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Genotype by environment interaction and association of yield contributing traits in sunflower genotypes under the environmental condition of Sargodha, Pakistan

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Abstract: Oil content and other yield contributing metric traits are highly influenced by environmental conditions hence, the phenotype of a trait is a response of interaction between environment and genetic makeup of crop. Climate change is one of the major challenge faced by growers nowadays because it adversely affects the growth and development of sunflower and ultimately reduce oil content. Therefore, keeping in view the challenge of climate change, the present research was conducted during 2019, to evaluate the performance of 28 sunflower hybrids under normal and terminal heat stress conditions at the research farms of the College of Agriculture, University of Sargodha, Sargodha-Pakistan. Pakistan. Data were recorded on days to 100% flowering, stem girth (cm), head diameter (cm), 100-achene weight (g) and oil contents (%). Analysis of variance revealed the presence of genetic diversity among 28 hybrids for all the traits under consideration. Irrespective of traits, the mean square revealed the role of experimental error was minimum than the environment, genotype and their interaction ($G \times E$). The environmental influence was found to be 68.94, 49.99, 53.94% for days to 100%

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flowering, stem girth (cm) and 100-achene weight (g), respectively. However, genotypes play a major source of variation for head diameter (cm) and oil content (%). Oil content has a significant positive correlation with traits under study. Based on mean performance under normal and terminal heat stress conditions hybrid SF-19033 and SF-19028 performed best for yield contributing traits and adoptable under the environmental conditions of Sargodha-Pakistan.

Keywords: climate change; correlation; genetic diversity; genotype by environment interaction; yield; yield related traits.

Introduction

Climate change is one of the chief recent issues categorized by the rise in temperature and CO_2 concentrations with less water availability. The productivity of many crops including sunflower is under major threat due to climate change specially heat stress conditions that hinder growth and development (Mohammadi 2003; Škorić 2009). Heat stress is the major challenge in crop production, which causes significant yield losses (Mohammadi 2003; Mohanasundaram et al. 2010). Heat stress can be defined as a rise in environmental temperature up to a threshold level that causes damage to the crop when plants grow under such circumstances for a longer time. Many factors are involved directly or indirectly with heat stress such as high temperature, altered soil structure, water scarcity and disease conducive environment (Ali et al. 2019). Under the alarming population growth rate, Pakistan is persistently inefficient in the production of edible oil and the situation is getting worse day by day (Amutha et al. 2007). Pakistan spends most of its foreign exchange on the import of edible oil which is second after mineral oil. Increasing population augmented demands of oil during last two decades with slow domestic production need to be addressed. In the current situation, local oilseed production meets only 27% of edible oil requirements while the rest 73% is met through imports (FAO 2019).

Oilseeds in Pakistan are classified into traditional and non-traditional crops. Traditional crops include mustard, rapeseed, sesame, cottonseed and groundnut while non-traditional oilseed crops are soybean, safflower and sunflower. Among the non-traditional oilseed crops, sunflower is contributing a lot to minimize the gap between production and imports (Khan et al. 2017). Sunflower (*Helianthus annuus* L.) is a non-traditional oilseed crop in Pakistan, belongs to the family *Composite* with chromosome number 34 (2n). Globally, sunflower ranks 4th in the oilseed industry. Russia, Ukraine, Argentina, China, India and USA are the major countries of sunflower cultivation

(FAO 2019). Its oil is also called health-promoting oil with a rich source of vitamin A, D, E and K (Samanta et al. 2016). Sunflower seeds contain oil (25–48%), protein (20–28%), linoleic acid (72%) and oleic acid (16.2%) (Farhatullah and Khalil 2006; Hasanuzzaman et al. 2013). Sunflower is a rain-fed crop and high temperature is the major problem for its stable yield potential (Samanta et al. 2016). Villalobos and Ritchie (1992) reported that heat stress at the seedling phase results in stunted growth of the sunflower plant. Chimenti et al. (2001) reported that 25 °C is the ideal temperature for the growth and development of sunflower but if temperature increases to 27 °C then it will reduce the growth of plants. Amutha et al. (2007) reported that high-temperature stress harms the developmental and physiological processes of sunflower crops while Prasad et al. (2008) reported that heat stress reduces head size and achene yield which ultimately reduce the oil content in sunflower. All growth stages of plants badly affected by heat stress result in low germination or failed germination (Hall 1992; Hedhly 2011; Hwang et al. 2014; Kafi et al. 2000; Kalyar et al. 2014; Wahid 2007).

