https://doi.org/10.17221/113/2022-CJGPB

Genotypic and environmental variability and stability of seed yield, oil content and fatty acids in high-oleic and high-linoleic safflower (*Carthamus tinctorius* L.) lines and cultivars

Sabri Erbaş[1], Hasan Baydar[1], Halil Hatipoğlu[2], Hasan Koç[3], Metin Babaoğlu[4], Arzu Köse[5]*

[1]*Department of Fied Crops, Faculty of Agricultural, Isparta University of Applied Sciences, Isparta, Türkiye*
[2]*GAP Agricultural Research Institute, Şanlıurfa, Türkiye*
[3]*Bahri Dağdaş International Agricultural Reseach Institute, Konya, Türkiye*
[4]*Trakya Agricultural Research Institute, Edirne, Türkiye*
[5]*Transitional Zone Agricultural Research Institute, Eskişehir, Türkiye*

**Corresponding author: sabrierbas@isparta.edu.tr*

Citation: Erbaş S., Baydar H., Hatipoğlu H., Koç H., Babaoğlu M., Köse A. (2024): Genotypic and environmental variability and stability of seed yield, oil content and fatty acids in high-oleic and high-linoleic safflower (*Carthamus tinctorius* L.) lines and cultivars. Czech J. Genet. Plant Breed., 60: 1–11.

Abstract: The present study was to determine the genotypic and environmental variability and stability in seed yield, oil content, oil yield, oleic and linoleic acid of 10 safflower lines derived from a cross of Dinçer 5-18-1 × Montola 2000 together with six cultivars under six environments at five locations. The effects of genotypes, environments and genotype × environment interactions were highly significant ($P < 0.01$) for seed yield and oil content. Averaged across all environments, the seed yield was lowest in the cultivar Olas (2 352 kg/ha), and highest in the line Bay-Er 5 (2 869 kg/ha). According to mean (x_i) and regression coefficient (b_i) values, the Bay-Er 16 was better adapted to unfavourable environmental conditions, whereas the Bay-Er 1, Bay-Er 5 and Bay-Er 14 were better adapted to favourable environmental conditions. The highest oil content across environments, over 35%, was recorded in the line Bay-Er 15 and the cultivars Olas and Linas. The best adaptability to the environments was observed in the cultivar Olas. The oleic acid content of genotypes increased and the linoleic acid contents decreased from the north to the south latitudes. The oil content of genotypes grown in Southeastern Anatolia was higher than in the other regions. Within the regions, seed yield and oil content was higher after autumn sowing than after spring sowing.

Keywords: agronomic and quality characters; *Carthamus tinctorius*; oleic and linoleic acid; stability analysis

Safflower (*Carthamus tinctorius* L.) is one the most important vegetable oil and bioenergy source. In the past and today, due to its high tolerance to salinity and drought, safflower maintains its feature as a promising alternative product in arid and saline agricultural ecosystems that can grow under water stress without significant reduction in oil and seed yield. In fact, safflower cultivation creates a more profitable product for farmers in some countries than other conventional products such as barley,

Supported by the Scientific and Technical Research Council of Turkey, Turkey, Project No. 214O211.

https://doi.org/10.17221/113/2022-CJGPB

lentils and chickpeas (Weiss 2000; Erbaş et al. 2016; Yeloojeh et al. 2020). Safflower is cultured in more than 25 countries; however Russian Federation, Kazakhstan, India, Argentina, Mexico, USA, Uzbekistan and Turkey are the leading countries (FAOSTAT 2022). According to the records of FAO, safflower cultivation area and seed production of Turkey were 14 588 ha and 16 200 tonnes in 2021. Safflower has a large growing potential for both continental and Mediterranean climate zones in Turkey. Significant agricultural supports to the safflower producers by the Turkish government to reduce Turkey's vegetable oil imports have been an important factor in the development of safflower cultivation in Turkey.

The seed yield and oil content are mainly selection criteria for safflower breeding programs. Plant height, primary branches number, head number, head diameter, seed number per head, harvest index, 1 000 seed weight and hull content are other properties that directly or indirectly affect the yield and oil content of safflower (Ramachandram & Goud 1981; Akbar & Karman 2006; Bidgoli et al. 2006). The research has been carried out on the oil content and fatty acid components of safflower, which has many varieties registered or populations in the world. Johnson et al. (1999) reported that the oil, oleic and linoleic contents in core and non-core safflower accessions from the USDA collection was 13–46%, 6.2–81.9%, and 11–86.5%, respectively. Guan et al. (2008) reported that the content of oil ranged from 9.1% to 25.1%, oleic acid from 7.9% to 32.9%, and linoleic acid from 62.7% to 83.7% in 21 safflower accessions from 12 countries. Fernández-Martinez et al. (1993) found that the oleic and linoleic acids have a huge variation from 3.1% to 90.60% and from 3.9% to 88.8%, respectively in safflower accessions originating from 37 countries. The two most important fatty acids that determine industrial and nutritional value of vegetable oils are oleic acid ($C18:1^{\Delta 9}$) and linoleic acid ($C18:2^{\Delta 9,12}$) which are the two major fatty acids found in safflower seed oil, together accounting for about 90% of the total fatty acids.

Conventional safflower oil is characterized by its relatively high level of linoleic acid content (Deharo et al. 1997). However numerous breeding lines with high levels of either oleic acid or linoleic acid have been selected as a result of intensive breeding efforts in the past six decades. Until the last quarter of the 20^{th} century, while almost all safflower cultivars were very rich in linoleic acid, first high oleic (HO) varieties (UC-1 was the first HO variety developed in the US in 1966) were developed thanks to an oleic acid-rich mutant detected by Knowles in an Indian originating material (Knowles & Hill 1964). Today, production and consumption of the vegetable oils with high oleic acid are becoming increasingly widespread in the world.

The first aim of plant breeders in a crop breeding programme is the development of cultivars which are stable or adapted to a wide range of diversified environments (Becker & Leon 1988). The genotype×environment interactions (G × E) are important sources of variation in any crop and the term stability can be used to characterize the performance of a genotype in different environments. Due to the importance of G × E in selecting the widely stable genotypes, various techniques of stability described by Finlay and Wilkinson (1963), Eberhart and Russell (1966), Pinthus (1973) and Smith (1982) had been extensively used by many researchers (Pourdad & Mohammadi 2008). The G × E interaction is closely related to the inheritance of traits. Because traits with high heritability are less affected by environmental conditions than traits with low heritability. A low to moderate heritability is predicted for seed yield in safflower (Ghongade et al. 1993; Reddy et al. 2003; Mohammadi & Pourdad 2009), while moderate and high for oil content (Ramachandram & Goud 1981; Parameshwar 2009; Golkar et al. 2011; Baydar & Erbaş 2014), a high heritability is estimated for oleic and linoleic acid (Hamdan et al. 2009; Erbaş 2012). On the other hand, it is reported that the inheritance of linoleic acid in safflower is gametophytic (Futehally & Knowles 1981) and dominant over oleic acid (Hamdan et al. 2009). The high oleic acid content of this safflower makes it very difficult to maintain the homogeneity of the variety. Because foreign pollination seen between 0–20% in safflower (Baydar & Gökmen 2003; Erbaş 2012) causes a decrease in the concentration of oleic acid in cultivars with high oleic acid content. Because the recessive allele gene (*ol*) responsible for oleic acid synthesis is suppressed by the dominant allele genes (*Ol*) responsible for linoleic synthesis in the developing embryo during fertilization, causing a decrease in oleic acid (Hamdan et al. 2009).

