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The Effects of Pruning Safflower (*Carthamus tinctorius* L.) as a Single Stemmed and Single-Headed Morphological Design on Growth and Development Characteristics and Agricultural Potential

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Abstract: The aim of this study was to determine the possible effects of pruning the side branches at different stages, designed as a single stem/single head, on the growth and development characteristics of the safflower (*Carthamus tinctorius* L.) plant and its agricultural potential under the different plant spacing. In the research, which was established with 3 replications according to the split-plot, 3 pruning times (beginning of budding, end of budding and beginning of flowering) and 3 different row distances (15 x 10, 30 x 10, and 45 x 10 cm) were applied. While pruning treatments had positive effects on chlorophyll content, plant height, head diameter, seed number, and 1000 seed weight, they had negative effects on seed weight, harvest index, oil ratio, seed and oil yield. Chlorophyll content, plant height, the number of branches, head diameter, the number of heads, the number of seeds, seed weight, and 1000 seed weight increased as row spacing widened; harvest index, seed and oil yield decreased; oil ratio was unaffected. The research findings showed that pruning time and sowing distances had non-significant effect on fatty acid composition. Despite having more seeds and a heavier 1000 seed weight, plants with a single stem/single head had lower seed and oil yields because they did not have as many heads as branched plants. The research findings are important in providing data that can be a role model for genetically non-branching plants.

Keywords: Agronomic potential, morphological design, pruning, safflower, single-stem and single-head

Aspir (*Carthamus tinctorius* L.) Bitkisinin Budanmasi ile Oluşturulan Tek Sap ve Tek Tabla Şeklindeki Morfolojik Tasarımın Büyüme ve Gelişme Özellikleri ile Tarimsal Potansiyeli Üzerine Etkisi

Öz: Bu araştırma, tek bir ana sap üzerinde tek bir ana tabla kalacak şekilde yan dalları budanarak dizayn edilen aspir (Carthamus tinctorius L.) bitkisinin farklı ekim sıklığı koşullarında büyüme ve gelişme özellikleri ile tarımsal potansiyelinin belirlenmesi amacıyla yürütülmüştür. Bölünmüş parseller deneme desenine göre 3 tekerrürlü olarak kurulan çalışmada, kontrol (budama yok) ile birlikte 3 budama zamanı (tomurcuklanma başlangıcı, tomurcuklanma sonu ve çiçeklenme başlangıcı) ve 3 sıra arası mesafe (15 x 10, 30 x 10 ve 45 x 10 cm) uygulanmıştır. Budama ile birlikte klorofil içeriği, bitki boyu, tabla çapı, tohum sayısı ve 1000 tane ağırlığı olumlu yönde, tohum ağırlığı, hasat indeksi, yağ oranı, tohum ve yağ verimi olumsuz yönde etkilenmiştir. Sıra arası mesafe genişledikçe klorofil içeriği, bitki boyu, dal sayısı, tabla çapı, tabla sayısı, tohum sayısı, tohum ağırlığı ve 1000 tane ağırlığı artarken, hasat indeksi, tohum ve yağ verimi azalmış, yağ oranı önemli düzeyde etkilenmemiştir. Yağ asitleri kompozisyonu üzerine hem budama zamanının hem de ekim sıklığının önemli bir etkisi olmamıştır. Tek sap/tek tabla bırakılan bitkilerin tablada tohum sayıları ve 1000 tane ağırlıkları fazla da olsa, dallanan bitkiler kadar çok tabla sayısına sahip olmadıklarından tohum ve yağ verimleri düşük kalmıştır. Budama yapılarak tek sap/tek tabla bırakılan bitkilerden elde edilen araştırma bulgularının, genetik dallanmayan bitkiler için rol model olabilecek veriler sunması bakımından oldukça önemli olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Tarımsal potansiyel, morfolojik tasarım, budama, aspir, tek sap ve tek tabla

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1. Introduction

Safflower (*Carthamus tinctorius* L., 2n = 2x = 24) is a valuable annual and herbaceous cultivar from the *Asteraceae/Compositae* family (Knowles, 1980). The seeds of the safflower plant, which are rich in fatty acids, are considered a source of omega vegetable oil, and the flowers, which are rich in color pigments such as carthamidin and carthamin, are used as a source of dye stuffs (Weiss, 2000). Safflower seeds contain between 13-46% crude oil (Johnson et al., 1999), and cultivars that are rich in linoleic acid (omega-6) and oleic acid (omega-9) are traditionally cultivated. Safflower oil is used as both cooking oil and industrial oil, especially for biodiesel production (Baydar and Erbaş, 2007). In recent years, safflower oil has also been used as a healthy weight-loss diet oil because it contains more conjugated linoleic acid (CLA) than other vegetable oils (Ma et al., 1999).

