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Gene action of achene yield traits in sunflower under drought stress condition

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Drought is one of the most damaging environmental stresses, which decreases the achene yield of sunflower (*Helianthus annuus* L.). The objectives of our experimentations were to determine the type of gene action in sunflower under drought stress, for the identification of the lines with higher achene yield for purpose of developing hybrid with higher achene yield. Thirty-two single cross hybrids from 12 inbred lines were developed through line × tester mating design through crossing 8 drought tolerant inbred lines with 4 drought susceptible lines. The evaluation experiment was performed under an alpha (0,1) lattice incomplete block design with three replications. The achene yield related traits like DF, DM, PH, NL/P, HD, SG, AY/P and TAW were evaluated under normal irrigation and drought stress conditions. Values of degree of dominance greater than one indicating that traits were under the control of dominant genetic effect. Based on GCA effects, L1 proved good combiner for early flowering, maturity and short stature; while L6 was a good combiner for NL/P, HD and AY/P while L8 for HD, SG, AY/P and TAW under drought stress condition. Based on SCA effects, Hybrid 20 was found a good SCA combiner for early flowering, early maturity, short stature, higher HD, AY/P and TAW under normal as well as drought stress conditions. It was suggested form our study that the lines L1, L6 and L8 can be further used to develop drought tolerant hybrids for higher yield and L5 × L12 (Hy 20) was proposed for general cultivation in irrigated as well as rainfed areas of Pakistan.
Keywords: additive gene action, combining ability, drought, sunflower, variance

Abbreviations: Analysis of variance (ANOVA), achene yield per plant (AY/P), cytoplasmic male sterility (CMS), additive variance (D), degree of freedom (df), days to flowering (DF), days to maturity (DM), Drought Susceptible at seedling and maturity stage (DS), Drought tolerant at seedling and maturity stage (DT), fertility restorer (FR), general combing ability (GCA), dominance variance (H), head diameter (HD), hybrid (Hy), Inbred line (L), number of leaves per plant (NL/P), Oilseed Research Institute, Faisalabad (ORI-FSD), plant height (PH), specific combing ability (SCA), stem girth (SG), source of variance (SOV), thousand achene weight (TAW), estimate of GCA variance (∂GCA), estimate of SCA variance (∂SCA).

INTRODUCTION

Sunflower has been grown on an area of 219000 acre with 40000 tonnes oil production in Pakistan while the demand of edible oil is around 3.255 million tonnes in the country. Local edible oil production is 0.507 million tonnes which has been produced from cotton, rapeseed/mustard, canola and sunflower. Pakistan has paid a huge bill (2.046 billion $) for the import of edible oil (Anonymous, 2019-20). The demand is growing day by day due to increasing population and lavish eating style (Fazal *et al.*,2015). Globally sunflower production was 54.45 million metric tonnes (MMT) (USDA, 2020). The edible oil imported from other countries has a major portion of palm oil which is poor in quality and creating health issues (Mustafa *et al.*, 2018).

One third land area of the world is arid and semi-arid. Drought has its impact in yield reduction that is increasing with changing climatic conditions and increasing population. To meet the moisture requirement of plant, water is not sufficient, produce water deficit conditions, that may cause plant injury is known as drought stress (Khan *et al.*, 2016). Randomly distributing rainfall and shortage of irrigated water during the sunflower growth stage cause severe reduction in achene and oil yield (Tahir *et al.*, 2002). Sunflower is sensitive to moisture stress and behaves differently at different growth stages. If moisture stress occurs at vegetative growth stage, it might cause less economic losses in yield as compared to reproductive and grain filling growth phase, where yield losses are more damaging (Reddy *et al.*, 2003).

