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Investigation of the Relationships Between Yield and Yield Components of Safflower (*Carthamus tinctorius* L.) Varieties by Multivariate Analysis

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Abstract

In this study, the relationships among yield, yield components and quality traits of 7 different safflower (*Carthamus tinctorius* L.) cultivars (Balcı, Dinçer, Göktürk, Linas, Olas, Yekta and Zirkon) were investigated by multivariate analysis methods. The parameters of plant height, first branch height, number of branches, number of heads, head diameter, the number of seeds per head, thousand seed weight, seed yield and oil content were evaluated. According to the results of analysis of variance, statistically significant differences were found among the varieties in terms of all traits analyzed ($p<0.01$). Correlation analysis revealed positive correlations between plant height and seed yield (r=0.6086) and first branch height (r=0.6814), while negative correlations were found between number of branches and seed yield (r=-0.5900) and number of seeds per head (r=-0.7291). Principal component analysis (PCA) revealed two principal components explaining 60% of the total variation. The first principal component (PC1) positively included the plant height, first branch height, head diameter, number of seeds per head and seed yield parameters, and negatively included the number of branches and oil content parameters. The second principal component (PC2) positively included the parameters of the number of heads and thousand seed weight. Hierarchical cluster analysis categorized the varieties and traits into two main groups. The variety Linas showed superior performance in terms of both seed yield (125,59 kg da^{-1}) and oil content (38.07%). Multivariate analyses provided valuable information for determination of selection criteria in safflower breeding studies and optimization of breeding practices.

Keywords: Safflower, Cultivars, Quality, Yield, Multivariate analysis

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INTRODUCTION

Safflower plant is a plant from the genus *Carthamus* of the *Compositeae* family. It has been determined that there are 25 species of safflower plants in the world and only *Carthamus tinctorius* L. species has been cultivated (Singh & Nimbkar, 2006). Safflower was cultivated from 2 different species, *Carthamus oxyacantha* (wild safflower) and *Carthamus lanatus* (saffron thistle) (Ahlawat, 2008). Safflower, known as false saffron and cultivated as an annual plant, is an important industrial plant with its thorny and thornless forms, yellow, red, orange and cream colored flowers and is relatively resistant to arid conditions. The oil obtained from its seeds is used in the production of edible oil and biofuel, and it has a significant potential in bringing barren and poor areas that do not receive sufficient rainfall into production (Kıllı, 2007). In addition to its use as an oilseed crop, it is used in traditional and modern medicine due to its medicinal properties. It is also a valuable plant that can be used in a wide variety of fields, ranging from the dye industry, cosmetic product manufacturing, the production of various foodstuffs, ruminant animal feed, bird feed, and beekeeping, to the production of biodiesel, which is an alternative to fossil fuels, a limited resource in today's world (Dinçel Kütük, 2024). Oilseed crops are considered as the second food source after cereals with a great expansion worldwide due to the high demand for vegetable edible oil (Ebrahimian et al. 2019). Among oilseed crops, safflower seeds have good quality with high oil content (35%-40%) (Torabi et al. 2015; Yazdani et al. 2019). Safflower is an important oil plant with the potential to close the oil deficit of our country. At the same time, its flowers are used as natural food coloring and textile dye. The colorant called cartamine, which contains around 0.4-0.5%, is also used edicinally (Dajue and Mündel 1996). Safflower plant can be of 2 different types as linoleic (Omega-6) type and oleic (Omega-9) type. The unsaturated fatty acids (78% linoleic acid) and vitamin E in the oil make an

important contribution to human health (Arslan et al., 2003). Safflower oil is used in many areas such as biodiesel, mayonnaise, plastic industry, insect poison, varnish and polishing as well as for cooking (Karaaslan & Hakan, 2007). The meal is used in animal nutrition with around 24% protein content (Babaoğlu, 2007). The antioxidant substances found in its flowers reveal that it is beneficial to consume it as tea.

Safflower, an oil crop of increasing importance in recent years, has a cultivation area of 910 848 ha in the world according to 2023 data, with a production of 723 874 tons and a seed yield of 79 kg da^{-1} (FAO, 2024). According to 2024 data, safflower cultivation area in Turkey is 254,175 ha, production is 29000 tons and seed yield is 114 kg da^{-1}. The highest safflower cultivation area in Turkey is realized in Kayseri province, followed by Isparta and Konya provinces. The yield per decare was 111, 112 and 131 kg da^{-1} in these provinces, respectively. In Kahramanmaraş province, safflower production in 2024 was realized on an area of 342 ha and yield per decare was determined as 120 kg (TUIK, 2025). When the above data are evaluated, it is seen that Kahramanmaraş province is at low levels in terms of safflower cultivation area. However, the average safflower yield in Kahramanmaraş is quite high compared to the average of Turkey. High-quality and high-yield genotypes that are suitable for the ecological conditions of Turkey are needed (Ozturk, 2019). Therefore, it is necessary to increase the safflower cultivation area and contribute to the national economy.

