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Oil quality of genetically modulated sunflower under drought

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Abstract

Drought stress is a limiting factor for yield and oil quality in sunflower (*Helianthus annuus* L.). The objective of current study was to determine the gene action for drought stress, and its impact on oil quality. Thirty-two single cross hybrids developed by crossing 8 drought tolerant inbred lines and four drought susceptible lines through line × tester mating design. The experiment was performed using randomized complete block design where two factors i.e., genotypes and stress and three replications were used. The oil quality related traits i.e., protein content (PC), oil content (OC), palmitic acid (PA), stearic acid (SA), oleic acid (OA) and linoleic acid (LA). Degree of dominance was higher than one indicating the over dominant type of gene action for all traits and could have the potential for hybrid breeding. Based on the GCA effects, L1, L6 and L7 were good combiners for oil quality traits. Based on SCA effects, the H25 was identified a good combiner for all the traits except LA. This hybrid is recommended for good quality oil seed production under arid and semi-arid areas.

Keywords: Breeding line, Dominance variance, Fatty acid, Specific combining ability

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Introduction

Sunflower (*Helianthus annuus* L.) is third most important edible oilseed crop in Pakistan after cotton and rapeseed / mustard. Sunflower covers an area of 264000 acres, gives 142000 tones seed production and 54000 tones oil production. In Pakistan, prolong scarcity of oilseed caused huge import bill (Mustafa et al., 2018) of worth 192.203 billion Rupees (U.S. Dollar 1.455 billion) to fulfill the country cooking oil requirement. The indigenous oilseed production is 0.5 million tones i.e.17 percent of total production while 83 % edible oil is imported i.e. 2.421 million tonnes (Govt. of Pakistan, 2018-19). Sunflower is only hoped to overcome the shortage of good quality oil in Pakistan by filling gaps between the edible oil production and consumption in the country (Khan et al., 2003). sunflower seed have a high ratio of poly-unsaturated fatty acids (60%) i.e. oleic acid and linoleic acid (Iqbal et al., 2013). Sunflower gives high yield production, takes short (90-110) maturation days, adaptation in different climatic condition and income-able source in the country both in irrigated and rain-fed environmental condition. Due to these reasons' sunflower is successful among other oilseed crops (Arshad et al., 2010; Onemli, 2012; Rehman et al., 2012).

About one forth area of the total world's productive region is affected by drought. Availability of water play an important role to identify the yield potential of different crop plants (Singh, 2000). In Pakistan, from 79.61 million hectares of the total area, 4.40 million hectares are drought affected (Govt. of Pakistan, 1999-2000). The severity of drought problem is aggregating with the increasing time due to water shortage and less precipitation (Ashraf and Foolad, 2006). Lack of available water to sunflower crop caused significantly reduction in OA, LA and PA content (Ebrahimian et al., 2019). Drought causes decrease in sunflower seed and oil yield production significantly (Mustafa et al., 2015). This deficit can be reduced by utilizing the area under drought stress condition and by increasing production of oilseed crops (Tan, 2010).

Drought resistant lines are good source to develop high yielding hybrids under abiotic stess (Mahmood et al., 2017). Genetic diversity is a very crucial point in any breeding improvement program to identify genetic variation among the genotypes (Riaz et al., 2019). Variability of yield and yield related component assist in improving the productivity of crop plants (Nehru and Manjunath, 2003). The ability of a line or parent to make a successful cross and inherit its traits in next generation is called combining ability. The parents have ability to produce superior progeny when combined are known as a good combiner (Khan et al., 2008). General combining ability (GCA) and specific combining ability (SCA) are two types of combining ability. GCA evaluates mainly the degree of additive gene action, whereas SCA evaluate the performance of specific cross of two lines, thus reproduce non-additive gene action (Din et al., 2014). SCA also response effectively in multi environmental conditions and have more stable effects with high heritability (Ghaffari and Shariati, 2018). Hybrids combinations gave the best performance by selecting the parents with good combining abilities. So, the selection of right parents is very important for combination breeding (Tan, 2005). In cross pollinated crops, SCA play important role, while in self-pollinated crops GCA effects play important role for the improvement. Sunflower showed high values of SCA effects than GCA for most of the traits due to cross pollinated species. The characters had higher SCA effects than GCA effects, governed by dominant gene action. Moreover, the combining ability importance for the selection of parental lines in the hybridization programme cannot be adjourned (Hladni et al., 2014).