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Sunflower is very important and successful crop in different climates and productive source of income in well irrigated as well as rainfed areas (Rehman *et al.*, 2012). Sunflower can tolerate water stress due to well established rooting system and have ability to avoid transitory wilting. Drought tolerant genotypes having less water requirement are the need of time to persist against drought stress (Saba *et al.*, 2016). The hybrids of sunflower have high genetic potential for yield and good quality oil to fill up the gap between demand and supply of edible oil in the country (Manzoor *et al.*, 2016). To find out best parent for hybridization with good combing ability and superior cross combinations, GCA and SCA was determined. GCA variances were controlled by additive genetic effects and SCA variances were controlled by dominant genetic effects. The epistatic effects may be due to non-significance of GCA and SCA effects (Manzoor *et al.*, 2016). GCA and SCA information is required to transfer superior or desirable genes into next generation during breeding experiments. Line × tester is the reliable mating design used for assessment of genetic makeup and combining abilities (Saba *et al.*, 2016). DF, DM, PH, NL/P, HD, SG, AY/P and TAW are the traits which directly contribute for the sunflower achene yield (Manzoor *et al.*, 2016).

To overcome the deficiency of edible oilseeds, the area under rainfed condition should be utilized for sunflower cultivation. So, there is a need to develop drought tolerant genotypes that can mitigate the risk of drought increase due to climate changes. Keeping the view of drought situation, a breeding programme to improve sunflower achene yield genetically was undertaken with the objectives of a) To develop drought tolerant breeding material for sunflower b) Study of inheritance pattern of the achene yields related traits and their behavior against drought.

MATERIALS AND METHODS

***Selection against drought*:** The eight-drought tolerant and four drought susceptible lines were screened out against drought from seventy diversifying genotypes (46 inbred A lines and 24 restorer lines) at seedling stage in glass house environment (Hasan *et al.,* 2020a) and these results was verified at maturity stage under field conditions in earlier experiments (Hasan *et al.,* 2020b). The fertility status of the drought tolerant lines was cytoplasmic male sterile (CMS) as well as drought susceptible lines was fertility restorer (FR) (Table 1).

***Hybrid development*:** All the drought tolerant and susceptible lines were sown at research area of ORI-FSD during autumn season, 2018 for the development of F_1 hybrids. The line × tester mating design was used for cross combination. Each FR line was crossed with each CMS line to develop 32 F_1 plant population (Table 2). Fiber sheet tunnel was used to avoid foreign pollination and contamination.

Table 1. Name, fertility status, origin and drought status of parental inbred lines.

Name	Lines	Fertility status	Origin	Drought status
ORI-25	L1	CMS	ORI-FSD	DT
ORI-26	L2	CMS	ORI-FSD	DT
ORI-27	L3	CMS	ORI-FSD	DT
ORI- 29	L4	CMS	ORI-FSD	DT
ORI-30	L5	CMS	ORI-FSD	DT
ORI-35	L6	CMS	ORI-FSD	DT
ORI-38	L7	CMS	ORI-FSD	DT
ORI-46	L8	CMS	ORI-FSD	DT
RL-37	L9	FR	ORI-FSD	DS
RL-39	L10	FR	ORI-FSD	DS
RL-101	L11	FR	ORI-FSD	DS
RL-103	L12	FR	ORI-FSD	DS

***Hybrid evaluation for yield related traits under drought stress*:** The 32 hybrids along with parental lines were evaluated at ORI-FSD during spring season 2019 under an alpha (0,1) lattice incomplete block design with three replications. The parent and hybrids were planted on ridges by keeping row to row distance 25 cm and plant to pant 75 cm. Two seed were sown in each hole. At V_3 leaf stage, one plant remained after thinning. All the cultural practices and plant protection measures was applied at optimal growth condition. At R_1 flowering stage, irrigation was held for drought stress treatment from flowering to maturity (Saba *et al.,* 2016; Hasan *et al.,* 2020b) by using rainshed out conditions. For normal treatment, normal irrigation was maintained up to maturity.

Table 2. Thirty-two cross combinations between eight lines and four testers.