In this study, the genotypic and environmental variability and stability of these characters were determined by using 6 cultivars and 10 lines with high-oleic and high-linoleic acid in the six different environments at five locations in Turkey. These results obtained from this research are expected

https://doi.org/10.17221/113/2022-CJGPB

Table 1. Monthly average rainfall, temperature and humidity values in the growing season of each location

Locations	Parameters	March	April	May	June	July	August
Edirne	rainfall (mm)	67.8*	44.4	45.2	31.0	2.0	24.9
	temperature (°C)	9.0	13.1	20.4	22.5	27.1	27.7
	humidity (%)	80.4	70.9	68.4	68.2	60.3	59.9
Eskişehir	rainfall (mm)	46.0	41.3	61.2	125.3	0.0	63.5
	temperature (°C)	5.7	7.9	15.7	17.2	22.1	22.7
	humidity (%)	78.6	68.0	64.7	80.1	63.0	66.3
Isparta	rainfall (mm)	111.6	26.1	67.5	92.2	3.0	43.4
	temperature (°C)	6.7	9.0	15.9	18.3	24.2	23.8
	humidity (%)	64.8	58.2	60.5	63.5	43.9	51.0
Konya	rainfall (mm)	55.9	7.6	55.2	39.6	8.6	17.2
	temperature (°C)	5.9	8.1	15.7	18.7	24.0	24.6
	humidity (%)	59.6	64.1	55.1	45.1	41.8	43.1
Şanlıurfa	rainfall (mm)	79.0	24.3	10.3	0.7	0.2	–
	temperature (°C)	11.7	15.7	22.8	27.7	33.2	31.5
	humidity (%)	58.9	49.7	39.0	35.3	26.5	37.4

*Data were collected from the records of the General Directorate of Meteorology in the year 2015

to ensure a significant contribution to the future safflower production projections.

MATERIAL AND METHODS

In this research, four oleic acid lines (Bay-Er 12, Bay-Er 13, Bay-Er 16 and Bay-Er 17) and six linoleic acid lines (Bay-Er 1, Bay-Er 2, Bay-Er 5, Bay-Er 14 and Bay-Er 15) obtained from hybridization of Dinçer 5-18-1 × Montola 2000 and 6 cultivars registered namely Dinçer 5-18-1, Montola 2000, Remzibey-05, Balcı, Linas and Olas were used as the genetic materials. The lines Bay-Er 13 (Olein), Bay-Er 14 (Askon-42) and Bay-Er 15 (Safir) are candidate cultivars, and their registration procedures have been carried out by the Variety Registration and Seed Certification Center in Ankara, Turkey. Field trials were established at five different locations in Eskişehir, Edirne, Isparta, Konya and Şanlıurfa provinces which were representative of different safflower growing areas under rain-fed conditions of Turkey. Monthly mean climate data for the locations are presented in Table 1.

Representative soil samples were taken from the five experimental fields prior to sowing, air-dried at room temperature, ground to pass through a sieve, and analysed at Isparta University of Applied Sciences Soil and Plant Analyses Laboratory. Some physicochemical properties of the experimental soils are shown in Table 2.

The field trials and laboratory analyses of this research were carried out in cooperation with a university and four Agricultural Research Institutes. The safflower lines and cultivars were sown on 20 March, 2015 at Trakya Agricultural Research Institute in Edirne and Isparta University of Applied Sciences in Isparta, on 7 March, 2015 at Transitional Zone

Table 2. Some physicochemical properties of the experimental soils

Locations	Texture	OM (%)	pH*	$CaCO_3$** (%)	EC (dS/m)
Edirne	clay loam	1.27	6.3	0.00	0.01
Eskişehir	clay loam	1.57	7.9	9.50	0.10
Isparta	clay loam	1.10	7.5	7.20	0.38
Konya	sandy clay loam	2.48	7.1	0.03	0.78
Şanlıurfa	clay loam	2.16	7.1	3.00	0.11

OM – organic matter; $CaCO_3$ – calcium carbonate; EC – electrical conductivity; *1 : 2.5 soil to water ratio; **calsimetric method

https://doi.org/10.17221/113/2022-CJGPB

Agricultural Research Institute in Eskişehir, on 8 April, 2015 at Bahri Dağdaş International Agricultural Research Institute in Konya, on 30 November, 2014 (autumn) and on 27 February, 2015 (spring) at GAP Agricultural Research Institute in Şanlıurfa. The trials were conducted using a randomized complete block design with four replications. Each plot consisted of 6 rows 5 m in length with 45 cm between rows. Plants were spaced 10 cm apart within rows 3 weeks after sowing. Based on soil test conducted in the test year, nitrogen and phosphorus at the rate of 80 kg N and 60 kg P_2O_5 per ha were applied, respectively. Cultural practices, control of insects, diseases and weeds were given as needed during the growth season according to the local recommendations. In the experiments, safflower genotypes were harvested in the third week of July, 2015 in Edirne and Şanlıurfa (autumn), in the first week of August, 2015 in Şanlıurfa (spring), and in the third week of August, 2015 in Eskişehir, Isparta and Konya. At the end of maturity, middle 4 rows of each plot were harvested and threshed to calculate seed yield (kg/ha).

The seed oil content (%) and fatty acid compositions were determined in the Department of Field Crops, Faculty of Agriculture, Isparta University of Applied Sciences in Isparta. The seed oil content was estimated by a nuclear magnetic resonance (NMR, Bruker mq_{one}) (Erbaş & Şeanteş 2020). Because seed from different genotypes had various moisture contents, oil contents were adjusted to 0% moisture content. The percentage of fatty acids were determined by a gas chromatography (GC-FID, Shimadzu 2010 Plus, Ant Teknik, Ankara, Turkey) according to the method described by Şenateş and Erbaş (2020). The seeds used in the fatty acid analyses were sampled by bulking of all replication in each experimental environment.

It was computed that the combined analysis of variance on seed yield and oil content data from the trials in 6 environments. No analysis of variance for fatty acids was performed because the data were derived from only one repeat at each environment. All statistical analyses were performed using the SAS (Ver. 9.1, 1999) statistical software program. The means were compared using a Tukey test at a 0.05 probability level. The grand mean, regression coefficient, and their confidence intervals were taken into account when the stability status of the genotypes was evaluated for 6 different environments. In the stability analyses according to the Proc REG procedure (x_i is the grand mean yield of genotypes, b_i is the regression coefficient, a is the regression line intercept, R_i^2 is the coefficient of determination and S^2d_i is the variance of the regression deviations) (Finlay & Wilkinson 1963; Eberhart & Russell 1966). Correlation coefficients (r) among the traits were calculated according to Proc CORR procedure in the SAS program.