To cope with the adverse effect of heat stress some agronomic practices have been reported like sowing dates, plant density, foliar applications of nutrients and seed treatments. Early sowing of sunflower under field conditions with medium plant density helps in avoidance of terminal heat stress (Bange et al. 1998; Barros et al. 2004; de la Vega and Hall 2002; Flagella et al. 2002). As aforementioned agronomic practices allied with high cost and labor that's why the economical approach to cope with heat stress is to develop heat resistant varieties or identify existing germplasm that can perform better under targeted environments. To reach this aim it is important to check genetic diversity among available germplasm. The objective of this study was to explore genetic diversity among sunflower genotypes and to identify heat resistant genotypes by $G \times E$ interaction.

Materials and methods

To check the performance of hybrids under normal and terminal heat stress conditions an experiment was conducted at the research farms of the College of Agriculture, University of Sargodha, Pakistan. Twenty-eight (28) sunflower hybrids were collected from National Agriculture Research Center (NARC) Islamabad (Table 1). These hybrids were sown in field conditions under two factors factorial Randomized Complete Block Design (RCBD) in triplicate using plot size (5×3 m^2) per genotype per replication. Seeds of each hybrid were planted in 4 rows having a length of 5 m by maintaining plant to plant distance of 25 cm and row to row distances 75 cm. Normal springs sowing of sunflower hybrids was done in February 2019 and late spring sowing was done one month later than normal sowing i.e. at the end of March 2019. Seed planting was done on a raised bed of 75 cm consecutively to expose the hybrid's reproductive growth cycle to the high

Table 1: List of sunflower hybrids used in the study under normal and heat-stressed environments.

Sr. No	Name of Hybrid	Sr. No	Name of Hybrid
1	SF-18003	15	SF-19003
2	SF-18005	16	SF-19004
3	SF-18009	17	SF-19005
4	SF-18019	18	SF-19008
5	SF-18020	19	SF-19010
6	SF-18035	20	SF-19012
7	SF-18045	21	SF-19015
8	SF-18060	22	SF-19019
9	SF-18070	23	SF-19021
10	SF-18080	24	SF-19025
11	SF-18090	25	SF-19028
12	SF-18100	26	SF-19030
13	SF-19001	27	SF-19033
14	SF-19002	28	SF-19036

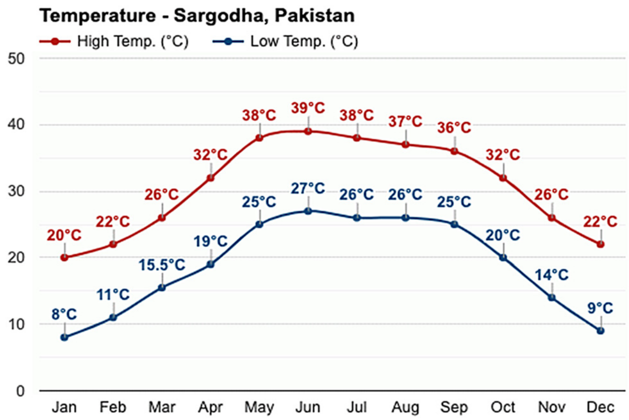

Figure 1: Mean temperature during the crop season year-2019.

temperature of May-June to observe differences in achene yield and yield-related traits (Figure 1). The crop was irrigated from canal water to avoid the water stress condition when soil moisture contents were below the field capacity. At the proper stage plant data were recorded on five randomly selected plants for days to 100% flowering, stem girth (cm), head diameter (cm), 100-achene weight and oil contents (%). Oil was extracted from dried sunflower seeds by crushing them in a blender and then subjected to cold pressing and Soxhlet extraction. For the Soxhlet method, the well-crushed seed samples were placed in a paper thimble and fed to a Soxhlet extractor which was fitted with a 500 mL round bottom flask and a condenser. The oil was extracted by using n-hexane (as an extracting solvent) on a water bath for 8 h. After extraction, the extra hexane was distilled off under vacuum in a rotary evaporator at 45 °C. After oil extraction oil content% was calculated by the following formula:

