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RESEARCH ARTICLE

Investigation on the genotype and environmental relationships on yield and its components in sunflower (*Helianthus annuus* L.) in eastern region of Türkiye

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Abstract

Since sunflower oil is popular cooking oil around the world, the demand for sunflower oil has been increasing recently. The investigation wsas carried out to study the interaction of diverse cultivars with environmental factors on sunflowers' yield components (*Helianthus annuus* L.). The seed yield and its components significantly varied depending on the variety and location. The maximum seed yield (3700.5 kg ha^{-1}) was recorded from Erzurum region in Bosfora cultivar while the minimum seed yield (3450.8 kg ha^{-1}) was obtained from Igdır region in Tunca cultivar. Correspondingly Tunca gave a maximum (1620.0 kg ha^{-1}) oil yield in Igdır region and a minimum (1550.6 kg ha^{-1}) oil yield in Erzurum region. Correlations among seed yield and plant height, head diameter, 1000-seed weight, hectoliter weight, oil concentration and oil yield also showed differences with regards to statistical significance and value at both locations as per the environmental conditions that influenced the individual traits. The results suggested the selection of suitable genotypes must consider the type of soil, local climate, and environmental conditions, which play an important role in oil concentration and seed yield of sunflower. The identified genotypes with high yield and oil content could be used in a breeding programme for the enhancement of genetic potential in sunflowers.

Keywords: Correlation, altitude, location, sunflower, oil content, seed yield.

Introduction

Very few numbers of plant species can be grown economically in arid and semi-arid regions because of irregular and low precipitation (Fiebig et al. 2002). Sunflower (Helianthus annuus L.) is an important oil plant that can adapt to adverse conditions. It is an oil plant that is increasingly gaining significance worldwide through its major adaptation ability, suitability for industrial puposes, and capacity to grow in dry and moist conditions. The sunflower is being cultivated worldwide mostly in Russia, Ukraine, Argentina, Romania, China and USA in about 26 million hectares with total oil production of about 57.32 million metric tones contributed by Russia (16.5 mt) followed by 10 mt by Ukraine (www.statista.com; www.latifundist.com). However, Srbia has the highest productivity level of 3.0 t/ha compared to Turkiye, which stands at 1.9 t/ha. In 2019, Russia ranked first in total sunflower production with a share of 32.1% and Ukraine ranked second with a share of 24.6%.

Sunflower is necessary to fulfill the vegetable oil deficit both in Turkey and in the world. For this reason, it is necessary to increase the production level of sunflower oil to meet the demand for vegetable oil. Although sunflower is tolerant to drought, it is essential to identify varieties that are compatible with climate change. Besides conventional breeding, hybrid breeding assisted by molecular breeding in sunflowers is a good option to enhance the genetic potential of oil and seed yield (Seiler et al. 2017; Babych et al. 2021). Although sunflower has high adaptability, the response of varieties to different ecologies can be different, and accordingly, their yield and yield components may change. Due to global warming and unexpected climatic changes in recent years, the spring crop sunflower is affected severely

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by these climatic conditions in the vegetative stage and loses seed yield (Pekcan et al. 2022). Therefore, sunflower's seed and oil yield may vary significantly depending on the region and genotype. In order to obtain a high yield per unit area, varieties with high yield potential should be preferred and cultivated under appropriate climatic conditions using suitable agronomic practices (Sefaoglu et al. 2021). The oil yield in sunflowers is determined by the grain yield, which is highly affected by environmental factors, and the oil ratio with high genetic-environment interaction. It is, therefore, very important to determine the suitable cultivation techniques considering climate and soil factor for each variety by testing the yield and its component characteristics under the given environment. Since these factors do not come under human control, the selection of varieties suitable for the ecological conditions of the region becomes most important.

Studies conducted on the effects of ecological factors on the growth and development of any species reduce yield and allow the selection of varieties suitable for the cultivation in particular regions (MarjanovićJeromela et al. 2011). Previous studies have indicated significant differences between varieties in plant height, seed yield and oil ratio (Alem et al. 2016; Joshan et al. 2019; De Faria et al. 2015) in different locations with divesre ecological conditions to determine the seed yield and oil ratio. Khoufi et al. (2013) and Gul and Çoban (2019) have also reported similar findings concerning morphological and phenological variations concerning genotypic performance. Sunflower is first among the oil plants that can be grown in Erzurum and Igdir regions of Turkiye. Most of the cultivated varieties or elite genotypes in these two locations are currently in cultivation. Therefore, it is important to determine the adaptability of the newly developed productive and high-quality varieties. This study aimed at the evaluation of different sunflower genotypes for their potential seed yield and the genotype×location×year interaction (G×L×Y) at two different locations in Eastern Anatolia region of Turkiye.

Materials and methods

Experimentation and materials used

In the present study a set of 10 cultivars, namely, P4ll62, Coral, Cadix, Lg 5582, Bosfora, Tunca, Pactol, Tarsan 1018, Dkf2525 and 08Tr003 was evaluated in randomized block design using four replications and two locations (Erzurum and Igdır) were evaluated to identify stable genotypes of sunflower (*Helianthus annuus* L.). The planting was done by hand in the field at Erzurum on 15 May 2016 and 18 May 2017, and in Igdır on 19 April 2016 and 22 April 2017 keeping 70 cm row spacing and 30 cm row spacing, respectively with 4 rows in each plot. Each plot had a length of 4 m at 1 m apart and 2 m distance among the blocks. The application of 80 kg ha^{-1} P_2O_5 prior to sowing, and half of the nitrogenous fertilizer (50 kg ha^{-1}, Ammonium sulfate) was was done just before planting and the residual half was applied when plants are 15-20 cm tall. Experimental plots were irrigated folllowing furrow irrigation method for 3 times in Erzurum and 4 times in Igdır, especially during the flowering period.