RESULTS AND DISCUSSION

Variability of seed yield, oil content and oil yield. The variance analysis results for seed yield, oil content and oil yield of 10 lines and 6 cultivars grown at six different environments are shown in Table 3. Genotypes (G), environments (E), G × E interaction were highly significant ($P < 0.01$) for all traits (Table 3). These results indicated that each genotype exhibited different response to different environment due to the G × E interaction.

The mean seed yields at the five locations ranged from 1 320 to 3 461 kg/ha, and were as follows: Konya > Şanlıurfa (autumn) > Edirne > Isparta > Şanlıurfa (spring) > Eskişehir. According to the average of the genotypes; the highest average seed yield was obtained from Bay-Er 5 and Bay-Er 14 genotypes compared to other genotypes. As the average of all

Table 3. The variance analysis results for seed yield, oil content and oil yield of 10 lines and 6 cultivars grown at six different environments

Source of variation	Degrees of freedom	Seed yield	Oil content	Oil yield
Replications	3	454.6[a]	2.1	31.4
Genotypes (G)	15	4 386.8**	139.2**	1 470.5**
Environments (E)	5	596 041.7**	109.1**	65 481.5**
G × E	75	4 147.2**	3.1**	513.6**
Error	285	449.2	1.4	57.4
CV (%)		8.4	3.6	9.2

CV – coefficient of variations; [a]mean square; ***P* < 0.01

https://doi.org/10.17221/113/2022-CJGPB

environments, the cultivar Olas gave the lowest seed yield (2 362 kg/ha). According to the genotype × environment interaction; The highest seed yield was obtained from Bay-Er 1, 5 and 6 genotypes at Edirne, Bay-Er 16 and 17 genotypes at Eskişehir, Bay-Er 2 and 14 genotypes at Isparta, and Bay-Er 1, 5 and Balcı genotypes at Konya. The mean seed yield within the genotypes was changed from 774 kg/ha in the cultivar Remzibey-05 at Eskişehir to 4 345 kg per ha in the line Bay-Er 5 at Konya. On the other hand, at Şanlıurfa, autumn sowing was sown 90 days earlier than spring sowing and seed yield increased more than 2 times, 3 301 and 1 359 kg/ha, respectively (Table 4). The mean oil contents of the genotypes ranged from 31.4 to 34.8%, and were as follows: Şanlıurfa (autumn) > Şanlıurfa (spring) > Edirne > Konya > Isparta. The lowest mean oil content was Dinçer 5-18-1 (27.4%) and the highest was Linas (35.3%) and Olas (36.4%). The mean oil content within the genotypes was changed from 26.4% in the cultivar Dinçer 5-18-1 at Isparta to 38.8% in the line Bay-Er 15 at Şanlıurfa (autumn). In addition, it was remarkable that Bay-Er 15 line had high oil content in all locations, except for the Konya (Table 4).

Genotypes with high seed yield and oil content of cultivars and lines were also found to have high oil yields. While the average seed yield of the genotypes was high in Konya, the oil yields of the genotypes grown in Şanlıurfa (autumn) were found to be higher than other locations due to higher oil content. According to the mean oil yield of cultivars; the highest oil yield was determined in Bay-Er 5 line (952 kg/ha), and the lowest in Dinçer 5-18-1 (684 kg/ha) and Remzibey-05 (703 kg/ha) cultivars. All lines in Edirne (except Bay-Er 12) and Şanlıurfa (spring) were statistically in the highest oil yield group. Among the lines, Bay-Er 5 and Bay-Er 14 lines were observed to have high oil yields in all locations, except Eskişehir (Table 4).

In our study, may rains might have contributed to the high seed yield and oil yield in varieties and lines in Edirne, Isparta and Konya locations, apart from Eskişehir. The trial areas in the Eskişehir are marginal agricultural lands, and the soil structure of the land is heavy, calcareous and alkaline (lime content: 9%; pH: 7.9) (Table 2), which could be cited as one of the main reasons for the low seed yield. Moreover, it is thought that plants grown under these conditions developed poorly and that less seed storage reserves accumulated after fertilization, resulted in a low seed yield. Insufficient rainfall in the same period in spring sowings in Şanlıurfa (Table 1) might also be the reason for the low seed and oil yield. In autumn sowing, the high rainfall from November to March and the fact that the plants enter the early spring period as a seedling with a strong root system might be the main reason for the high seed and oil yield and high oil content.

While 400–1 700 kg/ha of seed yield is obtained from safflower in arid conditions in the world, the yield can reach up to 3 000 kg/ha under suitable soil and climatic conditions in dry farming (Weiss 2000). In our study, many lines over 300 kg were determined in the locations and the seed yield determined by Weiss (2000) was exceeded. Cultivars with high genetic yield potential can give a high yield when suitable conditions are provided (Erbaş et al. 2016). In the studies, the seed yield from different safflower genotypes carried out in different arid areas in Turkey varied between 2 077–3 397 kg/ha in Eskisehir (Celikoglu 2004), 774–1 678 kg/ha in Erzurum (Ozturk et al. 2008), and 456–2 980 kg/ha in Samsun (Camas & Esendal 2006). In our study, it is seen that at least two genotypes give higher seeds than standard varieties in almost every location in the study. This indicates that seed yield may vary according to the soil, climate and genetic differences (Koutroubas et al. 2004; Erbaş et al. 2016).

While the seed yield shows a positive correlation with oil yield, these two characters show a negative correlation with oil content. Therefore, although conditions that promote seed yield generally reduce the oil content of seeds, oil yield is not affected up to a certain limit (Tabrizi 2000; Bagawan & Ravikumar 2001; Aşkın & Erbaş 2020). The fact that seed and oil yield is more affected by environmental conditions than oil content and is controlled by more additive effective gene according to oil content makes the correlation of yield and quality negative. (Ghongade et al. 1993; Reddy et al. 2003; Erbaş 2012). Because in the studies, a low and medium heritability for seed yield (Ghongade et al. 1993; Reddy et al. 2003; Mohammadi & Pourdad 2009) and a medium and high heritability for oil content (Ramachandram & Goud 1981; Parameshwar 2009; Baydar & Erbaş 2014) were predicted.