Oil content (%) = (W1 − W2)/W2 × 100
W1 = sample weight before loading over soxhlet
W2 = sample weight after loading over soxhlet

After data has been recorded, mean data of traits were subjected to analysis of variance so that our results were verified according to Steel et al. (1997). Significant variation among genotypes, environment and their interactions for yield contributing traits were compared by using the least significant differences (LSD) test at a 5% level of probability. Correlations analysis was performed by using the Mstat C programme (Bricker 1991).

Results and discussion

Analysis of variance

Analysis of variance (ANOVA) revealed highly significant results ($p \le 0.001$) for Environment (E), Genotypes (G) and $G \times E$ interaction for all the parameters except

Table 2: Mean Square Table for different yield contributing traits in sunflower hybrids.

Traits	S.O.V	D.F	S.S	M.S	% Total variation
Days to 100% flowering	R	2	385.0	192.5	4.2
	E	1	6265.9	6265.9[a]	68.9
	G	27	901.8	33.4[a]	9.9
	$G \times E$	27	1536.1	56.9[a]	16.9
Stem girth	R	2	1.7	0.9	0.2
	E	1	337.2	337.2[a]	49.9
	G	27	148.4	5.5[a]	22.0
	$G \times E$	27	188.8	6.9[a]	28.0
Head diameter	R	2	6.4	3.2	0.2
	E	1	40.3	40.3[a]	1.0
	G	27	2212.6	81.9[a]	56.7
	$G \times E$	27	1641.8	60.8[a]	42.09
100 achene weight	R	2	0.7	0.4	0.001
	E	1	39566.2	39566.2[a]	53.9
	G	27	13041.4	483.0[a]	17.8
	$G \times E$	27	20739.8	768.1[a]	28.3
Oil content	R	2	3.6	1.8	0.3
	E	1	533.0	533.0[a]	46.4
	G	27	598.6	22.2[a]	52.2
	$G \times E$	27	12.4	0.5[NS]	1.1

[a] = Significant at $p \le 0.01$, [b] = $p \le 0.05$, NS = Non-significant.

interaction for oil content (Table 2). The performance of genotypes always depends on the environment provided to them during their growth and development. Hence, interaction plays a major role in the performance of the genotypes. Percentage of the total sum of the square used as a per cent variation contributed by each source of variation for a trait (Table 2). Values for replication (R) ranged from 0.001 to 4.2%. It has been noticed that replication values are less than all other sources of variations reflecting that variation in the experiment is because of other sources. Values for the environment (E) ranged from 1.0 to 68.9% while, an environment highly affects the performance of days to 100% flowering and 100 achene weight than other traits. In the case of genotypes (G) as a source of variation values ranged from 9.9 to 56.7% while for interaction ($G \times E$) it ranged between 1.1 and 42.1%. The overall environment and its interaction is a major source of variation in all the traits except Oil content.