The plants were harvested by hand in Erzurum on 21 September 2016 and 1 October 2017, and in Igdır on 12 August 2016 and 14 August 2017. The data on plant height, head diameter, 1000 seed weight, seed yield, seed oil concentration and seed oil yield were recorded per plot (two middle rows) after removing the side rows and the area in the beginning and at the end of plots. The plants harvested were dried and threshed by a threshing machine.

Climatic and soil data of Erzurum and Igdır regions

The study was carried out in Erzurum (altitude:1663 m; location: 39° 97′ N, 41° 67 E) and Igdır (altitude: 851 m; location: 39° 55′ N, 44° 2′ E) provinces in 2016-2017 in eastern Anatolia region. In Erzurum, the summers are short and the winter season is long. Iğdır differs with regard to natural environmental factors such as climate, soil properties and vegetation. Igdır is one of the largest plains of Turkey with a difference in microclimate in the eastern Anatolia region, where cold climate prevails with a moderate warmness. The average temperatures, precipitation and yield per plot during 2016 and 2017 at Igdır and Erzurum locations is depicted in Fig. 1 and Table 1.

Oil determination and statistical analysis

The oil yield was determined from seed samples taken from each plot using the Trakya Agricultural Research Institute Laboratory NMR device. The total amount of oil in the samples was determined proportionally according to TS 9059 EN ISO 5511 using the "Continuous Wave Low Separation Power Nuclear Magnetic Resonance Spectrometric Method" (Fiebig and Lüttke 2003; Rodrigues et al. 2005).

The data recorded over two years of experimentation were subjected to Analysis of Variance using the JMP

Table 1. The soil properties of the experimental areas

Location	Years	Saturation %	pH	EC ds/m	Ca %	Organic Mat. (%)	Phosph. kg ha^{-1}	Potassium kg ha^{-1}
Erzurum	2016	50	7.10	5.82	0.18	1.21	50.59	1360
	2017	48	7.20	5.94	0.21	1.24	50.63	1500
Igdır	2016	53	7.55	3.40	0.45	1.35	60.84	2730
	2017	48	7.98	3.10	0.48	1.38	60.67	2430

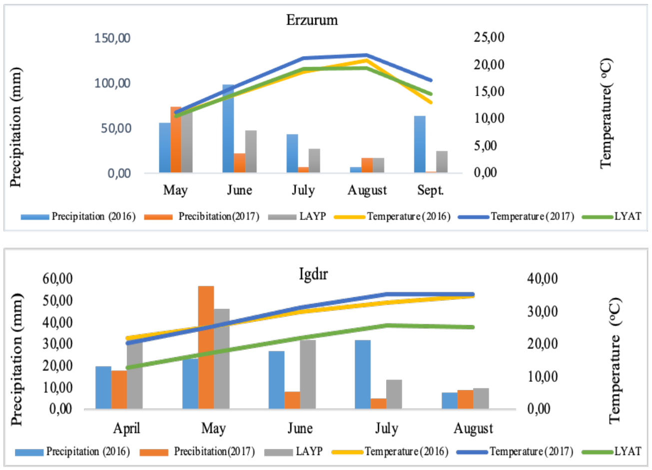

Fig. 1. Climate data of the study places locations for long term average 2016 and 2017

software package (5.0.1, SAS Institute 2002). The significant differences between the treatments were compared and grouped at the probability level of 5% using Duncan Multiple Comparison Test.

Results and discussion

The yield and yield components analysis showed significant differences among varieties, locations, and years (p<0.01). Plant height is an index that shows vegetative growth and the analysis showed all the parameters had significant effects on plant height (Table 2). The varieties were found to have higher average plant heights at Erzurum (143.6 cm) ranging from 133.6 to 161.2 cm as compared to Igdır (130.1 cm) with a range between 111.3 and 144.7 cm. The genotype Coral displayed the highest plant height (161.2 and 147.7 cm) at Erzurum and Igdır, respectively, whereas Tarsan 1018 showed the shortest (133.6 and 112.4 cm). Although the genotypes Bosfora and Tunca showed different results in different locations, it was determined that these genotypes had the values close to the average at both the locations. The plant height is determined by genetic constitution of a variety; however, it is affected by ecological factors and cultural practices (Adugna and Labuschagne 2003). Also the plant height is quantitatively inherited trait and variation in plant height have earlier been reported from different

Table 2. Plant height and variance analysis results of sunflower genotypes grown in Erzurum and Igdır conditions

