International Journal of Plant Production (2026) 20:15
https://doi.org/10.1007/s42106-025-00402-x

RESEARCH

Yield Performance and Oil Composition of Safflower (*Carthamus Tinctorius* L.) Cultivars Under Semi-Arid Conditions in Northern Türkiye

Ibrahim Cosar[1] · **Volkan Gul**[1] · **Firat Sefaoglu**[2]

Received: 8 August 2025 / Accepted: 9 December 2025 / Published online: 18 December 2025

Abstract

The shortage of vegetable oil in Turkey is escalating daily. Increasing the production of safflower oil seeds, which are particularly adapted to semi-arid climatic conditions, could reduce dependence on foreign sources for vegetable oil. In this study, the yield and quality characteristics of eight safflower varieties were evaluated under semi-arid ecological conditions in northern Turkey. Field trials were conducted over two years (2020–2021) with three replications, following the ''Randomized Block Experiment Design''. Significant differences were observed between the varieties in terms of the examined parameters. The highest average grain yield (1730.9 kg ha^{-1}) was obtained from the Göktürk variety, the highest oil content (30.7%) from the Balcı variety, and the highest oil yield (470.1 kg ha^{-1}) from the Olas variety. The highest oleic acid content (50.14% ± 3.9) was obtained from the Koc variety, and the highest stearic acid content (2.68% ± 0.1) was obtained from the Hasankendi variety. The linoleic acid (77.71% ± 0.4) and palmitic acid (5.92% ± 0.1) ratios were found to be higher in the Dincer variety compared to other varieties. The research highlights the importance of genotypes in asparagus. It demonstrates that the Göktürk and Olas varieties stand out in terms of yield and yield components in semi-arid ecosystems. These results provide variety-specific information for regional adaptation in safflower breeding and under challenging climatic conditions.

Keywords Cultivars · Northern Türkiye · Oil content · Oleic acid · Safflower · Seed traits

Introduction

Limited production can occur in semi-arid areas due to insufficient rainfall during the growing season. The need for alternative oil crops that can be produced under these conditions is increasing. The safflower is one of the significant oilseeds that can be cultivated in semiarid climate conditions. Safflower is a highly drought- and salinity-resistant plant (Bortolheiro & Silva, 2017; Aydin & Sarptas, 2018). Safflower contains high levels of unsaturated fatty acids (78–90%), especially oleic and linoleic acids, and has relatively low water requirements, and can be successfully grown in areas with annual rainfall as low as 280–380 mm (Sayilir et al., 2019; Alizadeh-Yeloojeh et al., 2020). It has been the center of attention of farmers and researchers due to its ease of cultivation in arid and semi-arid areas of limited irrigation (La Bella et al., 2019).

In countries like Türkiye, which have both an oil deficit and limited water resources, safflower has not been able to fully utilize its potential. Despite its high production potential, research on the performance of safflower cultivars in the semi-arid regions of northern Türkiye remains limited.

Baydar and Turgut (1999) laid an important foundation in their study by stating that the specific fatty acid composition of each oil plant is not constant; it is in a constant state of change under the influence of variety, intrinsic and extrinsic factors, and that such studies should be carried out in different regions. However, it was mostly limited to one-year trials, and no long-term analyses evaluating both yield and oil quality together were conducted.

Cavumirza and Demir (2024) investigated the yield performance of safflower cultivars under Kırşehir conditions,

✉ Volkan Gul
volkangul@bayburt.edu.tr

[1] Aydintepe Vocational School of Higher Education, Food Processing, Food Technology Program, Bayburt University, Aydintepe/Bayburt, Turkey

[2] Department of Genetics and Bioengineering, Faculty of Engineering and Architecture, Kastamonu University, Kastamonu, Turkey

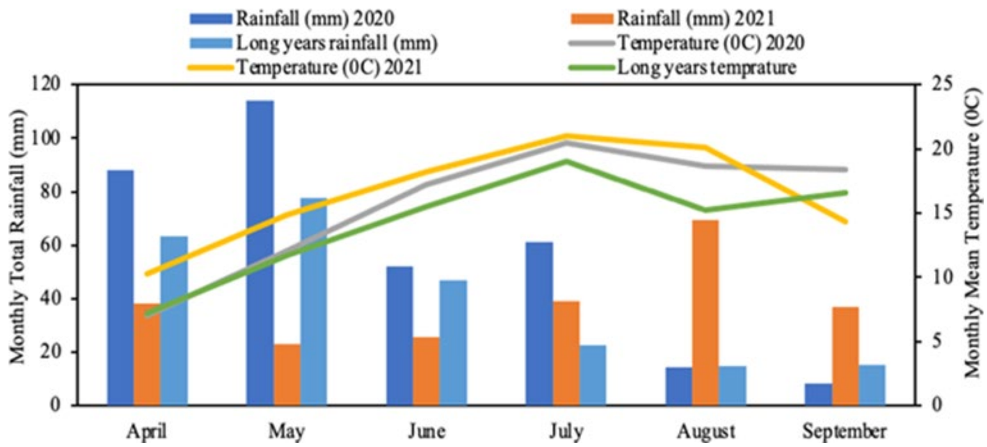

Fig. 1 Average air temperature, precipitation, and relative humidity during the growing seasons in Bayburt, Northern Türkiye

Table 1 Some characteristics of the soil of the experimental area for the year 2020–2021

Years	Depth (cm)	Sturation (%)	Texture Type	pH	Salt (%)	Lime (% $CaCO_3$)	Organic Matter (%)	Available	
								P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
2020	0–30	57	Clay-Loamy	8.0	0.02	19.55	1,00	0.175	4.57
2021	0–30	55	Clay-Loamy	7.9	0.01	17.31	0,99	0.133	4.38

but focused only on morphological characteristics and considered it a one-year study. In another study, Beyyavas et al. (2023) tried to determine the fatty acid composition of safflower cultivars under dry and irrigated conditions in Şanlıurfa, but did not integrate yield parameters. Zemour et al. (2021) studied the effects of environmental factors on oil quality, while Kina and Ozgokce (2023) studied phenological variations but did not evaluate oil components. Again, some researchers tried to determine drought-resistant varieties by taking phenological characteristics into consideration in determining safflower varieties suitable for the region (Yilmaz & Kinay, 2015; Bouhouhou & Mohamed, 2016; Aygun & Mert, 2020; Sefaoglu & Ozer, 2022).

