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Araştırma
(Research)

The Effect of Sowing Density on Yield and Quality of Safflower (*Carthamus tinctorius* L.) Varieties

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Abstract

Objective: This research was conducted in 2022 at the Igdir University Agricultural Practice and Research Center (TUAM) to determine the effects of row spacing on yield and quality in different safflower (*Carthamus tinctorius* L.) cultivars.

Materials and Methods: The field experiment was established in a factorial design with three replications, using five safflower cultivars (Dinçer, Balcı, Yekta, Safir, and Hasankendi) and three different row spacing distances (20, 40, and 60 cm). The variety and row spacing combinations were randomly assigned within the experimental layout. In the study, the agro-morphological characteristics of the cultivars were evaluated.

Results: The following results were obtained: plant height ranged from 56.47 to 74.27 cm, the number of fruit-bearing branches per plant varied between 5.10 and 7.57, the number of capitula per plant ranged from 6.77 to 17.00, and the number of seeds per capitulum was between 35.67 and 62.00. Additionally, seed yield per plant varied from 206.53 to 835.82 g/plant, overall seed yield ranged between 21.51 and 87.06 kg/da, and the thousand-seed weight was between 40.85 and 49.05 g. Furthermore, crude oil weight varied from 3.00 to 3.87 g, crude oil content ranged between 60.13% and 77.46%, linoleic acid content was found to be between 63.58% and 78.89%, and oleic acid content varied from 10.79% to 24.21%.

Conclusion: Based on the results obtained from this study, the highest seed-yielding cultivars were identified as Dinçer, Balcı, and Safir, while the cultivars with the highest crude oil yield were determined to be Hasankendi, Yekta, and Safir. According to this study, a row spacing of 20 cm stands out as the most advantageous and recommended spacing in terms of both seed yield and oil yield.

Keywords: Safflower, *Carthamus tinctorius* L., yield, variety, sowing density

Aspir Çeşitlerinde (*Carthamus tinctorius* L.) Ekim Sıklığının Verim ve Kalite Üzerine Etkisi

Öz

Amaç: Bu araştırma, farklı aspir (*Carthamus tinctorius* L.) çeşitlerinde ekim sıklığının verim ve kalite üzerine etkilerini belirlemek amacıyla 2022 yılında Iğdır Üniversitesi Tarımsal Uygulama ve Araştırma Merkezi (TUAM)'nde yürütülmüştür.

Materyal ve Yöntem: Tarla denemesi, beş aspir çeşidi (Dinçer, Balcı, Yekta, Safir ve Hasankendi) ile üç farklı sıra arası mesafesinin (20, 40 ve 60 cm) kullanıldığı faktöriyel düzende ve üç tekrarlamalı olarak kurulmuştur. Çeşit ve sıra arası mesafesi kombinasyonları deneme parsellerine tesadüfî olarak dağıtılmıştır. Çalışmada, çeşitlerin agro-morfolojik özellikleri değerlendirilmiştir.

Araştırma Bulguları: Elde edilen sonuçlara göre; bitki boyu 56.47 ile 74.27 cm arasında, bitki başına meyve veren dal sayısı 5.10 ile 7.57 arasında, bitki başına tabla sayısı 6.77 ile 17.00 arasında ve tabla başına tohum sayısı 35,67 ile 62,00 arasında değişmiştir. Ayrıca, bitki başına tohum verimi 206,53 ile 835,82 g arasında, dekara toplam tohum verimi ise 21.51 ile 87.06 kg arasında bulunmuştur. Bin tane ağırlığı ise 40.85 ile 49.05 g arasında değişmiştir. Bitki başına, ham yağ miktarı 3.00 ile 3.87 g arasında, kabuk dâhil ham yağ oranı ise %60.13 ile %77.46 arasında tespit edilmiştir. Linoleik asit içeriği %63.58 ile %78.89 arasında, oleik asit içeriği ise %10.79 ile %24.21 arasında değişmiştir.

Sonuç: Bu çalışmadan elde edilen sonuçlara göre, en yüksek tohum verimine sahip çeşitler Dinçer, Balcı ve

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Safir olarak belirlenmiş, en yüksek ham yağ verimine sahip çeşitler ise Hasankendi, Yekta ve Safir olarak tespit edilmiştir. Bu çalışmaya göre, 20 cm sıra arası ekim, hem tane verimi hem de yağ verimi bakımından en avantajlı ve önerilen sıra arası mesafe olarak öne çıkmaktadır.

Anahtar kelimeler: Aspir, *Carthamus tinctorius* L., çeşit, verim, ekim sıklığı

Introduction

Safflower (*Carthamus tinctorius* L.) is an annual herbaceous oilseed plant in the Asteraceae family. It is an industrial crop that can grow to a height of 80–100 cm, bears capitula of varying sizes, and has flowers in white, orange, cream, yellow, or red, while its seeds are typically white (Çelik, 2017; Kobuk et al., 2019). Safflower is one of the oldest cultivated plants, and domestication dates back approximately 3,000 years in the Middle East. Around 25 species belonging to the *Carthamus* L. genus have been reported globally. In Türkiye, safflower is commonly known by various names such as "American saffron," "false saffron," and "dyer's saffron." It is an alternative oilseed crop available in both spiny and spineless varieties. In other countries where it is cultivated, safflower is widely referred to as "kusum" in India and Pakistan, "kusumbha" in Sanskrit, and "honghua" (red flower) in China (Aktaş, 2022). Depending on growing conditions, safflower can be cultivated as a winter or spring crop. Due to its broad adaptability, it can be grown in almost all regions of Türkiye. Compared to other oilseed crops, safflower is a drought-tolerant alternative oilseed plant (Arslan et al., 2010). The United States, India, Mexico, Argentina, Ethiopia, and Australia are among the world's leading safflower producers. However, as of 2023, Kazakhstan has emerged as the top producer, accounting for around 33–42% of global safflower seed output followed by Russia, which produces approximately 14% of the world's safflower seed. These figures indicate that Kazakhstan and Russia should also be included among the primary safflower-producing countries (Uysal et al., 2006; Gomashe et al., 2021). According to the most recent FAOSTAT data (2023), the global safflower (*Carthamus tinctorius L.*) production was approximately 723,875 tons, with Kazakhstan remaining the world's leading producer, contributing about 242,000 tons (roughly 33% of global production). Other major producers include Russia, India, Mexico, and Turkey. Turkey ranks among the top eight safflower-producing countries, with an annual production of around 39,000 tons, accounting for approximately 5–6% of global safflower output. These figures indicate that while Kazakhstan continues to dominate global safflower production, Turkey's cultivation area and yield have shown a gradual upward trend in recent years, reflecting increasing interest in this oilseed crop for both biodiesel and functional food industries (Aşçı et al., 2022; FAOSTAT, 2024). Safflower is a valuable crop for meeting the increasing demand for oil due to the rapidly growing population. Safflower seeds contain approximately 30–50% crude oil (Khalid et al., 2017). In addition, these seeds contain essential fatty acids such as linoleic acid (C18:2), α-linolenic acid (C18:3), oleic acid (C18:1C), palmitic acid (C16), and stearic acid (C18), making safflower oil highly suitable for culinary use (Andırman and Karaaslan, 2021; Abou Chehade et al., 2022). Throughout history, humans have utilized various plants from both natural and cultivated environments to meet their needs, with health being one of the most significant aspects. The use of plants in healthcare remains important today (Rabetafika et al., 2011; Koçak, 2021). In this context, due to its high linoleic acid (omega-6) content, safflower oil is considered a valuable plant-based oil for the treatment of atherosclerosis and for lowering high blood cholesterol levels (Kobuk et al., 2019). Additionally, the flowers of the safflower plant contain a yellow-red pigment known as "carthamin" This pigment has been reported to be beneficial in treating cardiovascular diseases, swelling caused by trauma, menopausal symptoms, and blood circulation disorders (Özel et al., 2004).

