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Research Article

Effect of pollen sources on fruit set and quality of edible fig (*Ficus carica* L.) cv. 'Bursa Siyahı'

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Abstract

The caprification practice has been used widely in fig cultivation because it affects the yield and quality of fig fruits, a phenomenon known as the 'xenia effect'. The present study was conducted to investigate the effects of pollen sources on fruit sets and fruit quality in the 'Bursa Siyahı' fig cultivar in 2017 and 2018. The eleven male genotypes and five cultivars were used as pollen source. The findings obtained in the present study showed that pollen sources significantly affected fruit set, early fruiting rate, fruit size, ostiole width, skin and flesh thickness, titratable acidity (TA), pH, and soluble solids content (SSC). The fruit set ratio varied from 32.02% ('16 03 06') to 76.66% ('16 08 07'), and fruit weight varied from 77.29 g ('16 03 06') to 106.88 g ('16 00 01') based on pollen sources. The ostiole diameter ranged from 3.84 mm ('16 ZF 08') to 7.67 mm ('77 00 01'). The skin thickness ranged from 3.01 mm ('Havran') to 5.35 mm ('16 00 01'). The principal component analysis was performed to distinguish the pollen sources for the 'Bursa Siyahı' cultivar. The analysis proposed that the most important factors affecting the fig quality can be reduced to five components. Fruit weight (0.958), skin thickness (0.810), flesh l* value (0.821), pH (-0.872), and SSC (0.836) value could be regarded as the characteristic indicators for PC1, PC2, PC3, PC4, and PC5, respectively. The results showed that '16 09 10', '16 05 03', '16 08 07', and '16 08 12' pollen sources are adequate pollinators for the edible 'Bursa Siyahı' fig.

Keywords: caprifig; caprification; *Ficus carica*; fruit quality; pollen source; pollination

Introduction

Fig trees are among the most common tree species in the Mediterranean region. Turkey is a leading country in fig production and export, with many fig cultivars well adapted to local agro-ecological conditions (Çakan, 2020; FAOSTAT, 2020). Turkey's table fig exportation is carried out with the 'Bursa Siyahı' cultivar. In recent years, to increase its export potential, the number of orchards with the 'Bursa Siyahı' cultivar has been increasing (Çalışkan and Polat, 2007). However, since the cultivar needs pollination for the fruit set,

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fluctuations in fruit yield can be seen, mainly due to problems caused by pollination (caprification) (Çalışkan, 2012).

Based on cropping/pollination features, 'Smyrna' and 'San Pedro' figs require pollination to produce a commercial crop (Condit, 1947; Aksoy *et al.*, 2003; Anjam *et al.*, 2017). The other type, 'caprifig' (male fig), provides the source of pollen for commercial plantings of the main crop of edible figs. The pollen in caprifig is carried by a unique wasp (*Blastophaga psenes* L.) (Kjellberg *et al.*, 1988; Weiblen, 2004). The process of hanging the caprifig fruits on the female trees and enabling the wasp to reach the female fruits is called 'caprification.' The caprification process must be repeated two or three times to obtain an economic yield because the syconia of female fig trees gradually become receptive. Therefore, it is essential to determine two or three caprifig cultivars to extend the caprification period (Zare, 2008; Pourghayoumi *et al.*, 2012). Caprifig trees having good quality and quantity of pollen are essential for good caprification (Küden and Tanriver, 1998; Çalışkan *et al.*, 2017). Besides determining the quality and quantity characteristics of the pollen sources (caprifig types) in vitro conditions, it is also necessary to test them in vivo pollination (Ilgın *et al.*, 2007; Çalışkan *et al.*, 2017; Essid *et al.*, 2017).

Pollen sources can affect the size and shape ('xenoplasms' effect), color ('xenochromes' effect), and chemicals ('xenochems effect') of the fruits, and it is termed 'xenia' (Focke, 1881). It was reported that different pollen sources increase fruit set, fruit size, and quality for mandarin (Wallace and Lee, 1999; Wallace *et al.*, 2004), blueberry (Taber and Olmstead, 2016; Doi *et al.*, 2021), pistachio and chestnut (Rahemi and Abdollahi, 2004; Zhang *et al.*, 2016). Similarly, the pollen parent can affect the seed size of the date (Mohammadi *et al.*, 2017), almond (Kodad and Socias i Company, 2008), and hazelnut (Fattahi *et al.*, 2014). Also, several studies have been conducted in some countries on the effects of different pollen sources on the fruit set, ripening, and fruit quality of the edible fig cultivars, which are widely used in the region. In Tunisia (Gaaliche *et al.*, 2011a, b; Trad *et al.*, 2013), pollen sources affected the fruit quality of edible figs. In Iran, fruit weight, ostiole opening, and harvest time of fruits were affected by pollen (Rahemi and Jafari, 2008; Zare, 2008), while some studies were not affected (Pourghayoumi *et al.*, 2012).