Studies evaluating yield, yield components, and oil quality together, as well as over multiple years, in safflower grown under semi-arid conditions in north-eastern Türkiye are quite limited. The vast majority of existing studies are designed to be annual and one-sided, and semi-arid agricultural areas have not been sufficiently evaluated, with wet regions often being overlooked. The aim of this study is to make significant contributions to the existing literature by simultaneously evaluating both the agronomic performance and oil composition of eight different aspir varieties over two years under semi-arid conditions in Bayburt, and to provide scientific contributions to the identification of high-performance genotypes suitable for the region.

Materials and methods

The experiment was conducted in 2020 and 2021 at Bayburt University Organic Agriculture Research Area in the Eastern Black Sea Region of Türkiye. Total rainfall, monthly average relative humidity, and air temperatures for the experimental years and long years were obtained from the Bayburt Meteorological Department and presented in Fig. 1.

To determine the nutrient content of the experimental area, composite soil samples were taken from 0 to 30 cm soil depth at random. The soil samples were then sent to the Black Sea Agricultural Research Institute soil laboratory for analysis. It was found that the soil texture was clayey-loamy, moderately alkaline, low in phosphorus, moderate in organic matter, and sufficient in potassium (Table 1).

In the experiment, eight safflower cultivars (Hasankendi, Zirkon, Balcı, Dincer, Koc, Göktürk, Linas, and Olas) were used, all of which were obtained from research institutes affiliated with the Turkish Ministry of Agriculture and Forestry.

The trials were arranged using a "Randomized Block Experiment Design" with three repeats. The plots were 5 m long, 1.2 m wide, and consisted of four rows. The experiment was generally designed with a one-meter distance between the plots and a three-meter distance between the blocks.

In both years, 30 tons of farm manure per hectare were applied to the trial area in autumn. Afterwards, the experimental area, which had been plowed deeply and left as clods for the winter, was plowed superficially in the spring. The seedbed was then prepared by passing the disc harrow and tapan. The sowing process was carried out using a hand drill, with 30 cm between rows and 10 cm within rows, when soil conditions were suitable. This was done on May 5, 2020, in the first year of the study, and on May 8, 2021, during the second year. Three weeks after emergence, thinning was carried out with the first hoe for weed control. The second hoeing was repeated 20–25 days later, depending on weed status. Irrigation was applied twice in total, during the bud formation and flowering periods, when the plant needed water the most. In harvesting, one row from the edges of each plot, 50 cm from the head of each plot, was considered the edge effect, and the remaining two rows in the center were harvested. Under this arrangement, an average of 80 plants from each plot were assessed. The plants harvested on 12 September 2020 in the first year and on 11 September 2021 in the second year were then dried, and the seeds were removed by hand.

Plant height, head diameter, head number, branch number, and seed number were determined by taking the average of ten plants selected by chance from the middle two rows of each plot. Thousand-seed weight was obtained by averaging 100 seeds, counted three times, in grams and then multiplying by 1,000. Seed yield was calculated as the yield per hectare of the amount of seed obtained from each plot.

The total oil content of the samples obtained from the experimental area was determined by the Nuclear Magnetic Resonance Spectrometric Method (NMR) at the Central Research Laboratory of Kastamonu University (Rodrigues et al., 2005).

The fatty acid compositions of safflower oils, obtained by the Soxhlet method, were determined using gas chromatography-mass spectrometry in accordance with ISO (2015). Analysis of fatty acid methyl esters prepared according to ISO 12966-2 (2017) was performed on an Agilent Technologies (Palo Alto, CA, USA) gas chromatograph model 7890B coupled with a 5977 A mass selective detector using a DB-23 Agilent Technologies capillary column (60 m × 0.25 mm inner diameter, film thickness 0.25 µm). The initial GC oven temperature was set at 50 ◦C for 1 min, then increased to 200 ◦C at a rate of 25 ◦C/min, and subsequently raised to 230 ◦C at a rate of 3 ◦C/min, before being held at 230 ◦C for 7 min. The injector was maintained at 250 °C; the injection volume was 1.0 µL, and the split ratio was 1:50. Helium was used as the carrier gas at a constant flow rate of 1.0 mL/min. The mass spectrometer was operated in electron ionization mode (70 eV). Data acquisition was performed in scan mode (mass range: 50–400), with a solvent delay time of 5 min. Fatty acid peaks were identified by comparing their retention times with those of known standards and mass spectrum databases (Wiley 10th & NIST 2011 MS Library). A Supelco (Bellefonte, PA, USA) standard solution containing 37 FAME mixtures was used for peak determination. The resulting palmitic (C16:0), stearic (C18:0), oleic (C18:1), and linoleic (C18:2) fatty acids were expressed as percentages.

The results were analyzed using analysis of variance with JMP statistical software version 5.0.1 (SAS Institute, 2002). Significant treatment traits were grouped according to the Duncan Multiple Range Test at a 5% probability level. GT data were analyzed using Excel and GGEbiplot software (Yan &Kang, 2002). Additionally, the Pearson correlation was used to identify differences between variables (Cohen et al., 2009).

Results

All characteristics examined in the study, except for stearic and palmitic acid, were significantly affected by differences between years, clearly demonstrating the effect of climatic factors on sunflower varieties. Furthermore, the difference between varieties is of practical importance for all traits except head diameter, head number, and seed number. The interaction between year and variety is significant for all parameters evaluated, except for head diameter, thousand-seed weight, seed yield, and oil yield (Tables 2 and 3).

When evaluating sunflower varieties by year, the highest values for plant height (82.6 cm), head number (15.90 per plant), branch number (9.40 per plant), thousand seed weight (44.21 g), seed yield (1500.31 kg ha^{-1}), oil content (31.20%), oil yield (467.60 kg ha^{-1}) and oleic acid (%24.73) were determined to be the highest in 2020 (Tables 2 and 3). This situation can be attributed to the fact that 2020 offered more favourable conditions in terms of rainfall amount and distribution compared to 2021. In contrast, the linoleic acid ratio (68.09%) was higher in 2021 than in the other parameters (Table 3). The increase in linoleic acid in 2021 may be due to the warmer and drier conditions that year.