Sowing density and genotypic variation are among the primary factors influencing yield formation and quality parameters in safflower cultivation. The optimization of plant density plays a crucial role in determining the efficiency of light interception, nutrient uptake, and intra-specific competition among plants. High sowing density can lead to increased competition for water and nutrients, resulting in reduced branching and seed weight, while low density may enhance individual plant development but decrease total yield per unit area. Moreover, the response of safflower to sowing frequency is largely genotype-dependent, as different cultivars exhibit variable morphological plasticity, photosynthetic capacity, and resource allocation strategies. Genotypic diversity determines how plants adapt to environmental stressors and agronomic management, ultimately affecting yield stability and oil composition. Therefore, understanding the interaction between genotype and planting density is essential for identifying optimal cultivation strategies that maximize both seed yield and oil quality in safflower under specific ecological conditions (Steberl et al., 2020; Mosupiemang et al., 2023).

In recent years, safflower cultivation has regained significance worldwide. Kazakhstan and Russia, in particular, rank among the top producers and account for the majority of global production. According to FAOSTAT (2021-2023), the global safflower cultivation area is approximately 900 thousand hectares, with a production volume of around 700 thousand tons. Turkey has shown a remarkable increase in production in recent years and currently ranks eighth in the world, contributing about 6–7% of total production. The major safflower-producing countries include Kazakhstan, Russia, the United States, India, Mexico, Argentina, Ethiopia, and Australia (FAOSTAT, 2021-2023). In Turkey, safflower cultivation is particularly widespread in regions with arid conditions, such as Central Anatolia, Southeastern Anatolia, and Iğdır. Despite the increase in production in these regions, research on safflower has mostly been limited to variety performance or adaptation trials. However, sowing density in crop production is a critical agronomic factor that directly affects inter-plant competition, light interception, photosynthetic efficiency, and, consequently, both yield and quality (Uysal et al., 2006; Akgün and Söylemez, 2022). Sowing density, along with genotypic diversity, represents a key determinant of safflower yield and quality. Variations in sowing density not only influence plant height, branching, seed yield, and oil content, but also alter fatty acid composition through changes in photosynthetic efficiency and resource utilization (Khalil et al., 2017). On the other hand, genotypic diversity plays a vital role in determining the adaptability of safflower to diverse agro-ecological conditions. Different genotypes exhibit significant variation in traits such as drought tolerance, oil yield, fatty acid profile, and secondary metabolite content (Kurtet al., 2025). Therefore, the integration of optimized sowing density with the evaluation of genotypic diversity is essential for enhancing safflower productivity, improving oil quality, and ensuring its sustainable cultivation under varying environmental conditions. This study aims to determine the effects of row spacing on yield and quality in selected registered safflower cultivars under the ecological conditions of Igdir. Furthermore, the agro-morphological characteristics of the cultivars were evaluated following the field trials.

Materials and Methods

In this study, five different safflower varieties registered in Türkiye were used as plant material. The seed materials were obtained from various research institutes: Dinçer, Balcı, and Yekta varieties were sourced from the Transitional Zone Agricultural Research Institute, the GAP Agricultural Research Institute provided the Safir variety, and the Hasankendi variety was obtained from the Field Crops Central Research Institute.

The study was conducted in April 2022 at the Igdir University Agricultural Practice and Research Center (TUAM) experimental field under the ecological conditions of Igdir. The study aimed to investigate the effects of different row spacing on the yield and quality of certain safflower varieties..

Table 1. Soil Properties of the Experimental Field

Examined Parameter / Analysis Type	Value / Result	Status
pH	7.9	Sufficient
$CaCO_3$ (%)	11.32	Moderately Tolerant
Organic Matter (%)	2	Sufficient
P_2O_5 (ppm)	0.8	Low
K_2O (ppm)	9.28	Low
Soil Texture	Clay-Loam	

Soil samples collected from different locations within the research area at 0-30 cm depth were analyzed. The results indicated that the soil had a pH of 7,9 and a clay-loam texture. The organic matter content was determined to be 2%, while the lime ($CaCO_3$) content was 11.32%. The potassium (K_2O) content was also measured at 42.56 ppm, and the phosphorus content was found to be 0.8 ppm (Table 1).

Table 2. The climatic data for the region for the year 2021 and the long-term averages (LTA) were obtained from previous studies (Koçak, 2021; Alptekin & Gürbüz, 2022).

Parameter	Year	March	April	May	June	July	August	September	Average/Total
Temperature	2020	10.6	11.7	18.6	23.9	26.7	24.2	23.5	13.73
	2021	10.02	17.4	21.1	26.8	27.4	27.4	22.2	15.61
	UYO	6.3	13.1	17.8	22.2	25.9	25.4	20.5	12.21
Precipitation	2020	18.1	83.6	76.1	15.7	30.2	15.3	1.4	297
	2021	17.5	18.4	42.1	0.7	32.4	8.3	11.5	197.5
	UYO	21.9	34.6	47	32	13.9	9.8	11.4	261

'*Created using the data of the General Directorate of Meteorology between 1950-2021.'

Methods

Meteorological data from the stations in the research area were processed. and annual averages were calculated based on monthly climate data (Table 2). The field experiment was conducted at the Igdir University Agricultural Practice and Research Center (TUAM) experimental site. Where soil preparation, fertilization, and parcelization were carried out in 2022. The trial was established in a randomized block design with a factorial arrangement using three replications. Three row spacing distances were tested (20, 40 and 60 cm). Sowing was performed manually along lines marked for the specified row spacings. The combinations of cultivars and row spacings were randomly assigned to the plots within the blocks. The experiment consisted of three blocks each containing 15 plots due to the presence of five cultivars and three-row spacing treatments. In total, there were 45 plots across the three blocks. The dimensions of each plot were calculated as 4 × 2.4 m. A distance of 1.5 m was maintained between blocks while the spacing between plots was set at 0.5 m. Consequently, the total experimental area was calculated as 43 × 15 m = 645 m^2. Weed control was performed four times at different intervals until the harvest period. After harvesting. safflower plants were left to dry before threshing. The obtained seeds were subjected to the necessary measurements and stored under appropriate conditions for subsequent laboratory analyses. The general agro-morphological characteristics of the populations were evaluated based on the following parameters: Plant height (cm), number of branches per plant, number of capitula per plant (capitula/plant), number of seeds per capitulum (seeds/capitulum), seed yield (kg/da), seed yield per plant (g/plant), thousand-seed weight (g/plant), crude oil content (%), crude oil yield (kg/da), fatty acid composition. Ten randomly selected plants were measured in the laboratory for each plot and the averages were calculated accordingly.