The worldwide vegetable oil crisis and price hikes have increased the importance of safflower oil sources, which may be used as an alternative to oil plants such as palm, soybean, rapeseed, sunflower, and peanut. Safflower, which completes its biological growth and development cycles within 4–5 months, is gradually increasing its importance as an alternative plant that can be utilized, especially in agricultural areas where irrigation is not available in dry farming conditions (Baydar and Erbaş, 2014). The oil percentage of registered commercial safflower varieties in Turkey varies between 24-41%, and varieties that are rich in linoleic and oleic acid are cultivated (Arslan et al., 2019).

The three most important selection criteria determining the seed yield in safflower are the number of heads per plant, the number of seeds per head and unit seed weight (Ashri et al., 1974; Knowles, 1982; Golkar et al., 2011; Shinwari et al., 2014). High-yielding genotypes can be developed by selection, especially considering the number of heads per plant and the number of seeds per head (Erbaş, 2012). Both wild and cultivated varieties of safflower are branched, and the degree of branching is determined by both genotype and environment (Smith, 1996). Among safflower plants, unbranched, single-stemmed and single-headed plants are rarely seen (Deshpande, 1940; Claassen, 1952; Sheelavanter et al., 1974; Singh and Nimbkar, 2016), this idiotype is inherited as monogenic recessive (Deokar et al., 1978). Deshpande (1940), stated that plants forming a single terminal head on a single main stem carry a sufficient number of flowers with a normal appearance but produce very few seeds (1-20) due to sterility, whereas the number of seeds in normal branched and multi-headed plants is very high (200-2000).

While old varieties of sunflower (*Helianthus annuus* L.), which is in the same family as safflower (*Compositeae*) and is one of the most important vegetable oil sources in the world, branch and form multiple heads, today's modern hybrid sunflower varieties form a single stem and a single head as a product of genetic and breeding studies (Tang et al., 2006). In order for the sunflower varieties forming a single stem/single head to compete with the varieties forming many branches/multi-heads, the plant height was shortened, the diameter of the main head was enlarged, the number of seeds in the head and the seed size were increased, and the number of plants per unit area was increased (Fick et al., 1985; Skoric et al., 2007). Earliness, homogeneous flowering and maturation were achieved by the morphological design of the sunflower with genetic interventions, thus increasing the yield potential, oil percentage and market value (Heiser, 1955; Vear, 2016). However, all of the currently cultivated safflower cultivars branch and form many capitulums in primary, secondary and tertiary branches. The heterogeneous flowering interval, which starts with the main stem head and continues with the secondary and tertiary heads, respectively, from top to bottom and from the outside to the inside (Baydar and Turgut, 1999), delays the maturation period, reduces the generative efficiency (harvest index) and makes harvest mechanization difficult (Heiser, 1955; Singh and Nimbkar, 2016). Moreover, plants that branch excessively and produce more secondary and tertiary capitula prevent dense planting and tend to lodge due to excessive mass weight (Weiss, 2000).

Safflower is a very suitable plant for developing phenotypic designs or idiotypes with its very rich gene resources (Singh and Nimbkar, 2016). It has not been clarified yet what the ideal idiotype should be in order to obtain high quality safflower with a high yield. However, when a single main stem that develops upright and has a solid structure and carries a single large main head, it may be possible to eliminate the aforementioned problems to a large extent. The two main ways to develop a single-stemmed and single-headed plant in safflower are: (1) to obtain genetically unbranched mutant plants or (2) to leave a single main stem by physically pruning the plant (Baydar et al., 2022). Singh and Nimbkar (2016), reported that there is a wide variation in the number of seeds per head in unbranched mutant safflower plants, with some having no or very few seeds and some with 50–60 seeds. In the safflower genetics and breeding studies carried out at Isparta University of Applied Sciences, Faculty of Agriculture, Department of Field Crops, it was found that 60 of a total of 2800 plants (2.15%) were single-stemmed and single-headed spontaneous mutants in the trial field where the branching and multi-headed Olas variety was grown. It has been reported that they show sterility to a large extent due to pollination, fertilization and germination problems; however, there are also those with high fertility among them (Baydar et al., 2022).