Cultivars		Plant Height (cm)						General Mean
		Erzurum			Iğdır			
		2016	2017	Mean	2016	2017	Mean	
P4 II 62		147.7 ± 0.77de	138.3 ± 2.44bc	142.9 ± 2.14e	123.6 ± 2.44f	132.8 ± 0.77c	128.2 ± 2.11fg	135.6 ± 2.39d
Coral		173.3 ± 1.21a	149 ± 0.9a	161.1 ± 4.65a	133.4 ± 0.86d	156.1 ± 1.21a	144.7 ± 4.35a	152.9 ± 3.73a
Cadix		146.5 ± 0.92e	125.2 ± 0.68f	135.8 ± 4.06f	132.0 ± 0.68de	137.9 ± 0.92b	134.9 ± 1.22b	135.4 ± 2.05d
Lg 5582		138.8 ± 0.44g	134.0 ± 0.75de	136.4 ± 0.99f	131.2 ± 0.75de	134.6 ± 0.44bc	132.9 ± 0.76c	134.7 ± 0.75d
Bosfora		162.9 ± 0.93b	151.0 ± 1.29a	156.9 ± 2.36b	136.6 ± 0.93c	121.9 ± 1.29d	129.3 ± 2.87ef	143.1 ± 4.00b
Tunca		164.2 ± 0.75b	139.1 ± 1.39b	151.7 ± 4.80c	140.1 ± 0.75b	122.3 ± 1.39d	131.2 ± 3.43cd	141.4 ± 3.88b
Pactol		158.5 ± 0.54c	135.5 ± 0.97cd	147 ± 4.37d	144.7 ± 0.54a	116.4 ± 0.97e	130.6 ± 5.36de	138.7 ± 3.96c
Tarsan1018		148.7 ± 0.69d	118.4 ± 1.63g	133.5 ± 5.78g	125.0 ± 0.69f	97.6 ± 1.63f	111.3 ± 5.23h	122.4 ± 4.73f
Dkf2525		142.7 ± 0.81f	127.1 ± 1.30f	134.9 ± 3.02fg	138.0 ± 0.81bc	122.5 ± 1.31d	130.3 ± 3.02de	132.6 ± 2.15e
08tr003		140.1 ± 0.84g	131.2 ± 0.87e	135.7 ± 1.76f	130.2 ± 0.84e	123.6 ± 0.88d	126.9 ± 1.37g	131.3 ± 1.56e
Mean		152.3 ± 1.78a	134.9 ± 1.58b	143.6 ± 1.54a	133.5 ± 1.04a	126.6 ± 2.34b	130.0 ± 1.33b	136.8
Variation Sources	SD			P>F				
Year (Y)	1			337.49**			50.41**	164.26**
Location (L)	1							8884.23**
Y x L	1							1341.30**
Genotype (G)	9	548.08**	71.56**	240.53**	76.79**	216.94**	166.39**	179.27**
Y x G	9			42.64**			171.77**	76.43**
L x G	9							377.43**
Y x L x G	9							316.12**

ns = not significant, * significant at the level of 0.05, ** significant at the level of 0.01. Differences between values having the same letter within the same column are not significant geographical regions and diverse populations (Alem et al. 2016; Polat et al. 2017; Sefaoglu and Kaya 2018).

One of the significant yield components for sunflower is the head diameter. It is also affected by genotype, agricultural practices, soil type and ecological factors. The major objective of sunflower breeding is to get a larger head diameter as it is expected to produce higher number of seeds. The present study indicated that locations, interactions of year x location, year x genotype, and location x genotype significant effects on head diameter (p <0.01). The variation in head diameters were recorded as per tye season ranging from 17.6 and 22.3 cm at Erzurum and from 15.4 and 19.6 cm at Igdır (Table 3). The largest head diameter (22.3 and 20.9 cm, respectively) was observed from Tunca at both the locations. However, the varieties in general produced larger head diameters in Erzurum (average, 20.4 cm) as compared to Igdır (17.2 cm), which had warmer climate than Erzurum (Fig. 1). Hatfield and Prueger (2015) reported that the differences in the head diameters might be due to the lower temperature, which prolonged the crop growth period and extended the flowering time but higher temperature during hull genesis phase in arid zone. The size of head diameter is a varietal trait and based on the genetic constitution of a variety. The head diameters of sunflower varieties measured in different locations and years have been reported previously (Kaya et al. 2009; Sowmya et al. 2010; Gul and Coban 2020; Iqbal et al. 2018).

The average 1000-seed weight recorded in present study is 68.3 g at Erzurum and 62.5 g in Igdır. However a wide range of 1000-seed weights (61.7 and 77.2 g) was recorded at Erzurum as compared to 56.8 and 72.1 g in Igdır (Table 4). The differences in respect to 1000-seed weight amomng the varieties has been recorded earlier by Gul and Coban (2020) in a different set of varieties studied at different locations. The highest 1000-seed weight was recorded in 2016 with wide variation in values. However, the low rainfall was recorded in June and July during the flowering time in 2017, which might have affected the seed size. The high temperature in this period might have also caused the reduction in 1000-seed weights in 2017. The varieties, Tunca, Bosfora and Pactol produced highest 1000-seed weight in both the locations and the years. Nadh et al. (2007) reported that 1000-seed weight, which is rather under the influence of dominant genes, has less variation in comparison to other traits controlled by polygenes. The adverse climatic factors such as high temperature and lower precipitation may however, influenc the seed weight in sunflower particularly during the flowering period (Gonzalez-Barrios et al. 2017) and soil type and other ecological factors (Khan et al. 2008; Darvishzadeh et al. 2010).

Table 3. Head diameter and variance analysis results of sunflower genotypes grown in Erzurum and Igdır conditions.