Fatty acid profile

Flaxseed oil (0.2 g) samples were transferred into 15-ml centrifuge tubes and mixed with 10 ml of hexane. Subsequently, the mixture was dissolved in 0.2 ml of 1 N methanol, after which potassium hydroxide was added. The tubes were vigorously shaken to ensure complete mixing, followed by phase separation. The samples were then stored in darkness for approximately 2 h, until the upper layer became transparent. An aliquot of this clear phase was transferred into vials for fatty acid analysis. The analyses were performed using an Agilent 7820 high-performance liquid chromatograph (Agilent Technologies, USA) equipped with an SP 2560 capillary column (100 m × 0.2 mm × 0.2 μm) and a flame ionization detector (FID). Both the injection port and detector temperatures were maintained at 240 °C, with the system operated in split injection mode at a 1:10 split ratio and 400 ml/min pressure. The oven program began with an isothermal hold at 140 °C for 5 min, followed by a temperature increase of 4 °C per minute up to 250 °C, and subsequently raised to 260 °C after 15 min. Helium was used as the carrier gas at a linear velocity of 41 cm/sec (hydrogen). A 1 μl sample volume was injected, and fatty acid methyl ester (FAME) profiles were identified by comparison with chromatograms of the Supelco 37 Component FAME Mix standard (Sigma-Aldrich, Germany), with a retention time of 37.75 min (Koçak, 2021). The relative proportions of α-linolenic acid (C18:3n6), linoleic acid (C18:2n6), oleic acid (C18:1n9c), palmitic acid (C16:0), and stearic acid (C18:0) were quantified (Table 8).

Data Analysis

Each trait examined in the study was assessed using three replications with ten plants per plot for each replication. The analysis and observational results were evaluated using a one-way analysis of variance (ANOVA) with SPSS 22. Duncan's test was applied to determine significant differences among the means of different cultivars and plant densities. Furthermore, Principal Component Analysis (PCA) was performed using PAST software, and a heatmap clustering analysis (ClustVis) was conducted to visualize, differentiate, and determine the correlation among the examined parameters.

All registered safflower cultivars sown within the study successfully germinated. For measurement purposes, ten plants were randomly selected from each plot in the experimental area.

Results and Discussion

Table 3. Duncan grouping of plant height and number of fruiting branches in the plant

	Plant Height				Number Branches per Plant			
	Rows spacing			Mean*	Rows spacing			Mean*
Varieties	20 cm	40 cm	60 cm	40 cm	20 cm	40 cm	60 cm	
Dinçer	74.27	71.13	74.27	71.13	5.5	6.97	5.93	6.13a
Balcı	64.97	56.47	64.97	56.47	6.2	6.37	6.1	6.22a
Yekta	61.7	68.07	61.7	68.07	5.6	6.13	6.73	6.16a
Safir	61.4	65.8	61.4	65.8	5.23	6.3	5.1	5.54a
Hasankendi	67.9	62.9	67.9	62.9	5.93	7.57	5.77	6.42a
Mean	66.05a	64.87a	63.94a	64.95	5.69a	6.67a	5.93a	6.10

*There is no statistically significant difference between the means denoted by the same letter.

Table 4. Duncan grouping for the mean number of capitula per plant and the mean number of seeds per capitulum

	Number of Head Per Plant				Number of Seeds in a Head			
	Rows spacing			Mean*	Rows spacing			Mean*
Varieties	20 cm	40 cm	60 cm		20 cm	40 cm	60 cm	
Dinçer	9.3	17	10.7	12.33a	36.33	36.33	38	36.89c
Balcı	9.33	9.43	9.13	9.3a	35.67	35.67	36.33	35.89c
Yekta	7.73	11.57	11.57	10.29a	48	53	41.67	47.56b
Safir	6.83	11.97	6.77	8.52a	40.33	40	37	39.11c
Hasankendi	9.3	15.23	8.6	11.04a	62	55.33	58.67	58.67a
Mean	8.5b	13.04a	9.35ab	10.3	44.47a	44.07a	42.33a	43.62

*There is no statistically significant difference between the means denoted by the same letter.

Table 5. Duncan grouping of seed yield (g/parcel) and seed yield (kg/ha) means

	Seed Yield (g/parcel)				Seed Yield (kg/ha^{-1})			
Varieties	Rows spacing			Mean*	Rows spacing			Mean *
	20 cm	40 cm	60 cm		20 cm	40 cm	60 cm	
Dinçer	835.82	378.75	379.47	531.34a	87.07	39.45	39.53	55.35a
Balcı	694.54	395.50	602.97	564.34a	72.35	41.20	62.81	58.79a
Yekta	475.43	548.18	288.42	437.34a	49.52	57.10	30.04	45.55a
Safir	565.22	670.21	491.96	575.8a	58.88	69.81	51.25	59.98a
Hasankendi	414.68	440.94	206.53	354.05a	43.20	45.93	21.51	36.88a
Mean	597.14a	486.72ab	393.87b	492.57	62.20a	50.70ab	41.03b	51.31

*There is no statistically significant difference between the means denoted by the same letter.

Table 6. Duncan grouping of thousand (1000) grain weight and plot crude oil yield (g/plot) means.

	Thousand (1000) Grain Weight				Parcel Crude Oil Yields (g/parcel)			
	Rows spacing			Mean *	Rows spacing			Mean *
Varieties	20 cm	40 cm	60 cm		20 cm	40 cm	60 cm	
Dinçer	47.97	49.05	48.34	48.45a	255.37	123.46	128.17	169.00a
Balcı	44.81	43.25	47.86	45.31b	200.71	132.13	204.24	179.03a
Yekta	44.44	44.51	45.02	44.66b	162.70	187.58	90.43	146.90a
Safir	44.49	46.72	45.19	45.47b	189.23	213.48	158.35	187.02a
Hasankendi	40.85	43.31	43.33	42.49c	161.73	157.93	68.49	129.38a
Mean	44.511a	45.366a	45.948a	45.28	193.95a	162.92a	129.94a	162.27

*There is no statistically significant difference between the means denoted by the same letter.

Table 7. Duncan grouping of crude oil yield (kg/ha) and crude oil ratio (%) averages.

Varieties	Crude Oil Yields (kg/ha)				Crude Oil Ratios (%)			
	Rows spacing			Mean *	Rows spacing			Mean *
	20 cm	40 cm	60 cm		20 cm	40 cm	60 cm	
Dinçer	26.60	12.86	13.35	17.60a	30.07	32.03	32.83	31.64a
Balcı	20.91	13.77	21.27	18.65a	31.17	33.30	33.60	32.69a
Yekta	16.95	19.54	9.42	15.30a	33.57	33.80	32.87	33.41a
Safir	19.71	22.24	16.49	19.48a	33.17	31.47	31.83	32.16a
Hasankendi	16.85	16.45	7.14	13.48a	38.73	36.07	33.57	36.12a
Mean	20.20a	16.97a	13.53a	16.90	33.34a	33.33a	32.94a	33.20

*There is no statistically significant difference between the means denoted by the same letter.