Among the varieties, the highest plant height (79.4 cm) was observed in the Dincer variety, the highest number of branches (11.5 no plant^{-1}) from the Hasankendi variety, the highest thousand seed weight (46.0, 45.2, 44.9 and 44.6 g) from the Linas, Göktürk, Dincer and Olas varieties, and the highest seed yield (1730.9 kg ha^{-1}) from the Göktürk variety. The lowest plant height (62.8 cm) was observed in the Koc variety, while the Balcı, Göktürk, Linas, and Olas varieties were grouped statistically. The lowest branch number was obtained from the Göktürk variety, while the lowest thousand-seed weight and seed yield were obtained from the Hasankendi variety (Table 2). In contrast, no significant differences were found between varieties in terms of head diameter, head number, and seed number. These results indicate that the differences in yield parameters stem from the

Table 2 Means and analysis of variance results of plant height, head diameter, head number, branch number, seed number, thousand seed weight, and seed yield traits of different safflower cultivars grown in 2020 and 2021 under semi-arid climate conditions

Treatments		*P*.H.	H.D	H.*N*	B.*N*	S.*N*	T.S.W	S.Y
Year	2020	82.6a	2.50	15.90a	9.40a	40.92	44.21a	1500.31a
	2021	55.8b	2.38	11.35b	7.90b	35.58	40.52b	1300.7b
Cultivars	HASANKENDI	74.0b	2.44	15.00	11.50a	32.41	35.8d	1120.8e
	ZIRKON	72.0b	2.44	18.00	9.83b	38.16	42.9ab	1350.0ce
	BALCI	66.4c	2.32	13.10	10.17ab	36.29	41.0bc	1320.3ce
	DINCER	79.4a	2.60	11.50	8.11c	41.53	44.9a	1380.0bd
	KOC	62.8c	2.31	12.20	8.28c	35.93	38.6 cd	1201.3de
	GOKTURK	66.8c	2.54	13.20	6.67d	40.12	45.2a	1730.9a
	LINAS	66.9c	2.42	12.10	7.11 cd	38.82	46.0a	1490.8bc
	OLAS	65.1c	2.46	14.00	7.22 cd	41.72	44.6a	1600.7ab
	Mean	69.6	2.44	13.64	8.61	38.12	42.38	1404.9
Variation Sorces	SD	$P>F$						
Year (Y)	1	57.51**	4.86^{ns}	33.0**	12.37**	7.14^{ns}	13.64**	8.19*
Cultivar (C)	7	12.47**	2.06^{ns}	2.70^{ns}	12.65**	2.06^{ns}	14.95**	6.41**
Y X C	7	26.31**	1.92^{ns}	5.2**	12.87**	4.11**	1.86^{ns}	0.10^{ns}

*. ** significant at the 0.05 and 0.01 levels, respectively. For each main effect, values within columns followed by the same letter are insignificant, ns: nonsignificant. P.H: Plant height (cm); H.D: Head Diameter (cm); H.N: Head Number (no plant^{-1}), B.N: Branch Number (no plant^{-1}), S.N: Seed Number (no plant^{-1}), T.S.W: Thousand Seed Weight (g), S.Y: Seed Yield (kg ha^{-1})

Table 3 Means and analysis of variance results of oil content, oil yield, oleic acid, linoleic acid, stearic acid, and palmitic acid traits of different safflower cultivars grown in 2020 and 2021 under semi-arid climate conditions

Treatments		O.C (%)	O.Y (kg ha^{-1})	O.A (%) (C18:1)	L.A (%) (C18:2)	S.A (%) (C18:0)	*P*.A (%) (C16:0)
Years	2020	31.20a	467.60a	24.73±2.9a	67.48±2.8b	2.23±0.1	5.51±0.5
	2021	25.00b	325.60b	24.00±3.4b	68.09±3.3a	2.18±0.1	5.71±0.4
Cultivars	HASANKENDI	29.40b	329.20d	15.20±1.2f	76.67±1.2b	2.68±0.1a	5.45±0.1b
	ZIRKON	29.00b	391,00bd	16.99±0.8d	75.07±0.6d	2.44±0.1b	5.50±0.3b
	BALCI	30.70a	405.50ac	16.41±0.2de	75.55±0.2 cd	2.34±0.2bc	5.72±0.2ab
	DINCER	25.30d	348.70 cd	14.13±0.4 g	77.71±0.4a	2.23±0.1 cd	5.92±0.1a
	KOC	29.10b	349.60 cd	50.14±3.9a	43.04±4.0 g	1.83±0.1f	5.00±0.0c
	GOKTURK	24.80d	428.60ab	16.08±0.7e	75.78±0.7c	2.12±0.0de	5.87±0.1a
	LINAS	27.30c	406.80ac	22.20±2.8c	69.84±2.6e	2.07±0.1e	5.89±0.1a
	OLAS	29.40b	470.10a	43.81±7.2b	48.64±7.1f	1.92±0.0f	5.56±0.1b
Mean		28.10	396.0	24.40	67.80	2.20	5.60
Variation Sources	SD	$P>F$					
Year (Y)	1	111.80**	43.37**	8.979*	10.71*	1.113^{ns}	3.788^{ns}
Cultivars (C)	7	31.30**	3.21**	3743.09**	3738.62**	46.925**	9.618**
YX C	7	24.22**	1.05^{ns}	1026.37**	1048.66**	24.637**	5.522**

*. ** significant at the 0.05 and 0.01 levels, respectively. Each main effective value within columns followed by the same letter is insignificant. ns: nonsignificant; O.C: Oil Content, O.Y: Oil Yield; O.A: Oleic Acid; L.A: Linoleic Acid; S.A: Stearic Acid; P.A: Palmitic Acid

combined effect of both genetic make up and climatic and environmental variability between years.

When varieties were evaluated in terms of oil quality parameters, the highest oil content was obtained from the Balcı variety (30.70%), and the highest oil yield was from the Olas variety (470.10 kg ha^{-1}). In contrast, the Göktürk, Dincer, and Hasankendi varieties stood out with lower fat content (24.80–25.30%) and fat yield (329.20 kg ha^{-1}). Significant variation was observed among varieties in terms of fatty acid composition; the highest oleic acid content was found in the Koc variety (50.14±3.9%), while the highest linoleic acid content was determined in the Dincer variety (77.71±0.4%). When saturated fatty acids were examined, it was determined that the ratios of stearic and palmitic acids were relatively higher in the Hasankendi, Dincer, Göktürk, and Linas varieties, while the lowest values were observed in Koc and Olas (Table 3). In general, this study, conducted under semi-arid conditions, clearly demonstrates the effect of variety on fatty acids and fat quality parameters. This situation demonstrates that the fatty acid composition is sensitive to both genetic structure and environmental factors, such as temperature and rainfall, which change over time. Therefore, in determining suitable varieties for sunflower cultivation in semi-arid environments, both genetic variation and climatic variability must be considered together.