Stability of seed yield, oil content and oil yield. Stability parameters of safflower genotypes for seed yield, oil content, seed yield, oleic and linoleic acid contents were presented in Table 5. For seed yield, the b_i values for genotypes ranged from 0.70 (Bay-Er 17) to 1.24 (Bay-Er 5). Genotypes Bay-Er 2,

Table 4. Mean seed yield of the safflower genotypes at six environments

Genotypes	Edirne	Eskişehir	Isparta	Konya	Şanlıurfa		Mean
					spring	autumn	
Seed yield (kg/ha)							
Bay-Er 1	3 528^{ab,AB}	1 038$^{d–f,D}$	2 701^{b,C}	3 933^{ab,A}	1 401^{a,D}	3 200$^{a–f,B}$	2 634^{BC}
Bay-Er 2	3 155$^{b–e,AB}$	1 127$^{c–f,C}$	3 363^{a,A}	2 880^{de,B}	1 331^{a,C}	3 522$^{a–e,A}$	2 563$^{B–F}$
Bay-Er 5	3 540^{ab,B}	1 339$^{b–e,D}$	2 723^{b,C}	4 345^{a,A}	1 572^{a,D}	3 692^{a,B}	2 869^{A}
Bay-Er 6	3 763^{a,A}	1 140$^{c-f,C}$	2 531$^{b–d,B}$	3 724^{bc,A}	1 540^{a,C}	2 763^{f,B}	2 577$^{B–E}$
Bay-Er 12	2 703^{e,B}	1 432$^{b–d,C}$	2 742^{b,B}	2 820^{e,AB}	1 409^{a,C}	3 210$^{a–f,A}$	2 386$^{D–F}$
Bay-Er 13	3 035$^{b–e,B}$	1 168$^{c–f,D}$	2 581^{bc,C}	3 681^{bc,A}	1 274^{a,D}	3 048$^{c–f,B}$	2 465$^{C–F}$
Bay-Er 14	3 447$^{a–c,A}$	1 102$^{c–f,B}$	3 286^{a,A}	3 547^{bc,A}	1 376^{a,B}	3 550$^{a–d,A}$	2 718^{AB}
Bay-Er 15	2 960$^{c–e,B}$	1 542$^{a–d,C}$	2 678^{b,B}	2 831^{e,B}	1 489^{a,C}	3 643$^{a–b,A}$	2 524$^{B–F}$
Bay-Er 16	3 083$^{b–e,A}$	1 821^{ab,C}	2 278$^{b–d,B}$	3 315$^{c–e,A}$	1 472^{a,C}	3 460$^{a–e,A}$	2 572$^{B–F}$
Bay-Er 17	3 205$^{b–e,AB}$	1 980^{a,C}	2 108$^{c–d,C}$	2 850^{de,B}	1 415^{a,D}	3 352$^{a–e,A}$	2 485$^{C–F}$
Dinçer 5-18-1	3 420$^{a–d,AB}$	875^{ef,D}	2 649^{b,C}	3 758^{bc,A}	1 173^{a,D}	3 008$^{e–f,BC}$	2 481$^{C–F}$
Remzibey-05	2 693^{e,B}	774^{f,D}	2 617$^{b–c,B}$	3 378^{cd,A}	1 327^{a,C}	3 498$^{a–e,A}$	2 381^{EF}
Montola 2000	2 900$^{d–e,BC}$	1 364$^{b–e,D}$	2 490$^{b–d,C}$	3 351$^{c–e,A}$	1 121^{a,D}	3 029$^{d–f,AB}$	2 376^{EF}
Balcı	2 748^{e,B}	1 488$^{a–d,C}$	2 479$^{b–d,B}$	3 920^{ab,A}	1 352^{a,C}	3 578$^{a–c,A}$	2 594$^{B–D}$
Linas	2 863^{e,B}	1 605$^{a-c,C}$	2 681^{b,B}	3 438^{bc,A}	1 309^{a,C}	3 128$^{b-f,A}$	2 504$^{C–F}$
Olas	2 920$^{c-e,B}$	1 327$^{b-e,D}$	2 016^{d,C}	3 603^{bc,A}	1 175^{a,D}	3 130$^{b-f,AB}$	2 362^{F}
Mean	3 123^{C}	1 320^{E}	2 620^{D}	3 461^{A}	1 359^{E}	3 301^{B}	
Oil content (%)							
Bay-Er 1	32.6$^{c–e,B}$	31.5$^{c–f,B}$	31.2$^{c–e,B}$	31.3$^{c–g,B}$	32.1$^{d–g,B}$	35.0$^{b–e,A}$	32.3$^{F–H}$
Bay-Er 2	32.0$^{c–f,AB}$	30.2$^{e–g,B}$	31.0$^{c–e,AB}$	29.9$^{e–h,B}$	31.9$^{e–g,AB}$	33.2$^{d–f,A}$	31.4^{HI}
Bay-Er 5	32.9$^{b–d,AB}$	32.8$^{b–e,AB}$	32.7$^{a–d,AB}$	32.2$^{b–f,B}$	33.7$^{c–g,AB}$	34.6$^{b–e,A}$	33.2$^{D–F}$
Bay-Er 6	30.8$^{d–g,AB}$	29.0^{fg,B}	28.8$^{e–g,B}$	31.0$^{d–g,AB}$	31.4$^{g–h,A}$	31.5^{fg,A}	30.4^{I}
Bay-Er 12	31.4$^{c–f,C}$	33.2$^{a–d,BC}$	32.5$^{b–d,B}$	33.2$^{a–d,BC}$	34.7$^{a–e,AB}$	36.7$^{a–c,A}$	33.6^{DE}
Bay-Er 13	32.5$^{c–e,BC}$	31.3$^{d–f,C}$	31.1$^{c–e,C}$	31.5$^{c–g,C}$	34.5$^{b–f,AB}$	36.0$^{a–d,A}$	32.8$^{E–G}$
Bay-Er 14	33.4$^{b–d,BC}$	32.6$^{b–e,C}$	32.4$^{b–d,C}$	34.1$^{a–c,B}$	35.4$^{a–c,AB}$	37.0^{ab,A}	34.2^{CD}
Bay-Er 15	34.1$^{a–c,C}$	34.4$^{a–c,C}$	34.5^{ab,C}	31.6$^{c–g,D}$	37.6^{a,A}	38.8^{a,A}	35.2^{BC}
Bay-Er 16	31.8$^{c–f,AB}$	30.6$^{d–g,B}$	30.5$^{c–f,B}$	30.3$^{d–g,B}$	32.6$^{c–g,AB}$	33.9$^{c–f,A}$	31.6^{H}
Bay-Er 17	32.2$^{c–e,AB}$	33.2$^{a–d,A}$	30.2$^{d–f,B}$	30.9$^{d–g,AB}$	31.6^{fg,AB}	32.8^{ef,A}	31.8^{GH}
Dinçer 5-18-1	27.9^{g,AB}	26.0^{h,B}	26.4^{g,B}	27.1^{h,AB}	28.1^{i,AB}	29.0^{g,A}	27.4^{K}
Remzibey-05	29.2^{fg,B}	28.3^{gh,B}	27.9^{fg,B}	29.6$^{f–h,AB}$	28.5^{hi,B}	31.6^{fg,A}	29.2^{J}
Montola 2000	29.8$^{e–g,B}$	30.0$^{e–g,B}$	29.4^{ef,B}	28.9^{gh,B}	30.8$^{g–I,B}$	33.0^{ef,A}	30.3^{I}
Balcı	32.9$^{b–d,B}$	33.2$^{a–d,B}$	33.2$^{a–c,B}$	34.7^{ab,B}	34.8$^{a–e,AB}$	37.1^{ab,A}	34.3$^{B–D}$
Linas	35.7^{ab,BC}	35.9^{a,B}	34.4^{ab,BC}	32.7$^{b–e,C}$	35.0$^{a–d,BC}$	38.4^{a,A}	35.3^{AB}
Olas	36.5^{a,AB}	35.4^{ab,B}	35.6^{a,B}	35.9^{a,AB}	37.0^{A,AB}	38.2^{a,A}	36.4^{A}
Mean	32.2^{C}	31.7^{CD}	31.4^{D}	31.6^{D}	33.1^{B}	34.8^{A}	
Oil yield (kg/ha)							
Bay-Er 1	1 152^{a,A}	327^{de,C}	841$^{b–d,B}$	1 229^{ab,A}	451$^{a–c,C}$	1 121^{cd,A}	854$^{C–E}$
Bay-Er 2	1 009$^{a–c,BC}$	341^{de,D}	1 042^{a,AB}	859^{d,C}	425$^{a–c,D}$	1 169$^{b–d,A}$	807^{E}
Bay-Er 5	1 166^{a,B}	439$^{b–d,D}$	891$^{a–c,C}$	1 402^{a,A}	532^{ab,D}	1 279$^{a–c,AB}$	952^{A}
Bay-Er 6	1 158^{a,A}	330^{de,C}	728$^{c–e,B}$	1 155^{bc,A}	484$^{a–c,C}$	870^{e,B}	787^{EF}
Bay-Er 12	848^{cd,B}	474$^{a–d,C}$	893$^{a–c,B}$	936^{d,B}	490$^{a–c,C}$	1 180$^{b–d,A}$	803^{E}
Bay-Er 13	982$^{a–c,B}$	366$^{c–e,D}$	804$^{b–e,C}$	1 158^{bc,A}	440$^{a–c,D}$	1 097^{cd,AB}	808^{E}