The aim of this study was to investigate the relationships among yield, yield components and quality traits of different safflower (*Carthamus tinctorius* L.) cultivars using multivariate analysis methods. In the study, the agronomic performances of seven safflower cultivars were evaluated and the direct and indirect relationships between plant height, first branch height, number of branches, number of heads, head diameter, number of seeds per head, thousand seed weight, seed yield and oil content parameters were determined. In addition, multivariate statistical methods such as principal component analysis (PCA) and hierarchical cluster analysis were used to group safflower cultivars according to their genetic and phenotypic similarities and to reveal the complex interactions between yield and quality parameters. The findings obtained were aimed to contribute to the determination of selection criteria in safflower breeding programs and optimization of breeding practices.

Material and Method

Plant material and experimental area

Seven different safflower cultivars (Balcı, Dinçer, Göktürk, Linas, Olas, Yekta and Zirkon) were used in the study. This study was established and conducted in the experimental field of Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Field Crops in April 2021. Located in the Mediterranean region, between 37°35'40.86" north latitude and 36°48'47.51" east longitude, the trial area has a slope of 3-5%. It is 487 m above sea level. A soil sample was taken from 0-30 cm depth before planting. Soil analysis was performed to determine the physical and chemical properties of the sample. Some of the physical and chemical properties determined as a result of the analysis of the soil sample taken from 0-30 cm depth of the experimental soil at ÜSKİM are given in Table 1 (Anonymous, 2021a). According to the results of this analysis, soil pH value was measured as 7.71. Lime content was 6.09% and organic matter content was 1.58%. Salinity value was determined as 0.05%. Phosphorus content was measured as 2.84 kg da^{-1} P_2O_5 and potassium content as 55.51 kg da^{-1} K_2O. The water saturation value of soil samples was determined as 69.96% (Table 1)

Table 1. Physical and Chemical Properties of Soil from the Experimental Area

Parameters Analyzed							
Depth (cm)	Water Saturation	pH	Lime (%)	Organic Matter (%)	Salinity (%)	P_2O_5 (kg da^{-1})	K_2O (kg da^{-1})
0-30	69.96	7.71	6.09	1.58	0.05	2.84	55.51

In 2021, when the climatic data of Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Field Crops are examined, significant differences are observed in precipitation regime and temperature values compared to long-term averages. In the April-August period, total precipitation in 2021 was recorded as 32.30 mm, while the long-term average was 125.30 mm. This shows that 2021 received approximately 26% of the long-term average precipitation in the relevant period. Especially in April, 16.20 mm, only 22% of the long-term average (73.00 mm), and no precipitation was recorded in June. While a very low amount of precipitation (0.50 mm) was recorded in July, a precipitation (7.40 mm) above the long-term average (2.20 mm) was recorded in August. In terms of temperature values, values above the long-term averages were observed in all months in 2021. Higher temperatures of 1.5°C in April, 3.4°C in May, 0.6°C in June, 2.0°C in July and 1.6°C in August were recorded. In the light of these data, it can be said that 2021 was significantly hotter and significantly drier in the trial area (Table 2).

Table 2. Climate Data for 2021 and Long Years Measured at Kahramanmaraş Meteorological Station (Anonymous, 2021b).

	Total Precipitation (mm)		Average Temperature (°C)	
Months	2021	Long Years	2021	Long Years
April	16.20	73.00	16.60	15.10
May	8.20	38.80	23.50	20.10
June	0.00	8.60	25.50	24.90
July	0.50	2.70	30.30	28.30
August	7.40	2.20	30.00	28.40
Total/Average	32.30	125.30	-	-

Method

The experiment was established and carried out in the research field of KSU Faculty of Agriculture, Department of Field Crops according to the randomized block design with four replications. In the experiment, the plots were formed as 4 rows of 5 m length and the distance between rows was 70 cm and the distance between rows was 10 cm. The experimental area, which was plowed after the pre-plant harvest, was cultivated with a cultivator before sowing and made ready for sowing by pulling the plug. Before sowing, 30 kg of 20-20-0 compound fertilizer was applied per decare by hand sprinkling. Sowing was carried out on April 22, 2021 by manually sowing 50 seeds in each row. During the growing period, the plants were hoeed twice and irrigated 3 times on June 18, July 7 and July 20. The harvest of the experiment was carried out on August 5, 2015 by manually cutting the heads of the plants in the plot using pruning shears. The cut heads were pounded in sacks, sieved and the seeds were separated.

Statistical analysis

The experiment was established according to the Randomized Block Design with four replications. The data obtained were also evaluated for calculation of basic statistical parameters such as mean, minimum and maximum values, standard deviation, coefficient of variation, principal component analysis, cluster analysis and biplot plotting using JMP (pro 17). Descriptive statistics were calculated to determine the mean, standard deviation and range values for all measured parameters including yield components and oil quality parameters. Data were subjected to one-way analysis of variance (ANOVA) to evaluate differences among safflower cultivars. When significant differences ($p<0.05$) were detected, means were separated using Tukey's Honest Significant Difference (HSD) test at 5% probability level using the agricolae package (Mendiburu, 2023). Homogeneity of variances was verified using Levene's test before ANOVA. To determine the patterns of similarity among genotypes based on multiple traits simultaneously, hierarchical cluster analysis was performed using Euclidean distance as a measure of similarity and Ward's minimum variance method for clustering. The resulting dendrogram was used to identify groups of genotypes with similar performance traits (Wickham, 2016).