$G \times E$ interaction

Days to 100% flowering

The number of days to 100% flowering is an important trait in the determination of early maturing sunflower hybrids and seed production in heat stress conditions. Sunflower growth stages affect by some factors such as planting time and day length which affect maturity. Genotypic mean values for days to 100% flowering ranged from 38.3 to 46.2 days however, the mean of $G \times E$ interaction ranged from 26.7 to 51.3 days. Genotype SF-19001 and SF-18100 has taken minimum and maximum days to 100% flowering, respectively. It was also noticed on average all genotypes took minimum days (36.2) for flower completion under normal conditions but when terminal stress was introduced on the same genotypes they completed their flowering in 48.4 days (Table 3). Under normal conditions genotype, SF-19001 (26.7) took minimum days for flower completion while SF-18090 completed flowering in 45 days. But after the application of terminal stress, this ranking changed. Minimum days to flowering was taken by SF-19003 (44.7 days) while the maximum for SF-19015 (51.3 days). It has been noticed that the flowering and reproduction phase is highly sensitive to terminal heat stress and it reduces crop productivity and quality in sunflowers (Dong et al. 2007; Hedhly 2011; Hwang et al. 2014; Kalyar et al. 2014; Khan et al. 2017). However, adverse effect of terminal heat stress was also reported in cereals as it causes late flowering and yield reduction (Saha et al. 2010). Our results are following Khan et al. (2017) and Kholghi et al. (2011) who reported the same types of research findings in their sunflower experiments. They also reported that the environment has a strong influence on sunflower genotypes, which change the performance of genotypes

Table 3: Mean performance of sunflower genotypes for Days to 100% flowering as affected by the environment.

	Genotypes	Normal condition	Stressed condition	Means
1	SF-18003	38.3	45.7	42.0
2	SF-18005	40.7	47.3	44.0
3	SF-18009	42.0	48.3	45.2
4	SF-18019	42.3	49.3	45.8
5	SF-18020	40.0	47.0	43.5
6	SF-18035	40.0	46.7	43.3
7	SF-18045	41.7	48.7	45.2
8	SF-18060	40.0	45.7	42.8
9	SF-18070	42.0	47.3	44.6
10	SF-18080	42.0	46.0	44.0
11	SF-18090	45.0	45.7	45.3
12	SF-18100	43.0	49.3	46.2
13	SF-19001	26.7	50.0	38.3
14	SF-19002	31.0	49.7	40.3
15	SF-19003	32.3	44.7	38.5
16	SF-19004	30.7	50.0	40.3
17	SF-19005	31.0	47.7	39.3
18	SF-19008	32.0	49.0	40.5
19	SF-19010	31.3	47.7	39.5
20	SF-19012	35.0	49.3	42.2
21	SF-19015	38.0	51.3	44.7
22	SF-19019	28.0	50.0	39.0
23	SF-19021	33.0	51.0	42.0
23	SF-19025	34.7	50.0	42.3
25	SF-19028	30.3	49.0	39.7
26	SF-19030	33.7	50.0	41.8
27	SF-19033	35.3	50.0	42.7
28	SF-19036	33.3	49.0	41.3
	Means	36.2	48.0	

Genotypes $LSD_{0.05}$ = 0.021 Environment $LSD_{0.05}$ = 1.032 $G \times E$ $LSD_{0.05}$ = 0.234.

under different environmental conditions. Hedhly et al. (2009) and Arshad et al. (2010) observed that the flowering and reproduction phase is highly sensitive to terminal heat stress, which reduces productivity.

Stem girth

Stem girth is an important plant trait of sunflowers because it supports plant stem and determines lodging resistance. Stem diameter shows a positive association with achene weight and overall seed yield. Regarding mean values for stem girth data varied between 8.3 and 12.2 cm (Table 4). Values for $G \times E$ interaction ranged from 6.0 to 15.1 cm. Stem girth was found minimum for SF-19015 while, maximum for SF-19036. Overall, it was observed that under terminal stress conditions stem girth increased (11.5 cm) than normal condition (8.6 cm) condition. Under normal conditions, two genotypes revealed minimum (6.0 cm) stem girth i.e. SF-19015 and SF-190001. While, maximum (10.7 cm) stem girth was noticed in genotype SF-18035, SF-18100 and SF-19036. Terminal stress showed that SF-18003(8.4 cm) has a minimum while SF-18080 (15.1 cm) has maximum stem girth (Table 4). Our

Table 4: Mean performance of sunflower genotypes for Stem Girth (cm) as affected by the environment.