In the study conducted under semi-arid climate conditions, correlation analysis revealed relationships at various levels between the examined yield and oil quality components. It has been observed that it exhibits positive correlations with PH, HD, BN, and SN, but conversely, it has a strong negative correlation with HN. This result suggests that the increase in head diameter, branch number, and seed number promotes plant height elongation, whereas the rise in head number inhibits plant height elongation. A moderate positive correlation was obtained between SY and TSW with '$r=0.461$; $p<0.01$' and between SN with '$r=0.448$; $p<0.01$', while a high positive correlation was obtained between OY with '$r=0.817$; $p<0.01$'. The strong relationship between SY and OY suggests that changes in seed yield largely determine oil yield. Furthermore, these results clearly demonstrate that seed number and seed size are the most important factors determining yield under semi-arid climatic conditions. OC, PH ('$r=0.643$; $p<0.01$') and OY ("$r=0.636$; $p<0.01$') showed a high positive correlation, while BN ('$r=0.484$; $p<0.01$') and SN ('$r=0.323$; $p<0.05$") showed a moderate positive correlation. Additionally, a mild negative correlation was found between OC, HN ('r=-0.341; $p<0.05$') and PA ('r=-0.364; $p<0.05$'). A very strong and direct negative relationship ($r=-0.999$; $p<0.01$) between the fatty acid components OA and LA, indicating a metabolic transformation, was observed (Table 4; Fig. 2). This relationship confirms the biochemical mechanism involved in the conversion of oleic acid to linoleic acid in fatty acid biosynthesis. Saturated fatty acids, such as PA and SA, have shown directional relationships with some unsaturated fatty acids, specifically PA–LA positive and SA–OA negative, reflecting the sensitivity of fatty acid composition to climatic factors under semi-arid conditions. The correlations obtained generally indicate a biological link between moderate and strong relationships in yield and oil quality components, clearly demonstrating that both genetic factors and climatic variability must be considered together when evaluating aspir yield and oil composition under semi-arid conditions.

Based on the PCA biplot values calculated from the mean values of the examined characteristics, it was observed that the first and second components possessed eigenvalues greater than one. The first and second components have the highest variance at 19.55% and 17.96% respectively, explaining 37.5% of the total variance. PC1 particularly represents agronomic and yield components such as V1, V2, V4, V5, V6, V7, V8 and V9 to a high degree. The PC2 component, on the other hand, more effectively shows the variation in saturated and unsaturated fatty acids (V10, V11, V12, and V13). According to the biplot values obtained from the first and second components, the G6, G3, and G2 varieties were grouped together due to their high similarity and were observed to have high positive values on the PC1 axis for plant height, table diameter, number of branches, thousand-seed weight, seed yield, number of seeds, oil content, and oil yield. It is considered that the varieties within this group, in particular, possess superior characteristics in terms of yield and oil production. In biplot analysis, close positioning indicates that the varieties are similar and stable under semi-arid conditions. Similarly, the G1, G2, and G8 varieties showed convergence on the PC2 axis, and it was observed that these varieties had a stronger relationship with saturated and unsaturated fatty acids such as V10, V11, V12, and V13. Although the varieties in this group exhibit superior performance in terms of fatty acids, it is evident that they do not outperform the varieties in the PC1 group in terms of yield components (Fig. 3). According to these results, it is necessary to evaluate both yield components and oil quality characteristics together when selecting varieties under semi-arid conditions.

Discussion

The study, conducted under semi-arid climatic conditions, clearly demonstrated the effects of genetic, climatic, and environmental factors on the yield and oil quality characteristics of sunflower varieties. Significant climate changes, such as temperature fluctuations over the years and differences in rainfall amount and distribution, have seriously affected parameters such as plant height, head number, branch number, thousand seed weight, seed yield, oil content, oil yield, oleic acid, and linoleic acid (Tables 2 and 3). Compared to previous years, 2020 was particularly cooler, wetter, and had more evenly distributed rainfall, resulting in higher yields and better oil quality parameters compared to 2021. These results are consistent with similar studies (Killi et al., 2016; Gursoy et al., 2017; Bortolheiro & Silva, 2017; Demir & Kara, 2018; Khan et al., 2018; Gok & Ekin, 2019; Zamani et al., 2020; Sefaoglu et al., 2021; Abou Chehade et al., 2022; Pasban Eslam et al., 2024).

The genotypic characteristics of sunflower varieties, such as their sensitivity to environmental stress and climatic factors, have significantly affected parameters including plant height, branch number, thousand seed weight, seed yield, oil content, oil yield, oleic acid, linoleic acid, stearic acid, and palmitic acid (Gul & Coban, 2020; Vicianová et al., 2020), (Tables 2 and 3). The Göktürk and Balcı varieties were found to be the highest-yielding varieties in terms of the important parameters examined. The fact that the Göktürk variety yields the highest seed production is directly related to its high thousand-seed weight and oil yield compared to other varieties, sufficient seed number,

Table 4 Correlation analysis between different traits examined for safflower cultivars in two years together