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Another way to develop safflower plants with a single stem and a single head is to physically remove the side branches by pruning (removing all the buds from the nodes on the main stem or removing the shoots by pruning) and design them with a single main stem consisting of only the main head. For example, in castor oil (*Ricinus communis* L.), lateral buds are plucked and shoots are pruned to provide dwarfism and earliness and to increase yield and quality (Patel et al., 1976). To date, only one study has been found on pruning in safflower. Karve et al. (1976), by pruning all the side branches of the safflower plant except the main stem, determined that the main plate was larger, the number of seeds was higher and the unit seed weight was higher.

The aim of this study was to determine the growth and development characteristics and agricultural potential of safflower plants, which were grown in three different densities and designed with a single main stem and a single main head by pruning the side branches at three different times, in order to develop modern safflower cultivars with a single stem and a single head similar to the morphological design of sunflowers.

2. Material and method

This research was carried out at Isparta University of Applied Sciences, Faculty of Agriculture, Department of Field Crops' Experimental Field in 2021. The safflower variety "Olas" (thorny, yellow-flowered, white-seeded and rich in oleic acid) developed by Trakya Agricultural Research Institute was used as genetic material. The soil structure of the experimental area was clay-loam, the amount of lime was 7.2%, the amount of salt was determined as 0.4 mmhos/cm, usable phosphorus was 3.9 kg/da and potassium was 0.119 kg/da. In addition, it was determined that the soil in the trial area was slightly alkaline (pH 7.5) and insufficient in terms of organic matter (1.1%). The climate data for the year 2021, when the field trial was established, are given in Table 1 in comparison with the data for the long years (1929–2020). It is seen that the experimental area has properties suitable for safflower cultivation in terms of both its physical and chemical structure and climatic characteristics.

The field experiment was set up as a split-plot design in a complete randomized block design with 3 replications. Each main plot of the experiment was formed from 12 rows with a length of 5 m and each subplot was formed from 3 rows. Three different sowing densities (45 x 10 cm, 30 x 10 cm and 15 x 10 cm) were placed on the main plots and 3 different pruning times (BB: the beginning of the budding stage, EB: the end of the budding stage, and BF: the beginning of the flowering stage) together with unpruned plants (C: Control) were applied on the sub plots. Thus, a total of 12 parcels, 3 main and 4 sub-parcels, took place in each replication. On March 29, 2021, seeds were planted at a depth of 3-5 cm in rows opened with a marker at 15, 30 and 45 cm intervals, and thinning was done at 10 cm intervals on each row after emergence. Thus, plants were grown in three different densities: 45 x 10 cm (22.2 plants/m^2), 30 x 10 cm (33.3 plants/m^2) and 15 x 10 cm (66.6 plants/m^2). During sowing, 10 kg/da of DAP (18% N and 46% P_2O_5) fertilizer and 20 kg/da of AS (21% N) fertilizer were applied to the experimental plots during the stemming period; all of the phosphorus and half of the nitrogen were added with planting and the other half of the nitrogen was added during the stemming period (Erbaş, 2012). At the beginning of budding, at the end of budding and at the beginning of flowering, the lateral branches were pruned from the leaf axils with the help of pruning shears, leaving only the main head on the main stem (Figure 1). After pruning, the plants were kept under constant observation, and the shoots from the leaf axils were cut off and discarded. One of the sub-plots was left as a control and no pruning was applied. The dry farming cultivation techniques recommended for safflower were applied from emergence to harvest.