Some pollen sources' viability and germination percentages in Turkey have been reported (Zeybekoglu *et al.*, 1999; Ilgin *et al.*, 2007; Çalışkan *et al.*, 2017); however, their caprification potential has been limited, and producers use the pollen source randomly in the caprification process. The effects of pollen sources on fruit set and fruit quality characteristics of the 'Sarılop' cultivar grown in the Aegean region of Turkey was determined (Zeybekoglu *et al.*, 1999). However, there has been no published report on the effects of pollen on the 'Bursa Siyahı' cultivar, one of the high-quality fresh fig products preferred in the world market and whose export potential is increasing. The present study aimed to investigate the impacts of pollen sources on fruit set and quality and determine the best pollen source for caprification of the female cultivar 'Bursa Siyahı'.

Materials and Methods

Plant materials and experimental design

The experiment was carried out in the commercial fig orchard west of Bursa city in 2017 and 2018. The area is characterized by a maximum temperature of 43.8 °C, a minimum of -19.2 °C, and an average annual rainfall of 700 mm. The experimental orchard has typical sandy soils and a pH of 7.1- 7.5. Agricultural practices, including pruning, irrigation, and fertilization, were done according to standard procedures in the area.

For the caprification experiment, the 'Bursa Siyahı' cultivar, planted at 10x10 m intervals at 20 years old, was used as female fig. Five caprifig cultivars ('Mor Demirtaş', 'Havran', 'Çakın1', 'Karabulut', 'Kaba İlek') used in the Aegean region of Turkey that the Fig Research Institute in Aydın provided, and eleven caprifig genotypes ('16 00 01', '16 05 12', '16 03 06', '16 03 08', '16 05 03, 16 09 10', '16 09 11', '16 08 07', '16 08 12', '16 ZF 08', '77 00 01') selected from Bursa region were used as a pollen source for caprification. The caprifig fruits were harvested when *Blastophaga psenes* wasps emerged from the profichi fruit and the pollen matured. It was stored at 4 °C until the caprification experiment.

Pollination treatments

Ten days before the caprification, uniform 'Bursa Siyahı' branches (about 50 cm long) with female flowers (sixteen pollen sources x three replication x four branches) were selected and covered with isolation tulle. One caprifig fruit of each genotype or cultivar was placed in an isolation tulle, and caprification was repeated twice at seven days. The caprification was carried out in the early morning hours on June 05, 12 in 2017, and July 07 and 14 in 2018. The isolated tulle was removed from each branch about three weeks after the end of the caprification period.

Fruit characteristics

Fruit numbers on selected branches were recorded from caprification to harvest to determine the fruit set. Among the fruits of the 'Bursa Siyahı' cultivar pollinated with different pollen sources, those harvested in the middle of August (in the first seven days) were determined as early-ripening fruits (%). In terms of pomological characteristics, 15 fruits were collected randomly from each pollen source in each replication to measure fruit weight (g), fruit length (mm), fruit diameter (mm), ostiole diameter (mm), skin thickness (mm), flesh thickness (mm). Besides, soluble solids content (SSC) (°Brix determined with a digital refractometer, PR-101 ATAGO, Norfolk, VA), titratable acidity (TA) (citric acid g/100 ml determined by titrating fig juice with 0.1 M NaOH) were calculated. Fruit skin and flesh colour were measured using a colorimeter (Chroma Meter CR-400, Minolta, Japan). The air temperature was recorded during the caprification and fruit ripening period using a high accuracy humidity, temperature, and dew point data logger (Extech RHT20, A flir company).

Statistical analysis

Data were analysed statistically by ANOVA of Statistical Package for the Social Sciences (SPSS) version 23.0. The mean values were compared using Duncan's multiple range test ($P < 0.05$). Principle component analyses were performed by Minitab version 17, and scatter plots of the first two factors were created.

Results

Environmental conditions

The environmental conditions at the experimental site were characterized by temperature fluctuations in 2017 and 2018 (Figure 1). Due to the higher mean air temperatures at the beginning of June 2018, the caprification was carried out at 171 and 178 DOY (days of the year: calendar days), whereas in 2017, it was at 184 and 191 DOY. The mean temperature (Tmean) was higher in the summer of 2017, between 172 and 268 DOY, and maximum temperatures (Tmax) were around 38.4 °C, 38.6 °C, 37.6 °C, 40 °C (202, 203, 252, and 262 DOY). Although maximum temperatures were seen more between July and October in 2017, the mean temperatures were close to 2018 due to the difference between the maximum and minimum temperatures this year. Harvest started on August 15 and 26 in 2018 and 2017, respectively. During the harvest period of 2018, 10.4 mm, 11.2 mm, and 17 mm of precipitation were recorded (246, 256, 257 DOY).