Lines	Tester			
	L9	L10	L11	L12
L1	L1 × L9 (Hy1)	L1 × L10 (Hy2)	L1 × L11 (Hy3)	L1 × L12 (Hy4)
L2	L2 × L9 (Hy5)	L2 × L10 (Hy6)	L2 × L11 (Hy7)	L2 × L12 (Hy8)
L3	L3 × L9 (Hy9)	L3 × L10 (Hy10)	L3 × L11 (Hy11)	L3 × L12 (Hy12)
L4	L4 × L9 (Hy13)	L4 × L10 (Hy14)	L4 × L11 (Hy15)	L4 × L12 (Hy16)
L5	L5 × L9 (Hy17)	L5 × L10 (Hy18)	L5 × L11 (Hy19)	L5 × L12 (Hy20)
L6	L6 × L9 (Hy21)	L6 × L10 (Hy22)	L6 × L11 (Hy23)	L6 × L12 (Hy24)
L7	L7 × L9 (Hy25)	L7 × L10 (Hy26)	L7 × L11 (Hy27)	L7 × L12 (Hy28)
L8	L8 × L9 (Hy29)	L8 × L10 (Hy30)	L8 × L11 (Hy31)	L8 × L12 (Hy32)

***Data collection*:** Ten plants were marked from each replication to collect data for different yield and yield related traits i.e., DF, DM, PH, NL/P, HD, SG, AY/P & TAW. DF were counted from planting to 50% flower opening. DM were counted from planting to 50% physiological maturity at R_9 flowering stage (Schneiter and Miller, 1981). PH was measured with measuring tape in cm from the base point to head attachment point. NL/P were counted from base to flower. HD was measured with measuring tape in cm. SG was measured from base, middle and top with vernier caliper in mm and calculate the average. AY/P was taken by harvesting of each head at maturity and thrashed achenes were dried up to 12% moisture content by mearing with moisture meter GNR 3000. The dried achenes were weighed with electronic balance (Stanton Model-351BR) in grams. TAW was also taken with the same balance (after counting thousand achenes with seed counter (Model-SLY-C).

***Data analysis*:** ANOVA was calculated in an alpha (0,1) lattice incomplete block design (Patterson and Williams, 1976). Genetic analysis i.e., GCA and SCA was carried out by line × tester analysis (Kempthorne, 1957).

RESULTS

***Analysis of variance*:** Mean sum of squares of genotype, cross, lines, tester, L×T and parents were significantly differing at $p \leq 0.05$ for all yield and yield related traits under normal and drought stress conditions (Table 3, 4). Cross vs

Table 3. Mean square values of line × tester analysis for various traits under normal (control) and drought stress conditions.

SOV	Df	DF		DM		PH		NL/P	
		Control	Stress	Control	Stress	Control	Stress	Control	Stress
Replication	2	15.79	7.46	9.09	84.69	8.27	109.12	17.14	108.48
Genotype	43	102.62**	128.51**	12.75**	44.97**	18.03**	70.40**	895.01**	996.66**
Cross	31	62.18**	112.22**	11.63**	59.10**	9.96**	92.32**	472.39**	671.09**
Line (L)	7	68.83**	110.36**	32.99**	74.52**	18.59**	123.88**	920.86**	1505.28**
Tester (T)	3	153.96**	148.21**	5.34**	60.74**	8.63**	45.51**	276.29**	479.79**
L×T	21	46.85**	107.70**	5.42**	53.72**	7.27**	88.49**	350.92**	420.36**
Parent	11	111.48**	185.95**	14.64**	5.97**	21.89**	9.06**	976.92**	1055.67**
Cross vs Parent	1	1258.90**	1.76	26.73**	36.06**	225.92**	65.35**	13095.48**	10440.03**

*=Significant at .05 probability level, **= Significant at .01 probability level.

Table 4. Mean square values of line × tester analysis for various traits under normal (control) and drought stress conditions.