		Head diameter (cm)						General Mean
Cultivars		Erzurum			Iğdır			
		2016	2017	Mean	2016	2017	Mean	
P4 ll 62		20.4 ± 0.12de	19.6 ± 0.56bc	20.0 ± 0.30b	15.8 ± 0.42cd	16.1 ± 0.37c	16.0 ± 0.26d	18.0 ± 0.55cd
Coral		20.1 ± 0.58de	19.4 ± 0.26bc	19.7 ± 0.32b	15.2 ± 0.58ce	15.7 ± 0.39c	15.4 ± 0.34d	17.6 ± 0.59de
Cadix		20.6 ± 0.36de	19.9 ± 0.81bc	20.3 ± 0.43b	14.4 ± 0.56e	16.6 ± 0.82c	15.5 ± 0.62d	17.9 ± 0.71cd
Lg 5582		19.6 ± 0.26e	19.1 ± 0.43c	19.4 ± 0.25b	16.2 ± 0.26c	16.9 ± 0.89c	16.6 ± 0.45cd	18.0 ± 0.43cd
Bosfora		23.2 ± 0.62a	22.0 ± 0.67a	22.6 ± 0.47a	18.6 ± 0.69b	20.6 ± 0.63ab	19.6 ± 0.57ab	21.1 ± 0.52a
Tunca		22.5 ± 0.57ab	22.2 ± 0.56a	22.3 ± 0.37a	20.3 ± 0.47a	21.5 ± 0.73a	20.9 ± 0.46a	21.6 ± 0.34a
Pactol		21.8 ± 0.46bc	18.8 ± 0.63c	20.3 ± 0.66b	14.7 ± 0.62de	19.3 ± 0.47b	17.0 ± 0.94cd	18.7 ± 0.69c
Tarsan1018		21.1 ± 0.39cd	18.3 ± 0.75c	19.7 ± 0.65b	14.2 ± 0.75e	19.5 ± 0.57b	16.8 ± 1.09cd	18.2 ± 0.72cd
Dkf2525		23.5 ± 0.73a	20.8 ± 0.41ab	22.1 ± 0.64a	16.5 ± 0.26c	19.8 ± 0.39ab	18.2 ± 0.67bc	20.1 ± 0.67b
08tr003		19.5 ± 0.70e	15.5 ± 0.38d	17.5 ± 0.84c	16.0 ± 0.70cd	16.8 ± 0.37c	16.4 ± 0.39cd	17.0 ± 0.47e
Mean		21.2 ± 0.26a	19.6 ± 0.33b	20.4 ± 0.23a	16.2 ± 0.33b	18.3 ± 0.35a	17.2 ± 0.25b	18.80
Variation Sources	SD			P>F				
Year (Y)	1			14.96**			18.57**	0251ns
Location (L)	1							660.31**
Y x L	1							236.06**
Genotype (G)	9	13.540**	12.13**	21.46**	16.15**	17.58**	27.15**	32.26**
Y x G	9			3.78**			6.62**	1.98ns
L x G	9							9.26**
Y x L x G	9							12.21**

ns = not significant, * significant at the level of 0.05, ** significant at the level of 0.01. Differences between values having the same letter within the same column are not significant

Table 4. Thousand seed weight and variance analysis results of sunflower genotypes grown in Erzurum and Igdır conditions

Cultivars		1000 seed weight (g)						General Mean
		Erzurum			Iğdır			
		2016	2017	Mean	2016	2017	Mean	
P4 ll 62		74.0 ± 1.12c	60.8 ± 0.59ef	67.4 ± 2.56cd	50.8 ± 0.59g	64.1 ± 0.42e	57.5 ± 2.55f	62.4 ± 2.16f
Coral		61.7 ± 0.85f	60.2 ± 0.17ef	61.0 ± 0.48f	54.4 ± 0.48f	59.3 ± 1.13f	56.8 ± 1.09f	58.9 ± 0.78g
Cadix		63.1 ± 0.67ef	60.7 ± 0.39ef	61.9 ± 0.58f	56.2 ± 0.85e	56.9 ± 0.68f	58.0 ± 0.86f	59.9 ± 0.71fg
Lg 5582		68.9 ± 0.73d	62.2 ± 1.13de	65.5 ± 1.41e	60.6 ± 0.73d	66.0 ± 1.12d	63.3 ± 1.19d	64.4 ± 0.94e
Bosfora		77.8 ± 0.38b	75.4 ± 1.01a	76.6 ± 0.67ab	63.6 ± 0.33bc	71.3 ± 1.42b	67.5 ± 1.59b	72.0 ± 1.44b
Tunca		80.4 ± 0.47a	73.9 ± 0.98a	77.2 ± 1.32a	70.5 ± 0.39a	73.8 ± 0.48a	72.1 ± 0.68a	74.6 ± 0.97a
Pactol		79.9 ± 1.42a	71.0 ± 0.51b	75.5 ± 1.82b	65.3 ± 1.12b	67.5 ± 0.98cd	66.4 ± 0.80bc	70.9 ± 1.51b
Tarsan1018		69.9 ± 0.43d	64.4 ± 1.85cd	67.1 ± 1.36d	56.6 ± 1.33e	57.2 ± 0.39g	56.9 ± 0.65f	62.0 ± 1.51e
Dkf2525		72.1 ± 1.12c	65.3 ± 0.88c	68.7 ± 1.44c	63.5 ± 0.59c	68.8 ± 1.01c	66.2 ± 1.14c	67.4 ± 0.94c
08tr003		64.0 ± 1.02e	59.4 ± 1.10f	61.7 ± 1.11f	57.5 ± 1.10e	62.5 ± 1.03e	59.9 ± 1.17e	60.8 ± 0.81f
Mean		71.2 ± 1.07a	65.3 ± 0.94b	68.3 ± 0.78a	59.9 ± 0.92b	65.0 ± 0.86a	62.5 ± 0.69b	65.40
Variation Sources	SD			P>F				
Year (Y)	1			49.27**			29.80**	0.16ns
Location (L)	1							972.39**
Y x L	1							874.07**
Genotype (G)	9	97.521**	52.84**	132.60**	88.42**	90.35**	161.98**	210.17**
Y x G	9			10.51**			16.61**	5.64**
L x G	9							33.93**
Y x L x G	9							25.33**

ns = not significant, * significant at the level of 0.05, ** significant at the level of 0.01. Differences between values having the same letter within the same column are not significant