https://doi.org/10.17221/113/2022-CJGPB

Table 4 to be continued

Genotypes	Edirne	Eskişehir	Isparta	Konya	Şanlıurfa		Mean
					spring	autumn	
Oil yield (kg/ha)							
Bay-Er 14	1 150^{a,B}	359$^{c-e,C}$	1 064^{a,B}	1 212^{ab,AB}	488$^{a-c,C}$	1 315^{ab,A}	931^{AB}
Bay-Er 15	1 009$^{a-c,B}$	534$^{a-c,C}$	924^{ab,B}	897^{d,B}	561^{a,C}	1 414^{a,A}	890^{A-D}
Bay-Er 16	979$^{a-c,B}$	558^{ab,CD}	695^{de,C}	1 006^{cd,B}	480$^{a-c,D}$	1 172$^{b-d,A}$	815DE
Bay-Er 17	1 032$^{a-c,AB}$	657^{a,C}	637^{e,C}	881^{d,B}	447$^{a-c,D}$	1100^{cd,A}	792^{EF}
Dinçer 5-18-1	955$^{b-d,A}$	228^{e,D}	700^{de,B}	1 020^{cd,A}	330^{c,C}	871^{e,A}	684^{G}
Remzibey-05	786^{d,B}	222^{e,C}	728$^{c-e,B}$	1 001^{cd,A}	379$^{a-c,C}$	1104$^{c-d,A}$	703^{G}
Montola 2000	864^{cd,AB}	409$^{b-e,C}$	732$^{c-e,B}$	970^{cd,A}	345^{bc,C}	999^{de,A}	720^{FG}
Balcı	904$^{b-d,B}$	496$^{a-d,C}$	824$^{b-e,B}$	1 358^{a,A}	470$^{a-c,C}$	1 328^{ab,A}	897^{A-C}
Linas	1 022$^{a-c,BC}$	576^{ab,D}	923^{ab,C}	1 127^{bc,AB}	460$^{a-c,D}$	1 200^{bc,A}	885^{A-D}
Olas	1 065^{ab,B}	470$^{a-d,D}$	718$^{c-e,C}$	1 293^{ab,A}	435$^{a-c,D}$	1 194^{bc,AB}	863^{B-E}
Mean	32.2^{C}	31.7C^{D}	31.4^{D}	31.6^{D}	33.1^{B}	34.8^{A}	

Within each genotype and location, means followed by the same letter are not significantly different; small letters show the differences between genotypes over all environments; capital letters show the differences between environments over all genotypes

Bay-Er 6, Bay-Er 13, Montola 2000, Balcı and Olas, with b_i values closer to 1 were more stable. While Bay-Er 12 and Bay-Er 17, with the lowest b_i values, were adapted to marginal environments, Bay-Er 5 and Dinçer 5-18-1, with the highest b_i values, were adapted to favourable environments. When grand mean and b_i values were considered, Bay-Er 2, Bay-Er 6, Bay-Er 13 and Balcı had average adaptability

Table 5. Stability parameters of safflower genotypes for seed yield, oil content and oil yield

Genotypes	Seed yield					Oil content					Oil yield				
	x_i	b_i	a	R_i^2	S^2d_i	x_i	b_i	a	R_i^2	S^2d_i	x_i	b_i	a	R_i^2	S^2d_i
Bay-Er 1	2 634	1.19**	–38.6	0.96	618.0	32.3	1.04**	–1.6	0.29	0.81	854	1.18**	–11.9	0.96	72.4
Bay-Er 2	2 563	1.00*	4.2	0.83	2 427.9	31.4	0.83*	4.3	0.46	0.76	808	0.97*	0.6	0.82	273.5
Bay-Er 5	2 869	1.24**	–26.4	0.97	541.2	33.2	0.64**	12.4	0.06	0.93	952	1.23**	–6.2	0.97	62.5
Bay-Er 6	2 577	1.05**	–6.6	0.86	2 048.2	30.4	0.64	9.7	0.96	0.47	788	0.96*	–0.1	0.80	289.2
Bay-Er 12	2 386	0.76**	45.2	0.92	601.9	33.6	1.23*	–6.4	1.11	0.74	804	0.81**	13.4	0.90	96.9
Bay-Er 13	2 465	1.05**	–19.5	0.98	284.0	32.8	1.51**	–16.4	0.20	0.96	808	1.04**	–5.4	0.99	21.7
Bay-Er 14	2 718	1.16**	–22.9	0.95	821.9	34.2	1.28**	–7.4	0.49	0.87	931	1.24**	–9.2	0.97	69.7
Bay-Er 15	2 524	0.82**	44.7	0.87	1 149.8	35.2	1.75*	–21.7	2.07	0.75	889	0.90*	14.9	0.79	279.3
Bay-Er 16	2 572	0.83**	47.9	0.92	698.1	31.6	1.07**	–3.3	0.14	0.94	815	0.83**	12.9	0.93	72.2
Bay-Er 17	2 485	0.70*	71.0	0.78	1 638.7	31.8	0.42	18.2	1.26	0.22	792	0.68*	22.7	0.75	201.6
Dinçer 5-18-1	2 481	1.21**	–58.6	0.96	679.8	27.4	0.76*	2.5	0.35	0.78	684	1.01**	–14.6	0.93	89.6
Remzibey-05	2 381	1.11**	–43.1	0.94	845.0	29.2	0.82	2.5	0.82	0.63	703	1.05**	–16.6	0.96	60.0
Montola 2000	2 376	0.95**	–3.0	0.99	140.2	30.3	1.06**	–5.1	0.80	0.94	719	0.88**	–0.4	0.99	11.3
Balcı	2 594	1.05**	–5.1	0.91	1 106.2	34.3	1.15*	–0.1	1.64	0.75	896	1.14**	–4.8	0.90	186.5
Linas	2 504	0.87**	29.4	0.97	266.4	35.3	0.79	–2.1	0.07	0.63	885	0.92**	11.9	0.97	32.1
Olas	2 362	1.01**	–18.7	0.94	795.2	36.4	1.09**	10.9	0.17	0.95	862	1.13**	–6.9	0.94	102.5
Grand mean	2 531	1.00				32.5	1.00				824	1.00			