Table 1. Isparta province's monthly average climatic data for the trial year*

Months	Long years (1929 – 2020)			2021 Year		
	Rains (mm)	Temperature (°C)	Humidity (%)	Rains (mm)	Temperature (°C)	Humidity (%)
January	81.0	1.8	75.3	88.3	5.2	77.8
February	67.6	2.9	71.7	16.3	6.5	62.5
March	58.8	6.0	65.9	45.0	6.7	62.4
April	52.1	10.7	61.3	8.0	12.8	54.2
May	57.0	15.4	59.2	2.3	19.6	42.7
June	34.3	19.9	52.7	145.0	19.9	58.6
July	15.9	23.4	45.6	8.4	25.9	39.4
August	14.3	23.3	46.3	1.1	26.3	34.6
September	18.5	18.9	52.2	13.5	20.4	47.3
October	38.4	13.4	62.3	12.8	14.9	53.7
November	44.8	7.8	69.9	22.1	11.8	61.4
December	86.7	3.6	76.0	124.9	6.0	77.0
Total	**569.4**	-	-	**487.7**	-	-
Average	-	**12.3**	**61.5**	-	**14.7**	**56.0**

* Climate data from Isparta Provincial Directorate of Meteorology, Isparta Province, Central District.

Figure 1. Pruned (right rows) and unpruned (left rows) safflower plants

Chlorophyll concentration measurements were made in leaves with the Minolta SPAD-502 (Minolta Co. Ltd., Japan) during the full bloom period. Plant height (cm), the number of branches, the number of heads, diameter of the main head (mm), the number of seeds in the main head, 1000 seed weight (g), harvest index (%) [(Seed Weight/Plant Weight) x 100] were determined in 10 randomly selected plants in the experimental plots that were not affected by the margin effect, and seed yield (kg/da) was determined in the remaining all plants in the plot harvested after the border effect was removed (Baydar and Erbaş, 2016). After drying for 48 hours in an oven set at 70 °C, the seed samples representing each trial plot were read in a Nuclear Magnetic Resonance (NMR) device (Bruker: mq one Total Fat Analyzer), and the oil percentage (%) was determined. After grinding the safflower seeds used in NMR measurement, cold extraction was performed with n-hexane and the crude oils obtained were converted into fatty acid methyl esters (FAME), and the percentages of fatty acids (palmitic C16:0, stearic C18:0, oleic C18:1, linoleic C18:2, and linolenic C18:3) that make up safflower oil were determined by injecting them into the column (Teknokroma TR-CN100) of the Gas Chromatography device (Shimadzu GC/FID-2025) (Baydar and Ebaş, 2016). The collected data were analyzed for variance using the TOTEM-STAT statistical program based on the split plot design in a completed randomized block, and the differences between the averages were classified into significance groups using the Duncan test (Açıkgöz et al., 2004).

3. Results and Discussion

Table 2 shows the results of planting in different densities and pruning of the safflower plant in terms of the effects of morphological design in the form of single stem and single head plants on growth and development characteristics and Duncan's important groups. Plants that were not pruned (control) flowered 86 days after emergence, plants pruned at the beginning of budding flowered 81 days after emergence, plants pruned at the end of budding flowered 83 days after emergence and plants pruned just before the flowering period begins flowered 85 days after emergence. According to these results, the plants that are pruned to leave a single stem/single head bloomed earlier than the plants that are not pruned, and the transition to flowering is delayed as the pruning time is delayed. During the full flowering period, SPAD readings were made on the leaves and the total chlorophyll amounts were measured. In terms of chlorophyll content, statistically significant differences were found among sowing densities at the level of 5% ($P<0.05$) among pruning times and between sowing density x pruning time interaction at the level of 1% ($P<0.01$). While the average SPAD value was determined as 72.3 in unpruned plants, this value was measured as 86.9 at the first pruning time and 74.7 at the third pruning time (Table 2). According to these results, as the pruning time was delayed, the average SPAD value of the leaves decreased. The removal of the side branches, which reduced the light radiation by creating a shadow effect in the plant habitus, increased the chlorophyll density in the leaves exposed to more light on the main stem.