Seed yield mostly depends on the cumulative effects of several yield components under the given environmental conditions, type of the agricultural practices and the genotype. In the present study, the years, varieties, and locations had significant (p <0.01) effects on the seed yield. In addition, the effects of all the interactions were also significant, except for the interaction of location x year (Table 5). Seed yield of sunflower varieties studied showed varied response in both the locations. The mean grain yield recorded was 2970.6 kg ha^{-1} at Erzurum and 2730.8 kg ha^{-1} in Igdır. The differences may be due to type of genotypes, and the ecological conditions prevailed. The differences in yield due to the above described factors have been reported earlier by several workers (Kaleem et al. 2011; Onemli 2012; Polat et al. 2017; Marjanović-Jeromela et al. 2011; Cvejić et al. 2015). The maximum seed yield over the years was recorded by Tunca and Bosfora varieties at both the locations. The variety Bosfora had given the highest average seed yield (3700.5 kg ha^{-1}) at Erzurum, followed by Tunca (3320.7 kg ha^{-1}). On the contrary, Tunca had the highest yield (3450 kg ha-1) in Igdır, followed by Bosfora (3340.9 kg ha^{-1}). The varieties' seed yield differences can be related to the different genotypic constitutions having other favourable and desirable characteristic features (Sefaoglu and Kaya 2018). Cvejić et al. (2015) and Iqbal et al. (2018) studied different sunflower genotypes at different locations in the world have reported seed yield as high as 4028.0 kg ha^{-1} and indicated that there are great chances to enhance the genetic potential of the genotypes through concerted breeding efforts. Since yield is a quantitative characterthat is manifested by additive effect of genes. Influence of environment on growing period and yield, protein, oil and α-linolenic content of three chia (*Salvia hispanica* L.) selections (Coates 2009) and interpretation of genotype by environment interaction in sunflower experimental networks (Foucteau et al. 2011). The present study has also indicated that the sunflower genotypes are sensitive to environmental factors and, therefore, the seed yield varies according to the location and genetic structure.

The seed oil concentrations were affected by variety and location and their interaction. The oil concentration was found to be higher (400.5 g kg^{-1}) in Igdır location as compared to Erzurum (390.6 g kg^{-1}) (Table 6). This difference may be ascribed to the differences among location in terms of the soil's heat, humidity and moisture content during the seed filling period. The seed oil concentration of the sunflower differed between the varieties, and the highest seed oil concentration was recorded Tunca variety

Table 5. Seed yield and variance analysis results of sunflower genotypes grown in Erzurum and Igdır conditions.

Cultivars		Seed yield (kg ha-1)						General Mean
		Erzurum			Iğdır			
		2016	2017	Mean	2016	2017	Mean	
P4 II 62		2770.5 ± 1.03e	2270.9 ± 2.68e	2520.7 ± 3.31g	2040.9 ± 2.68gh	2430.6 ± 0.80h	2240.3 ± 7.42h	2380.5 ± 4.85h
Coral		2580.9 ± 1.49f	2550.2 ± 2.18d	2570.1 ± 3.40fg	2010.8 ± 1.52h	2360.2 ± 2.18ı	2190.0 ± 6.62ı	2380.1 ± 3.89h
Cadix		2900.6 ± 1.44e	2210.8 ± 2.62e	2560.2 ± 3.42fg	2080.9 ± 0.98g	2610.6 ± 1.44g	2350.3 ± 9.90g	2455.3 ± 5.47g
Lg 5582		3610.5 ± 1.10b	2530.9 ± 0.47d	3070.7 ± 3.87d	2300.9 ± 0.47e	3180.5 ± 1.10d	2740.7 ± 12.5d	2905.7 ± 9.47d
Bosfora		4220.2 ± 0.88a	3180.8 ± 2.86a	3700.5 ± 4.64a	2920.8 ± 2.86b	3770.2 ± 0.88b	3340.9 ± 11.02b	3520.7 ± 10.01a
Tunca		3440.9 ± 1.32c	3200.6 ± 1.88a	3320.8 ± 4.37b	2970.6 ± 1.14a	3930.9 ± 1.32a	3450.8 ± 13.51a	3385.8 ± 6.32b
Pactol		3440.8 ± 0.91c	2830.8 ± 1.15c	3140.3 ± 3.51cd	2400.9 ± 1.15d	3310.7 ± 1.21c	2860.3 ± 12.44c	3000.3 ± 7.6c
Tarsan1018		3160.2 ± 0.92d	2800.1 ± 1.21c	2980.2 ± 5.85e	2310.4 ± 1.21e	3030.2 ± 0.91f	2670.3 ± 10.57e	2825.3 ± 5.36e
Dkf2525		3370.7 ± 1.21c	3060.2 ± 2.55b	3210.9 ± 5.01c	2600.1 ± 2.55c	3130.8 ± 0.92e	2860.9 ± 8.23c	3035.9 ± 4.31c
08tr003		2790.5 ± 1.06e	2500.4 ± 1.52d	2645.9 ± 4.57f	2210.4 ± 1.52f	3050.5 ± 1.06f	2630.5 ± 11.9f	2635.8 ± 5.15f
Mean		3230.4 ± 3.45a	2710.8 ± 2.49b	2970.6 ± 5.48a	2390.1 ± 5.24b	3080.5 ± 6.54a	2735.3 ± 612b	2852.9
Variation Sources	SD			P>F				
Year (Y)	1			788.54**			2828.00**	67.47**
Location (L)	1							465.16**
Y x L	1							2999.87**
Genotype (G)	9	75.30**	145.05**	152.27**	514.35**	2531.07**	2154.72**	645.57**
Y x G	9			28.39**			153.71**	27.02**
L x G	9							22.75**
Y x L x G	9							46.49**

ns: not significant, * significant at the level of 0.05, ** significant at the level of 0.01. Differences between values having the same letter within the same column are not significant.

in Erzurum and Igdır (450.7 and 480.1 g kg^{-1}, respectively), whereas the lowest average seed oil concentration was recorded in the variety Cadix at Erzurum. However, the average seed oil concentrations were estimated in Tunca and Bosfora varieties at both locations. Many researchers have reported that the difference in oil concentration between the varieties has been was due genetic factors (Zheljazkov et al. 2008; Cvejić et al. 2015). The differences in temperature and precipitation between the years and locations significantly affected the oil content (Gul and Coban 2020), and the oil content decreased as the seed filling period was warmer (Sefaoglu et al. 2021).