*,**Significant difference at $P < 0.05, 0.01$; x_i – mean; b_i – regression coefficient; a – regression line intercept; R_i^2 – coefficient of determination; S^2d_i – regression deviation mean square

https://doi.org/10.17221/113/2022-CJGPB

to all environmental conditions. Bay-ER 14 had poor adaptability to favourable environmental conditions, whereas Bay-Er 12, Bay-Er 15, Bay-Er 17 and Linas had poor adaptability to unfavourable environmental conditions. While the line Bay-Er 16 had better adaptability to unfavourable environmental conditions, the highest seed yielding lines Bay-Er 1, Bay-Er 5 and Bay-Er 14 had better adaptability to favourable environmental conditions. Based on Eberhart & Russell's (1966) definition of stability (b_i close to 1, S^2d_i close to 0), no genotype could be considered stable for all environments (Table 5).

The lines Bay-Er 5, 12, 13 and 14, the cultivars Balcı, Linas and Olas had oil content above the grand mean value (32.5%) (Table 5). The b_i values for this trait ranged from 0.42 (Bay-Er 17) to 1.75 (Bay-Er 15). The S^2d_i were non-significant for the genotypes Bay-Er 6, Bay-Er 17 indicating that all these genotypes do not differ significantly from 0. The R_i^2 values were low for the genotypes except Bay-Er 12, 15, 17 and Balcı. When grand means and b_i values for oil content were taken into account, Bay-Er 16 and Montola 2000 had poor adaptability, Bay-Er 5 had average adaptability, and Olas had better average adaptability to all environmental conditions (Table 5).

For oil yield, the b_i value of Bay-Er 2, 6 and 13 lines and Dinçer 5-18-1 and Remzibey-05 varieties is close to 1. Bay-Er 1, 5 and 14 lines can give an above mean oil yield under optimum growing conditions. On the other hand, Bay-Er 15 can be obtained with above-mean oil yield under adverse growing conditions. The location results of the Bay-Er 1, 5, 13, 14 and 16 lines were found to be more reliable for oil yield if the a value was close to 1 and the S^2d_i value was lower (Table 5).

Genotypic and environmental variability's of oleic and linoleic acids. The contents of oleic and linoleic acids in safflower lines and cultivars at different environments are given in Table 6. Although GC-FID analysis included palmitic and stearic acids in safflower oil, only oleic and linoleic acids, the main determinants of oil quality, were considered in this study. The G × E interaction may be important as genotypes exhibited a wide variation among themselves and in the different environments in terms of the contents of oleic acid and linoleic acid (Table 5). Among the genotypes, the lines Bay-Er 12, Bay-Er 13, Bay-Er 16 and Bay-Er 17 and the cultivars Olas and Montola 2000 contained high concentration of oleic acid in their seed oils. In safflower, three alleles (*Ol*, *ol'* and *ol*) are involved in the synthesis of oleic and linoleic acid; *OlOl* allele pair is responsible for the synthesis of high linoleic acid (75–80%)/low oleic acid (10–15%), whereas the *olol* allele pair is responsible for the synthesis of low linoleic acid (12–30%)/high oleic acid (64–83%) (Knowles 1969). Knowles (1989) reported that the genotypes *OlOl* and *olol* were more stable with regard to temperature changes, in contrast to the gene *ol'*.

Although Safflower is usually considered to be a self-pollinated crop, the observed average outcrossing rate was 26.6%, ranging from 8.3 to 53% at single plant level and from 0 to 79% at single head level when used high oleic acid biochemical marker (Nabloussi et al. 2013). When oleic acid type cultivars are pollinated with linoleic type cultivars by means of insects or wind in the open field conditions, oleic acid ratio tends to decrease in favor of linoleic acid ratio in the next generations because the dominant linoleic allele (*Ol*) on the recessive oleic allele (*ol*). So the genetic purity of high-oleic cultivars must be preserved against the possibility of foreign pollination with high-linoleic cultivars.

Mean oleic and linoleic contents of the genotypes within the environments are given in Table 6. The variation for oleic acid was between 8.2% in the cultivar Dinçer 5-18-1 at Şanlıurfa (autumn) and 79.1% in the line Bay-Er 13 at Konya. On the other hand, linoleic acid was varied from 13.5% in the line Bay-Er 13 at Konya to 82.6% in the cultivar Dinçer 5-18-1 at Edirne (Table 5). Based on the geographical position of the experimental locations, the oleic content of genotypes increased and the linoleic acid contents decreased from the north to south latitudes. For example, in Edirne and Eskişehir, which were located in more northern latitudes than the others, oleic acid contents were generally lowest and linoleic acid contents were generally highest (Table 6). It could be said that the oleic acid content increases as the temperature increases towards southern latitudes. For example, the oleic acid content of the cultivar Olas, a high-oleic cultivar, was found to be 45.0% in Eskişehir conditions, 62.2% in Edirne conditions and 70.0% in Şanlıurfa (spring) conditions. The mean temperature values of the summer months June, July, and August coinciding with the flowering, seed filling and maturity stages were respectively 17.2, 22.1 and 22.7 °C in Eskişehir, 22.5, 27.1 and 27.7 °C in Edirne, and 27.7, 33.2 and 31.5 °C in Şanlıurfa (Table 1). These findings indicate that oleic acid increased while linoleic acid decreased with increasing temperature. It is known that the temperature increases during seed formation and maturation promotes the synthesis of oleic acid (Bartholomew 1971). For better adaptation to cold conditions, the wild safflower species distributed in the northern hemisphere contain linoleic acid at high rates in their oils (Arslan & Hacıoğlu 2018). Since the oil content

https://doi.org/10.17221/113/2022-CJGPB

in the safflower seeds was controlled by the genes with additive effects and degree of heritability for this character was higher than the oleic and linoleic acids, the environmental sensitivity of the seed oil content is not as high as fatty acids (Baydar & Erbaş 2014). The fatty acid composition of oilseed crops is influenced by aerial temperature during seed development. A research by Canvin (2011) concluded that the oil content of safflower plants which were grown at temperatures of 10, 16, 21, and 26.5 °C for the period of seed development was not affected by temperature, whereas fatty acids were importantly affected.