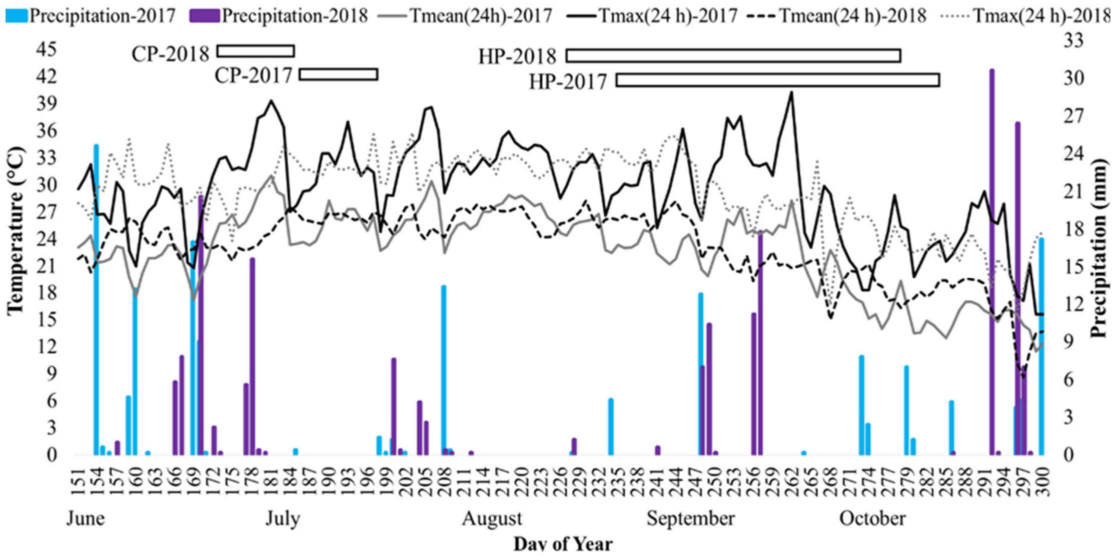

Figure 1. Temperatures (max and mean) and precipitation in caprification and fruit ripening period in 2017 and 2018

Fruit set and fruit characteristics

Analysis of variance for measured characteristics of 'Bursa Siyahı' fig pollinated with different pollen sources is shown in Table 1. The pollen source significantly affected the fruit set in both years. The fruit set varied from 35.77% ('16 03 06') to 71.03% ('16 05 03') during 2017. Pollens of '16 05 03' (71.03%), '16 09 10' (69.84%) and '16 03 08' (68.91%) increased the fruit set and followed by 'Mor Demirtaş' (61.94%) and '16 08 07' (61.58%). In 2018, the fruit set ranged from 32.02% ('16 03 06') to 76.66% ('16 08 07'). '16 08 07' (76.66%), 'Mor Demirtaş' (71.30%), 'Karabulut' (70.47%), 'Kaba İlek' (68.62%) pollen sources increased the fruit set and followed by '16 05 03' (67.48%) and '16 09 10' (66.75%). The lowest fruit set was obtained when '16 03 06' and '16 ZF 08' were used as a pollen source for both years. The year was significant for the fruit set and was higher in 2018 than in 2017.

Table 1. Analysis of variance for measured characteristics of 'Bursa Siyahı' fig pollinated with different pollen sources

Source of variation	df	Mean square					
		Fruit Set (%)	Early ripening Fruit (%)	Fruit weight (g)	Fruit diameter (mm)	Fruit lenght (mm)	Ostiole diameter (mm)
Pollen source	15	553.168*	33.737*	371.352*	30.004*	42.931*	4.142*
Year	1	374.618*	28.831*	7536.493*	651.093*	829.609*	178.787*
Pollen source x year	15	100.99*	18.405*	171.249*	24.856*	25.977*	2.650*

Source of variation	Mean square					
	df	Flesh thickness (mm)	Skin thickness (mm)	SSC (°Brix)	TA (g/100 ml)	pH
Pollen source	15	9.079*	1.253*	553.168*	33.737*	371.352*
Year	1	42.920*	3.096*	374.618*	28.831*	7536.493*
Pollen source x year	15	7.401*	2.602*	100.99*	18.405*	171.249*

* indicate a significant difference at the probability level of %5

The early ripening fruit was affected by pollen sources. In 2017, within seven days of the harvest, 15.13% of 'Bursa Siyahı' fruits ripened were pollinated with the 'Karabulut' pollen, whereas 2.72%, 3.17%, and 3.26% were pollinated with '16 ZF 08', '16 08 07', and '16 03 06' pollen sources, respectively. For 2018, the highest early ripening 'Bursa Siyahı' fruit rate was obtained when 'Karabulut' (10.54%), 'Kaba İlek' (8.93%), and '16 00 01' (8.87%) were used as pollen sources. In contrast, the lowest fruit rate was obtained by '16 ZF 08' (2.36%), and 'Çakın1' (2.98%) were used as pollen sources (Table 2).