Keeping the view of oilseed requirement and drought stress conditions, the breeding strategies with these objectives should be adopted to improve the sunflower i.e. screening of sunflower germplasm for drought tolerance, development of hybrid to estimate combining abilities, estimation of genetic effect of oil quality traits and to understand the genetic and physiological mechanism for drought tolerance and their inheritance patterns.

Materials and Methods

Selection of drought tolerant and susceptible lines: 70 diverse genotypes were screened for drought stress in glass house condition at seedling stage by Hasan et al. (2020a) and the results were confirmed at field condition up to maturity by Hasan et al. (2020b). From the basis of screening experiments, the eight cytoplasmic male sterile (CMS) inbred lines were found as drought tolerant lines and four fertility restorer (FR) lines as drought susceptible lines (Table 1).

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

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

L= Inbred line, ORI-FSD= Oilseed research Institute, Faisalabad, CMS= Cytoplasmic male sterile, FR= Fertility restorer, DT= Drought tolerant at seedling and maturity stage, DS= Drought Susceptible at seedling and maturity stage.

Developments of hybrids: A set of eight CMS lines and four FR lines were sown at field area of Oilseeds Research Institute, Faisalabad, Pakistan to develop F_1 plant population during autumn-2019. Each CMS line was crossed with each FR line to obtain 32 F_1 hybrids by using line × tester mating design (Table 2). To avoid foreign pollination/contamination fiber sheet tunnel was used.

Evaluation of quality traits of hybrids under drought stress: The hybrids along with parents were evaluated in the field condition at oilseeds Research Institute, Faisalabad by using RCBD under two factor factorial during spring-2020 in three replication. These hybrids and parents were sown on ridges keeping line to line distance 75 cm and plant to plant 25 cm separately. Two seeds were sown per hole, after germination thinning was done at leaf stage of V3 and one plant per hole left. All recommended agronomic and plant protection measures were applied for optimum plant growth. In drought stress treatment, irrigation was completely held on the R1 stage of the flowering up to physiological maturity (Hassan et al., 2020b; Saba et al., 2016) under rain-shed out conditions. The normal treatment was irrigated to maintain soil moisture content near to field capacity. Quality traits (PC, OC, PA, SA, OA & LA) were used in final assessment of hybrids along with parents.

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

Lines	Tester			
	L9	L10	L11	L12
L1	L1*L9 (H1)	L1*L10 (H2)	L1*L11 (H3)	L1*L12 (H4)
L2	L2*L9 (H5)	L2*L10 (H6)	L2*L11 (H7)	L2*L12 (H8)
L3	L3*L9 (H9)	L3*L10 (H10)	L3*L11 (H11)	L3*L12 (H12)
L4	L4*L9 (H13)	L4*L10 (H14)	L4*L11 (H15)	L4*L12 (H16)
L5	L5*L9 (H17)	L5*L10 (H18)	L5*L11 (H19)	L5*L12 (H20)
L6	L6*L9 (H21)	L6*L10 (H22)	L6*L11 (H23)	L6*L12 (H24)
L7	L7*L9 (H25)	L7*L10 (H26)	L7*L11 (H27)	L7*L12 (H28)
L8	L8*L9 (H29)	L8*L10 (H30)	L8*L11 (H31)	L8*L12 (H32)

H= hybrid

Collection and calculation of data: Ten plants from each replication were selected for data collection and tagged them from both drought stress and normal moisture conditions. Hybrids and parents were harvested at maturity to collect achene. 12 % moisture content of sun-dried achenes was measured by GRN 3000 moisture meter. The oil was extracted from each plant achenes through Oxford NMR. Quality traits like PC, OC were measured with the help of FT-NIR Spectrometer and PA, SA, OA & LA from fatty acid profile were also taken by FT-NIR Spectrometer at Centre of Advance Studies, University of Agriculture, Faisalabad. The data of ten selected hybrid plants were used to assess the oil quality of the hybrids.