	Genotypes	Normal condition	Stressed condition	Means
1	SF-18003	9.0	8.4	8.7
2	SF-18005	9.7	9.8	9.7
3	SF-18009	8.7	10.1	9.4
4	SF-18019	7.0	12.1	9.6
5	SF-18020	8.3	10.8	9.6
6	SF-18035	10.7	10.6	10.6
7	SF-18045	9.3	10.1	9.7
8	SF-18060	9.7	10.6	10.1
9	SF-18070	9.7	10.6	10.1
10	SF-18080	9.0	15.1	12.2
11	SF-18090	9.0	10.7	9.8
12	SF-18100	10.7	11.2	10.9
13	SF-19001	6.0	11.6	8.8
14	SF-19002	6.3	11.3	8.8
15	SF-19003	10.3	10.3	10.3
16	SF-19004	8.0	13.3	10.7
17	SF-19005	8.7	12.6	10.6
18	SF-19008	10.3	11.1	10.7
19	SF-19010	7.0	12.4	9.7
20	SF-19012	7.3	10.7	9.0
21	SF-19015	6.0	10.6	8.3
22	SF-19019	6.3	11.9	9.1
23	SF-19021	7.7	13.2	10.4
23	SF-19025	8.3	12.4	10.4
25	SF-19028	8.3	12.6	10.4
26	SF-19030	10.3	12.4	11.4
27	SF-19033	9.0	11.1	10.1
28	SF-19036	10.7	13.6	12.1
	Means	8.6	11.3	

Genotypes $LSD_{0.05} = 1.231$ Environment $LSD_{0.05} = 1.032$ $G \times E$ $LSD_{0.05} = 0.012$.

findings confirm with Dong et al. (2007) and Habib et al. (2006). They stated that under terminal stress conditions increase in stem girth was observed in sunflower for those genotypes which can withstand stress. They further stated that stem girth is positively genetically correlated with 100 seed weight, seeds per plant and seed yield. Karasu et al. (2010) also observed stem girth in the range of 3–11 cm in most of the sunflower under their studies. However, our findings are in contradiction with (Arshad et al. 2010; Buriro et al. 2015) explored that drought stress reduces stem girth while Hedhly (2011) stated that reduction in stem girth under water stress is because of slow radial growth of the stem.

Head diameter

Head diameter is an important yield contributing trait which affects both the number of seeds and seed size. Considering head diameter, mean values ranged between 13.3 (SF-18003) to 29.6 cm (SF-19028), interaction means ranged between 8.3 (SF-18005) to 31.4 cm (SF-19028) (Table 5) while most of the genotypes were exposed with maximum head diameter. Mean values for head diameter under normal conditions was 21.6 cm while under terminal stress it increases up to 22.5 cm. It has been observed that under terminal stress conditions head diameter and yield in sunflower decreases (Dong et al. 2007; Hedhly 2011; Hwang et al. 2014; Kalyar et al. 2014; Khan et al. 2017) but our findings exposed that under stress condition genotypes performed well which revealing that genotypes used under-study has strong genetic makeup.

100-achene weight

A hundred achene weight is an important yield contributing trait in sunflowers because it directly affects seed yield. Mean values for 100-achene weight varied between 18.9 and 57 g. While $G \times E$ interaction values ranged between 7.1 and 103.3 g. Genotype SF-18045 gained minimum and SF-19028 showed maximum weight. Overall, 100-achene weight was decreased (17.1 g) under stress conditions than normal (47.7 g) (Table 6). Under terminal stress conditions achene weight decreases along with a decrease in head size in sunflowers (Farhatullah and Khalil 2006; Khan et al. 2017; Khokhar and Murray 2006). Our results revealed that because of favorable environmental conditions and the broad genetic base of hybrids, the performance of genotypes was notable for 100-achene weight. Khokhar and Murray (2006) stated

Table 5: Mean performance of sunflower genotypes for Head Diameter (cm) as affected by the environment.