According to the result, pollen sources considerably affected fruit weight. The highest fruit weight was obtained when used the pollens of 'Mor Demirtaş' (88.56 g), 'Karabulut' (87.75 g), '16 05 12' (86.31 g), '16 08 12' (83.53 g), and '16 00 01' (81.43 g). For 2018, the highest fruit weight was obtained when '16 08 07' (107.53 g), '16 00 01' (106.88 g), '77 00 01' (106.20 g), '16 08 12' (104.24 g), and 'Karabulut' (103.28) was used as a pollen source. Results showed that fruit length and diameter were significantly affected by pollen sources. A significant increase in the diameter of 'Bursa Siyahı' was recorded during 2018 when it was pollinated with '16 00 01' (66.80 mm), '77 00 01' (65.25 mm), and '16 08 12' (63.98 mm). In contrast, in 2017, pollen sources had no significant effect on fruit diameter. The fruit length ranged from 44.00 mm ('Kaba İlek') to 58.71 mm ('16 08 07') in 2017, whereas it was between 49.44 mm ('16 ZF 08') and 57.83 mm ('16 08 12') in 2018 (Table 2).

The ostiole diameter of fruits varied from 2.48 mm ('16 09 11') to 5.99 mm ('16 08 12') in 2017, whereas it was between 5.25 mm ('16 05 03') and 7.70 mm ('Mor Demirtaş') in 2018. Ostiole diameter was affected by pollen sources, especially 'Mor Demirtaş', and '16 08 12' increased it in both years. Also, the year was significant for ostiole diameter and was higher in 2018 than in 2017. Pollen sources significantly affected fruit's flesh and skin thickness in both years. Flesh thickness ranged from 19.05 mm ('16 03 06') to 24.07 mm ('16 05 12') in 2017, whereas it was between 18.30 mm ('16 ZF 08') and 25.24 mm ('16 00 01') in 2018. In 2018, the thickest fruit skin was obtained when '16 09 11' (5.43 mm), 'Çakın1' (5.23 mm), '77 00 01' (5.15 mm), '16 03 06' (5.10 mm), '16 03 08' (5.10 mm) and '16 05 12' (4.92 mm) used as a pollen source while in 2018, it was obtained from '16 00 01' (5.35 mm), '16 08 12' (5.25 mm) and '16 05 12' (5.12 mm) (Table 2).

Fruit's skin and flesh color

The findings showed that skin color (H° value) was significantly affected by pollen sources. Also, pollen sources significantly affected l*, a*, and b* values, but the C value was insignificant. Fruit skin a* and b* values were positive for all pollen sources, indicating red and green color, respectively. Compared with other caprifigs, the pollen of '16 09 11', '16 05 03', and '77 00 01' significantly increased the b* and H° values of the 'Bursa Siyahı' fruits. The H° angle value of 'Bursa Siyahı' fruits pollinated with all caprifigs corresponds to the color between were yellow and red-purple. The lowest values of Hue (H°, the lowest values of redness) were obtained from '16 03 08' (3.08°), '16 03 06' (4.70°), and '16 ZF 08' (7.18°) pollen sources, and when these were used as pollen sources, fruits were redder than others. The highest Chroma value (C, lowest values are most density) was obtained from '16 09 11' (12.29) and '16 05 03' (11.20), whereas clear color was found for '16 08 07' (6.75) and '16 08 12' (7.57). Also, 'Çakın1' (31.93) caprifig increased l* value, followed by 'Havran' (31.07) and '16 03 06' (30.66), '16 09 11' (30.40), '77 00 01' (30.22), and 'Kaba İlek' (30.14) (Table 3). Pollen sources affected fruit flesh color (H° value) considerably. Also, b* values were significantly affected by pollen sources; however, there was no effect on l*, a*, and C values. '16 03 06' (14.44), '16 00 01' (11.75), '77 00 01' (11.04), and 'Kaba İlek' (11.05) increased the b* value of 'Bursa Siyahı' fruits. In contrast, 'Havran' (5.67) and 'Çakın1' (5.33) decreased it. The highest values of H° were obtained from '16 05 03' (57.06°) and '16 03 06' (53.23°), whereas the lowest values were obtained from 'Çakın1' (23.47°), '16 03 08' (25.05°), and 'Havran' (31.29°), and those were redder than the others.

Table 2. Mean comparison of fruit set and fruit characteristics of 'Bursa Siyahı' pollinated with different pollen source