Data Analysis: Analysis of variance was carried out in completely randomized design under two factor factorial (Steel et al., 1997). Line x tester analysis was performed to study genetic analysis, i.e. general combining ability (GCA), specific combining ability (SCA) (Kempthorne, 1957). Contribution of Lines, testers and their interaction to total variance was determined by given formulas

Lines contribution= {SS (L)/SS (crosses)} ×100

Testers contribution = {SS (T)/SS (crosses)} ×100

Line × tester contribution = {SS (line × tester)/SS (crosses)} ×100

Results

Genotypes mean sum of square was significantly differed at $p \leq 0.05$ for all traits expect OA under normal irrigation and drought stress conditions (Table 3). All the hybrids mean square showed significant difference for all traits expect SA and OA under normal condition while under drought stress condition, traits like OC, PA, SA and LA showed significant difference. All the lines expressed significantly difference for all traits expect SA and OA in normal condition but OA under drought stress. Significant mean squares of testers were significantly differed for PC, OC, PA and LA in normal condition. whilst OC, PA and LA under drought condition. Line x tester mean squares were significant differ for OC, PA and LA in normal condition whilst OC, PA, SA and LA under drought condition. Mean square for parents had significant difference for the traits like PC, OC, PA, SA and LA in normal irrigation, while for PA, SA and LA under drought stress. Cross vs Parent

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

SOV	df	PC		OC		PA		SA		OA		LA	
		Control	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**
Replication	2	0.43	0.55	0.64	5.48	0.43	12.93	0.17	1.13	0.17	0.04	0.14	29.17
Genotype	43	2.14**	1.23*	4.02**	4.44**	14.75**	20.80**	1.94**	1.81**	0.34	0.31	107.50**	75.86**
Cross	31	2.12**	1.28	4.11**	5.26**	15.41**	23.98**	1.40	1.85**	0.22	0.28	28.14**	33.58**
Line	7	4.10**	3.80**	7.38**	7.00**	4.25**	22.65**	0.74	2.05*	0.09	0.19	50.86**	62.18**
Tester	3	2.43**	0.74	6.41**	3.16**	52.58**	73.21**	1.64	1.02	0.67	0.38	67.46**	14.99**
Line× Tester	21	1.42	0.52	2.69**	4.97**	13.82**	17.39**	1.58	1.90*	0.20	0.29	14.95**	26.71**
Parent	11	1.78*	0.85	3.97**	1.36	14.20**	13.71**	3.66**	1.84*	0.38	0.17	240.74**	191.08**
Cross vs Par	1	6.64**	3.75*	1.75	13.22**	0.52	0.01	0.07	0.14	3.68*	2.72	1101.93**	119.18**

*=Significant at 5%, **= Significant at both 5% and 1%, SOV= source of variance, df=degree of freedom, PC= protein content (%), OC= oil content (%), PA= palmitic acid (%), SA= stearic acid (%), OA= oleic acid (%) and LA: linoleic acid (%).

showed significantly difference for PC, OA and LA in normal irrigation, while for PC, OC and LA under drought stress condition.

Assessment of genetic components of variation under normal and drought stress conditions: Genetic components (∂ GCA, ∂ SCA, additive variance (D) dominance variance (H) and degree of dominance $(H/D)^{1/2}$) were calculated for different traits under normal and drought stress conditions (Table 4). GCA variances were higher than SCA variances for all traits in normal irrigation condition. PC, OC, PA, OA & LA had higher GCA variances than SCA variances, while SA had also higher values but in negative direction under drought stress condition. Dominance variances were higher than additive variances for all traits in normal irrigation condition. Dominance variances were also higher than additive variances for all traits except SA that had also higher values but in negative direction under drought stress condition. The degree of dominance $(H/D)^{1/2}$ was higher for PA (12.05), SA (11.85) and OA (12.26) in normal irrigation condition. Under drought stress condition, SA (15.73) and OA (11.15) had higher values for degree of dominance $(H/D)^{1/2}$. The degree of dominance was higher than one for all the traits under both environmental conditions.