The Duncan grouping for the mean plant height and the mean number of fruit-bearing branches per plant is provided in Table 3. In the study, the plant height across different row spacing distances ranged from 63.94 cm to 66.05 cm. with no statistically significant difference. The average plant height of the cultivars ranged from 62.38 cm to 71.06 cm and no significant differences were found between the cultivars. However, in the study conducted by Bozdemir (2020), the average plant height of the varieties ranged from 52.7 to 87.17 cm. When analyzed, the results were found to be consistent. It is anticipated that the study will be carried out under similar soil and ecological conditions, and that it will proceed in parallel with previous research. When our study was compared with previous research, the current findings were found to be consistent with those of earlier studies (Aslantaş, 2019; Özaydın, 2020; Aktaş, 2022; Erpay, 2022; Coşar, 2023). Additionally, some studies (Yıldırım, 2021; Ay, 2022; Çelik, 2022) reported higher plant height values, whereas others (Ekin, 2019; Aslan, 2021) reported lower values. The observed differences may be attributed to variations in treatments, cultivars, and ecological conditions of the experimental sites. Additionally, regarding the number of fruit-bearing branches per plant, the row spacing averages ranged from 5.69 to 6.67, with no statistically significant difference detected. The cultivar averages for the number of branches per plant ranged from 5.54 to 6.42, with no statistically significant difference between the cultivars (Table 3). The Duncan grouping for the mean number of capitula per plant and the mean number of seeds per capitulum is provided in Table 4. The study observed significant differences in the mean number of capitula per plant between row spacings. The highest average was obtained at a 40 cm row spacing (13.04 capitula), followed by a 60 cm row spacing (9.35 capitula), and the lowest average was obtained at a 20 cm row spacing (8.5 capitula). No significant differences were found between the cultivar averages. However, significant differences were detected in the number of seeds per capitulum with the Hasankendi (58.67 seeds/capitulum) and Yekta (47.56 seeds/capitulum) cultivars forming separate statistical groups. The highest average was observed in Hasankendi (58.67 seeds/capitulum). followed by Yekta (47.56 seeds/capitulum), with other cultivars such as Safir (39.11 seeds/capitulum), Dinçer (36.89 seeds/capitulum), and Balcı (35.89 seeds/capitulum) falling within the same group (Table 4). The Duncan grouping for seed yield (g/plot) and seed yield (kg/da) is presented in Table 5. A statistically significant difference was observed in seed yield (g/plot) across row spacings. with the highest average observed at a 20 cm row spacing (597.14 g), followed by 40 cm row spacing (486.72 g) and the lowest value at 60 cm row spacing (393.87 g). No significant difference was found among the cultivars for seed yield (kg/da), with average values ranging from 36.88 to 59.98. When comparing the row spacing averages for seed yield (kg/da) the highest average was recorded at 20 cm row spacing (62.20 kg/da), followed by 40 cm (50.70 kg/da) and 60 cm (41.03 kg/da) indicating a decline in yield with increasing row spacing and reduced plant density per decare (Table 5). The Duncan grouping for thousand-seed weight and crude oil yield (g/plot) is provided in Table 6. Significant differences were observed in thousand-seed weight among the cultivars, with the Dinçer cultivar forming a separate statistical group. The Balcı, Yekta, and Safir cultivars were grouped while the Hasankendi cultivar was in a separate group. The highest thousand-seed weight was found in Dinçer (48.45 g) followed by Balcı (45.31 g) with the lowest average recorded for Hasankendi (42.49 g). When our current findings are compared with those of previous studies (Erbaş, 2012: 33.10–40.70 g; İnan, 2014: 26.00–39.30 g; Özaşık, 2015: 42.60–48.00 g; Özaydın, 2020: 34.80–39.30 g; Ögetürk, 2018: 32.61–39.18 g; Ekin, 2019: 34.20–39.97 g; Aydın, 2019: 41.98–44.19 g; Aslantaş, 2019: 26.40–41.00 g; Bozdemir, 2020: 34.65–42.49 g; Aslan, 2021: 40.94–44.13 g; Yıldırım, 2021: 28.51–36.06 g; Çelik, 2022: 34.63–42.23 g; Erpay, 2022: 31.20–47.30 g; Ay, 2022: 37.13–42.20 g; Coşar, 2023: 36.16–43.89 g) it appears that the results are generally comparable.The observed differences in yield-related morphological characteristics are thought to result primarily from varietal differences and ecological variations. Regarding crude oil yield (g/plot), significant variation was not found between cultivars or row spacings. The average crude oil yields ranged from 129,38 to 187,02 g/plot for cultivars and 129,94 to 193,95 g/plot for row spacings (Table 6). The Duncan grouping for crude oil yield (kg/da) and crude oil content (%) is provided in Table 7. No significant differences were found between cultivar averages or row spacing averages for crude oil yield (kg/da). The cultivar averages ranged from 13.48 to 19.48 kg/da, and the row spacing averages ranged from 13.53 to 20.20 kg/da. Furthermore, no statistical differences were observed in crude oil content (%) between cultivars or row spacings. The cultivar averages ranged from 31.64% to 36.12%, and the row spacing averages ranged from 32.94% to 33.34% (Table 7). Previous studies have reported crude oil content as follows: Gencer (2023), 35.51–37.58%; Çakır (2023), 26.46–37.23%; Özer (2022), 23,4–33,0%; and Daniş (2022), 27.94–32.39%. In this context, it can be concluded that the current findings are in agreement with previous studies. The observed differences in crude oil content are likely attributable to ecological conditions, genetic variations among the cultivars used, and differences in the applied agronomic practices..

Table 8. Average fatty acid contents of safflower (*C. tinctorius* L.) cultivars sown at different row spacings.

Variety/Application	Linoleic acid (C18-2)	α-Linolenic acid (C18-3)	Oleic acid (C18-1C)	Palmitic acid (C16)	Stearic acid (C18)
Dinçer S1	78.89	0.25	10.94	6.97	2.26
Dinçer S2	77.83	0.41	11.82	6.96	2.25
Dinçer S3	77.18	0.21	12.54	7.03	2.39
Balcı S1	77.46	0.27	11.73	7.3	2.58
Balcı S2	77.02	0.19	12.58	6.82	2.69
Balcı S3	75.76	0.34	13.47	7.17	2.43
Yekta S1	73.55	0.32	15.79	7.11	2.60
Yekta S2	75.34	0.25	14.23	7.03	2.49
Yekta S3	70.28	0.28	19.20	7.02	2.62
Safir S1	67.18	0.25	22.49	6.72	2.64
Safir S2	63.58	0.60	24.21	6.48	2.55
Safir S3	65.54	0.45	23.97	6.61	2.60
Hasankendi S1	77.29	0.24	12.28	6.34	3.08
Hasankendi S2	77.083	0.19	12.27	6.83	2.99
Hasankendi S3	78.67	0.31	10.79	6.45	3.07

In addition. the fatty acid values obtained from the oil analyses of safflower seeds (10 g) used in the thesis study are presented in Table 8.

Linoleic Acid (C18-2)

The linoleic acid content in the oils obtained from the varieties has been found to be statistically significant at the 1% level. However, the effects of row spacing and variety × row spacing interactions on linoleic acid content were not statistically significant (Table 9).