SOV	Df	HD		SG		AY/P		TAW	
		Control	Stress	Control	Stress	Control	Stress	Control	Stress
Replication	2	45.01	4.93	13.45	4.80	57.19	37.66	17.78	20.97
Genotype	43	70.43**	33.71**	34.75**	22.11**	45.04**	21.75**	771.40**	541.39**
Cross	31	48.67**	30.84**	18.34**	13.53**	33.03**	20.82**	632.41**	414.41**
Line (L)	7	19.52**	15.89**	14.61**	10.38**	28.99**	30.74**	1182.70**	1243.12**
Tester (T)	3	364.59**	156.87**	65.73**	37.08**	99.52**	27.39**	719.38**	53.19**
L×T	21	13.25**	17.82**	12.82**	11.21**	24.88**	16.58**	436.55**	189.78**
Parent	11	134.60**	44.80**	64.82**	24.88**	81.79**	23.32**	563.62**	323.41**
Cross vs Parent	1	39.33**	0.82	212.77**	257.96**	12.76**	33.38**	7365.81**	6875.66**

*=Significant at .05 probability level, **= Significant at .01 probability level.

Table 5. Assessment of variation of genetic components under normal (control) and drought stress conditions.

Traits		DF	DM	PH	NL/P	HD	SG	AY/P	TAW
Normal (Control)	∂ GCA	0.30	0.12	0.05	2.41	0.70	0.11	0.16	3.89
	∂ SCA	7.41	1.59	2.14	103.51	2.81	2.37	5.81	139.91
	Additive Variance (D)	1.22	0.49	0.21	9.66	2.82	0.44	0.65	15.57
	Dominance Variance (H)	29.64	6.36	8.55	414.02	11.24	9.49	23.22	559.64
	Degree of Dominance $(H/D)^{1/2}$	4.93	3.59	6.33	6.55	2.00	4.65	5.99	6.00
Drought stress	∂ GCA	0.09	0.11	-0.08	4.98	0.26	0.05	0.08	4.46
	∂ SCA	25.63	2.47	-2.89	52.02	2.72	0.45	1.09	21.71
	Additive Variance (D)	0.36	0.43	-0.30	19.93	1.03	0.18	0.34	17.86
	Dominance Variance (H)	102.54	9.87	-11.57	208.08	10.87	1.78	4.36	86.82
	Degree of Dominance $(H/D)^{1/2}$	16.90	4.81	6.17	3.23	3.24	3.11	3.60	2.21

parent mean sum of squares were significantly differ for all traits under normal irrigation condition, but for DM, PH, NL/P, SG, AY/P and TAW under drought stress condition.

***Assessment of variation of genetic components*:** GCA variance, SCA variance, additive variance (D), dominance variance (H) and degree of dominance $(H/D)^{1/2}$ were determined for all traits under both environmental conditions in Table 5. SCA variances were high than GCA variances for all traits under normal and drought stress conditions. Dominance variances were also higher than additive variances for all traits under normal and drought stress. Degree of dominance was higher than one for all traits under normal and drought stress condition.

***General combining ability estimates*:** Analysis of GCA showed negative and positive values for different traits (Table 6). Negative and significant GCA effects were desirable for DF, DM and PH, while positive and significant GCA effects were desirable for NL/P, HD, SG, AY/P and TAW. Negative and significant GCA effects were found in L1, L6 and L9 in normal irrigation, but in L1 and L9 under drought stress for DF. The lines L1, L3, L5 and L12 showed significantly negative GCA effects in normal irrigation, but

Table 6. General combining ability effects under normal (control) and drought stress conditions.