Many plants respond to lower temperatures by increasing the level of unsaturation in the fatty acids

Table 6. The contents of oleic and linoleic acids in safflower lines and cultivars at different environments

Genotypes	Edirne	Eskişehir	Isparta	Konya	Şanlıurfa		Mean
					spring	autumn	
Oleic acid (%)							
Bay-Er 1	24.1	20.9	37.0	19.7	40.6	50.3	32.1
Bay-Er 2	26.9	30.0	45.5	39.4	30.5	12.9	30.9
Bay-Er 5	25.6	17.5	29.1	15.9	17.6	19.0	20.8
Bay-Er 6	15.8	11.7	28.4	31.4	11.1	13.0	18.6
Bay-Er 12	43.5	28.9	70.2	70.2	73.7	76.1	60.4
Bay-Er 13	68.4	72.5	54.4	79.1	64.9	74.6	69.0
Bay-Er 14	43.5	37.6	41.4	38.7	42.0	40.0	40.5
Bay-Er 15	30.6	26.6	29.4	18.5	24.6	23.6	25.6
Bay-Er 16	55.9	47.9	58.0	66.7	73.1	65.2	61.1
Bay-Er 17	47.5	64.3	40.6	65.2	45.6	34.2	49.6
Dinçer 5-18-1	8.7	15.9	9.0	10.2	11.1	8.2	10.5
Remzibey 05	12.7	14.1	12.3	16.1	14.8	15.8	14.3
Balcı	12.5	14.6	11.9	26.1	28.0	22.7	19.3
Linas	19.3	15.0	17.6	11.1	10.9	12.2	14.4
Olas	62.2	45.0	69.5	69.8	70.0	68.3	64.1
Montola 2000	76.6	67.7	71.6	62.4	68.6	74.4	70.2
Mean	32.0	30.4	35.9	37.9	36.3	34.5	34.5
Linoleic acid (%)							
Bay-Er 1	65.2	69.6	54.1	69.6	50.4	40.7	58.3
Bay-Er 2	63.6	61.4	45.3	52.0	59.9	76.5	59.8
Bay-Er 5	63.7	73.7	61.2	72.0	71.6	71.7	69.0
Bay-Er 6	74.0	79.5	60.7	59.3	79.2	76.2	71.5
Bay-Er 12	47.8	62.9	22.2	22.6	18.7	16.7	31.8
Bay-Er 13	23.9	19.8	37.0	13.5	27.0	17.6	23.1
Bay-Er 14	50.2	54.2	50.7	53.4	49.3	51.2	51.5
Bay-Er 15	58.6	65.6	61.6	72.7	65.4	67.0	65.2
Bay-Er 16	35.3	43.2	34.2	26.1	19.5	27.1	30.9
Bay-Er 17	42.4	28.5	40.4	26.9	45.6	56.4	40.0
Dinçer 5-18-1	82.6	75.9	82.0	80.9	79.1	81.7	80.4
Remzibey 05	75.1	77.8	79.2	75.7	76.5	74.6	76.5
Balcı	76.8	76.4	78.6	64.9	64.0	66.9	71.3
Linas	71.8	75.6	72.8	79.6	79.1	77.6	76.1
Olas	28.5	47.2	22.6	22.7	21.7	23.2	27.7
Montola 2000	15.1	23.5	19.5	28.9	22.0	16.0	20.8
Mean	58.5	61.2	54.6	53.4	54.7	56.2	56.4

https://doi.org/10.17221/113/2022-CJGPB

of membrane glycolipids and to higher temperatures by reducing the level of unsaturation of their membrane fatty acids. In general, these studies showed negative correlations between the levels of oleic acid ($C_{18:1}$) and linoleic acid ($C_{18:2}$) in the seed oil, with the degree of unsaturation decreasing when the crops were grown at higher temperatures (Deng & Scarth 1998). Usually, there was an inverse relationship between oleic acid and linoleic acid (Guan et al. 2008; Golkar et al. 2011). The results of our study also showed that linoleic acid is negatively correlated with oleic acid (r = 0.99**). While oleic acid was positively correlated with oil content (r = 0.31**), linoleic acid was negatively correlated with oil content (r = –0.32**). Since oil content was positively correlated with oleic acid and negatively correlated with linoleic acid, it should be possible to breed new safflower cultivars with simultaneously high oil content and high oleic or low linoleic acid content.

CONCLUSION

Safflower which is a valuable field crop in high-quality oil in the seeds can be mainly utilized in arid and semi-arid farming areas. However, there is a need the novel cultivars that have high seed yield, high oil content and high oil quality, which are priority requirements for an oilseed crop. On the other hand, these cultivars need to be highly adaptive and stable in changing environments. Because farmers especially in developing countries which use no or limited inputs or growing safflower under unfavourable or unpredictable environments, prefer the cultivars with good performance and stability.

In our study, the line Bay-Er 6 for Edirne, Bay-Er 17 for Eskişehir, Bay-Er 2 for Isparta, Bay-Er 5 for both Konya and Şanlıurfa locations can be recommended for their high seed yield performances. On the other hand, while the line Bay-Er 16 had better adaptability to unfavourable environmental conditions, the lines Bay-Er 1, Bay-Er 5 and Bay-Er 14 had better adaptability to favourable environmental conditions according to the stability analyses. The cultivars Olas, Linas and the line Bay-Er 15 had the highest seed oil content over 35% based on overall environments, and the cultivar Olas had better average adaptability to all environmental conditions. The safflower genotypes grown in the Southeastern Anatolia region had higher oil content than the other regions. This region is partly influenced by the Mediterranean climate and high temperatures from the flowering to maturation promote oil synthesis of safflower plants. In the same region, autumn sowing was preferable for high seed yield and oil content to the spring sowing. The study revealed that high air temperatures in seed maturity periods also promoted oleic acid synthesis against linoleic acid. On the basis of this knowledge, regional safflower production programs should be made to encourage production of oleic varieties in the southern hot regions and linoleic varieties in the northern cool regions.

REFERENCES

Akbar A.A., Karman M. (2006): Relationship among yield components and selection criteria for yield improvement in safflower (*C. tinctorius* L.). Journal of Applied Sciences, 6: 2853–2855.

Arslan Y., Hacıoğlu T. (2018): Seed fatty acid compositions and chemotaxonomy of wild safflower (*Carthamus* L., Asteraceae) species in Turkey. Turkish Journal of Agriculture and Foresty, 42: 45–54.

Aşkın E., Erbaş S. (2020): Superior lines for agro-technological traits in safflower (*C. tinctorius* L.). Turkish Journal of Field Crops, 25: 50–56.

Bagawan I., Ravikumar R.L. (2001): Strong undesirable linkages between seed yield and oil components – A problem in safflower improvement. In: 5th Int. Safflower Conf., Williston, July, 2001: 23–27.

Bartholomew S.B. (1971): Temperature effects on the fatty acid composition of developing in safflower (*C. tinctorius* L.). [MS Thesis.] Davis, University of California.

Baydar H., Erbaş S. (2014): Estimates for broad sense heritability and heterosis of agronomic and quality characters of safflower (*C. tinctorius* L.). Scientific Papers, Series A, Agronomy, 57: 110–115.

Baydar H., Gökmen O.Y. (2003): Hybrid seed production in safflower (*C. tinctorius* L.) following the induction of male sterility by gibberellic acid. Plant Breeding, 122: 459–461.

Becker H.C., Leon J. (1988): Stability analyses in plant breeding. Plant Breeding, 101: 1–23.