Table 9. Analysis of variance for linoleic acid (C18:2) content

Sources of the variation	SD	Mean Square	F
Variety	4	250,208	46,552**
Row Spacing	2	7,401	1,377
Variety × Row Spacing	8	7,286	1,356
Error (Residual)	30	5,375	
Total	44		

Significant at the *0.05 probability level. Highly significant at the **0.01 probability level.

Table 10. Duncan's grouping of means for linoleic acid (C18:2) content.

Variety	Row Spacing			Mean*
	20 cm	40 cm	60 cm	
Dinçer	78.99	77.84	77.19	78.00a
Balcı	77.46	77.03	75.77	76.75a
Yekta	73.55	75.34	70.29	73.06b
Safir	67.19	63.58	65.54	65.44c
Hasankendi	77.30	77.09	78.68	77.69a
Mean*	74.90a	74.18a	73.49a	74.19

*Means followed by the same letter do not differ significantly

In the study, the highest average value of linoleic acid was found in the Dinçer variety at 78%. The Hasankendi (77.69%) and Balcı (76.75%) varieties in the same group followed this value in succession. The lowest average value was observed in the Safir variety at 65.44% (Table 10). In the study conducted by Çelik (2022), it was reported that the linoleic acid values ranged from 58.85% to 74.96%, and the nitrogen doses applied in the experiment significantly affected the average linoleic acid content, showing statistical significance. Additionally, Şeker (2019) stated that the linoleic acid content varied between 33.93% and 76.52%.

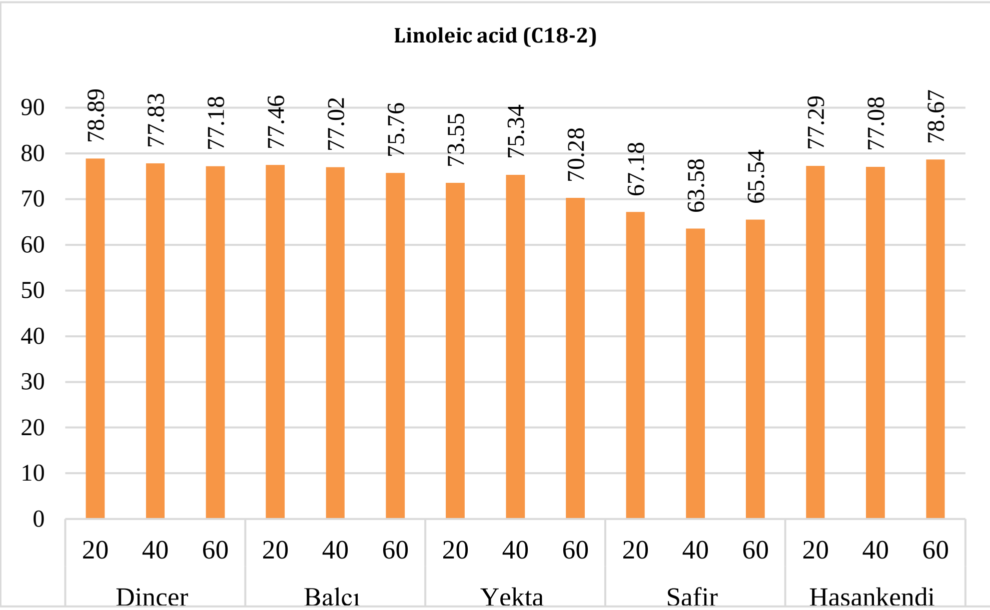

Figure 1. Graphical illustration of linoleic acid (C18:2) content across varieties

α-Linolenic Acid (C18-3)

In the study, the effect of variety, row spacing, and their interactions on α-linolenic acid was found to be statistically insignificant (Table 11).

Table 11. Variance analysis of α-linolenic acid (C18:3) data

Sources of the variation	SD	Mean Square	F
Variety	4	0.049	0.910
Row Spacing	2	0.017	0.322
Variety × Row Spacing	8	0.035	0.640
Error (Residual)	30	0.054	
Total	44		

Significant at the *0.05 probability level. Highly significant at the **0.01 probability level

Table 12. Duncan grouping of the means for α-linolenic acid (C18:3)

Variety	**Row Spacing**			**Mean****
	20 cm	**40 cm**	**60 cm**	
Dinçer	0.25	0.42	0.21	0.29a
Balcı	0.27	0.19	0.34	0.27a
Yekta	0.32	0.25	0.29	0.29a
Safir	0.25	0.60	0.45	0.44a
Hasankendi	0.24	0.20	0.31	0.25
Mean	0.27a	0.33a	0.32a	0.31

* There is no statistically significant difference between means denoted by the same letter

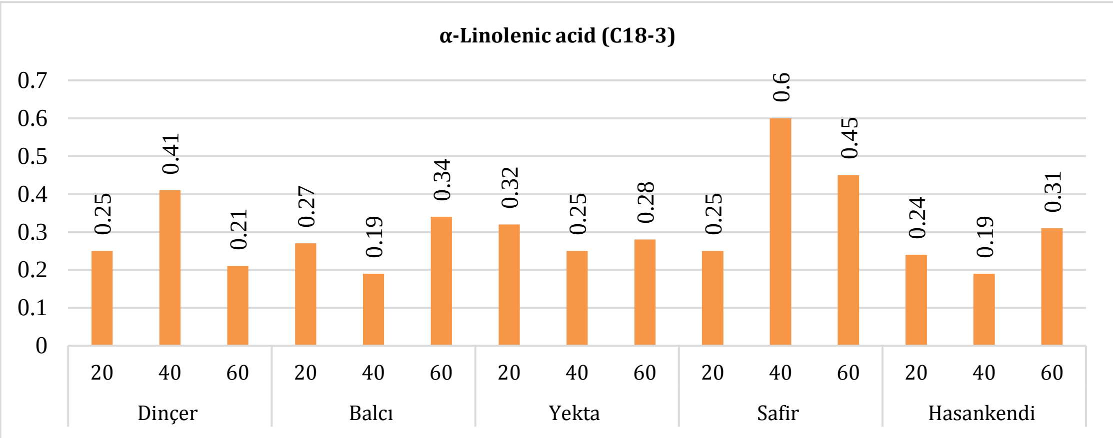

Figure 2. Graphical illustration of α-Linolenik (C18-3) content across varieties

Additionally, the average values for the varieties ranged from 0.25 to 0.44, and all were grouped into the same category. The average values for row spacings ranged from 0.27 to 0.33 (Table 12)

Oleic acid (C18-1C)

The effect of the studied varieties on oleic acid was found to be statistically significant at the 1% level. However, the effects of row spacing and the variety × row spacing interaction on oleic acid were not found to be statistically significant (Table 13).

Table 13. Variance analysis of oleic acid (C18:1C) data

Sources of the variation	**SD**	**Mean Square**	**F**
Variety	4	228.644	41.125**
Row Spacing	2	7.268	1.307
Variety × Row Spacing	8	5.280	0.950
Error (Residual)	30	5.560	
Total	44		

Significant at the *0.05 probability level. Highly significant at the **0.01 probability level.