Gen.	DF		DM		PH		NL/P		HD		SG		AY/P		TAW	
	Control	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**
Lines																
L1	-3.41*	-6.24**	-0.66**	-5.19**	-0.94**	-7.72**	-11.28**	-19.05**	1.61*	-1.24	0.68	-0.75	-0.04	-1.47**	-11.33**	-13.41**
L2	1.30	3.41*	-0.16	0.31	-0.44	0.70	-5.36**	-6.80	-0.55	0.51	-0.07	0.17	-0 .01	-0.15	-13.65**	-6.60*
L3	3.26*	2.38	-1.66**	-0.77	-0.69**	0.20	-7.95**	-6.39	-0.22	-0.16	-0.99	-0.08	-0.64	-0.35	3.58**	3.93
L4	0.02	-1.02	0.84**	1.06	0.06	1.36**	9.97**	8.20**	-0.64	0.01	-1.82**	-1.5**	-1.66*	0.19	5.01**	4.67
L5	0.05	0.86	-1.91**	-0.77	-0.94**	0.36	11.72**	13.45**	-1.89**	-1.82	1.93**	0.92**	-0.79	-1.41**	-1.67	-7.87**
L6	-3.58*	-1.41	3.34**	3.48**	2.81**	2.70**	5.39**	8.45**	1.45*	1.01**	0.18	0.75*	3.21**	2.30**	11.01**	0.12
L7	1.73	2.07	-0.41	0.56	-0.44	1.11	3.72*	8.36**	-0.97	-0.07	0.01	-0.67	-1.22	-1.54**	-6.17**	-0.90
L8	0.62	-0.05	0.59*	1.31	0.56**	1.28**	-6.20**	-6.22	1.20	1.76**	0.09	1.17**	1.16	2.43**	13.23**	20.05**
S. E	**1.43**	**1.60**	**0.23**	**1.96**	**0.26**	**1.84**	**0.83**	**0.69**	**0.63**	**1.47**	**0.69**	**0.98**	**0.79**	**0.87**	**1.18**	**3.22**
Testers																
L9	-3.54**	-3.71**	0.09	-2.19	0.81**	-2.05**	-0.66	-6.47	4.20**	1.22**	-2.32**	-1.54**	-2.93**	-1.18**	-1.09	-0.53
L10	-0.05	0.94	0.47**	1.44**	-0.56**	0.91**	1.26	2.91*	2.28**	2.97**	0.01	-0.04	1.01	0.41	4.86**	2.08**
L11	2.13*	1.52	0.09	0.85**	0.06	0.57	-4.32**	0.49	-4.18**	-1.57	0.89	0.08	0.27	-0.50	-7.27**	-1.42
L12	1.47	1.25	-0.66**	-0.10	-0.31	0.57	3.72**	3.07**	-2.3**	-2.61*	1.43**	1.50**	1.65**	1.27**	3.50**	-0.14
S.E	**1.01**	**1.13**	**0.16**	**1.38**	**0.18**	**1.01**	**0.29**	**0.53**	**0.44**	**1.01**	**0.48**	**0.72**	**0.55**	**0.74**	**0.83**	**2.27**

*=Significant at .05 probability level, **= Significant at .01 probability level.

Table 7. Specific combining ability effects of hybrids under normal (control) and drought stress conditions