The effects of sowing density, pruning time and the interaction of sowing density x pruning time on plant height were found to be statistically significant ($p<0.01$). The average plant height values of pruned plants measured in the BB, EB and BF times (55.3, 60.2 and 57.7 cm, respectively) were higher than the average plant height value measured in the unpruned control (55.1 cm) plants. On the other hand, plant height values were measured as 52.5, 60.4 and 58.4 cm at 15, 30 and 45 cm row spacing, respectively. The plants grown with 30 cm and 45 cm row spacing gave higher average plant heights than plants grown with 15 cm row spacing (Table 2). In studies on the effect of planting density on plant height in safflower, it was generally seen that plant height increased in crowded densities compared to uncrowded densities (Omidi and Sharifmogadasi, 2010; Zarei et al., 2011; Hamza, 2015; Köse and Bilir, 2017; Sampaio et al., 2017; Çalışkan and Yüksel, 2022), while in some studies,

Table 2. Averages obtained for characteristics measured in the safflower at different planting distances and pruning times and Duncan importance groups

Characteristics	Pruning time	Row spacing (cm)			Average
		15	30	45	
Chlorophyll content (SPAD)	Beginning of Budding (BB)	83.0 A b*	86.0 A b	91.7 A a	**86.9 a**
	End of Budding (EB)	74.0 B b	82.0 B a	80.3 B a	**78.8 b**
	Beginning of Flowering (BF)	76.0 B a	72.0 D b	76.0 C a	**74.7 c**
	Control (C)	70.7 C b	76.0 C a	70.3 D b	**72.3 c**
	Average	**75.9 B**	**79.0 AB**	**79.6 A**	
Plant height (cm)	Beginning of Budding (BB)	58.6 A a	54.5 B b	52.8 B b	**55.3 b**
	End of Budding (EB)	58.5 A a	62.7 A a	59.4 A a	**60.2 a**
	Beginning of Flowering (BF)	49.1 B b	62.5 A a	61.6 A a	**57.7 ab**
	Control (C)	43.6 C b	62.0 A a	59.6 A a	**55.1 b**
	Average	**52.5 B**	**60.4 A**	**58.4 A**	
Number of branches (plant)	Beginning of Budding (BB)	1.0	1.0	1.0	**1.0 b**
	End of Budding (EB)	4.4 c	6.2 b	8.9 a	**6.4 a**
Number of heads (plant)	Beginning of Flowering (BF)	1.0	1.0	1.0	**1.0 b**
	Control (C)	5.3 c	11.0 b	13.7 a	**10.0 a**
	Average	**5.8 B**	**7.2 A**	**7.3 A**	
Main head diameter (mm)	Beginning of Budding (BB)	26.6 A b	27.8 A b	31.3 A a	**28.6 a**
	End of Budding (EB)	26.3 A b	29.1 A a	29.6 B a	**28.3 a**
	Beginning of Flowering (BF)	24.2 B b	26.3 B a	26.3 C a	**25.8 b**
	Control (C)	19.2 C b	21.1 C a	21.7 D a	**20.7 c**
	Average	**24.1 B**	**26.2 A**	**27.2 A**	
Number of seeds (head)	Beginning of Budding (BB)	43.3 A a	40.3 A a	38.7 B b	**40.7 a**
	End of Budding (EB)	46.1 A a	41.9 A b	44.0 A a	**44.0 a**
	Beginning of Flowering (BF)	35.9 B b	44.1 A a	42.7 A a	**40.9 a**
	Control (C)	18.1 C b	27.4 B a	30.7 C a	**25.4 b**
	Average	**35.8 B**	**38.4 A**	**39.1 A**	
1000 seed weight (g)	Beginning of Budding (BB)	45.9 A b	52.9 A a	55.5 A a	**51.4 a**
	End of Budding (EB)	44.9 A b	49.6 A b	57.7 A a	**50.8 a**
	Beginning of Flowering (BF)	42.6 A b	41.5 B b	52.7 A a	**45.6 a**
	Control (C)	35.5 B a	35.6 B a	38.8 B a	**36.6 b**
	Average	**42.2 B**	**44.9 B**	**51.2 A**	
Harvest index (%)	Beginning of Budding (BB)	10.7 C a	8.7 B a	11.1 B a	**10.0 b**
	End of Budding (EB)	13.1 B a	10.2 B b	11.7 B a	**11.7 b**
	Beginning of Flowering (BF)	15.1 B a	9.6 B b	12.7 B a	**12.5 b**
	Control (C)	19.3 A a	16.1 A b	16.1 A b	**17.2 a**
	Average	**14.4 A**	**11.1 B**	**12.9 AB**	
Seed yield (kg/da)	Beginning of Budding (BB)	133.7 B a	71.3 B b	42.0 B b	**82.4 b**
	End of Budding (EB)	125.7 B a	67.9 B b	54.8 B b	**82.8 b**
	Beginning of Flowering (BF)	102.4 B a	65.3 B b	55.1 B b	**74.2 b**
	Control (C)	211.7 A a	201.3 A a	159.4 A b	**190.6 a**
	Average	**143.3 A**	**101.5 B**	**77.8 B**	