Applications		*P*.H	H.D	H.*N*	B.*N*	T.S.W	S.Y	S.*N*	O.C	O.Y	*P*.A	S.A	O.A	L.A
P.H	Pearson Correlation	1												
	Sig. (2-tailed)	---												
H.D	Pearson Correlation	,361*	1											
	Sig. (2-tailed)	,012	---											
H.N	Pearson Correlation	-,573**	-,176^{ns}	1										
	Sig. (2-tailed)	,000	,231	---										
B.N	Pearson Correlation	,523**	,153^{ns}	-,290*	1									
	Sig. (2-tailed)	,000	,299	,046	---									
T.S.W	Pearson Correlation	,255^{ns}	,435**	-,294*	-,306*	1								
	Sig. (2-tailed)	,081	,002	,042	,034	---								
S.Y	Pearson Correlation	,231^{ns}	,261^{ns}	-,269^{ns}	-,252^{ns}	,461**	1							
	Sig. (2-tailed)	,114	,074	,065	,083	,001	---							
S.N	Pearson Correlation	,463**	,591**	-,408**	,084^{ns}	,440**	,448**	1						
	Sig. (2-tailed)	,001	,000	,004	,572	,002	,001	---						
O.C	Pearson Correlation	,643**	,195^{ns}	-,341*	,484**	,129^{ns}	,084^{ns}	,323*	1					
	Sig. (2-tailed)	,000	,183	,018	,000	,384	,570	,025	---					
O.Y	Pearson Correlation	,536**	,285*	-,397**	,073^{ns}	,412**	,817**	,516**	,636**	1				
	Sig. (2-tailed)	,000	,050	,005	,623	,004	,000	,000	,000	---				
P.A	Pearson Correlation	-,175^{ns}	,023^{ns}	,215^{ns}	-,339*	,273^{ns}	,218^{ns}	,009^{ns}	-,364*	-,039^{ns}	1			
	Sig. (2-tailed)	,233	,879	,142	,019	,060	,137	,950	,011	,791	---			
S.A	Pearson Correlation	,367*	,088^{ns}	,108^{ns}	,493**	-,186^{ns}	-,274^{ns}	,108^{ns}	,263^{ns}	-,074^{ns}	,079^{ns}	1		
	Sig. (2-tailed)	,010	,551	,464	,000	,205	,059	,464	,071	,617	,594	---		
O.A	Pearson Correlation	-,087^{ns}	-,086^{ns}	-,163^{ns}	-,052^{ns}	-,051^{ns}	,039^{ns}	,101^{ns}	,178^{ns}	,127^{ns}	-,532**	-,526**	1	
	Sig. (2-tailed)	,555	,563	,267	,727	,731	,793	,494	,226	,388	,000	,000	---	
L.A	Pearson Correlation	,088^{ns}	,082^{ns}	,160^{ns}	,063^{ns}	,051^{ns}	-,044^{ns}	-,112^{ns}	-,179^{ns}	-,132^{ns}	,525**	,520**	-,999**	1
	Sig. (2-tailed)	,550	,581	,277	,672	,732	,766	,448	,223	,371	,000	,000	,000	---

The correlation is significantly at $p < 0.05$ and $p < 0.01$ levels, ns: no significantly

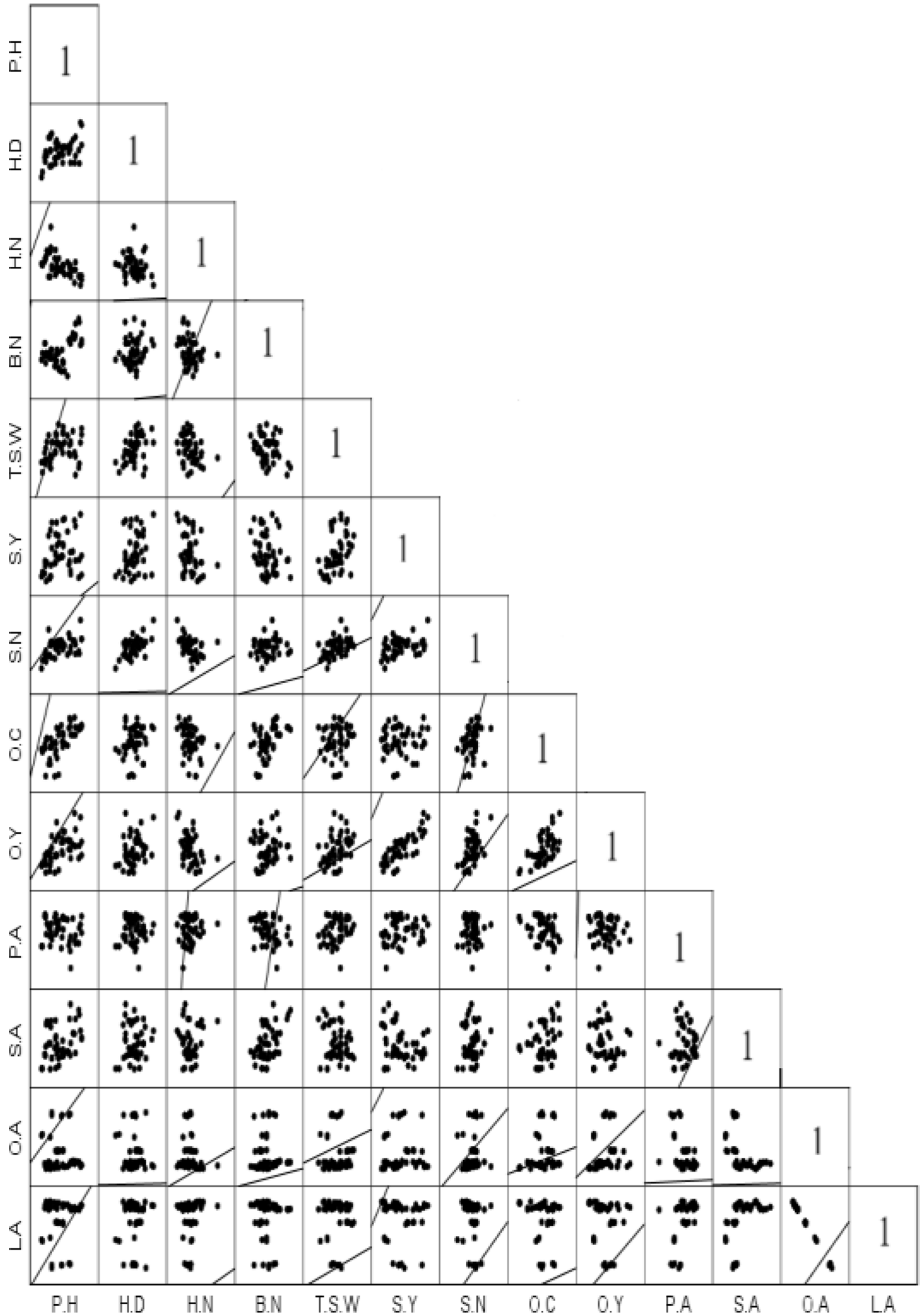

Fig. 2 Matrix of binary scatter plots between variables for safflower cultivars

and balanced plant architecture. Indeed, these yield components are important parameters that directly affect seed yield (Emongor et al., 2017). Certain morphological traits directly related to seed yield indicate that they can increase the seed yield gains of aspir varieties and enable effective selection of varieties (Pattar & Patil, 2020). Under semi-arid climatic conditions, increased plant height due to suitable air temperature and rainfall enhances photosynthetic production, seed formation, and seed yield,