Pollen Source	Fruit set (%)		Early ripening fruit (%)		Fruit weight (g)		Fruit diameter (mm)		Fruit length (mm)		Ostiole diameter (mm)		Flesh thickness (mm)		Skin thickness (mm)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
'16 00 01'	53.49 def	50.38 cde	9.24 bc	8.87 ab	81.43 abc	106.88 a	54.45	66.80 a	46.76 d	54.07 cdef	3.28 cde	6.62 bcd	21.37 bcdef	25.24 a	4.71 abcd	5.35 a
'16 03 06'	35.77 g	32.02 f	3.26 g	7.98 abcd	64.73 h	77.29 g	51.39	55.72 f	47.49 bcd	52.84 ef	2.90 de	6.25 cde	19.05 f	20.36 g	5.10 abc	3.36 gh
'16 03 08'	68.91 abc	61.61 bc	10.31 b	8.08 abcd	76.61 cdef	92.62 def	55.37	62.03 cd	47.11 cd	54.69 abcdef	3.01 de	7.14 ab	23.45 ab	23.52 bcd	5.10 abc	3.09 gh
'16 05 03'	71.03 a	67.48 ab	6.87 cdef	4.09 def	79.69 bcd	102.76 abc	57.52	62.25 bcd	46.67 d	56.20 abcd	2.50 de	5.25 f	22.86 abcd	23.63 bcd	5.09 abc	4.63 cd
'16 05 12'	54.31 def	61.90 bc	8.49 bcd	5.28 bcdef	86.31 ab	90.55 ef	59.74	60.46 de	45.48 d	54.40 cdef	3.42 bcde	5.63 ef	24.07 a	22.73 de	4.92 abc	5.12 abc
'16 08 07'	61.58 abcd	76.66 a	3.17 g	4.13 def	78.95 bcd	107.53 a	54.46	61.82 cd	51.12 bc	51.56 fg	4.42 b	6.12 de	19.33 f	23.41 bcde	2.84 f	4.81 bcd
'16 08 12'	60.04 cde	61.62 bc	10.12 b	6.74 bcde	83.53 abc	104.24 ab	57.55	63.98 abc	58.71 a	57.83 a	5.99 a	6.46 bcd	21.25 bcdef	24.49 abc	4.26 bcd	5.25 ab
'16 09 10'	69.84 ab	66.75 ab	5.41 defg	6.68 bcdef	81.97 abc	100.52 abcd	55.97	62.57 bcd	45.67 d	54.19 cdef	4.19 cd	6.40 bcde	20.20 ef	23.79 abcd	3.80 de	4.82 bcd
'16 09 11'	47.52 f	49.23 de	7.77 bcde	6.93 bcde	73.41 defg	86.54 fg	56.28	57.44 f	47.77 bcd	54.52 bcdef	2.48 e	6.93 abc	21.07 cdef	21.22 fg	5.43 a	3.27 gh
'16 ZF 08'	48.41 f	45.59 e	2.72 g	2.36 f	68.52 gh	70.10 h	55.15	51.59 g	46.18 d	49.44 g	2.78 de	3.94 g	21.81 abcde	18.30 h	4.93 bcd	3.98 ef
'77 00 01'	59.48 cde	60.63 bcd	8.05 bcd	4.08 def	70.53 efgh	106.20 a	55.67	65.25 ab	46.45 d	52.66 f	2.64 de	7.67 a	22.45 abcde	24.71 ab	5.15 abc	4.69 cd
'Havran'	50.50 ef	59.75 bcd	4.31 fg	8.53 abc	77.58 cde	88.55 ef	55.72	61.45 cd	44.54 d	55.94 abcde	2.58 de	6.59 bcd	23.86 a	23.22 cde	4.19 cde	3.01 h
'Çakın1'	52.75 def	59.34 bcd	8.31 bcd	2.98 ef	72.34 defgh	89.95 ef	53.76	61.41 cd	47.69 bcd	56.75 abc	4.19 bc	6.67 bcd	19.57 efg	23.21 cde	5.23 ab	3.18 gh
'Kaba İlek'	48.43 f	68.62 ab	4.76 efg	8.93 ab	69.21 fgh	93.56 cdef	52.40	58.23 ef	44.00 d	52.92 ef	3.54 bcd	7.14 ab	20.59 def	23.63 bcd	4.67 abcd	4.51 d
'Mor Demirtaş'	61.94 abcd	71.30 ab	8.51 bcd	4.27 cdef	88.56 a	97.36 bcde	58.02	62.27 bcd	51.30 b	57.59 ab	5.70 a	7.70 a	23.00 abc	21.95 ef	4.86 abc	3.59 fg
'Karabulut'	60.33 bcd	70.47 ab	15.13 a	10.54 a	87.75 a	103.28 abc	57.46	62.98 bcd	56.76 a	53.45 def	5.53 a	6.38 bcde	21.40 bcdef	23.99 abcd	3.20 ef	4.35 de
Year	56.32^b	60.27^a	7.34^a	6.24^b	77.38^b	95.10^a	55.8^b	61.01^a	48.44^b	54.32^a	3.69^b	6.42^a	21.62^b	22.96^a	4.55^a	4.19^b

* Different letters in each column indicate significant differences at the 5% Duncan test

Table 3. Mean comparison of skin and flesh color of 'Bursa Siyahı' pollinated with different pollen source