*There is no statistical difference between the averages shown with the same character(s). Capital characters indicate the importance level of planting density, small characters indicate the importance level of pruning time.

similar to our findings, it has been reported that plant height decreases with an increase in plant density (Yau, 2009; Noroozi and Kazemini, 2013). The relationship between plant density and plant height is related to the competition between plants in terms of light, air, water and nutrients. Plants can get stressed under high-density growing conditions and shorten their height.

According to the analysis of variance results, both the number of branches per plant and the number of heads per plant were statistically significantly ($p<0.01$) affected by the pruning time in the branching plants left as controls. Unpruned plants formed 4.4, 6.2 and 8.9 branches, 5.3, 11.0 and 13.7 heads, respectively, at 15, 30 and 45 cm row spacings, and as the plant density

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decreased, the number of branches and the number of heads per plant increased (Table 2). The number of plants per unit area has a very decisive effect on the number of branches and indirectly on the number of heads (Weiss, 2000), as the number of plants per unit area decreases, the plants branch more and increase the number of secondary and tertiary tables, thus compensating for the possible decrease in yield (Weiss, 2000; Elfadl et al., 2009).

The effects of sowing density, pruning time and the pruning time x sowing density interaction on the main head diameter was found to be statistically significant (p<0.01). The head diameter of pruned safflower plants was higher than that of unpruned safflower plants. By delaying the time for pruning from the beginning of budding to the beginning of flowering, the average head diameter decreased from 28.6 mm to 25.8 mm. On the other hand, as the spacing between rows expanded, the average head diameter increased from 24.1 mm to 27.2 mm (Table 2). It has also been reported in many other research findings that the diameter of the main head increases as the row spacing increases (Uslu et al., 1998; Bellé et al., 2012; Al-Doori, 2013; Köse and Bilir, 2017; Jaffar and Al-Refai, 2021).

The effect of the sowing density on the number of seeds per head was statistically significant at the level of 5%, the pruning time and the interaction of pruning time x sowing density were found to be significant at the level of 1%. As the spacing between rows expanded, the number of seeds produced per head also increased (35.8, 38.4 and 39.1, respectively) (Table 2). There are many research findings that the number of seeds produced per head increases as the planting distances increase (Hoag et al., 1968; Abel, 1976; Nasr et al., 1978; Ehsanzadeh and Baghdad-Abadi, 2003; Mohamadzadeh et al., 2011; Çalışkan, 2018; Gürsoy et al., 2018; Omidi et al., 2021). In our study, the number of seeds per head in pruned plants increased almost twice as much as compared to unpruned plants (Table 2). On average, 100 flowers are formed per head of safflower plant, but only half of these flowers can form seeds. The fact that plants whose lateral branches are removed by pruning, leaving only one main head, devote all the products of photosynthetic absorption to feeding this main head, may have caused the flowers formed in the main head to form more seeds. Based on our research findings, it is possible that single-stemmed/single-headed plants, whether they were obtained by genetic intervention or physical intervention, compete with standard branching varieties by planting so densely that the number of plants per unit area increases at least 10 times compared to the standard planting density applied to branching varieties.

While the effect of sowing density and pruning time on 1000 seed weight was statistically significant (p<0.01), the interaction of pruning time x sowing density was not significant. The 1000 seed weight of the pruned plants was higher than the control. Although all three pruning times are in the same importance group, the plants pruned at the beginning of budding had a higher 1000 seed weight than the other two pruning times (Table 2). Similarly, Karve et al. (1976), reported that safflower plants with pruned lateral branches had higher seed size and unit weight. In our study, as the distance between sowing rows expanded, the number of heads per plant, the number of seeds per head and the weight of seeds per plant increased, as well as the 1000 seed weight (p<0.01). 1000 seed weight was 42.2, 44.9 and 51.2 g at 15, 30 and 45 cm row spacings, respectively (Table 2). Polat (2007) reported that the 1000 seed weight of the plants increased as the spacing between rows expanded.