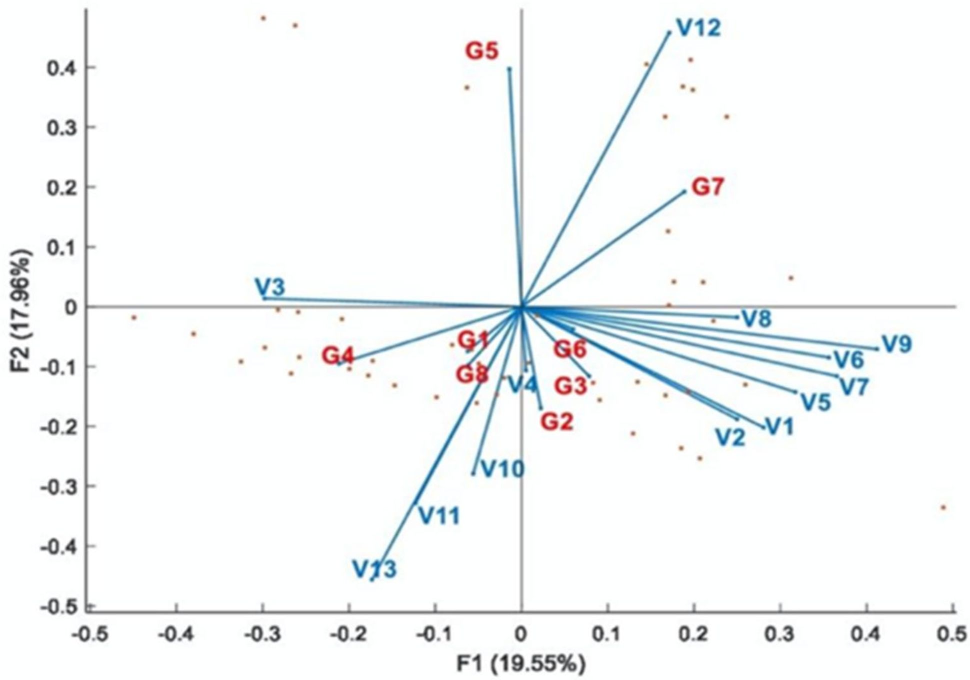

Fig. 3 Relationship between variety and trait based on principal component analysis using biplot according to years average, V1: Plant height (cm); V2: Head diameter (cm); V3: Head number (no plant^{-1}); V4: Branch number (no plant^{-1}), V5: Thousand seed weight (g); V6: Seed yield (kg ha^{-1}); V7: Seed number (no plant^{-1}); V8: Oil concentrate (%) V9: Oil yield (%); V10: Palmitic acid (%); V11: Stearic acid (%); V12: Oleic acid (%); V13: Linoleic acid (%); G1: Hasankendi; G2: Zircon; G3: Balci; G4: Dincer; G5: Koc; G6: Göktürk; G7: Linas; G8: Olas

resulting in significant positive correlations with morphological traits such as branch number, oil content, oil yield, seed number, and head diameter (Sirel & Aytac, 2016; Naziha & Kurt, 2023). The high yield of the Balcı variety is due to its high oil content. Under semi-arid climatic conditions, the oil content is sensitive to environmental stress factors, and it is clear that the Balcı variety is genetically predisposed to high oil accumulation under these conditions (Golkar, 2014; Emongor et al., 2017; Abou Chehade et al., 2022). Indeed, the results clearly indicate that the Göktürk variety exhibits superior genetic traits in terms of yield parameters, whereas the Balcı variety demonstrates superior genetic traits in terms of oil content. Some researchers have reported significant differences in seed yield and oil content among sunflower varieties depending on genotype and environmental factors (Bouhouhou & Mohamed, 2016; Demir & Kara, 2018; Khan et al., 2018; Zemour et al., 2021; Abou Chehade et al., 2022; Kina & Ozgokce, 2023; Cavumirza & Demir, 2024). The Olas variety stood out with the highest oil yield in the study (Table 3). The superiority of the Olas variety in terms of oil yield is attributed to its strong positive correlation with seed yield and oil content. The Olas variety stands out as a strong candidate for oilseed production under semi-arid climatic conditions. Asparagus varieties grown under semi-arid climatic conditions exhibit reduced seed yield and oil content when subjected to low rainfall and high air temperatures. In short, changes in seed yield and oil content due to climate change directly affect oil yield (Gul & Coban, 2020; Sefaoglu et al., 2021). The primary reason for the high linoleic acid content in the fatty acid composition of the Dincer and Hasankendi varieties and the high oleic acid content in the Koc and, to a lesser extent, Olas varieties compared to other varieties (Table 3) stems from the interaction between their genetic structure and climatic conditions. There is a very strong negative correlation between oleic acid and linoleic acid. Therefore, the flowering and ripening periods are critical, as low temperatures during these periods increase the linoleic acid content, while high temperatures increase the oleic acid content (Ferfuia & Vannozzi, 2015; Popa et al., 2017; Sahin et al., 2022). This situation clearly demonstrates why the interaction of year x is significant.

PCA-biplot analysis has divided sunflower varieties into two groups based on their yield and oil quality characteristics. The Göktürk (G6), Balcı (G3) and Zircon (G2) varieties showed a strong relationship with the yield components plant height, branch number, thousand seed weight, seed yield, oil content and oil yield on the PC1 axis, while the Hasankendi (G1), Dincer (G4) and Olas (G8) varieties showed a strong relationship with the oleic acid, linoleic acid, stearic acid, and palmitic acid components on the PC2 axis. This difference supports studies indicating that yield and oil quality parameters of varieties can be observed in different combinations in line with genetic diversity (Elfadl et al., 2010).

Conclusion

This study aimed to compare the yield and oil quality traits of eight different safflower cultivars under semi-arid climatic conditions in northern Turkey to evaluate their responses to genetic variation and environmental variability. The results showed that year effect was the most important source of variation on seed traits, except for head diameter, seed number, stearic acid and palmitic acid. On the other hand, for all seed traits except head diameter, number of heads and number of seeds, inter-cultivar differences were found to be more dominant. In addition, year × variety interaction was statistically significant in all traits except head diameter, thousand seed weight, seed yield and oil yield, indicating that the responses of genotypes to environmental conditions differed by year.

Considering the climatic and environmental variability of the research region, significant differences were observed in the performance of safflower varieties. Especially Göktürk and Olas varieties were found to be prominent in terms of drought resistance against variable climatic conditions. However, the inconsistent performance of some cultivars between years revealed the importance of evaluating stability once again. For example, while Remzibey variety attracts attention with its high seed yield and oil content, its ability to maintain this superiority under different environmental conditions is an important area of evaluation for future studies.