Bidgoli A.M., Akbari G.A., Mirhadi M.J.Z., Soufizadeh S. (2006): Path analysis of the relationships between seed yield and some morphological and phenological traits in safflower (*C. tinctorius* L.). Euphytica, 148: 261–268.

Camas N., Esendal E. (2006): Estimates of broad-sense heritability for seed yield and yield components of safflower (*C. tinctorius* L.). Hereditas, 143: 55–57.

Canvin D.T. (2011): The effect of temperature on the oil content and fatty acid composition of the oils from several oil seed crops. Canadian Journal of Botany, 43: 63–69.

Celikoglu F. (2004): Determination of yield characters of some safflower (*C. tinctorius* L.) lines under Eskisehir conditions. [MS Thesis.] Ankara, Ankara University.

Deharo A., Del Rio M., Lopez J.C., Garcia M.A., Palomares M.J., Fernandes Martines J. (1997): Evaluation of the world collection of safflower for oil quality and other seed characters. Sesame and Safflower Newsletter, 6: 94–99.

Deng X., Scarth R.J. (1998): Temperature effects on fatty acid composition during development of low-linolenic

https://doi.org/10.17221/113/2022-CJGPB

oilseed rape (*B. napus* L.). Journal of the American Oil Chemists' Society, 75: 759–766.

Eberhart S.A., Russel W.A. (1966): Stability parameters for comparing varieties. Crop Science, 6: 36–40.

Erbaş, S. (2012): Development of safflower (*C. tinctorius* L.) lines with high oil, oleic acid content and seed yield through hybridization breeding. [PhD Thesis.] Isparta, SDÜ Graduate School of Applied and Natural Sciences.

Erbaş S., Şenateş A. (2020): Effects of nitrogen and sulfur fertilization on yield and quality in sunflower (*Helianthus annuus* L.). Journal of Natural and Applied Sciences, 24: 217–225.

Erbaş S., Tonguç M., Şanli A. (2016): Variations in the agronomic and quality characteristics of domestic and foreign safflower (*C. tinctorius* L.) genotypes. Turkish Journal of Field Crops, 21: 110–119.

FAOSTAT (2022): FAOSTAT Online Database. Available at http://faostat3.fao.org/saffower.

Fernandez-Martinez J., Del Rio M., De Haro A. (1993): Survey of safflower (*C. tinctorius* L.) germplasm for variants in fatty acid composition and seed characters. Euphytica, 69: 115–122.

Finlay K.W., Wilkinson G.N. (1963): The analysis of adaptation in a plant breeding program. Australian Journal of Agricultural Research, 14: 742–754.

Futehally S., Knowles P.F. (1981): Inheritance of very high levels of linoleic acid in an introduction of safflower (*Carthamus tinctorius* L.) from Portugal. In: Proc. 1st Int. Safflower Conference, Davis, July 12–16, 1981: 56–61.

Ghongade R.A., Navale P.A., Joshi B.P. (1993): Estimates of variability parameters in safflower. Journal of Maharashtra Agricultural Universities, 18: 461–462.

Golkar P., Arzani A., Rezaei A.M. (2011): Genetic analysis of oil content and fatty acid composition in safflower (*C. tinctorius* L.). Journal of the American Oil Chemists' Society, 88: 975–982.

Guan L.L., Wu W., Zheng Y.L. (2008): Seed oil and fatty acids of different safflower genotypes and their correlations with agronomic traits and photosynthetic parameters. The Philippine Agricultural Scientists, 91: 383–388.

Hamdan Y.A.S., Pérez-Vich B., Velasco L., Fernández-Martínez J.M. (2009): Inheritance of high oleic acid content in safflower. Euphytica, 168: 61–69.

Johnson R.C., Bergman J.W., Flynn C.R. (1999): Oil and meal characteristics of core and non-core safflower accessions from the USDA Collection. Genetic Resources and Crop Evolution, 46: 611–618.

Knowles P.F. (1969): Modification of quantity and quality of safflower oil through plant breeding. Journal of American Oil Chemists' Society, 46: 130–132.

Knowles P.F. (1989). Safflower. In: Oil Crops of the World. New York, McGraw-Hill: 363–374.

Knowles P.F., Hill A.B. (1964): Inheritance of fatty acid content in the seed oil of a safflower introduction form Iran. Crop Science, 4: 406–409.

Koutroubas S.D., Papakosta D.K., Doitsinis A. (2004): Cultivar and seasonal effects on the contribution of pre-anthesis assimilates to safflower yield. Field Crops Research, 90: 263–274.

Mohammadi R., Pourdad S.S. (2009): Estimation, interrelationships and repeatability of genetic variability parameters in spring safflower using multi-environment trial data. Euphytica, 165: 313–324.

Nabloussi A., Velasco L., Fernandez-Martines J.M. (2013): Cross pollination of safflower (*C. tinctorius* L.) under Moroccan environmental conditions. International Journal of Plant Breeding, 7: 145–147.

Ozturk E., Ozer H., Polat T. (2008): Growth and yield of safflower genotypes grown under irrigated and non-irrigated conditions in a highland environment. Plant Soil Environment, 54: 453–460.

Parameshwar K.B. (2009): Stability of non-spiny breeding lines in safflower (*Carthamus tinctorius* L.). [MS Thesis.] Dharwad, Dharwad University of Agricultural Sciences.

Pinthus M.J. (1973): Estimates of genotypic value a proposed method. Euphytica, 22: 345–351.

Pourdad S.S., Mohammadi R. (2008): Use of stability parameters for comparing safflower genotypes in multi-environment trials. Asian Journal of Plant Science, 7: 100–104.

Ramachandram M., Goud J.V. (1981): Genetic analysis of seed yield, oil content and their components in safflower (*C. tinctorius* L.). Theoretical and Applied Genetics, 60: 191–195.

Reddy M.V.S., Chand P., Vidyadhar B., Devi I.S.L. (2003): Correlation and path coefficient analysis of various component on seed yield in F_3 generation safflower (*Carthamus tinctorius* L.). Progress in Agricultural Engineering, 3: 57–59.

Şenateş A., Erbaş S. (2020): Determination of agricultural and technological characters of Safflower (*C. tinctorius* L.) lines developed by single seed descent selection methods. Journal of Natural and Applied Sciences, 24: 143–151.

Smith E.L. (1982): Heat and drought tolerant wheats of the future. In: Proc. Natl. Wheat Res. Conf. Betswille. Washington, National Association of Wheat Growers Foundation.

Tabrizi A.H.O. (2000): Correlation between traits and path analysis for grain and oil yield in spring safflower. Sesame and Safflower Newsletter, 15: 78–82.

Weiss E.A. (2000): Oilseed Crops. 2nd Ed., Victoria, Blackwell Science Ltd.

Yeloojeh K.A., Saeidi G., Sabzalian M.R. (2020): Drought stress improves the composition of secondary metabolites in safflower flower at the expense of reduction in seed yield and oil content. Industrial Crops & Products, 154: 112496.

Received: December 16, 2022
Accepted: April 17, 2023
Published online: June 19, 2023