RESULT AND DISCUSSION

In the study, agronomic and quality characteristics of 7 different safflower varieties were examined and when the descriptive statistics results obtained were evaluated; plant height values varied between 44.20-58.40 cm and the average was 48.76 cm. The coefficient of variation (10.23%) shows a moderate level of variability. Significant differences were observed among the varieties in terms of first branch height and values ranging between 11.63-21.67 cm were obtained. The high coefficient of variation (18.66%) of this trait indicates that the genetic differences between the varieties are significant. The average number of branches was 7.10 and varied between 5.63-8.27 among the varieties. The coefficient of variation (12.82%) reveals that this trait exhibits moderate variability. In terms of the number of heads, cultivars varied between 23.40-30.33 and the average was 28.29. The low coefficient of variation (8.52%) indicates that this trait was relatively stable among the varieties.

Head diameter varied between 24.97-29.10 mm, with an average of 27.13 mm. With a coefficient of variation of 6.45%, the diameter of the head was one of the parameters with the lowest variability among the traits examined. Significant differences were observed among the varieties in terms of the number of seeds in the head and values ranging between 28.43-44.43 were obtained. The coefficient of variation (16.57%) indicates that this trait showed significant differences among the varieties. Thousand seed weight averaged 39.25 g and varied between 34.28-43.30 g. The low coefficient of variation (8.07%) indicates that this trait was relatively homogeneous among the varieties. In terms of seed yield, the varieties exhibited values ranging between 85.42-125.59 kg da^{-1}, with an average of 105.38 kg da^{-1}. The coefficient of variation (13.69%) shows that there is a moderate variability among the varieties in terms of yield. Oil content varied between 28.72-38.07%, with an average of 34.07%. The low coefficient of variation (9.27%) indicates that oil content was relatively stable among the varieties (Table 3).

Table 3. Descriptive statistics values of the agronomic characteristics of safflower (*Carthamus tinctorius* L.) cultivars

Traits	Min.	Max.	Mean	StDev	CV%
Plant height (cm)	44.20	58.40	48.76	4.99	10.23
First branch height (cm)	11.63	21.67	16.88	3.15	18.66
Branch number (quantity)	5.63	8.27	7.10	0.91	12.82
Number of heads (quantity)	23.40	30.33	28.29	2.41	8.52
Head diameter (mm)	24.97	29.10	27.13	1.75	6.45
The number of seed per head (quantity)	28.43	44.43	32.70	5.42	16.57
Thousand seed weight (g)	34.28	43.30	39.25	3.17	8.07
Seed yield (kg da^{-1})	85.42	125.59	105.38	14.43	13.69
Oil content (%)	28.72	38.07	34.07	3.16	9.27

In this study, agronomic and quality traits of different safflower cultivars (Balcı, Dinçer, Göktürk, Linas, Olas, Yekta and Zirkon) were analyzed and according to the results of analysis of variance, statistically highly significant differences were found between the cultivars in terms of all traits ($p<0.01$). This clearly shows that the safflower cultivars used in the study have different genetic structures and the cultivars exhibit different agronomic performances. Some traits of safflower genotypes are not only controlled by genetic factors but also affected by different agronomic practices and environmental conditions (Köse and Bilir, 2017). Significant differences were observed among the varieties in terms of plant height. Linas

variety had the longest plant height with 58.40 cm, followed by Dinçer variety with 52.07 cm. The shortest plant height was measured in Balcı (44.20 cm) and Göktürk (44.27 cm) varieties. The other cultivars (Olas, Yekta and Zirkon) were in the same group statistically and showed moderate plant height (47.20-47.83 cm).

Plant height is an important parameter in terms of mechanization and lodging resistance. Medium height varieties are generally more resistant to lodging and provide advantages in terms of mechanization. Studies have shown that plant height is higher in early sowing (Özel et al., 2004; Coşge and Kaya, 2008). Hatipoğlu et al. (2012), in their study conducted at different sowing times in safflower plant, it is seen that there is a similarity between their results obtained at April sowing time and our findings. Significant variation was observed among the varieties in terms of first branch height. Dinçer variety showed the highest value with 21.67 cm, followed by Linas variety with 19.63 cm. The lowest first branch height was found in Göktürk variety with 11.63 cm. Balci, Olas, Yekta and Zirkon varieties were statistically in the same group and showed moderate values (15.90-16.57 cm).

First branch height is an important feature especially in mechanized harvesting. High first branch height may provide an advantage in terms of reducing harvest losses. Çamaş et al. (2005) reported that the first branch height was between 19.80-60.16 cm. Yurteri (2016) determined the first branch heights between 21.23-35.30 cm, Aslan et al. (2022) determined the first branch heights as 29.04- 31.91, respectively, in safflower varieties sown in summer. It is thought that the reason for the different heights of the first branch in plants may be the climate and soil types of the ecological conditions where the studies were carried out (Demirel, 2024).