In this context, it was confirmed that genotype × environment interaction is a critical factor in safflower breeding and variety selection. It was concluded that cultivars should be recommended based on their suitability to specific environmental conditions and that these recommendations should be based on stability as well as average performance. Both simple correlation and GGE biplot analyses were effective tools for evaluating the adaptability and stability of safflower cultivars in various environments.

In practice, it is recommended that when planning safflower production in semi-arid agricultural regions, high performance and stable varieties suitable for regional environmental conditions should be preferred. In the future, these findings should be supported by multi-year and multi-location validation trials and more accurate variety recommendations should be developed for region-specific production systems.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42106-025-00402-x.

Acknowledgements Ibrahim Cosar presented the 2021 experiment year of this study as a Master's Thesis in the Department of Organic Agricultural Management (Interdisciplinary) of the Bayburt University Institute of Natural Sciences. The authors are grateful for the assistance and support given by the Bayburt University Organic Agriculture Experiment Field staff members of Türkiye.

Author Contributions Conceptualization: I. Cosar: V. Gul; methodology: I. Cosar: V. Gul: F. Sefaoglu; investigation: I. Cosar: V. Gul: F. Sefaoglu; formal analysis: I. Cosar: V. Gul: F. Sefaoglu; resources: I. Cosar: V. Gul: F. Sefaoglu; writing-original draft preparation: I. Cosar: V. Gul: F. Sefaoglu; writing-review and editing: V. Gul: F. Sefaoglu; project administration: V. Gul; statistical analysis: F. Sefaoglu.

Funding The authors received no funding for this study.

Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing Interests The authors declare no competing interests.

References

Abou Chehade, L., Angelini, L. G., & Tavarini, S. (2022). Genotype and seasonal variation affect yield and oil quality of safflower (*Carthamus tinctorius* L.) under mediterranean conditions. *Agronomy*, *12*(1), 122. https://doi.org/10.3390/agronomy12010122

Alizadeh-Yeloojeh, K., Saeidi, G. H., & Sabzalian, M. R. (2020). Drought stress improves the composition of secondary metabolites in the safflower flower at the expense of reducing seed yield and oil content. *Industrial Crops and Products*, *154*, 1–10. https://doi.org/10.1016/j.indcrop.2020.112496

Aydin, F., & Sarptas, H. (2018). The impact of climate change on crop cultivation: The case study with model crops for Turkey. *Pamukkale University Journal of Engineering Sciences*, *24*, 512–521. https://doi.org/10.5505/pajes.2017.37880

Aygun, Y. Z., & Mert, M. (2020). Effects of soil conditioners and nitrogen applications on cotton (*Gossypium hirsutum* L.) yield and fiber technological properties. *Biological Diversity and Conservation*, *13*, 290–299. https://doi.org/10.46309/biodicon.2020.783255

Baydar, H., & Turgut, I. (1999). Variations of fatty acid composition according to some morphological and physiological properties and ecological regions in oilseed plants. *Turkish Journal of Agriculture and Forestry*, *23*, 81–86. https://journals.tubitak.gov.tr/agriculture/vol23/iss7/10

Beyyavas, V., Dogan, L., & Haliloglu, H. (2023). Determination of fatty acid compositions of some safflower (*Carthamus tinctorius* L.) cultivars in dry and wet conditions. *International Journal of Agriculture and Wildlife Science*, *9*, 229–238. https://doi.org/10.24180/ijaws.1208463

Bortolheiro, F., & Silva, M. (2017). Physiological response and productivity of safflower lines under water deficit and rehydration. *Anais Da Academia Brasileira De Ciências*, *89*, 3051–3066. https://doi.org/10.1590/0001-3765201720170475

Bouhouhou, M., & Mohamed, S. M. (2016). Yield components and oil content of safflower in Eastern Algeria. *International Journal of Innovation and Applied Studies*, *17*, 813–818.

Cavumirza, M., & Demir, İ. (2024). Determination of yield and yield components of different safflower (*Carthamus tinctorius* L.) varieties and genotypes under Semi-Arid conditions. *Science and Technique in the 21st Century*, *11*, 72–80.

Cohen, I., Huang, Y., Chen, J., Benesty, J., Benesty, J., Chen, J., & Huang, Y. (2009). Pearson correlation coefficient. *Noise Reduction Speech Process*, *2*, 1–4.

Demir, I., & Kara, K. (2018). Effect of different environmental conditions on safflower yield and oil rates (*Carthamus tinctorius* L). *Fresenius Environmental Bulletin*, *27*, 989–995. http://www.prt-parlar.de/../

Elfadl, E., Reinbrecht, C., & Claupein, W. (2010). Evaluation of phenotypic variation in a worldwide germplasm collection of safflower (Carthamus tinctorius L.) grown under organic farming