Hybrid	DF		DM		PH		NL/P		HD		SG		AY/P		TAW	
	Control	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**
Hy1	-13.81**	-20.96**	-0.59	-15.48**	-0.06	-19.61**	10.99**	-25.28**	2.47**	-6.55**	0.49	-5.21**	0.99	-3.54**	9.47**	-3.38*
Hy2	3.68 **	6.92**	1.03*	5.56**	0.31	6.76**	-3.93	11.68**	-1.28	4.70**	-1.84	1.96**	-1.90	1.60*	-16.08**	-4.46**
Hy3	4.73 **	5.57**	-0.59	4.81**	0.69	6.76**	-7.01	3.43	0.18	-0.43	-0.05	0.17	1.47	1.57*	9.82**	0.67
Hy4	5.40**	8.48**	0.16	5.10**	-0.94	6.09**	-0.05	10.18**	-1.36	2.28**	1.41	3.08**	-0.55	0.38	-3.21 **	7.17
Hy5	2.73 *	4.04**	-0.09	1.69*	0.44	3.30**	-14.93**	-11.53**	-1.36	0.70	-1.43	0.21	-0.44	2.34**	-6.72**	1.24
Hy6	-1.36	-0.74	-0.47	-0.94	-1.19*	-1.99**	3.16	-5.24**	2.22**	1.61*	1.57	0.38	-0.33	0.76	6.92**	-0.04
Hy7	-1.78	-2.92*	-0.09	-0.69	1.19*	-0.66	7.41*	7.84**	-0.66	-1.51*	0.03	-0.75	-0.21	-1.66*	6.50**	1.93
Hy8	0.42	-0.38	0.66	-0.06	-0.44	-0.66	4.36	8.93**	-0.20	-0.80	-0.18	0.17	0.98	-1.44	-6.70**	-3.14*
Hy9	0.90	6.11**	-0.59	2.10**	-1.31*	1.80**	14.66**	18.72**	1.30	2.36**	1.49	3.46**	1.54	1.54*	8.54**	2.70
Hy10	0.98	-1.17	-0.97*	-1.85*	0.06	-1.16	-2.59	0.01	-0.45	-3.05**	0.82	-0.71	-0.68	0.09	-13.02**	6.61**
Hy11	0.53	-0.02	2.41**	0.06	0.44	-0.16	-5.68	-12.24**	0.01	0.16	-0.39	-0.83*	1.65	-0.26	1.46	-7.15**
Hy12	-2.41 *	-4.91**	-0.84	-0.31	0.81	-0.49	-6.39	-6.49**	-0.86	0.53	-1.93	-1.92**	-2.52	-1.37	3.02**	-2.16
Hy13	2.91 *	-1.76	0.91	2.60**	1.94**	4.97**	-0.93	-6.53**	-0.61	0.86	-2.34	-0.79	1.94*	2.39**	0.12	5.65**
Hy14	-2.45 *	-0.24	-0.47	-0.69	0.31	-0.66	-8.84*	-7.91**	-0.36	-1.22*	1.99	0.71	0.32	-0.20	-2.49	-2.35
Hy15	-1.63	0.81	-1.09*	-1.44*	-1.31*	-1.99**	3.07	7.18**	0.43	-0.01	-0.22	1.25**	0.17	-0.07	6.93**	-5.01**
Hy16	1.17	1.19	0.66	-0.48	-0.94	-2.32**	6.70	7.26**	0.55	0.36	0.57	-1.17**	-2.43	-2.11**	-4.57 **	1.71
Hy17	2.65 *	4.10**	-1.34**	1.77*	-2.06**	1.64*	3.32	17.55**	-0.36	2.03**	-3.76**	-0.88**	-4.21**	-3.99**	-1.02	5.46**
Hy18	1.03	0.12	0.28	-0.85	2.31**	-0.32	5.74	1.18	-3.78**	-3.72**	0.24	1.29**	2.26**	-1.03	-9.97**	-11.64**
Hy19	-0.55	-1.66	2.66**	0.73	0.69	0.34	-10.34**	-10.07**	2.01**	0.16	-0.3	-0.83*	-0.03	2.57**	1.29	2.43
Hy20	-3.13 **	-2.56*	-1.59**	-1.65*	-0.94*	-1.66*	1.28	-8.66**	2.14**	1.53*	3.82**	0.42	1.99*	2.44**	9.69**	3.74*
Hy21	2.54 *	2.87*	0.41	1.52*	1.19*	1.97**	-5.68	2.22	-2.36	-0.80	3.32**	1.96**	3.42**	0.91	-12.33**	-5.44**
Hy22	-1.21	-2.18*	1.03*	-0.10	-0.44	0.01	3.41	-1.16	-0.11	0.78	-0.68	-1.21**	2.62**	2.92**	9.21**	1.87
Hy23	-0.60	-0.80	-1.59**	-0.85	-2.06**	-2.32**	3.99	-0.07	-1.99	0.32	-0.89	-0.67	-2.23 **	-2.00**	-12.20**	-1.16
Hy24	-0.73	0.11	0.16	-0.56	1.31*	0.34	-1.72	-0.99	4.47**	-0.30	-1.76	-0.08	-3.81**	-1.83*	15.32**	4.73**
Hy25	-0.07	1.25	-0.84	2.44**	-2.56**	0.89	11.66**	8.30**	0.72	0.61	2.49*	0.04	-0.30	2.02**	15.19**	9.56**
Hy26	0.18	-0.36	-0.22	-0.85	-0.19	-1.07	10.41**	8.93**	1.30	0.53	-1.51	-0.79	-3.63**	-2.58**	-0.40	-7.51**
Hy27	-0.04	0.42	0.16	-0.94	1.19*	-0.07	-5.34	-2.32	0.09	0.41	-0.72	0.42	-2.73**	-1.32	-5.65**	5.14**
Hy28	-0.08	-1.31	0.91	-0.65	1.56**	0.26	-16.72**	-14.91**	-2.11	-1.55*	-0.26	0.33	6.66**	1.88*	-9.13**	-7.19**
Hy29	2.14 *	4.34**	2.16**	3.35**	2.44**	5.05**	-19.09**	-3.45	0.22	0.78	-0.26	1.21**	-2.94 **	-1.68*	-13.26**	-15.80**
Hy30	-0.85	-2.34*	-0.22	-0.27	-1.19*	-1.57*	-7.34*	-7.49**	2.47**	0.36	-0.59	-1.63**	1.34	-1.55*	25.84**	17.52**
Hy31	-0.66	-1.39	-1.84**	-1.69*	-0.81	-1.91**	13.91**	6.26**	-0.07	0.91	2.53*	1.25**	1.91*	1.17	-8.15**	3.15*
Hy32	-0.63	-0.61	-0.09	-1.40*	-0.44	-1.57*	12.53**	4.68	-2.61*	-2.05**	-1.68	-0.83*	-0.31	2.05**	-4.42 **	-4.87**
S.E.	**2.86**	**1.26**	**0.46**	**1.17**	**0.53**	**1.83**	**1.66**	**1.95**	**1.26**	**1.26**	**0.97**	**0.98**	**1.57**	**1.12**	**1.16**	**1.46**