In terms of number of branches, Balcı variety showed the highest value with 8.27, followed by Olas (7.87) and Yekta (7.63) varieties. The lowest number of branches was determined in Dinçer variety with 5.63 pieces. The number of branches is an important parameter affecting the number of plant heads and thus yield potential. Although safflower is a plant adapted to arid conditions, the number of branches increases when the necessary maintenance procedures such as irrigation and fertilization are fulfilled when grown in the bottom land (Kaya and Tunçtürk, 2018). However, high number of branches does not always mean high yield, as a matter of fact, in this study, it is noteworthy that Balcı variety, which has a high number of branches, showed low performance in terms of yield. Kaya et al. (2004) reported that the number of branches varied between 1.53-7.20 and Keleş and Öztürk (2012) reported that the number of side branches per plant was between 4.04-7.88 in their study conducted in Konya province. Balci (30.33 pieces) and Yekta (30.20 pieces) varieties showed the highest values in terms of the number of heads, while Olas variety showed the lowest value with 23.40 pieces. The other varieties (Dinçer, Göktürk, Linas) were in the same group statistically and showed a medium level of head number (28.97-29.10 pieces).

The number of head is an important component that determines the yield potential of the plant. However, a high number of heads alone does not provide high yield, and other yield components such as the number of seeds per head and thousand seed weight are also important. Atan et al. (2019) determined the average number of heads per plant as 11.53 and 16.20, Karaca Öner and Şeker (2020) determined the number of heads per plant as 7.28-10.43. It can be said that the difference between the values obtained from the researches on the number of heads per plant may be due to the differences in the varieties used in the research and especially the differences in the climate and soil structure of the location where the researches were carried out and the different maintenance techniques applied (Keleş, 2010).

In terms of head diameter, Linas (29.10 mm), Dinçer (28.73 mm) and Olas (28.70 mm) varieties were in the same group statistically and showed the highest values. The lowest head diameter was measured in Yekta (24.97 mm), Göktürk (25.13 mm) and Balcı (26.20 mm) varieties. Head diameter is a trait that can affect the number of seeds in the table. It is noteworthy that the variety Dinçer, which has the highest diameter, also showed the highest value in terms of the number of seeds in the table. In the studies conducted on safflower, Sirel (2011) reported that the values of the diameter of the head varied between 10.80-20.53 mm, Kunt (2012) between 20.01-20.20 mm, Aydın (2012) between 20.52-40.13 mm and Birben (2015) between 10.42-20.16 mm. In terms of the number of seeds in the table, Dinçer variety exhibited a significantly higher value than all other varieties with 44.43 seeds. The other varieties were statistically in the same group and showed values ranging between 28.43-33.03 pieces.

The number of seeds per head is an important component that directly affects yield. The superiority of Dinçer variety in terms of this trait suggests that it can be a valuable genetic resource in breeding studies. In different studies on safflower, Andırman (2011); 27.2-28.3 and Kaya and Tunçtürk (2018) determined the number of seeds per head between 28.8-31.1 based on variety averages. These findings coincide with our findings. In terms of thousand seed weight, Zirkon variety showed the highest value with 43.30 g, followed by Yekta (42.12 g), Linas (40.29 g) and Balci (40.17 g) varieties. The lowest thousand seed weight was found in Olas variety (34.28 g). Thousand seed weight is an important parameter affecting seed size and thus yield. It may also be related to oil content. Kaya et al. (2005) reported thousand seed weight values between 29.87- 34.23 g, Uysal et al. (2006) between 28.30 - 38.70 g, Kıllı and Ermiş (2009) between 42.32 - 46.84 g. Our thousand seed weight values ranging between 34.28 - 43.30 g are similar to the findings of many researchers.

In terms of seed yield, Linas variety showed the highest value with 125.59 kg da^{-1}, followed by Göktürk (116.16 kg da^{-1}) and Dinçer (114.78 kg da^{-1}) varieties. The lowest yield was determined in Olas (85.42 kg da^{-1}) and Balci (90.77 kg da^{-1}) varieties. Seed yield is the most important parameter determining the economic value of the varieties. The superior performance of Linas variety in terms of both seed yield and oil content reveals the potential of this variety for commercial production. Aydın (2012) reported that seed yield varied between 87.75-146.3 kg da^{-1}. Ekin (2019) reported that seed yield ranged between 70.4 and 101.7 kg da^{-1}, Demir and Kara (2018) reported that the highest seed yield for Kırıkkale was 207 kg da^{-1} (Remzibey) and the lowest was 119 kg da^{-1} (Olas), while the highest was 193 kg da^{-1} (Dinçer) and the lowest was 114 kg da^{-1} (Ayaz) for Kırşehir conditions. In addition, Demir (2019) reported that seed yield of Balcı safflower variety

varied between 104.8-162.6 kg da^{-1} according to different N doses (0,4,8,12,15 and 20 kg N/da). These findings support our findings.

In terms of oil content, Linas (38.07%), Balcı (36.44%), Olas (35.13%) and Yekta (34.81%) varieties were statistically in the same group and showed the highest values. The lowest oil content was found in Dinçer variety (28.72%). Oil content is the most important quality parameter that determines the economic value of safflower. It can be said that varieties with high oil content are advantageous in terms of oil yield (Table 4 and Table 5). Çavumirza and Demir (2024) determined the crude oil content between 30.8% and 39.77%, Eslam et al. (2010) 24.5-31.8%, Demir and Karaca (2018) 35.35-38.59%, Ünlüer (2018) 24.6-37.4% and Bozdemir (2020) 24.64-37.10%. These findings are in agreement with our findings.