The most economically important yield criterion for oil seed crops is the oil yield. The oil yield obtained from sunflower seeds in the present study varied due to year, variety and location (Table 3). All the factors and interactions were found to have affected oil yield. The highest average oil yield (1615.5 kg ha^{-1}) was recorded in the variety, Tunca at both the locations (Table 7). The average oil yield displayed a wide range from 870.2 kg ha^{-1} in Cadix to 1615.5 kg ha^{-1}in Tunca. At individual location also Tunca recorded highest mean yield (1550.6 kg ha^{-1}) at Erzurum and 1680.5 kg ha^{-1} at Igdir. Seed oil concentration is a complex trait, which is a quantitatively inherited trait and therefore additive effects play a major role in accumulation of oil in the seed. A sum of small contributions of several genes functioning in additive manner are also influenced by environment x genetic interaction (phenotype = genetic + environment). Several studies conducted earlier have also emphasized the role of the above described factors for seed oil yield and its components (Sobrino et al. 2003; Zheljazkov et al. 2008; Sefaoğlu and Kaya 2018; Gül and Coban 2019). The pootr

Table 6. Seed oil concentration and variance analysis results of sunflower genotypes grown in Erzurum and Igdır conditions

Cultivars		Seed oil concentration (g kg^{-1})						General Mean
		Erzurum			Igdır			
		2016	2017	Mean	2016	2017	Mean	
P4 ll 62		410.1 ± 1.14cd	380.9 ± 0.97c	395.5 ± 0.81cd	410.6 ± 0.70bc	470.4 ± 0.64b	440.5 ± 1.17b	420.3 ± 0.98b
Coral		370.4 ± 0.98ef	360.6 ± 0.75de	365.5 ± 0.59e	370.8 ± 0.96d	400.1 ± 0.60e	380.9 ± 0.68d	370.5 ± 0.50e
Cadix		350.3 ± 0.41f	320.5 ± 0.24g	335.4 ± 0.57f	360.6 ± 0.41d	370.4 ± 0.25f	360.9 ± 0.26e	345.9 ± 0.50f
Lg 5582		390.0 ± 0.82de	380.4 ± 0.48cd	385.2 ± 0.45d	370.8 ± 0.39d	400.6 ± 0.89de	390.2 ± 0.70cd	385.3 ± 0.41de
Bosfora		350.9 ± 0.61f	340.4 ± 0.88f	345.7 ± 0.52f	360.4 ± 0.88de	370.9 ± 0.30bf	370.1 ± 0.52e	360.15 ± 0.423f
Tunca		490.7 ± 0.87a	430.6 ± 0.43a	460.7 ± 1.23a	440.0 ± 0.75a	520.3 ± 0.57a	480.1 ± 1.63a	465.4 ± 1.01a
Pactol		410.7 ± 1.08c	370.8 ± 0.52cd	390.8 ± 0.91cd	400.7 ± 0.52c	400.1 ± 1.08e	400.4 ± 0.56c	395.6 ± 0.52c
Tarsan1018		450.8 ± 0.71b	350.0 ± 0.59ef	400.4 ± 2.08c	330.3 ± 0.61f	420.7 ± 0.71cd	380.0 ± 1.83de	390.2 ± 1.37cd
Dkf2525		440.8 ± 1.04b	400.8 ± 0.20b	420.8 ± 0.91b	430.3 ± 0.46ab	430.3 ± 1.04c	430.3 ± 0.52b	425.6 ± 0.51b
08tr003		450.2 ± 0.48b	380.8 ± 0.63c	4200 ± 1.26b	340.6 ± 0.63ef	410.2 ± 0.48de	370.9 ± 1.28de	395.5 ± 1.01cd
Mean		411.19 ± 0.75a	371.58 ± 0.51b	391.4 ± 0.51b	380.6 ± 058b	420.3 ± 0.71a	400.4 ± 0.50a	395.96
Variation Sources	SD			P>F				
Year (Y)	1			302.38**			218.89**	0.866ns
Location (L)	1							15.13**
Y x L	1							324.36**
Genotype (G)	9	30.184**	26.00**	48.9**	29.51**	38.62**	55.87**	79.93**
Y x G	9			8.54**			13.03**	2.99**
L x G	9							14.16**
Y x L x G	9							21.12**

ns = not significant, * significant at the level of 0.05, ** significant at the level of 0.01. Differences between values having the same letter within the same column are not significant

rainfall in the season and warmer post-flowering conditions in 2017 might have caused a decline in the seed yield and oil content (Sefaoglu et al. 2021). The previous studies have also supported the results of high oil and seed yield (Sefaoglu et al. 2021; Vaghar et al. 2014; Joshan et al. 2019).

The correlation coefficients between yield and yield component traits were examined in different sunflower cultivars grown at two locations (Tables 8 and 9). Pant height showed significantly positive correlation with head diameter and seed yield whereas it had significantly negative correlation with oil yield in 2016 at Eruzurum-Idgir. Further, head diameter displayed significantly positive correlation with low correlation coefficient values with 1000 seed weight, seed and oil yield. Similarly, 1000 seed weight showed very high positive and significant correlation with seed yield and seed oil concentration (Table 8). In 2017, plant height showed a negative correlation with head diameter, seed yield, and seed oil concentration but a positive significsant correlation with seed yield with low correlation coefficient values. Head diameter displayed significantly positive correlation with 1000 seed weight and oil yield, whereas 1000 seed weight was observed positively correlated with seed yield and seed yield with oil yield. Negative significant correlations observed between plant height and head diameter, seed yield, and oil ratio, which varied in the correlation coefficients value was likely due to temperature, soil moisture, and soil properties between the years. Wazid et al. (2016) have also advocated that soil condition with respect to its nutrient contents may influence the correlation values.