*=Significant at .05 probability level, **= Significant at .01 probability level.

only L1 under drought stress for DM. The lines L1, L3, L5 and L10 showed significantly negative GCA effects for PH in normal irrigation, while L1 and L9 under drought stress. Other lines showed positive or non-significant GCA effects that were not desirable for DF, DM and PH. Positively significant GCA effects were found for NL/P in L3, L4, L5, L7 and L12 in normal irrigation, while in L3, L4, L5, L6, L7, L10 and L12 under drought stress. The lines L1, L6, L9 and L10 showed significantly positive GCA effects for HD in normal irrigation as well as L6, L8, L9 and L10 under drought stress. Positively significant GCA effects were showed for SG in lines L5 and L12 in normal irrigation where as L5, L6, L8 and L12 under drought stress. AY/P showed positive and significant GCA effects in lines L6 and L12 under normal irrigation, while in L6, L8 and L12 under drought stress. The lines L3, L4, L6, L8, L10 and L12 showed significantly positive GCA effects for TAW in normal condition, but L8 and L10 under drought stress conditions. Other lines had negative or non-significant GCA effects for NL/P, HD, SG, AY/P and TAW that were not beneficial. Based on GCA effects under drought stress, the line L1 was a good combiner for early flowering, early maturity and short stature. L6 was a good combiner for DF, NL/P, HD, AY/P and TAW as well as L12 for DM, NL/P, SG, AY/P and TAW under normal irrigation condition. Under drought stress condition, L6 was a good combiner for NL/P, HD, SG and AY/P, while L8 for HD, SG, AY/P and TAW, as well as L12 for NL/P, SG and AY/P.