Table 4. Mean Values and Groupings of agronomic traits of Safflower (*Carthamus tinctorius* L.) cultivars.

Cultivar	Plant height (cm)	First branch height (cm)	Branch number (quantity)	Number of heads (quantity)	Head diameter (mm)
Balcı	44.20±1.11 c	16.33±0.42 c	8.27±0.70 a	30.33±1.22 a	26.20±0.52 b
Dinçer	52.07±1.45 b	21.67±0.50 a	5.63±1.01 b	29.10±1.27 ab	28.73±0.50 a
Göktürk	44.27±0.70 c	11.63±0.87 d	7.20±0.52 ab	29.00±1.63 ab	25.13±0.70 b
Linas	58.40±2.27 a	19.63±1.07 b	6.73±0.92 ab	28.97±0.40 ab	29.10±1.65 a
Olas	47.83±2.50 bc	15.90±0.78 c	7.87±0.70 a	23.40±1.11 c	28.70±0.79 a
Yekta	47.20±2.36 bc	16.47±1.33 c	7.63±0.55 a	30.20±0.72 a	24.97±0.15 b
Zirkon	47.40±0.92 bc	16.57±0.45 c	6.43±0.06 ab	27.03±0.85 b	27.10±0.51 ab
Anova					
F Ratio	24.25**	42.36**	5.04**	14.47**	13.79**

Table 5. Mean Values and Groupings of agronomic traits of Safflower (*Carthamus tinctorius* L.) cultivars.

Cultivar	The number of seeds per head (quantity)	Thousand seed weight (g)	Seed yield (kg da^{-1})	Oil content (%)
Balcı	28.43±0.60 b	40.17±1.70 a-c	90.77±8.12 de	36.44±2.47 ab
Dinçer	44.43±0.40 a	36.36±1.22 cd	114.78±1.21 b	28.72±1.19 d
Göktürk	32.07±1.55 b	38.28±1.35 b-d	116.16±2.89 ab	31.23±0.38 cd
Linas	33.03±5.98 b	40.29±1.76 a-c	125.59±1.15 a	38.07±0.77 a
Olas	30.90±0.79 b	34.28±1.09 d	85.42±2.39 e	35.13±0.81 ab
Yekta	28.83±0.57 b	42.12±2.30 ab	100.38±2.21 cd	34.81±0.69 ab
Zirkon	31.27±1.85 b	43.30±1.82 a	104.58±0.64 c	34.12±0.79 bc
Anova				
F Ratio	14.34**	11.01**	49.59**	20.89**

The correlation relationships between the agronomic and quality traits examined in 7 different safflower cultivars in the study are comprehensively evaluated below. Strong positive correlations were found between plant height and first branch height (r=0.6814) and head diameter (r=0.6809). This indicates that taller plants have higher first branching height and form wider heads. There was also a significant positive correlation between plant height and seed yield (r=0.6086). This relationship indicates that plants with higher plant height may have higher yield potential. A moderate positive correlation (r=0.3645) was also observed between plant height and number of seeds per head. On the other hand, a negative correlation (r=-0.3484) was found between plant height and number of branches, indicating that plants with higher plant height tend to branch less. There were strong positive correlations between first branch height and head diameter (r=0.6030) and number of seeds per head (r=0.6228).

This indicates that plants with higher first branching height formed wider heads and had more seeds in the head. On the other hand, a significant negative correlation (r=-0.5331) was found between the first branching height and the number of branches. This relationship reveals that plants with a higher first branching height tend to branch less. Strong negative correlations were found between the number of branches and the number of seeds per head (r=-0.7291) and seed yield (r=-0.5900).

This indicates that plants with more branches have fewer seeds in the head and have lower yield potential. On the other hand, a moderate positive correlation (r=0.4359) was found between the number of branches and oil content. This relationship indicates that plants with more branches may have higher oil content. A moderate positive correlation was also found between the number of heads and thousand seed weight (r=0.5176) and seed yield (r=0.3685). On the other hand, a negative correlation (r=-0.4049) was obtained between the number of heads and head diameter, indicating that plants forming more heads tend to have smaller heads. There was a moderate positive correlation (r=0.3331) between head diameter and number of seeds per head. This indicates that wider heads can contain more seeds. On the other hand, a negative correlation (r=-0.3545) was detected between head diameter and thousand seed weight, indicating that wider heads tend to have smaller seeds. There was a moderate positive correlation (r=0.4333) between the number of seeds per head and seed yield. This indicates that plants with more seeds in the head may have higher yield potential. On the other hand, there was a strong negative correlation (r=-0.6332) between the number of seeds per head and oil content and a moderate negative

correlation (r=-0.4207) with thousand seed weight. These relationships suggest that plants with more seeds in the head tend to have lower oil content and smaller seeds. There was a moderate positive correlation (r=0.3175) between thousand seed weight and oil content. This indicates that larger seeds may have higher oil content. There was also a weak positive correlation (r=0.1615) between thousand seed weight and seed yield. A negative correlation (r=-0.1674) was found between seed yield and oil content. This indicates that high yielding varieties may tend to have lower oil content. However, since this correlation coefficient is relatively low, it can be said that this relationship is weak (Table 6). Köse et al. (2021) reported that there were statistically significant positive correlations between seed yield and head diameter (r=401**), oil content (r=299**) and number of head per plant (r=0.182*). In addition, Köse et al. (2021) reported statistically significant negative relationships between seed yield and plant height (r=421**).