Contribution of lines, testers and their interaction for traits expression under normal and drought stress conditions: The proportional contribution of lines, testers and their interaction in the phenotypic and quality traits expression was given in Table 5. Line ×

Table 4. Assessment of genetic components of variation under normal and drought stress conditions

Trait	Normal (Control)					drought stress				
	∂ GCA	**∂ SCA**	**Additive Var. (D)**	**Dominance Var. (H)**	**Degree of Dominance $(H/D)^{1/2}$**	**∂ GCA**	**∂ SCA**	**Additive Var. (D)**	**Dominance Var. (H)**	**Degree of Dominance $(H/D)^{1/2}$**
PC	0.01	0.45	0.06	1.81	5.68	0.01	0.02	0.06	0.09	1.25
OC	0.03	0.88	0.11	3.52	5.58	0.01	0.13	0.02	0.51	4.75
PA	0.03	4.59	0.13	18.34	12.05	0.13	0.65	0.52	2.59	2.22
SA	0.004	0.52	0.02	2.08	11.89	-0.001	-0.25	-0.004	-1.01	15.73
OA	0.001	0.06	0.002	0.24	12.26	0.002	0.04	0.001	0.15	11.15
LA	0.26	4.96	1.05	19.85	4.35	0.14	2.66	0.55	10.66	4.42

∂ GCA = Estimate of GCA variance, ∂ SCA = Estimate of SCA variance, PC= protein content (%), OC= oil content (%), PA= palmitic acid (%), SA= stearic acid (%), OA= oleic acid (%) and LA: linoleic acid (%).

tester (parental and maternal interaction) showed higher contribution for PC (45.24%), OC (44.33%), PA (60.75%), SA (76.70%) and OA (61.74%) than lines and testers under normal condition. Under drought stress condition, contribution by lines x tester was higher OC (64.09 %), PA (49.13%), SA (69.64), OA (71.32) and LA (53.83 %) than lines and testers, while contribution of lines was higher for PC (66.92%) than testers and line x tester.

Table 5. Proportional contribution of lines, testes and their interaction under normal and drought stress conditions

Traits	Normal irrigation			drought stress		
	Contribution of lines	**Contribution of tester**	**Contribution of lines x tester**	**Contribution of lines**	**Contribution of tester**	**Contribution of lines x tester**
PC	43.69	11.07	45.24	66.92	5.62	27.47
OC	40.58	15.09	44.33	30.08	5.82	64.09
PA	6.23	33.02	60.75	21.32	29.54	49.13
SA	11.95	11.35	76.70	25.02	5.34	69.64
OA	9.13	29.13	61.74	15.29	13.38	71.32
LA	40.81	23.20	36.00	41.81	4.32	53.87

PC= protein content (%), OC= oil content (%), PA= palmitic acid (%), SA= stearic acid (%), OA= oleic acid (%) and LA: linoleic acid (%).

Estimation of General Combining Ability: GCA analysis showed positive and negative values for different traits (Table 6). Positive and significant GCA effects were desirable for PC. L6, L7 & L10 showed positive and significant GCA effects for PC under both environmental conditions, demonstrating that these lines were good combiner for PC. To increase the oil production, significant positive GCA effects were useful. The lines like L1, L8 & L11 were exhibited significant positive GCA effects for OC in normal irrigation, but L1, L3, L4, L5 & L11 in drought stress. These lines were good source of genes for the enhancement of oil production in the country. Negative values of saturated fatty acid (PA and SA) were desirable for improvement of oil quality. The line L1 & L9 expressed the significant negative GCA effects under both environmental conditions for PA and SA. So, these lines were good combiner for PA and SA. Positive and significant values of GCA effects were required for unsaturated fatty acid (OA and LA) to enhance the oil quality. L5 & L6 had positive and significant values of GCA effects for OA and LA under both environmental conditions. These lines might be used as good combiner for betterment of oil quality of sunflower.

