent performance at both locations may be recommended for wider adaptability. Characters showing high heritability may be selected in early generations, while characters with low heritability are greatly influenced by the environment and are suggested to be tested over a wide range of environments.

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