When the PCA graph is examined, it is seen that the first principal component (PC1) explains 39.6% of the total variation, the second principal component (PC2) explains 20.4%, and cumulatively the two principal components represent 60% of the total variation. This ratio shows that multivariate data are adequately represented in the two-dimensional plane. When the distribution of the vectors was analyzed, it was found that the parameters plant height, first branch height, head diameter, number of seeds per head and seed yield were located in the positive direction of the PC1 axis and there were strong positive correlations between them. These parameters can be grouped as the main agronomic traits determining yield potential. On the other hand, the number of branches and oil content parameters were located in the negative direction of the PC1 axis and showed negative correlation with the first group. This situation reveals that genotypes with high number of branches and high oil content tend to exhibit low values in terms of plant height, first branch height and number of seeds per head.

In the positive direction of the PC2 axis, it was observed that the parameters of the number of heads and thousand seed weight were located and there was a positive correlation between them. These parameters can be considered as the traits representing seed size and number of heads. When the distribution of the cultivars in the PCA plane was analyzed, it was found that the cultivars located in the upper right region showed superior performance in terms of seed yield, plant height and first branch height; the cultivars located in the lower left region stood out in terms of number of branches and oil content; and the cultivars located in the upper left region exhibited high values in terms of thousand seed weight and the number of heads. These findings provide valuable information for determination of selection criteria in safflower breeding studies and optimization of breeding practices. In particular, in order to break the negative correlation between yield and oil content, it may be recommended to crossbreed genotypes with moderate performance in terms of both traits or to apply repeated selection methods. Furthermore, it is important to examine the stability of these traits under different ecological conditions and cultivation techniques in order to determine the adaptability of the varieties (Figure 1). Salamatı et al. (2011), in their study, when the results of principal component analysis were considered, it was observed that the first principal component was most related to seed yield/plant and its components. According to the correlation results, there was a positive and high correlation between all traits in this factor, so this factor may have an important role as a selection index in breeding programs for the production of varieties with high seed yield. Amini et. al. (2007) in their study on 32 safflower genotypes identified six principal components explaining 81.81% of the total variation among the traits.

Table 6. Correlaon coeftificients among agronomic traits of Safflower (*Carthamus tinctorius* L.) cultivars

Traits	Plant height	First branch height	Branch number	Number of heads	Head diameter	The number of seed per head	Thousand seed weight	Seed Yield	Oil content
Plant height	1,0000	0,6814	-0,3484**	0,0298*	0,6809	0,3645	-0,0110**	0,6086	0,1874
First branch height		1,0000	-0,5331**	0,0900	0,6030	0,6228	-0,0635**	0,2614	-0,0466**
Branch number			1,0000	-0,0242**	-0,3180**	-0,7291**	0,0310*	-0,5900**	0,4359
Number of heads				1,0000	-0,4049**	0,0292*	0,5176	0,3685	-0,0815**
Head diameter					1,0000	0,3331	-0,3545**	0,1545	0,0736
The number of seed per head						1,0000	-0,4207**	0,4333	-0,6332**
Thousand seed weight							1,0000	0,1615	0,3175
Seed Yield								1,0000	-0,1674**
Oil content									1,0000