While sowing density and pruning time did not have a statistically significant effect on the harvest index, the interaction of pruning time x sowing density was found to be statistically significant (p<0.01). In the safflower plant, the harvest index expresses the share allocated to the seed in the total photosynthetic dry matter production. In our study, the harvest index in control plants that were not pruned was determined to be 17.2%, while the harvest index in single-steemed/single-headed pruned plants varied between 10-12.5%. With a delay in pruning time, the harvest index increased from 10% to 12.5% (Table 2). As the distance between the rows increased, the harvest index decreased from 14.4% to 12.9% (Table 2). When the plants are grown at wider distances, the harvest index decreases due to excessive branching. In support of our research findings, Ehsanzadeh and Baghdad-Abadi (2003), found that the harvest index decreased as the planting distances increased in safflower.

While there were statistically significant differences at the level of 1% between sowing densities and pruning times in terms of seed yield, the interaction of pruning time x sowing density was not significant. While the average seed yield of the controls was 190.6 kg/da, it was 82.4, 82.8 and 74.2 kg/da, respectively, in the BB, EB and BF pruning times (p<0.01). The highest seed yield (211.7 kg/da) was obtained from control plants grown at 15 cm row spacing, while the lowest seed yield (42.0 kg/da) was obtained from plants pruned at the beginning of budding and grown at 45 cm row spacing. Although pruning times are in the same importance group, seed yield was higher on plants pruned at the beginning of budding compared to the other two pruning times. As the distance between sowing rows expanded, the seed yield decreased significantly due to the decrease in the number of plants per unit area (p<0.01); it was 143.3, 101.5 and 77.8 kg/da at 15, 30 and 45 cm row spacings, respectively (Table 2).

Although the most important yield determinants such as the number of heads per plant, the number of seeds per head and 1000 seed weight increased as the planting

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distances expanded, the seed yield decreased as the number of plants per unit area (45x10 cm = 22.2 plants/m^2, 30x10 cm = 33.3 plants/m^2 and 15x10 cm = 66.6 plants/m^2) decreased significantly. In support of our findings, there are many studies reporting that seed yield decreases as planting spacing is expanded in safflower (Hoag et al., 1968; Nasr et al., 1978; Ehsanzadeh and Baghdad-Abadi, 2003; Yau, 2009; Sharifmoghaddasi and Omidi, 2009; Mohamadzadeh et al., 2011; Zarei et al., 2011; Hamza, 2015; Caliskan and Caliskan, 2018). Although the number of seeds per head and the 1000 seed weight of pruned plants with a single stem/single head were higher, the seed yields of the pruned plants were lower because they do not branch as much as unpruned plants. It is only possible for single-stemmed/single-headed plants to compete with classically branching plants in conditions where planting is done very densely, because as the planting distances decrease, the number of branches on the branching plants decreases rapidly.

The crude oil percentages and fatty acid compositions of the single-steemed, steemed/single-headed pruned plants and the unpruned control plants are presented in Table 3.

While the effect of sowing density on oil percentage was not statistically significant, the effect of pruning time was significant ($p<0.01$). The seeds of single-steemed/single-headed pruned safflower plants contained less crude oil than the seeds of unpruned plants. In addition, as the pruning time was delayed, the crude oil percentage in the seeds increased from 25.4% to 28.3% (Table 3). Photosynthetic assimilates produced by leaves attached to the main stem are transferred to the seeds on the main head, making them bigger and heavier, whereas in single-headed pruned plants, the hull ratio increases. Due to the significant and negative relationships between hull ratio and oil percentage (Knowles, 1967, Ebert and Knowles, 1968; Urie and Zimmer, 1970; Ranga Rao et al.,1977; Urie, 1986), and between 1000 seed weight and oil percentage (Eslam et al., 2010; Erbaş, 2012; Eryiğit et al., 2015; Demir, 2021), the oil percentage decreased as the hull ratio and 1000 seed weight increased. The sowing density did not have a significant effect on the crude oil percentage. Similarly, Nasr et al. (1978), reported that the seed oil content of safflower is not affected by sowing density.