Pollen Source	Skin Colour					Flesh Colour				
	l^*	a^*	b^*	C	H°	l^*	a^*	b^*	C	H°
'16 00 01'	27.25^{abcd}	7.81^{bcd}	5.23^{abcde}	9.63	32.65^{ab}	37.56	11.44	11.75^{ab}	16.46	46.14^{abc}
'16 03 06'	30.66^{ab}	11.05^{a}	0.93^{f}	11.12	4.70^{c}	33.47	10.73	14.44^{a}	18.04	53.23^{ab}
'16 03 08'	28.39^{abcd}	10.38^{ab}	0.56^{f}	10.52	3.08^{c}	32.34	13.57	6.20^{def}	15.10	25.05^{e}
'16 05 03'	29.75^{abc}	7.95^{abcd}	7.83^{a}	11.20	38.33^{a}	35.49	6.60	10.10^{bcd}	12.37	57.06^{a}
'16 05 12'	24.79^{cd}	6.60^{cd}	1.93^{ef}	6.99	13.41^{bc}	36.02	11.52	9.66^{bcde}	15.23	40.12^{cd}
'16 08 07'	24.25^{d}	5.25^{d}	3.56 b^{cdef}	6.75	31.04^{ab}	34.33	10.45	9.70 b^{cde}	14.26	44.07^{bc}
'16 08 12'	23.77^{d}	6.90^{cd}	2.83^{def}	7.57	19.10^{bc}	36.29	10.63	10.30^{abcd}	14.92	43.41^{bc}
'16 09 10'	25.63^{bcd}	8.00^{abcd}	3,33^{cdef}	8.80	20.82^{bc}	36.15	9.93	10.53^{abc}	14.51	47.39^{abc}
'16 09 11'	30.40^{ab}	7.59^{bcd}	8.26^{a}	12.29	43.56^{a}	30.99	8.44	6.57^{cdef}	10.73	38.26^{cd}
'16 ZF 08'	23.39^{d}	10.72^{ab}	1.36^{f}	10.82	7.18^{c}	35.69	9.85	8.80^{bcdef}	13.29	41.57^{bcd}
'77 00 01'	30.22^{ab}	7.00^{cd}	6.90^{ab}	10.29	40.20^{a}	36.08	12.77	11.04^{ab}	16.97	40.80^{cd}
'Havran'	31.07^{a}	10.36^{ab}	2.53^{def}	10.73	13.79^{bc}	33.12	9.39	5.67^{ef}	11.02	31.29^{de}
'Çakın1'	31.93^{a}	5.20^{d}	5.60^{abcd}	7.75	43.63^{a}	31.94	12.38	5.33^{f}	13.54	23.47^{e}
'Kaba İlek'	30.14^{ab}	6.50^{cd}	6.60^{abc}	9.42	39.42^{a}	34.04	10.14	11.05^{ab}	15.07	46.63^{abc}
'Mor Demirtaş'	23.43^{d}	6.97^{cd}	2.80^{def}	7.51	22.45^{bc}	36.64	12.93	10.50^{abc}	16.70	38.95^{cd}
'Karabulut'	27.24^{abcd}	8.48^{abc}	5.30^{abcd}	10.05	32.75^{ab}	35.58	11.42	9.76^{bcde}	15.29	41.10^{cd}
F-value	3.03*	2.74*	4.50*	1.58 ns	5.41*	0.54 ns	1.36 ns	2.80*	1.24 ns	4.46 *

* and ns indicate a significant difference at the probability level of %5 and no significant difference, respectively

SSC, TA, and pH

There were significant differences between pollen sources regarding the SSC of fruits. In 2017, the highest SSC was obtained when '16 03 06' (18.26 °Brix) was used as a pollen source, followed by '16 00 01' (17.46 °Brix), whereas the lowest SSC was obtained from 'Karabulut' (12.96 °Brix) and 'Havran' (12.53 °Brix). '16 08 07' (18.23 °Brix) and '16 09 10' (18.00 °Brix) increased the SSC percentage by about 1.20-fold compared to 'Havran' (15.23 °Brix) and '16 03 08' (14.76 °Brix) pollen sources in 2018. '16 00 01' pollens increased, and 'Havran' decreased the SSC value in both years compared to other pollen sources.

TA was significantly affected by pollen sources. TA varied from 0.15 g/100 ml ('16 ZF 08') to 0.35 g/100 ml ('Havran') in 2017 and ranged from 0.14 g/100 ml ('16 05 12') to 0.30 g/100 ml ('16 09 11') in 2018. Pollens of 'Havran' and '16 08 12' provided the highest acid fruits in both years. The least acid fruits were obtained from the pollen of '16 ZF 08' (0.15 g/100 ml) in 2017, whereas from the pollens of '16 05 12' (0.14 g/100 ml), '16 00 01' (0.18 g/100 ml), and '16 09 10' (0.18 g/100 ml) in 2018 (Table 4). pH was significantly affected by pollen sources in 2018. The highest pH was obtained when '16 00 01' (5.26) was used as a pollen source, followed by 'Çakın1' (5.21), '16 03 08' (5.08), and 'Havran' (5.06).