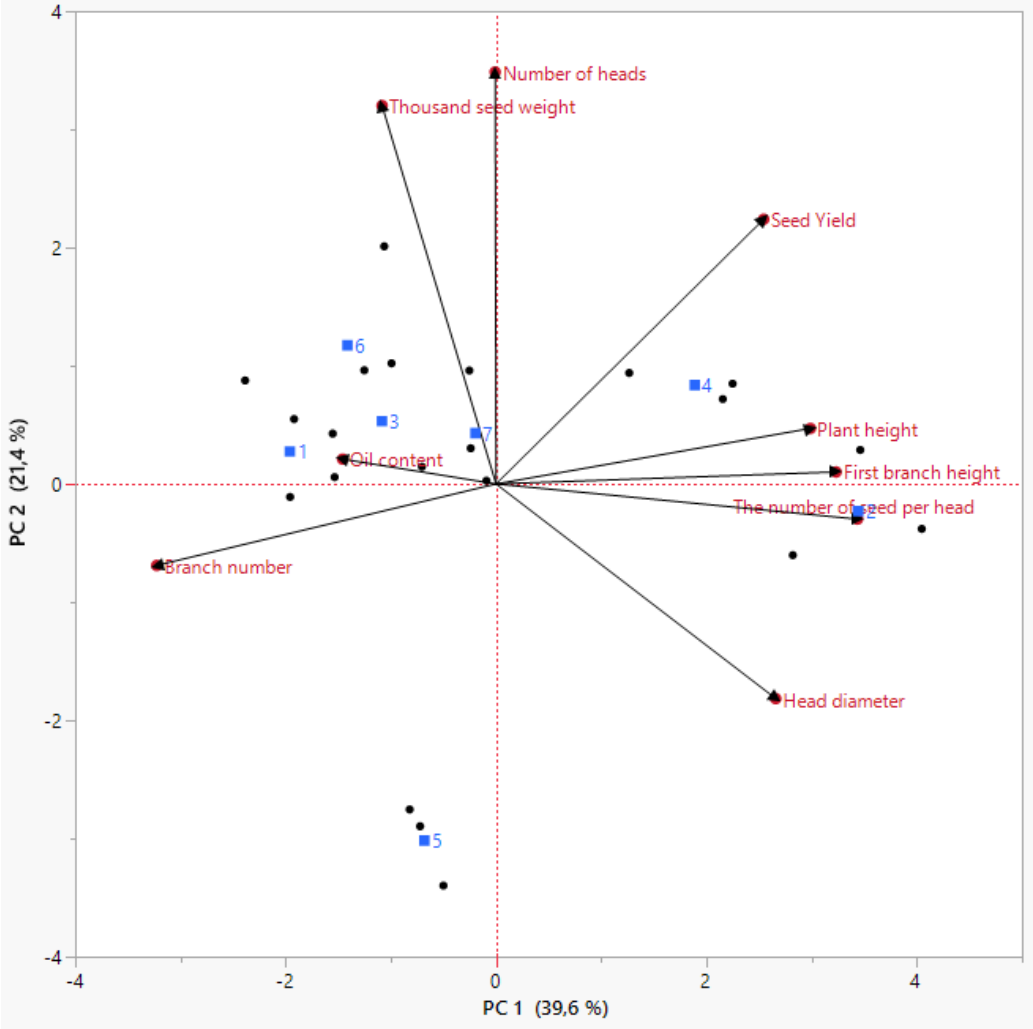

Figure 1. Biplot between PC1 and PC2 for agronomic traits of Safflower (*Carthamus tinctorius* L.) cultivars

The heat map and dendrogram show the results of hierarchical cluster analysis of safflower cultivars according to agronomic and quality traits. This analysis allows grouping of cultivars according to their similarities and visualizing the relationships among traits. In the heat map, blue colors represent low values and red colors represent high values. Gray tones indicate medium values. The horizontal axis of the map shows the traits examined (plant height, first branch height, number of branches, number of heads, head diameter, number of seeds per heads, thousand seed weight, seed yield and oil content) and the vertical axis shows safflower cultivars (1-7). The traits were divided into two main groups, A and B: Group A (A1 and A2) includes parameters related to general growth and development characteristics of the plant such as plant height, first branch height, head diameter and number of seeds per head; Group B (B1 and B2) includes traits related to yield and quality components of the plant such as number of branches, number of heads, thousand seed weight, seed yield and oil content. Varieties are divided into two main clusters, X and Y: Cluster X (X1 and X2) includes varieties numbered 1, 2, 6, 7, 3 and 5; while Cluster Y (Y1 and Y2) includes varieties numbered 2, 5, 4 and 4. When the trait profiles of the varieties are examined, variety 1 (Balcı) shows low values in the traits in group A and high values in some traits in group B; variety 2 (Dinçer) shows high values in the traits in group A and low values in some traits in group B; variety 3 (Göktürk) shows low values in the traits in group A and high values in some traits in group B; Variety 4 (Linas) shows high values in both A and B group traits; Variety 5 (Olas) shows high values in some traits in A group and low values in some traits in B group; Variety 6 (Yekta) shows medium values in some traits in A group and high values in some traits in B group; Variety 7 (Zirkon) shows medium values in some traits in A group and high values in some traits in B group. As seen in the dendrogram, cultivars were grouped hierarchically according to their genetic and phenotypic similarities. Varieties in cluster X were divided into X1 (1, 2, 6, 7) and X2 (3, 5) subclusters. Similarly, the varieties in cluster Y were further subdivided into Y1 (2, 5) and Y2 (4, 4). The cultivars in subcluster X1 are characterized by moderate to high levels of number of stems and thousand grain weight, while cultivars in subcluster X2 are characterized by low first branch height and variable seed yield. The cultivars in subcluster Y1 are characterized by a high head diameter and variable seed yield, while the cultivars in subcluster Y2 are characterized by high plant height, seed yield and oil content (Figure 2).