Table 6: Estimation of general combining ability effects for various traits under normal (control) and drought stress conditions

Gen.	**PC**		**OC**		**PA**		**SA**		**OA**		**LA**	
	Control	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**
Lines												
L1	-0.39**	-0.56**	1.63**	1.64**	-0.13*	-2.69**	-0.22**	-0.86**	0.06	-0.25**	-0.36**	-3.61**
L2	-0.83**	-0.68**	-0.07	-0.32*	0.26**	-0.05	-0.27**	-0.20	-0.03	0.06	-0.74**	-2.58**
L3	0.26**	-0.15	0.06	0.43*	-0.22**	0.06	0.53**	0.60**	-0.03	-0.01	-2.84**	-0.49
L4	-0.46**	0.20	-0.19**	0.95**	-1.16**	-1.15*	0.08	0.11	-0.12**	-0.03	-0.19*	1.66**
L5	0.02	0.13	-0.01	0.31*	0.40**	1.11**	-0.12**	0.05	0.13**	0.10**	0.74**	0.94**
L6	1.11**	1.09**	-0.65**	0.26	0.91**	1.47**	-0.07	0.02	0.10*	0.15**	4.29**	3.15**
L7	0.17*	0.27*	-1.05**	-0.10	-0.12*	0.13	0.01	0.14	0.02	0.04	-1.34**	-0.64
L8	0.13	-0.30	0.29**	0.10	0.04	1.11**	0.06	0.16	-0.10*	-0.07	0.44**	1.56**
S.E	**0.07**	**0.19**	**0.06**	**0.61**	**0.07**	**1.26**	**0.04**	**0.30**	**0.04**	**0.12**	**0.07**	**0.65**
Testers												
L9	0.14**	-0.04	-0.03	-0.54**	-1.77**	-2.51**	-0.08**	-0.25*	0.15**	-0.06	2.28**	-0.90*

L10	0.32**	0.25**	-0.65**	0.19	1.46**	0.71**	0.04	0.10	0.13**	0.17**	-0.75**	0.11
L11	-0.43**	-0.16	0.61**	0.21*	0.94**	1.49**	-0.29**	-0.07	-0.08*	0.02	-1.64**	-0.2
L12	-0.03	-0.05	0.07	0.14	-0.64**	0.31	0.33**	0.22**	-0.20**	-0.12**	0.11*	1.00**
S.E	**0.05**	**0.13**	**0.05**	**0.43**	**0.05**	**0.89**	**0.03**	**0.21**	**0.03**	**0.06**	**0.05**	**0.58**

Based on the GCA effects, any line did not meet the criteria of good combiner for all the traits in both environments. However, drought tolerant lines (Table 1), L6 was a good combiner for PC, OA and LA while, L1 was a good combiner for OA, PA and SA (Table 6). Drought susceptible line L7 also good combiner for PC, PA, SA, OA and LA under normal condition, while for PA, SA and LA under drought stress condition.

Estimation of Specific Combining Ability: Significance of SCA effects were measured at P≤ 0.05 at normal irrigation and drought stress conditions (Table 7). Significantly positive SCA effects were required for PC, OC, OA and LA but negative significant SCA effects were desirable for PA and SA for oil quality improvement. H14, H25 and H32 had positive significant SCA effects, these were good SCA combiner for PC under both environments. H2, H4, H5, H11 and H25 had significantly positive SCA effects for OC under both environmental conditions. All other significant but negative crosses and non-significantly positive crosses were not beneficial. H7, H8, H14, H23, H25 and H31 under both environmental conditions showed significant and negative SCA effects for PA. Cross combinations H1, H4, H5, H7, H9, H13, H17, H21, H25, H26, H27, H29 and H31 had significant negative SCA effects for SA in both environments. For PA and SA, significant positive and non-significant negative crosses were undesirable. The good SCA combiners were H6, H7, H10, H13, H16, H17, H18, H19, H20, H22, H23, H24, H25, H30 and H32 that had significant positive SCA effects for OA in both environments. For LA, the H1, H22, H23 and H24 had positive significant SCA effects under normal and drought stress conditions. The H25 was good SCA cross combination for all the traits except LA.