Table 4. Mean comparison of SSC, TA, and pH of 'Bursa Siyahı' pollinated with different pollen source

Pollen sources	SSC (°Brix)		TA (g/100 ml)		pH	
	2017	2018	2017	2018	2017	2018
'16 00 01'	17.46^{b}	17.30^{abc}	0.26^{bcd}	0.18^{cd}	4.80	5.26^{a}
'16 03 06'	18.26^{a}	16.13^{cd}	0.32^{ab}	0.23^{bc}	4.78	4.85^{cdef}
'16 03 08'	16.53^{bc}	14.76^{e}	0.25^{bcd}	0.26^{ab}	5.07	5.08^{abc}
'16 05 03'	15.33^{cde}	16.43^{bcd}	0.31^{abc}	0.22^{bc}	4.51	4.87^{bcdef}
'16 05 12'	14.23^{efgh}	17.16^{abc}	0.24^{cd}	0.14^{d}	5.00	4.96^{abcd}
'16 08 07'	15.00^{defg}	18.23^{a}	0.26^{bcd}	0.21^{bc}	4.79	4.91^{bcde}
'16 08 12'	14.66^{defg}	17.00^{abc}	0.31^{abc}	0.23^{abc}	4.49	4.59^{ef}
'16 09 10'	14.10^{efgh}	18.00^{a}	0.30^{abc}	0.18^{cd}	5.11	4.77^{cdef}
'16 09 11'	13.86^{fghı}	17.13^{abc}	0.26^{bcd}	0.30^{a}	4.84	4.84^{cdef}
'16 ZF 08'	13.76^{fghı}	17.96^{a}	0.15^{e}	0.25^{abc}	5.08	4.53^{f}
'77 00 01'	15.76^{cd}	16.26^{cd}	0.24^{cd}	0.27^{ab}	4.77	4.64^{def}
'Havran'	12.53^{ı}	15.23^{de}	0.35^{a}	0.24^{abc}	4.71	5.06^{abc}
'Çakın1'	13.56^{ghı}	17.90^{a}	0.21^{d}	0.23^{abc}	4.83	5.21^{ab}
'Kaba İlek'	15.20^{cdef}	16.36^{cd}	0.21^{d}	0.22^{bc}	5.10	4.61ef
'Mor Demirtaş'	14.03^{efgh}	17.33^{abc}	0.28^{bcd}	0.24^{abc}	4.68	4.62^{def}
'Karabulut'	12.96^{hı}	17.66^{ab}	0.22^{d}	0.22^{bc}	4.78	4.83^{cdef}
Year	14.89^{b}	16.93^{a}	0.26^{a}	0.23^{b}	4.84	4.86

* and ns indicate a significant difference at the probability level of %5 and no significant difference, respectively

Principal Component Analysis (PCA)

PCA was applied to evaluate the data set and structure for the most important variables. Analysis indicated that the first five principal components had eigenvalues greater than 1.0, and the total variance explained was 75.40%. The variations of the first five principal components were 28.70%, 14.20%, 11.00%, 11.00%, and 10.50%, respectively (Table 5). The PC1 represented the maximum variation of the data set and was positively connected with fruit weight, fruit diameter, ostiole diameter, flesh thickness, fruit length, and fruit set. Skin thickness, flesh l^*, and $H^°$ value were positively correlated with PC2. Skin l^* and $H^°$ values were correlated with PC3. Whereas in proceeding from positive to negative values of PC4, TA increased, pH decreased. SSC was positively correlated with PC5 and negatively associated with early ripening fruit. According to the weight values of indicators for PCs, fruit weight (0.958), skin thickness (0.810), skin l^* value (0.821), pH (-0.872), and SSC (0.836) value could be regarded as the characteristic indicators for PC1, PC2, PC3, PC4, and PC5, respectively (Table 5).

Table 5. Eigenvalues and cumulative variance for five factors resulted from principal component analysis

Parameter	1	2	3	4	5
Fruit weight	0.958**	0.016	0.011	0.003	0.112
Fruit diameter	0.931**	0.051	0.109	-0.188	0.030
Ostiole diameter	0.773**	-0.453	-0.121	0.095	0.233
Flesh thickness	0.766*	0.198	0.171	-0.296	-0.247
Fruit lenght	0.726*	-0.437	-0.196	0.232	0.156
Fruit set	0.657*	0.144	-0.072	0.083	-0.222
Skin thickness	0.034	0.810*	0.258	-0.134	0.084
l^* (Flesh) value	0.052	0.747*	-0.438	0.245	-0.179
H° (Flesh) value	-0.111	0.569*	-0.153	0.440	0.356
l^* (Skin) value	-0.348	-0.171	0.821*	-0.093	-0.201
H° (Skin) value	0.241	0.164	0.721*	0.149	0.036
pH	-0.058	-0.156	0.042	-0.872*	-0.027
TA	-0.237	-0.227	0.260	0.625*	-0.305
SSC	0.239	0.019	0.007	-0.025	0.836**
Early ripening fruit	0.320	-0.009	0.076	0.052	-0.614**
Eigen Value	4.341	2.129	1.650	1.649	1.578
% Of Variance	28.700	14.200	11.000	11.000	10.500
Cumulative Variance %	28.700	42.900	53.900	64.900	75.400

* Significant factor loading (values above 0.50).