***Specific combining ability estimates*:** SCA effects significance was measured under normal and drought stress conditions (Table 7). Significantly negative SCA effects were useful for DF, DM and PH but significantly positive SCA effects were desirable for NL/P, HD, SG, AY/P and TAW. Under normal and drought stress conditions, Hy1, Hy12 and Hy20 had significantly negative SCA effects for DF, while Hy1, Hy10, Hy15, Hy20 and Hy31 for DM, as well as Hy6, Hy15, Hy20, Hy23 and Hy30 for PH. Under normal and drought stress conditions, Hy7, Hy9, Hy25, Hy26 and Hy31 had significantly positive SCA effects for NL/P, whereas Hy6 and Hy20 for HD, as well as Hy21 and Hy31 for SG, while Hy13, Hy20, Hy22 and Hy28 for AY/P but Hy20, Hy24, Hy25 and Hy30 for TAW. From all the hybrids, Hy20 was a good SCA combiner for DF, DM, PH, HD, AY/P and TAW under both environmental conditions.

DISCUSSION

For the improvement of genetic material under drought stress, it is very important that genetic diversity should be present against drought. Higher genetic diversity was found in sunflower breeding material under drought stress (Jannatdoust *et al.,* 2016; Hasan *et al.,* 2020a). With the use of combined analysis of variance, significant differences were found among genotypes and levels of drought (Farooq *et al.,* 2018; Hasan *et al.,* 2020b). Dagustu, (2002); Shahsavari *et al.* (2010) practically found significant differences for SG and PH in different genotypes. Significant differences were found for DF among genotypes as reported by Khan *et al*. (2007). HD also showed highly significant differences for all the genotypes by Khan *et al*. (2007); Shahsavari *et al.,* (2010). Khokhar *et al.,* (2006); Nasreen *et al.,* (2011); Hassan *et al.,* (2012) observed highly significant differences among genotypes for TAW and AY/P.

Higher values of SCA variances than GCA variances indicating that non-additive (dominance and epistatic) gene action played more role for all the traits than additive gene action (Aguiar *et al.,* 2003; Ahmad *et al.,* 2012). Dominance variance values were also higher than additive variance showed that traits were under the control of dominant gene action. Higher SCA variances than GCA variances for most of the traits and degree of dominance $(H/D)^{1/2}$ values were more than one indicating that over dominant type of gene action was involved for given traits (Aleem *et al.,* 2015). Higher SCA variances than GCA variances were reported for HD, AY/P, TAW by Khan *et al.* (2008); Tan, (2010); Ghaffari *et al.* (2011); Ahmad *et al.* (2012); Aleem *et al*. (2015); Dhillon and Tyagi (2016).

Significant but negative GCA and SCA effects were useful for DF, DM & PH by decreasing maturity time to escape from drought and short stature to avoid from lodging (Khan *et al.,* 2008; Ghaffari *et al.,* 2011; Aleem *et al.,* 2015). Significantly positive GCA and SCA effects were useful for NL/P, HD (Ahmad *et al.,* 2012), SG (Manzoor *et al.,* 2016; Hussain *et al.,* 2017), AY/P (Ahmad *et al.,* 2012; Din *et al.,* 2014; Imran *et al.,* 2014) and TAW (Aghdam *et al.,* 2019) to enhanced to the productivity of sunflower. Non-significant hybrids were not beneficial under normal and drought stress conditions.

Conclusion: The non-additive gene action played more role than additive gene action in controlling all yield traits. The dominant gene action was found instead of epistatic gene action from non-additive gene action. The degree of dominance expressed over-dominance type of gene action that was very useful for hybrid development programme in sunflower. Drought tolerant line like L1 proved good GCA combiner for early flowering, early maturity and short stature, L6 was a good combiner for NL/P, HD and AY/P while L8 for HD, SG, AY/P and TAW under drought stress condition. Hybrid 20 was found a good SCA combiner for early flowering, early maturity, short stature, higher HD, AY/P and TAW under normal as well as drought stress conditions.

The lines L1, L6 and L8 can be further used to develop drought tolerant hybrids for higher yield in hybrid develop programme. Hybrid 20 was proposed for general cultivation in irrigated as well as rainfed areas of the Pakistan to increase the area under oilseed crop cultivation and productivity enhancement.

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