	Genotypes	Normal condition	Stressed condition	Means
1	SF-18003	18.0	8.7	13.3
2	SF-18005	19.4	8.3	13.9
3	SF-18009	19.3	24.0	21.6
4	SF-18019	16.6	31.0	23.8
5	SF-18020	21.1	19.3	20.2
6	SF-18035	18.9	21.7	20.3
7	SF-18045	19.6	22.3	21.0
8	SF-18060	18.7	23.3	21.0
9	SF-18070	19.4	24.7	22.1
10	SF-18080	19.5	26.3	22.9
11	SF-18090	17.3	24.0	20.7
12	SF-18100	21.9	21.7	21.8
13	SF-19001	18.7	25.7	22.2
14	SF-19002	19.9	19.0	19.4
15	SF-19003	30.3	25.7	28.0
16	SF-19004	16.7	22.0	19.3
17	SF-19005	29.2	17.7	23.4
18	SF-19008	25.3	23.0	24.2
19	SF-19010	20.8	16.7	18.7
20	SF-19012	18.3	22.0	20.2
21	SF-19015	23.9	29.7	26.8
22	SF-19019	15.3	23.0	19.2
23	SF-19021	21.6	24.3	22.9
23	SF-19025	22.0	22.3	22.2
25	SF-19028	31.4	27.7	29.6
26	SF-19030	21.8	30.3	26.1
27	SF-19033	29.1	23.0	26.1
28	SF-19036	29.4	24.0	26.7
	Means	21.6	22.5	

Genotypes $LSD_{0.05} = 0.221$ Environment $LSD_{0.05} = 0.341$ $G \times E$ $LSD_{0.05} = 0.471$.

that terminal stress has negative impacts on achene yield as drought conditions promote pollen sterility and less achene in sunflowers. Farhatullah and Khalil (2006) and Kholghi et al. (2011) also observed a reduction in achene weight under a drought stress condition when imposed at early developmental stages in sunflower. Jabari et al. (2007) observed that under drought stress conditions 83% yield reduction in sunflower is possible.

Table 6: Mean performance of sunflower genotypes for the 100-achene weight (g) as affected by the environment.

	Genotypes	Normal condition	Stressed condition	Means
1	SF-18003	29.1	20.2	24.7
2	SF-18005	31.2	21.7	26.4
3	SF-18009	32.2	37.9	35.1
4	SF-18019	23.6	37.9	30.7
5	SF-18020	30.4	23.7	27.1
6	SF-18035	28.2	19.3	23.8
7	SF-18045	29.0	8.8	18.9
8	SF-18060	31.4	15.7	23.5
9	SF-18070	28.2	21.5	24.9
10	SF-18080	28.6	8.6	18.6
11	SF-18090	28.8	7.1	17.9
12	SF-18100	33.2	11.1	22.2
13	SF-19001	66.3	10.8	38.6
14	SF-19002	50.0	13.0	31.5
15	SF-19003	58.3	15.2	36.8
16	SF-19004	55.7	12.9	34.3
17	SF-19005	58.0	11.6	34.8
18	SF-19008	60.7	19.4	40.0
19	SF-19010	63.3	19.3	41.3
20	SF-19012	69.7	14.5	42.1
21	SF-19015	60.7	15.8	38.2
22	SF-19019	51.0	14.3	32.6
23	SF-19021	64.7	9.9	37.1
23	SF-19025	64.3	11.0	37.7
25	SF-19028	103.3	10.7	57.0
26	SF-19030	42.7	19.0	30.8
27	SF-19033	52.7	21.7	36.8
28	SF-19036	62.0	26.0	44.0
	Means	47.7	17.1	

Genotypes $LSD_{0.05}$ = 0.356 Environment $LSD_{0.05}$ = 0.013 $G \times E$ $LSD_{0.05}$ = 1.021.

Oil contents (%)

Oil contents is an important trait of sunflower hybrids because it determines the acceptability of hybrid for its general cultivation due to the high concentration of edible oil in the seed. Oil formation starts after several days of embryo development due to this reason very small amount of oil is deposited during the first third stage of the seed filling period. Mean values for the current study for oil content ranged from 29.1 to 37.3%. Regarding interaction data ranged between 27.0 and

39.2%. However minimum oil content was observed for SF-19030 while the maximum for SF-19033 (Table 7). Overall oil content reduced from 35.6% (normal condition) to 32.1% (a terminal stress condition) revealing the negative impact of terminal stress on oil content. Researchers reported that when drought stress is imposed on different stages in sunflower crop it adversely affect the root system and morphological traits which ultimately reduce oil content (Farhatullah and Khalil 2006; Khan et al. 2017; Khokhar and Murray 2006; Kholghi et al. 2011). Bakht et al. (2010) found that under optimum water conditions maximum oil content found in achene while under drought stress oil content decreases according to the

Table 7: Mean performance of sunflower genotypes for Oil content (%) as affected by the environment.