During 2016-17 at Erzurum, plant height showed a very high and significantly positive correlation with head diameter, 1000 seed weight, and seed yield. Seed oil concentration and oil yield. Significantly positive correlation between and among all the six traits studied was observed. However, Idgir plant height showed significantly negative correlleation with head diameter, seed yield, oil yield but low and –ve correlation with 1000 seed weight and seed oil concentration, respectively (Table 9). The variation recporded in the correlation values at both the locations due to agro-climatic/ecological factors prevailed during the period crop growth and flowering (Fig. 1).

Studies have reported that there are positive and significant correlations between plant height and head diameter, seed weight, oil yield, and seed yield (Tahir et al. 2019; Chikkadevaiah et al. 2002). Correlation between the

Table 7. Seed oil yield and variance analysis results of sunflower genotypes grown in Erzurum and Igdır conditions.

Cultivars	Oil yield (kg ha $^{-1}$)						General Mean
	Erzurum			Igdır			
	2016	2017	Mean	2016	2017	Mean	
P4 ll 62	1140.1 ± 3.31d	880.5 ± 2.12e	1010.4 ± 4.48g	850.3 ± 0.54e	1152.4 ± 1.93e	1000.4 ± 5.76e	1005.4 ± 4.19f
Coral	960.7 ± 2.84e	903.3 ± 2.60de	950 ± 0.89h	760.3 ± 2.33f	940.8 ± 2.22f	850.6 ± 3.81f	900.3 ± 2.39g
Cadix	1002.6 ± 0.78e	720.1 ± 2.07f	870.3 ± 3.85ı	760.4 ± 1.11f	970.8 ± 0.40f	870.1 ± 4.06f	870.2 ± 3.44g
Lg 5582	1400.9 ± 3.28b	970.4 ± 1.19d	1190.2 ± 6.37e	870.2 ± 0.77e	1290.5 ± 3.23cd	1080.3 ± 7.13d	1135.25 ± 5.81d
Bosfora	1510.7 ± 1.57b	1090.7 ± 3.52c	1300.7 ± 6.13c	1060.5 ± 3.34c	1420.9 ± 1.45b	1240.8 ± 7.09b	1270.75 ± 5.26b
Tunca	1710.4 ± 3.00a	1390.8 ± 1.86a	1550.6 ± 4.20a	1300.8 ± 2.66a	2060.1 ± 2.80a	1680.5 ± 11.38a	1615.55 ± 5.52a
Pactol	1430.8 ± 3.39b	1070.3 ± 1.19c	1250.6 ± 5.11cd	980.1 ± 1.72d	1330.1 ± 3.45c	1150.6 ± 5.84c	1200.6 ± 4.93c
Tarsan1018	1440.9 ± 2.13b	980.1 ± 1.40d	1210.5 ± 6.92de	770.0 ± 1.03f	1290.5 ± 2.04cd	1030.3 ± 8.89e	1120.4 ± 5.88d
Dkf2525	1510.4 ± 3.63b	1240.9 ± 1.56b	1380.2 ± 3.32b	1120.7 ± 1.98b	1350.9 ± 3.52c	1240.3 ± 4.78b	1310.3 ± 3.89b
08tr003	1260.3 ± 0.94c	970.2 ± 2.05d	1110.8 ± 3.59f	760.7 ± 1.82f	1250.7 ± 1.10d	1010.2 ± 8.31e	1060.5 ± 5.42e
Mean	*1340.8 ± 3.76a*	*1021.7 ± 2.94b*	*1182.4 ± 2.94a*	*923.4 ± 2.94b*	*1305.8 ± 3.76a*	*1115.4 ± 3.49b*	*1148.92*

Variation Sources	SD			P>F				
Year (Y)	1			835.66**			1102.21**	23.82**
Location (L)	1							72.80**
Y x L	1							1969.30**
Genotype (G)	9	37.944**	79.68**	87.51**	106.62**	160.86**	250.05**	232.31**
Y x G	9			7.79**			32.43**	7.51**
L x G	9							12.39**
Y x L x G	9							26.20**

ns = not significant, * significant at the level of 0.05, ** significant at the level of 0.01. Differences between values having the same letter within the same column are not significant

Table 8. Correlation coefficients for traits observed in sunflower cultivars in 2016 and 2017

Erzurum-Igdır (2016)						
	(01)	(02)	(03)	(04)	(05)	(06)
(01) Plant height	1	0.3453**	0.3697	0.0350**	0.0339	-0.0653**
(02) Head diameter	-	1	0.0691**	0.0372**	-0.022**	0.0711**
(03)1000 seed weight	-	-	1	0.1140**	-0.0166**	0.2400**
(04) Seed yield	-	-	-	1	-0.9723**	0.9775**
(05) Seed oil concentration	-	-	-	-	1	0.9825**
(06) Oil yield	-	-	-	-	-	1
Erzurum-Igdır (2017)						
	(01)	(02)	(03)	(04)	(05)	(06)
(01) Plant height	1	-0.1756	0.5196	-0.1561**	-0.0357*	0.0186**
(02) Head diameter	-	1	0.4616**	-0.3039**	-0.3544	0.3224**
(03)1000 seed weight	-	-	1	0.3203**	0.1592*	-0.1555**
(04) Seed yield	-	-	-	1	-0.9278**	0.9667**
(05) Seed oil concentration	-	-	-	-	1	0.9765**
(06) Oil yield	-	-	-	-	-	1

Table 9. Correlation coefficients for traits observed in sunflower cultivars in Igdır and Erzurum locations