Table 14. Duncan grouping of the means for oleic acid (C18:1C)

Variety	**Row Spacing**			**Mean***
	20 cm	**40 cm**	**60 cm**	
Dinçer	10.94	11.83	12.54	11.77c
Balcı	11.74	12.58	13.48	12.60c
Yekta	15.79	14.24	19.21	16.41b
Safir	22.50	24.22	23.97	23.57a
Hasankendi	12.29	12.27	10.80	11.79c
Mean	14.65	15.03	16.00	15.23

* There is no statistically significant difference between means denoted by the same letter.

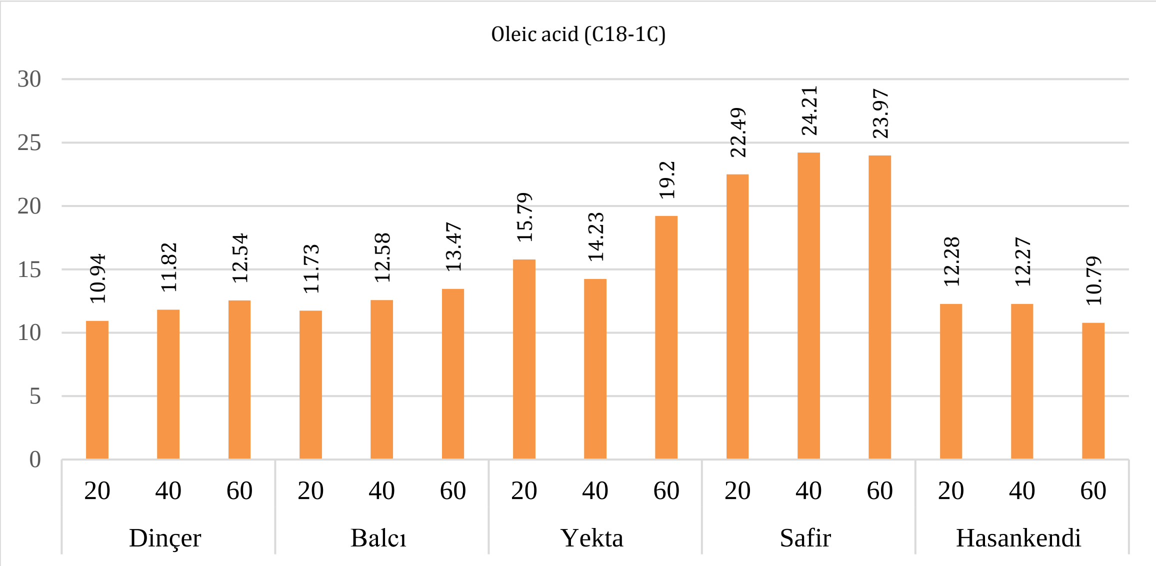

Figure 3. Graphical illustration of oleic acid content across varieties

A statistically significant difference at the 1% level was observed among the varieties. with the Safir and Yekta varieties each forming distinct statistical groups. The other varieties were placed in the same statistical group. The highest average value was obtained from the Safir variety. with 23.57% (Table 13). Similarly, in a study by Şeker (2019). the oleic acid content was reported to range between 5.53% and 6.49%. Ay (2022) found that these values varied between 13.08% and 25.85% in his study.

Palmitic acid (C16)

Among the existing varieties the effect on palmitic acid was found to be statistically significant at the 1% level; however, the effects of row spacing and the variety × row spacing interaction were not found to be statistically significant (Table 15).

Table 15. Variance analysis of palmitic acid (C16) data

Sources of the variation	SD	Mean Square	F
Variety	4	0.619	11.501**
Row Spacing	2	0.016	0.299
Variety × Row Spacing	8	0.105	1.951
Error (Residual)	30	0.054	
Total	44		

Significant at the *0.05 probability level. Highly significant at the **0.01 probability level.

Table 16. Duncan grouping of the means for palmitic acid (C16)

Variety	Row Spacing			Mean*
	20 cm	40 cm	60 cm	
Dinçer	6.98	6.96	7.04	6.99a
Balcı	7.30	6.83	7.17	7.10a
Yekta	7.11	7.03	7.00	7.05a
Safir	6.72	6.48	6.61	6.61b
Hasankendi	6.35	6.84	6.45	6.55b
Mean	6.89	6.83	6.86	6.86

* There is no statistically significant difference between means denoted by the same letter.

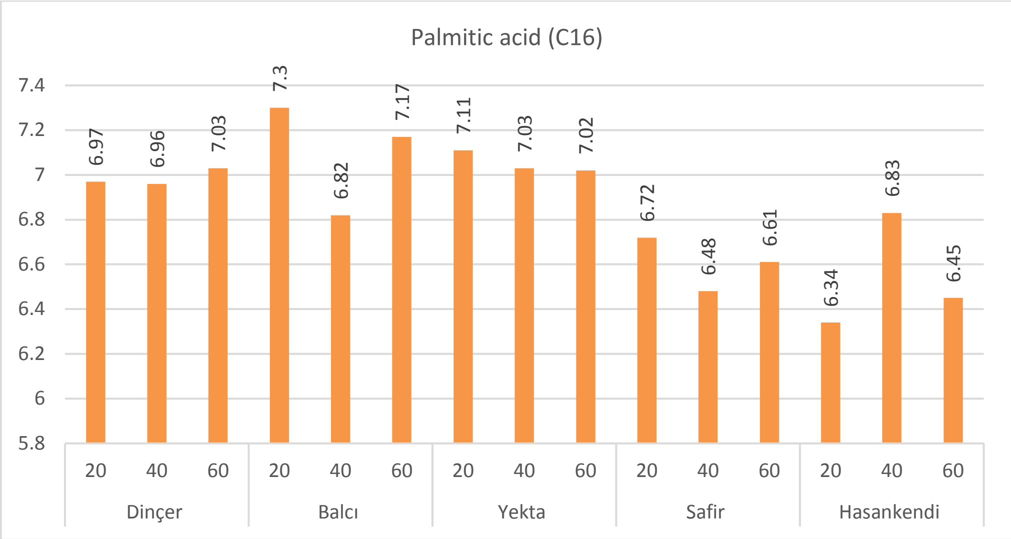

Figure 4. Graphical illustration of palmitic acid content across varieties.

Furthermore. based on the variety means. the highest values were obtained from the cultivars Balcı (7.10%), Yekta (7.05%) and Dinçer (6.99%), which were grouped together in the same statistical group. On the other hand. the cultivars Safir (6.61%) and Hasankendi (6.55%) had lower mean values and were placed in a different group (Table 16).

In addition. Daniş (2022) reported in his study that the palmitic acid content ranged between 6.86% and 7.72%. This result was found to be in line with the findings of our study.

Stearic Acid (C18)

In the study. the effect of the cultivars on stearic acid was found to be statistically significant at the 1% level. However, the effects of row spacing and the cultivar × row spacing interaction on stearic acid were not found to be statistically significant (Table 17).

Table 17. Variance analysis of stearic acid (C18) data

Sources of the variation	**SD**	**Mean Square**	**F**
Variety	4	0.652	18.852**
Row Spacing	2	0.006	0.168
Variety × Row Spacing	8	0.023	0.678
Error (Residual)	30	0.035	
Total	44		

Significant at the *0.05 probability level. Highly significant at the **0.01 probability level.