	Genotypes	Normal condition	Stressed condition	Means
1	SF-18003	36.3	33.6	34.9
2	SF-18005	35.7	32.9	34.3
3	SF-18009	36.9	33.3	35.1
4	SF-18019	34.5	31.7	33.1
5	SF-18020	36.1	32.7	34.4
6	SF-18035	38.4	34.1	36.3
7	SF-18045	36.2	31.6	33.9
8	SF-18060	35.6	31.1	33.3
9	SF-18070	35.6	32.7	34.1
10	SF-18080	32.0	28.1	30.0
11	SF-18090	37.5	33.5	35.5
12	SF-18100	36.9	33.5	35.2
13	SF-19001	32.8	29.8	31.3
14	SF-19002	35.4	31.3	33.4
15	SF-19003	32.3	28.4	30.4
16	SF-19004	36.7	33.6	35.2
17	SF-19005	34.3	31.7	33.0
18	SF-19008	34.5	31.5	33.0
19	SF-19010	35.8	32.7	34.2
20	SF-19012	35.4	31.8	33.6
21	SF-19015	34.2	31.1	32.6
22	SF-19019	37.2	34.0	35.6
23	SF-19021	34.5	30.6	32.5
23	SF-19025	37.5	33.6	35.5
25	SF-19028	37.5	33.6	35.6
26	SF-19030	31.2	27.0	29.1
27	SF-19033	39.2	35.5	37.3
28	SF-19036	37.5	33.3	35.4
	Means	35.6	32.1	

Genotypes $LSD_{0.05}$ = 0.137 Environment $LSD_{0.05}$ = 1.201 $G \times E$ $LSD_{0.05}$ = N.S.

Table 8: Correlation of oil content with yield contributing traits in sunflower as affected by environments.

Traits	Correlation of oil content with other traits
Days to 100% flowering	0.2[b]
Stem girth	0.1[b]
Head diameter	0.7[b]
100 achene weight	0.2[b]

[a] = Significant at $p \leq 0.01$, [b] = significant at $p \leq 0.05$.

severity of drought. Moreover, it also reduces the quality of the oil by reducing protein content (Hassan et al. 2010). According to Tabatabaei et al. (2012) yield and its contributing parameters are affected by drought stress.

Correlation

A correlation study figures out the nature of the association between traits. Oil content is the outcome of many interconnected traits hence, it is a polygenic metric trait therefore, to improve the quality and quantity of oil in sunflower it is important to study correlation among yield contributing traits. It is distinct from present results (Table 8) that oil content (%) is positively significantly correlated with days to 100% flowering ($r = 0.2^*$), stem girth ($r = 0.1^*$), head diameter ($r = 0.7^*$) and 100 achene weight ($r = 0.2^*$). As flowering is a crucial phase in the growth and development of sunflowers, therefore, if flowering takes proper time then it will lead to a big size head and more numbers of achene on it which ultimately contributes to an increase in oil content. Moreover, sunflowers with strong and wide stems are lodging resistant and hence improve the yield of the crop. Therefore, the aforementioned positively correlated traits reveal that these traits can be improved altogether along with improvement in oil content. Our results are supported by Safavi et al. (2015), Razzaq et al. (2014), Ilahi et al. (2009), Moorthy (2004), Chikkadevaiah et al. (2002) and Sasikala (2000). Results depicting that to improve quality and quantity of oil content selection pressure should be imposed on days to 100% flowering, stem girth, head diameter and 100 achene weight.

Conclusions

Based on observation, it was determined that interaction between genotype and environment has a significant role in the expression of a trait. Genotype SF-19033 and SF-19028 performed best under terminal stress conditions for yield contributing traits and adoptable under the environmental conditions of Sargodha-Punjab.

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