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

Hybrid	**PC**		**OC**		**PA**		**SA**		**OA**		**LA**	
	Control	**Stress**	**Control**	**Stress**	**Control**	**stress**	**Control**	**Stress**	**Control**	**Stress**	**Control**	**Stress**
H1	0.29*	-0.66**	-1.38**	-4.40**	2.61**	-7.48**	-0.59**	-2.44**	-0.45**	-1.03**	4.85**	-8.15**
H2	0.02	0.27*	0.76**	1.31**	0.83**	4.37**	1.38**	1.36**	0.38**	0.35**	-2.12**	4.22**
H3	-0.03	0.20	-0.32*	1.07**	-1.13**	2.09**	-0.38**	0.83**	-0.03	0.37**	-0.74**	2.77**
H4	-0.26	0.19	0.93**	2.02**	-2.31**	1.01*	-0.41**	0.24	0.12	0.31**	-1.99**	1.16*

H5	-0.4**	0.25*	1.45**	0.69*	2.57**	2.06**	0.06	0.26	0.15	0.20**	-0.58**	0.50
H6	-0.03	-0.15	-0.93**	-0.35	1.93**	0.96*	0.03	-0.03	-0.02	-0.03	1.75**	0.73
H7	0.34*	0.18	0.93**	-0.07	-0.63**	-0.24	-0.13	-0.15	0.08	-0.01	0.54**	1.27*
H8	0.09	-0.28*	-1.45**	-0.27	-3.87**	-2.79**	0.04	-0.08	-0.20*	-0.17**	-1.71**	-2.50**
H9	0.23	0.21	-0.22*	0.31	-0.26	-0.49	-0.54**	-0.27	-0.02	0.04	0.72**	-0.29
H10	-1.21**	-0.17	-0.48**	-0.29	0.51**	0.03	-0.37**	-0.49	0.10	0.04	-2.75**	-2.30**
H11	1.17**	0.14	1.14**	0.65*	0.89**	0.68	1.27**	0.65*	-0.10	-0.04	-0.56**	-2.62**
H12	-0.20	-0.18	-0.45**	-0.66*	-1.14**	-0.22	-0.36**	0.12	0.02	-0.04	2.59**	5.21**
H13	-0.19	0.03	1.33**	0.56	-1.46**	0.94*	0.01	0.31	0.38**	0.43**	-2.63**	3.60**
H14	0.50**	0.28*	0.42**	0.11	-2.53**	-2.73**	-0.62**	-0.44	-0.40**	-0.24**	4.40**	-0.01
H15	0.58**	0.13	-0.41**	-0.25	2.59**	0.33	0.02	-0.24	0.30**	-0.02	0.19	-1.11*
H16	-0.89**	-0.44**	-1.34**	-0.42	1.40**	1.46**	0.59**	0.37	-0.27**	-0.18**	-1.96**	-2.48**
H17	-0.64**	-0.30**	-0.65**	1.16**	-2.32**	0.14	0.41**	0.77**	0.13	0.06	-1.65**	-1.18*
H18	0.84**	0.17	-0.10	0.65*	-0.26	-0.84	-0.92**	-0.65*	-0.25**	-0.10*	-2.23**	-1.19
H19	-1.13**	0.01	-0.42**	-1.19	1.63**	0.28	0.62**	-0.08	-0.05	-0.08	1.06**	0.95*
H20	0.93**	0.13	1.17**	-0.61	0.95**	0.42	-0.11	-0.04	0.17*	0.12*	2.81**	1.42*
H21	0.05	0.07	-0.03	0.61	-0.79**	1.09**	-0.14	0.19	0.05	0.18**	-0.80**	1.78**
H22	0.25	0.24	0.05	-0.85*	0.22	-0.06	0.13	-0.03	-0.03	-0.05	1.22**	0.47
H23	-0.51**	-0.34**	-0.57**	-0.06	-1.80**	-1.38**	-0.23**	-0.19	-0.02	-0.07	-0.89**	-0.99*