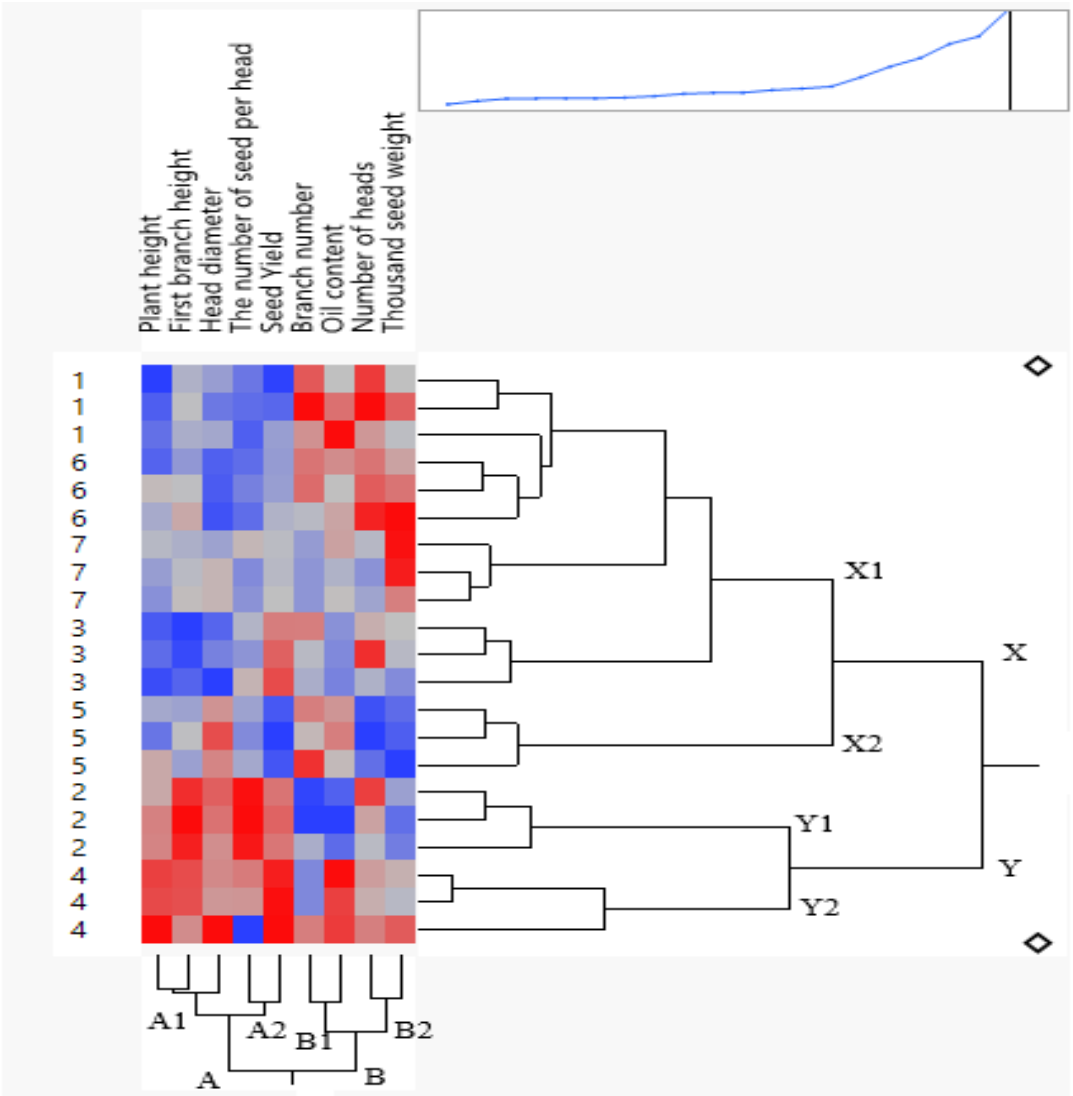

Figure 2. Heat map obtained as an output of the hierarchical cluster analysis of varieties and traits studied

Conclusion

In this study, the relationships among yield, yield components and quality traits of safflower cultivars were comprehensively investigated by multivariate analysis methods. The results obtained revealed important findings in terms of safflower breeding and cultivation. Among the safflower varieties examined, it was determined that Linas variety stood out especially in terms of economically important traits such as seed yield and oil content. This variety outperformed the other varieties with 125,59 kg da^{-1} seed yield and 38.07% oil content. In addition, Linas cultivar also showed high values in plant height, head diameter and thousand seed weight. Correlation analysis results showed that there were significant relationships among yield components. The positive correlation between plant height and seed yield (r=0.6086) indicates that plants with higher plant height have higher yield potential. On the other hand, the negative correlation between number of branches and seed yield (r=-0.5900) indicates that plants with more branches have lower yield potential. In addition, there was a strong negative correlation (r=-0.6332) between the number of seeds per head and oil content. Principal component analysis (PCA) clearly visualized the complex relationships between agronomic and quality traits of safflower cultivars. The first principal component (PC1) positively included the traits that determine yield potential (plant height, first branch height, head diameter, number of seeds per head and seed yield) and negatively included the traits associated with oil content (number of branches and oil content). This confirms the negative relationship between yield and oil content. Hierarchical cluster analysis grouped the varieties according to their genetic and phenotypic similarity. This grouping provides valuable information for the evaluation of genetic diversity and parent selection in breeding studies. Crosses between varieties in different clusters can increase genetic diversity. In conclusion, the findings obtained in this study can be guiding in determining selection criteria in safflower breeding studies and optimization of breeding practices. In particular, in order to break the negative correlation between yield and oil content, genotypes such as Linas variety, which shows superior performance in terms of both traits, may be recommended to be used in breeding programs. In addition, it is important to examine the stability of these traits under different ecological conditions and cultivation techniques in order to determine the adaptability of the varieties.

Compliance with Ethical Standards

Peer Review

This article has been reviewed by independent experts in the field using a rigorous double-blind peer review process.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

All authors contributed equally to the study design, data collection, analysis, and manuscript preparation.

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