Erzurum (2016-2017)						
	(01)	(02)	(03)	(04)	(05)	(06)
(01) Plant height	1	0.4893**	0.4725**	0.4219**	0.2423*	0.4221**
(02) Head diameter	-	1	0.6657**	0.5904**	0.2932**	0.5826**
(03)1000 seed weight	-	-	1	0.7578**	0.3952**	0.7479**
(04) Seed yield	-	-	-	1	0.3007**	0.8561**
(05) Seed oil concentration	-	-	-	-	1	0.7462**
(06) Oil yield	-	-	-	-	-	1
Igdır (2016-2017)						
	(01)	*(02)*	*(03)*	*(04)*	*(05)*	*(06)*
(01) Plant height	1	-0.3811**	0.0242	-0.3818**	-0.1274	-0.3358*
(02) Head diameter	-	1	0.6873**	0.8042**	0.4605**	0.7757**
(03)1000 seed weight	-	-	1	0.8134**	0.5055**	0.7978**
(04) Seed yield	-	-	-	1	0.4628**	0.9196**
(05) Seed oil concentration	-	-	-	-	1	0.7621**
(06) Oil yield	-	-	-	-	-	1

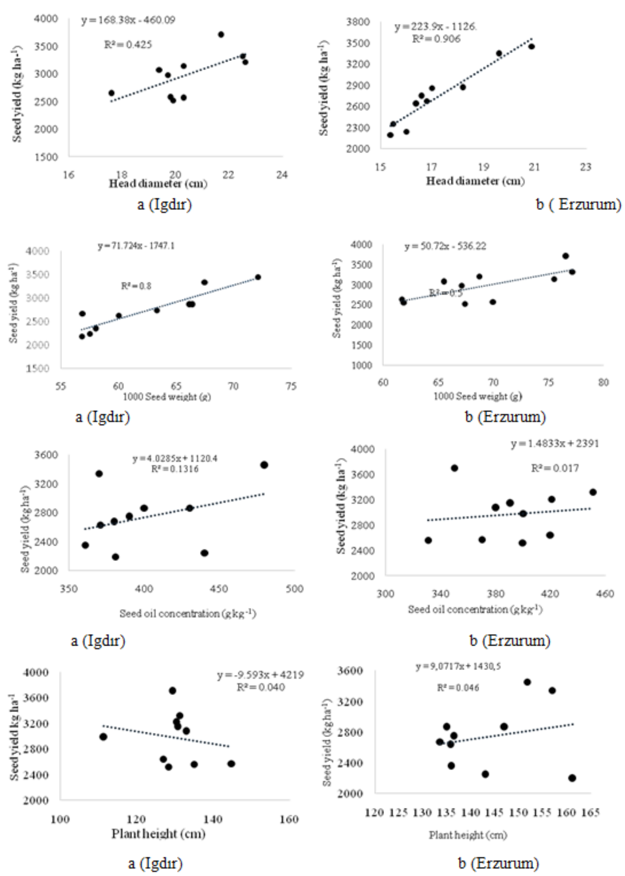

Fig. 2. Correlations among seed yield and plant height, head diameter, thousand-seed weight and oil concentration in Erzurum and Igdır locations. *: Correlation is significant at the 0.05 level. **: Correlation is significant at the $p < 0.01$ level

main characters such as number of seeds per plant and 1000 seed weight was found positive with the seed yield per plant in sunflower (Yankov and Tahsin 2015). However, the oil content was lower but not significantly correlated concerning the head. In the present study also, the positive correlation between head diameter and 1000-seed weight, seed yield and oil concentration at the probability level of p<0.01 in both locations (Fig. 2). In previous studies conducted in different ecological conditions with different genotypes (Vidhyavathi et al. 2005; Darvishzadeh et al. 2010; Sincik and Göksoy 2014) positive and correlations among head diameter and seed yield has been recorded which is important for selection suitable sunflower genotypes. Such breeding material can be used in the breeding program for the enhancement of sunflower yield (Chaudhary et al. 2022).

The positive correlation recorded in present study among 1000-seed weight, seed yield, oil concentration and oil yield at both the locations but these correlations were stronger in Igdır (Fig. 2). These results determined that 1000 seed weight and seed yield play the most decisive role in oil yield. The relationships between seed yield and other yield traits varied significantly between the locations. The study revealed that temperature and humidity which varied between the locations have substantial impact on sunflower yield. Significant effects of environmental conditions and genotype x environment interaction on quantitative traits such as seed yield and oil concentration were more potent on mean and correlation values.

Sunflower is sensitive to environmental conditions including the temperature, humidity and soil properties at the locations at Erzurum and Igdir. A few sunflower genotypes were found to give high yield potential in the regions at high altitude with shorter vegetative growth (Erzurum) compared to lower altitude having long growing seasons, such as Igdır. This region in eastern Türkiye is however more suitable as compared to other regions. Sunflower cultivation is important for Igdır region because many other plant species have little opportunity to grow due to its salty soils. It was noticed that oil quality was affected by elevation, climate and soil characteristics of the region.

As per the correlation analysis made on the basis of locations, significant difference between plant height and all other yield traits was observed. This difference was however, negative in Igdır location and positive in Erzurum location. When all other data regarding seed yield and oil concentration were evaluated, it was determined that positive and significant correlations were emerged in both locations, but the coefficient of correlation in Igdır location was higher and hence, sunflower cultivation gains importance in such locations. To determine the level and forms of the relationships between the traits, regression analysis was utilized. Plant height, 1000 seed weight and head diameter were found positively and significantly correlated with sunflower yield. The equations for different traits were based on the combination of the highest coefficient of determination (R^2) e.g., for head diameter 0.905, 1000 seed weight 0.58 and plant height 0.040 at Erzurum and at Igdir for respective traits, 0.425, 0.83 and 0.040, respectively determining the role of relationship among the traits (Fig. 2). The results clearly showed that there is an inverse correlation between oil content and seed yield based on climatic factors (*e.g.,* precipitiation and temperature) and elevation indicating that high yield does not necessarily mean high quality. This situation reveals the importance of regional sunflower cultivation as well as the importance of such investigations. Oil quality is significantly affected by elevation, climate, and soil characteristics of the region. High-quality products and efficient cultivation could be achieved by determining the oil sunflower genotypes suitable for the region.

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