H24	0.21	0.03	0.56**	0.29	2.37**	0.35	0.24**	0.02	0.01	-0.06	0.46**	-1.26*
H25	0.29*	0.52**	0.25**	0.94**	-2.40**	-1.40**	1.28**	1.18**	0.23*	0.29**	0.22	2.36**
H26	0.18	0.12	-0.05	-0.17	0.18	-1.43**	-0.64**	-0.13	-0.05	0.02	-0.45**	-2.11**
H27	0.07	-0.19	-0.18	-0.43	0.46**	-0.01	-0.71**	-0.73**	-0.15	-0.22**	0.34**	0.03
H28	-0.54**	-0.45**	-0.02	-0.33	1.77**	0.04	0.07	-0.32	-0.03	-0.09	-0.11	-0.28
H29	0.37*	-0.12	-0.74**	0.14	2.07**	2.34**	-0.47**	-0.01	-0.45**	-0.16**	-0.15	1.37*
H30	-0.53**	-0.76**	0.32*	-0.41	-0.89**	-0.31	1.01**	0.41	0.27**	0.01	0.18	0.19
H31	-0.51**	-0.12	-0.18	0.27	-1.99**	-1.75**	-0.46**	-0.09	-0.45**	0.06	0.06	-0.30
H32	0.67**	1.00**	0.60**	-0.01	0.81**	-0.29	-0.08	-0.31	0.38**	0.10*	-0.09	-1.27*
S.E.	**0.14**	**0.38**	**0.13**	**0.83**	**0.15**	**0.76**	**0.32**	**0.61**	**0.11**	**0.22**	**0.16**	**0.87**

Discussion

Diversity in genetic material is important component for the development of breeding material in crop plants against abiotic stress like drought (Shamshad et al., 2014; Tyagi et al., 2014; Jannatdoust et al., 2016; Hasan et al., 2020). Significant interaction among genotypes and drought level in combined analysis of variance was also reported by Farooq et al. (2018); Hasan et al. (2020). Rodriguez et al. (2002); Qadir et al. (2006) reported significant differences for oleic acid, linoleic acid and oil content. Khan et al. (2007) found highly significant differences for oil content among different accessions. Hassan et al. (2012) observed significant differences for protein content.

Dominance variance (variance due to SCA) was more important than additive variance (variance due to GCA) for all characters under normal and drought stress conditions. The degree of dominance greater than one indicated that all the traits were showing over dominance type of gene action except protein content which has dominant type of gene action under drought stress condition. Higher SCA variances than GCA variances were reported for oil content by Goksoy et al. (2000); Khan et al. (2008); Tan (2010); Andarkhor et al. (2011); Ghaffari et al. (2011); Ahmad et al. (2012); Aleem et al. (2015); Dhillon and Tyagi (2016), for palmitic acid, stearic acid, oleic acid and linoleic acid by Joksimović et al. (2006).

Positive and significant GCA and SCA effects were desirable for PC, OC, OA and LA to choose the best combiner and enhance the oil quality (Tabrrizi et al., 2012; Nasreen et al., 2014; Manzoor et al., 2016; Ghaffari and Shariati 2018; Aghdam et al., 2019; Chahal et al., 2019). Significant but negative GCA and SCA effects were also required for saturated fatty acids (PA and SA) to choose best combiner and quality improvement (Nasreen et al., 2014; Manzoor et al., 2016; Chahal et al., 2019). Non-significant cross combinations and their parents were not useful under normal and drought stress conditions.

Conclusion

Diversity in genetic material was found in both environmental conditions. The degree of dominance $(H/D)^{1/2}$ was higher than one for all the traits indicating that over dominance type of gene action was controlling these traits. Under drought stress condition, higher contribution of lines x tester was found than lines and testers for all the traits except PC. Drought tolerant lines like L1 and L6 were good combiner for different contrasting traits and environments. Drought susceptible line L7 was a good combiner for PC, PA, SA, OA and LA under normal condition, while for PA, SA and LA under drought stress condition. Single cross hybrid H25 exhibited higher SCA effects for all the traits except LA under normal irrigation and drought stress conditions. The Lines L1, L6 and L7 can be further used in hybrid development programme to develop drought tolerant hybrids with good quality oil. Hybrid H25 was recommended for general cultivation in irrigated and rainfed areas of the country for good quality oil production of sunflower

Disclosure statement

There is no conflict of interest.

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