conditions in Germany. *Genetic Resources and Crop Evolution*, *57*(2), 155–170. https://doi.org/10.1007/s10722-009-9458-7
Emongor, V. E., Orabile, P., Phuduhudu, D., & Oagile, O. (2017). Effects of genotype on vegetative growth, yield components, and yield, as well as oil content and oil yield in safflower. *Agricultural Science Research Journal*, *7*(12), 381–392.
Ferfuia, C., & Vannozzi, G. P. (2015). Material effects on seed fatty acid composition in a reciprocal cross of high oleic sunflower (*Helianthus annuus* L). *Euphytica*, *205*, 325–336. https://doi.org/10.1007/s10681-015-1378-3
Gok, N., & Ekin, Z. (2019). Effect of different sowing dates on the yield and quality of some safflower (*Carthamus tinctorius* L.) cultivars in Hakkâri dry conditions. *Yuzuncu Yil University Journal of the Institute of Natural and Applied Sciences*, *24*, 88–96. https://dergipark.org.tr/tr/pub/yyufbed/issue/48502/512983
Golkar, P. (2014). Breeding improvements in safflower ('Carthamus tinctorius' L.): A review. *Australian Journal of Crop Science*, *8*(7), 1079–1085.
Gul, V., & Coban, F. (2020). Determination of yield and quality parameters of oil sunflower genotypes grown in Turkey. *Turkish Journal of Field Crops*, *25*, 9–17. https://doi.org/10.17557/tjfc.609749
Gursoy, M., Basalma, D., & Nofouzi, F. (2017). Effects of safflower cultivars (*Carthamus tinctorius* L.) on yield and yield components of different row and row spaces. *Selcuk Journal of Agriculture and Food Sciences*, *32*, 20–28.
ISO U (2015). 12966-4 Animal and vegetables fats and oils-Gas chromatography of fatty acid methyl ester-Part 4: Determination by capillary gas chromatography, International Organization for Standardization: Geneva, Switzerland.
ISO 12966-2. (2017). Animal and vegetable fats and oils-Gas chromatography of fatty acid methyl esters-Part 2: Preparation of methyl esters of fatty acids, international organization for standardization. Switzerland.
Khan, H., Safdar, A., Ijaz, A., Khan, I., Hussain, S., Khan, B. A., & Suhaib, M. (2018). Agronomic and qualitative evaluation of different local sunflower hybrids. *Pakistan Journal of Agricultural Research*, *31*, 1–10. https://doi.org/10.17582/journal.pjar/2018/31.1.69.78
Killi, F., Kanar, Y., & Tekeli, F. (2016). Evaluation of seed and oil yield with some yield components of safflower cultivars in Kahramanmaraş (Turkey) conditions. *International Journal of Environmental & Agriculture Research*, *2*, 136–140. https://ijoear.com/issue-detail/issue-July-2016
Kina, E., & Ozgokce, M. S. (2023). Determination of some morphological parameters of five different safflower varieties in field conditions. *Journal of Science and Technology*, *2*, 39–43.
La Bella, S., Tuttolomondo, T., Lazzeri, L., Matteo, R., Leto, C., & Licata, M. (2019). An agronomic evaluation of new safflower (*Carthamus tinctorius* L.) germplasm for seed and oil yields under mediterranean climate conditions. *Agronomy*, 9468. https://doi.org/10.3390/agronomy9080468
Naziha, E. L., & Kurt, O. (2023). Correlation and path coefficient analysis for seed yield and yield contributing components, as well as phenological and some morphological traits in safflower (*Carthamus tinctorius* L). *International Journal of Phytology Research*, *3*, 01–06.
Pasban Eslam, B., Chenari Bouket, A., Oszako, T., & Belbahri, L. (2024). Physiological indices for the selection of Drought-Tolerant safflower genotypes for cultivation in marginal areas. *Applied Sciences*, *14*(12), 5106. https://doi.org/10.3390/app14125106
Pattar, V. K., & Patil, R. (2020). Correlation and path analysis in safflower (*Carthamus tinctorius* L.) genotypes. *Journal of Pharmacognosy and Phytochemistry*, *9*, 1717–1719.
Popa, M., Anton, G. F., Rişnoveanu, L., Petcu, E., & Babeanu, N. (2017). The effect of planting date and Climatic condition on oil content and fatty acid composition in some Romanian sunflower hybrids. *AgroLife Scientific Journal*, *6*, 212–217. https://agrolifejournal.usamv.ro/pdf/vol.VI_1/Art29.pdf
Rodrigues, A. B., Werner, E., & Moses, K. (2005). Genetic and biochemical analysis of the role of Egfr in the morphogenetic furrow of the developing drosophila eye. *Development*, *132*, 4697–4707. https://doi.org/10.1242/dev.02058
Sahin, C. B., Yilmaz, M., & Isler, N. (2022). Determination of oil quality and fatty acid compositions of some peanut (*Arachis Hypogaea* L.) genotypes grown in the mediterranean region. *Turk Journal of Field Crops*, *27*, 142–148. https://doi.org/10.17557/tjfc.1095649
SAS Institute (2002) SAS User's Guide: Statistics, Version 8. SAS Institute., Cary, NC, USA.
Sayilir, C., Cinar, V. M., & Unay, A. (2019). Determination of yield and yield components in safflower (*Carthamus tinctorius* L.) cultivars under Menemen-Izmir ecological conditions. *Anadolu Journal of Aegean Agricultural Research Institute*, *29*, 71–75. https://doi.org/10.18615/anadolu.568851
Sefaoglu, F., & Ozer, H. (2022). Response of safflower (*Carthamus tinctorius* L.) to planting rate and row spacing in a high-altitude environment. *Journal of Erciyes Agriculture and Animal Science*, *5*, 1–10. https://doi.org/10.55257/ethabd.1090609
Sefaoglu, F., Ozturk, H., Ozturk, E., Sezek, M., Toktay, Z., & Polat, T. (2021). Effect of organic and inorganic fertilizers or their combinations on yield and quality components of oilseed sunflower in a semi-arid environment. *Turkish Journal of Field Crops*, *26*, 88–95. https://doi.org/10.17557/tjfc.869335
Sirel, Z., & Aytac, Z. (2016). Relationships between the seed yield and some agronomic characteristics of safflower (*Carthamus tinctorius* L.) under semi-arid conditions. *Turkish Journal of Field Crops*, *21*, 29–35.
Vicianová, M., Ducsay, L., Ryant, P., Provazník, M., Zapletalová, A., & Slepčan, M. (2020). Oilseed rape (*Brassica Napus* L.) nutrition by nitrogen and phosphorus and its effect on the yield of seed oil and higher fatty acids content. *Acta Universitatis Agriculturae ET Silviculturae Mendelianae Brunensis*, *68*, 129–136. https://doi.org/10.11118/actaun202068010129
Yan, W., & Kang, M. S. (2002). *GGE biplot analysis: A graphical tool for breeders, geneticists, and agronomists*. CRC. https://doi.org/10.1201/9781420040371
Yilmaz, G., & Kinay, A. (2015). Determination of yield and yield components of some sunflower (*Helianthus annuus* L.) cultivars in Tokat-Kazova conditions. *Anadolu Journal of Agricultural Sciences*, *30*, 281–286. https://doi.org/10.7161/anajas.2015.30.3.281-286
Zamani, S., Naderi, M. R., Soleymani, A., & Nasiri, B. M. (2020). Sunflower (*Helianthus annuus* L.) biochemical properties and seed components affected by potassium fertilization under drought conditions. *Ecotoxicology and Environmental Safety*, *190* 110017. https://doi.org/10.1016/j.ecoenv.2019.110017 PMID: 31846.
Zemour, K., Adda, A., Labdelli, A., Dellal, A., Cerny, M., & Merah, O. (2021). Effects of genotype and Climatic conditions on the oil content and fatty acid composition of Carthamus tinctorius L. seeds. *Agronomy*, *11*, 2048. https://doi.org/10.3390/agronomy11102048

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.