Table 18. Duncan grouping of the means for stearic acid (C18)

Variety	**Row Spacing**			**Mean****
	20 cm	**40 cm**	**60 cm**	
Dinçer	2.26	2.25	2.40	2.30c
Balcı	2.58	2.69	2.43	2.57b
Yekta	2.60	2.49	2.62	2.57b
Safir	2.64	2.55	2.60	2.60b
Hasankendi	3.08	2.99	3.07	3.05a
Mean	2.63	2.60	2.63	2.62

* There is no statistically significant difference between means denoted by the same letter.

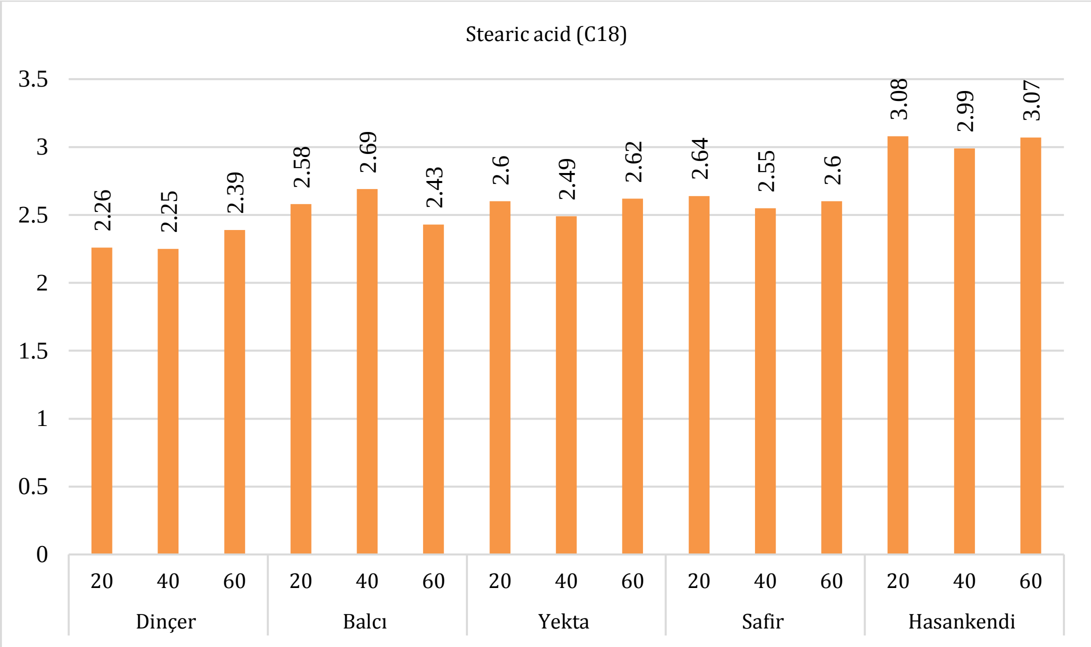

Figure 5. Graphical illustration of stearik acid content across varieties.

Based on the variety means. the highest value was observed in the Hasankendi cultivar (3.05%). followed by Safir (2.60%), Yekta (2.57%) and Balcı (2.57%), which were placed in the same statistical group. The Dinçer cultivar had the lowest value (2.30%) (Table 18).

In a related study. Daniş (2022) reported that the stearic acid content ranged between 2.67% and 3.15%. Hacıkamiloğlu (2023) on the other hand. indicated that the stearic acid content varied between 2.2% and 4.8% in his study. While the findings of our study showed a parallel trend with those of Daniş (2022) discrepancies were observed when compared with the results of Hacıkamiloğlu (2023). These differences in fatty acid composition are thought to be due to variations in genetic makeup and the different locations from which the plants were collected.

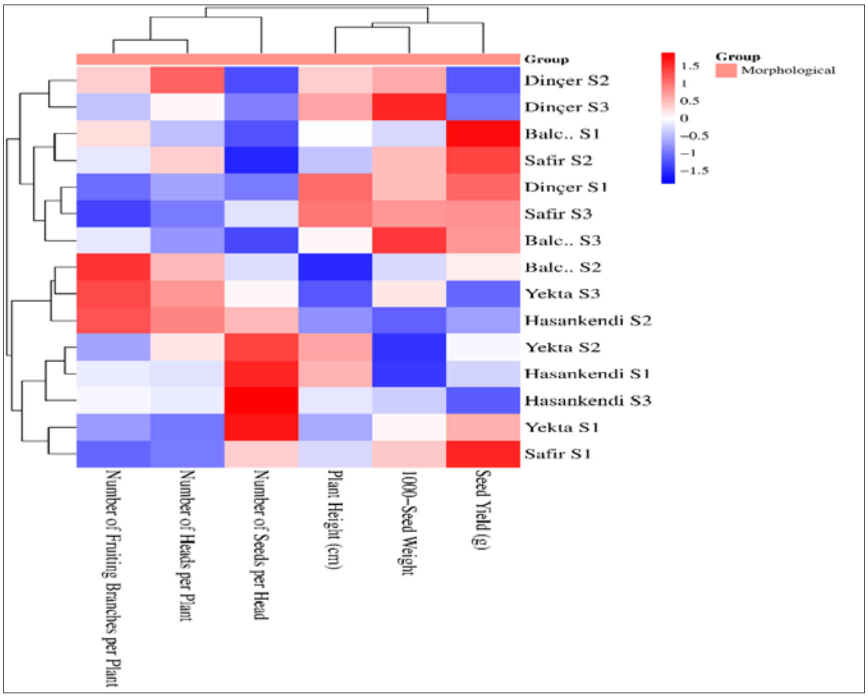

Figure 6. Heatmap of agro-morphological and agronomic traits across safflower varieties.

Figure 7. Principal component analysis (PCA) of agro-morphological and agronomic traits in safflower varieties

In the heatmap clustering performed for the cultivars used in the present study (Figure 6). both the cultivars and their agro-morphological traits were grouped into two main clusters. Accordingly, the first main cluster based on cultivar similarities. was further divided into two sub-clusters. The first sub-cluster included Hasankendi S2. Balcı S2. Yekta S3. Hasankendi S3. Yekta S2. and Hasankendi S1. while the second sub-cluster consisted of Dinçer S2, Dinçer S3, Yekta S1, Safir S1, Balcı S1, Safir S2, Balcı S3, Dinçer S1 and Safir S3. Similarly, the second main cluster which was based on agro-morphological characteristics was also divided into two sub-clusters. The first sub-cluster included seed yield (g), plant height (cm) and 1000-seed weight, whereas the second sub-cluster comprised the number of seeds per head, number of fruiting branches per plant and number of heads per plant. Additionally, within the first main cluster identified based on cultivar differences the highest 1000-seed weight was observed in Yekta S2 and Hasankendi S1. However, the lowest number of seeds per head was recorded in Yekta S2. Hasankendi S1 and Hasankendi S3. Furthermore, Balcı S2 had the greatest plant height while Yekta S3 exhibited both high plant height and seed yield (g).

In the second cluster the highest number of seeds per head was found in Safir S2, Balcı S1 and Balcı S3, whereas Yekta S1 had the lowest value for this trait. In addition. Safir S3 showed a high number of fruiting branches per plant while it had low values for seed yield (g), plant height (cm) and 1000-seed weight. It was also determined that seed yield (g) was relatively low in Balcı S1, Safir S1, Safir S2, Balcı S3, Dinçer S1 and Safir S3. while the lowest 1000-seed weights were recorded in Dinçer S3 and Balcı S3.