According to the results of the GC/FID analysis, approximately 10% of safflower (cv. Olas) oil is saturated fatty acids like palmitic (C16:0) and stearic (C18:0), and 90% is unsaturated fatty acids like oleic (C18:1) and linoleic (C18:2). Different pruning times and planting density had no significant effect on the fatty ascid composition (Table 3). It has been found that single-steemed/single-headed pruned plants contain lower oleic acid and higher linoleic acid than unpruned branching plants. Baydar et al. (2022), reported that single-stemmed/single-headed safflower mutants have a similar fatty acid composition to the Olas variety from which they originate, containing 6.3% palmitic acid, 1.5% stearic acid, 77.0% oleic acid and 15.2% linoleic acid. There is a significant and negative relationship between oleic and linoleic acids, since fatty acids are synthesized by elongase and desaturase enzymes under the control of FAD1//FAD2 genes, following a pathway as Palmitic →Stearic →Oleic →Linoleic →Linolenic (Baydar, 2021).

4. Conclusion

Pruning is an agricultural process used primarily in fruit and vegetable species, as well as some perennial and shrub forms of medicinal and aromatic plants, to create a balance between vegetative and productive organs, give them shape, provide light and air distribution, and, finally, to improve performance and quality by physically interfering with the plant's growth and development. The goal of this study was to develop a more homogenous, early, more resistant to lodging, and more suited mechanization in crowded planting situations by designing a big single head on a strong main stem in the safflower plant.

Even though the number of seeds per head and 1000 seed weight of single-steemed/single-headed plants were higher, the seed yield and harvest indexes remained low as they did not have as many heads as the branched plants. It has been predicted that the plants with a single stemmed/single headed can compete with classically branching plants, but only in conditions where planting is done very densely. However, even at the highest plant density of 15 x 10 cm, an average of 1.6 times lower yield was obtained compared to unpruned branching plants. In addition, the seeds of single-steemed/single-headed

Table 3. Crude oil content and fatty acid composition (%) at different pruning times and different planting densities

Applications	Oil Percentage (%)	Palmitic (C16:0)	Stearic (C:180)	Oleic (C18:1)	Linoleic (C18:2)
Pruning 1 (BB)	25.4 d*	5.46	1.72	75.78	17.16
Pruning 2 (EB)	26.9 c	6.22	2.71	74.58	16.49
Pruning 3 (BF)	28.3 b	6.00	1.72	74.37	17.92
Density 1 (15 cm)	27.5 c	6.12	1.77	73.50	18.70
Density 2 (30 cm)	27.4 c	6.79	1.73	75.48	16.00
Density 3 (45 cm)	27.8 c	6.02	1.71	74.60	17.67
Control (C)	29.7 a	5.56	1.86	77.71	14.86

*There is no statistical difference between the averages shown with the same character(s).

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safflower plants contained an average of 2.8% less oil than the seeds of unpruned (control) plants, lower oleic acid and higher linoleic acid compared to unpruned branching plants.

It is reported that the plants forming a single head should produce 400-500 seeds in the main head in order to compete with the multi-headed classic safflower plants. However, the average number of seeds in the main head is 35-45 in plants where we left a single main stem by pruning. Our research findings have shown that single-stemmed/single-headed safflower plants that will be grown in dense planting conditions where the number of plants per unit area will be at least 10 times higher compared to the standard planting density, will be able to compete with standard branching varieties. But pruning plants and forming single-stemmed/single-headed plants in large areas where commercial safflower cultivation is carried out is not economical and practical. As a result, substantial studies are required to choose productive types with high fertility among the mutant plants that occur naturally in safflower populations and produce one giant head on a strong short main stem, as in oil sunflower varieties, and cultivate them under dense growing conditions. The research findings we obtained from the single-steemed/single-headed pruned safflower plants were found to be very important in terms of providing data that can be a role model for the genetically unbranched plants.

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Author Contributions

The authors contributed equally to the article.

Conflict of Interest

As the authors of this study, we declare that we do not have any conflict of interest statement.

Ethics Committee Approval

As the authors of this study, we declare that we do not have any ethics committee approval.

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