Moreover, to enhance interpretability alongside the heat map clustering principal component analysis (PCA) was also conducted in the study (Figure 7). The PCA results were found to be consistent with the heat map clustering. According to the PCA the number of seeds per head and the number of fruiting branches per plant formed one distinct cluster while the number of heads per plant, plant height (cm) and 1000-seed weight constituted another. Additionally, seed yield (g) was found to form a separate cluster indicating its distinct behavior compared to the other traits (Figure 7).

Oil Yield and Composition

As with the agro-morphological parameters a heat map clustering (Figure 8) and principal component analysis (PCA) (Figure 9) were conducted in order to provide a clearer interpretation of the cultivars based on fatty acid composition crude oil content and fatty acid quantities. In this context, the heat map clustering revealed two main clusters for both the cultivars and the examined oil traits. Regarding the cultivars Safir S2, Safir S3, Yekta S3 and Safir S1 were grouped in the first main cluster, while the remaining cultivars were placed in the second main cluster. In the clustering based on crude oil content and fatty acid composition α-linolenic acid and oleic acid were grouped together in one cluster whereas stearic acid crude oil yield (g), crude oil content (%), linoleic acid and palmitic acid formed a separate cluster. Based on these results it was observed that in cultivars with higher crude oil yield and crude oil content the levels of linoleic acid, oleic acid, α-linolenic acid and palmitic acid were lower, whereas stearic acid levels were relatively higher.

Additionally, a principal component analysis (PCA) was performed to assess the extent to which the parameters obtained from the oil analysis contributed to the clustering of the cultivars (Figure 9). Similar to the heat map clustering the PCA revealed that α-linolenic acid and oleic acid were grouped into one cluster while stearic acid, crude oil yield (g) and crude oil content (%) formed another cluster. Palmitic and linoleic acids each appeared to form distinct separate clusters.

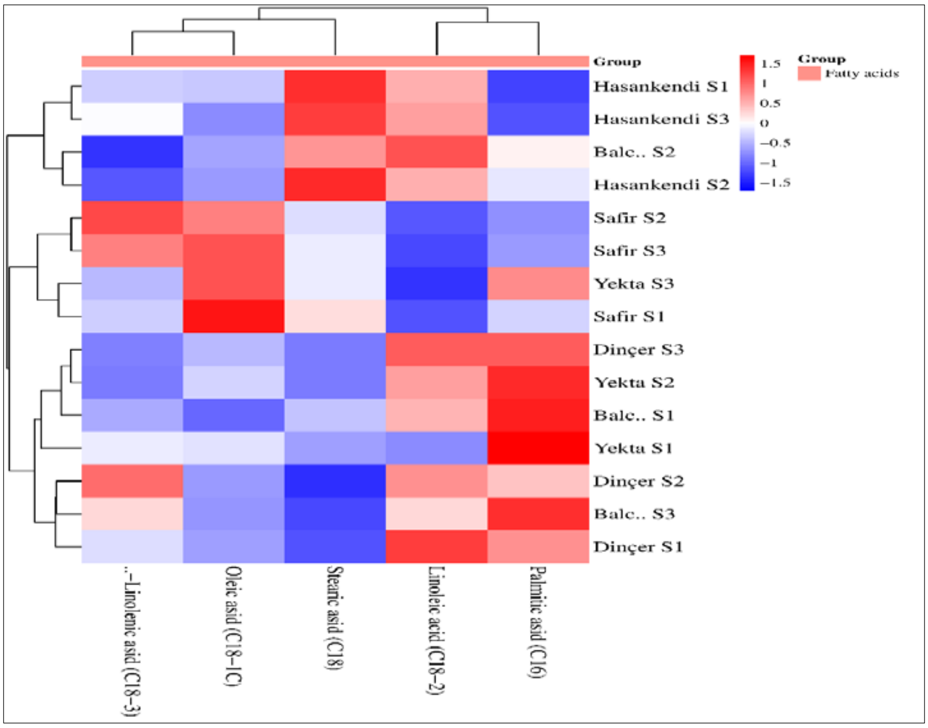

Figure 8. Heatmap of oil and fatty acids in safflower varieties

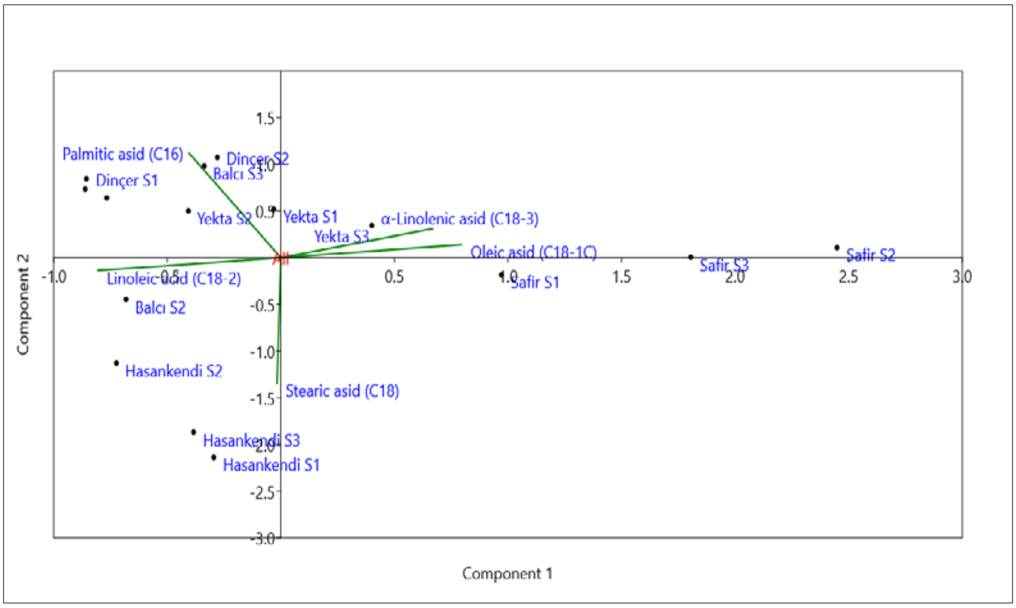

Figure 9. Principal Component Analysis (PCA) of oil and fatty acids in safflower varieties

Conclusion

The present investigation revealed significant variability among safflower cultivars with respect to agro-morphological characteristics, seed yield, oil content, and fatty acid composition under the agro-ecological conditions of Iğdır, Türkiye. Dinçer, Balcı, and Safir cultivars exhibited superior seed yield performance, while Hasankendi, Yekta, and Safir were distinguished by their comparatively higher oil yields. Linoleic and oleic acids predominated in the fatty acid profile, underscoring the nutritional and industrial relevance of safflower oil. Although differences among row spacings did not always reach statistical significance, the 20 cm row spacing consistently resulted in higher seed and oil yields, thereby indicating its potential suitability as an optimal sowing density for safflower production in this region. To further optimize safflower cultivation, future research should focus on genotype × environment interactions, as well as the integration of advanced agronomic practices aimed at enhancing both quantitative and qualitative yield parameters.

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