The plot of the PC1 versus PC2 (Figure 2) identified a group containing 2017, which were collocated on the negative side of PC1, in general, with smaller fruit sizes and lower fruit sets. Most pollen sources located in the negative part of PC1 and the positive part of PC2 presented that fruit had a smaller size and lower fruit set but higher skin thickness and flesh l^* value. '16 05 03', '77 00 01', '16 00 01', and '16 05 12' were located top of the positive side of the PC2 because of the higher skin thickness and flesh l^* value. '16 03 06' was quite some distance away from the others and indicated the smallest fruit size and lowest fruit set.

In 2018, the fruit set, fruit weight, and fruit flesh color values of most pollen sources were higher than in 2017; they were located in the positive part of PC1 and PC2. '16 00 01', '16 09 10', '16 08 12' were located top of the PC1 and PC2 due to the increased fruit set and size. However, '16 03 08', 'Havran', 'Çakın1', and 'Mor Demirtaş' were in the negative part of PC2 due to the lower skin thickness and l^* values. '16 ZF 08', '16 03 06', and '16 09 11' pollen sources were in the negative part of PC1 because they had smaller fruits and lower fruit set values.

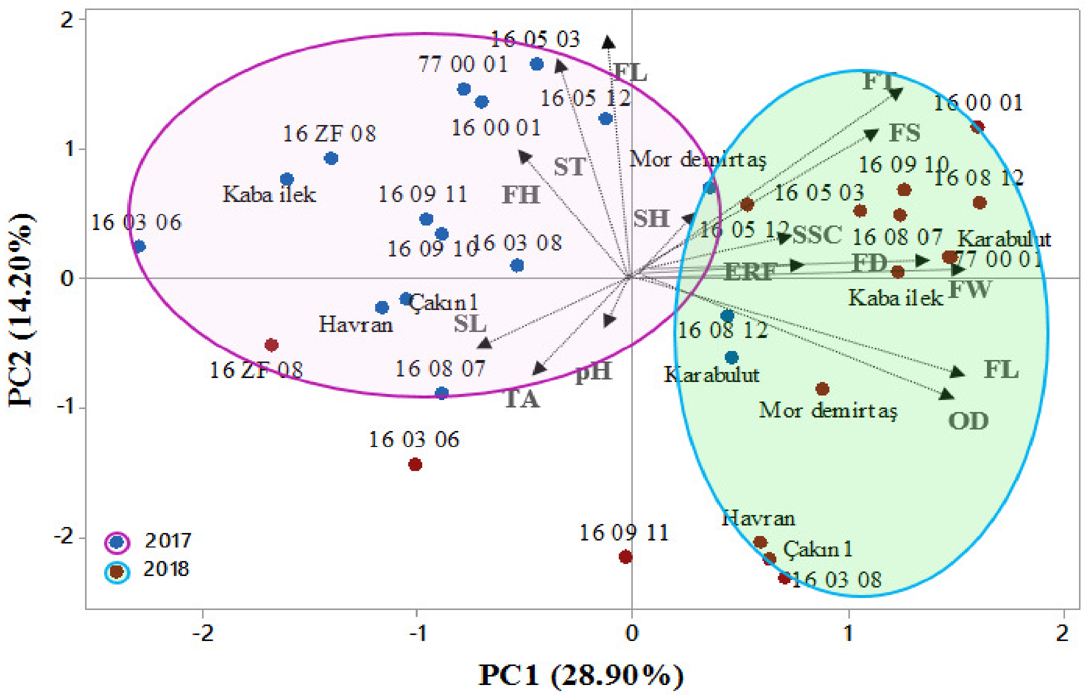

Figure 2. The scatter plot of the variables of the first two factors shows the distribution of different pollen sources used in the pollination of the 'Bursa Siyahı' cultivar in 2017 and 2018

*Flesh l^* value (Fl), Skin Hue value (SH), Flesh thickness (FT), Fruit set (FS), Early ripening Fruit (ERF), Fruit diameter (FD), Fruit weight (FW), fruit length (FL), ostiole diameter (OD), skin l^* value (SL), flesh H value (FH), skin thickness (ST)

According to the average data of 2017 and 2018, '16 05 12', '16 09 10', '77 00 01', '16 08 12', '16 00 01', and '16 05 03' pollen sources located in the positive part of PC1 and PC2 because of had a higher average fruit weight, fruit size, fruit set, skin thickness, and flesh l^* value. Moreover, '16 08 12' was quite far from them because of had a higher fruit weight and lower skin thickness and flesh l^* value. '16 03 08', 'Karabulut', 'Mor Demirtaş', and '16 08 07' pollen sources were included in the negative part of PC2 because of the lower skin thickness and flesh l^* values. Since the fruit set, size, and flesh l^* values of 'Çakın1', 'Havran', '16 09 11', and '16 03 06' were lower, they were included in the negative part of PC1 and PC2. Among them, '16 03 06' has the lowest value in terms of these features, so it was on the farthest side. The fruit set and size of the 'Bursa Siyahı' cultivar pollinated with '16 ZF 08' genotype was lower, but skin thickness and flesh l^* values were higher; therefore, it was included in the negative part of PC1 and positive part of PC2 (Figure 3).

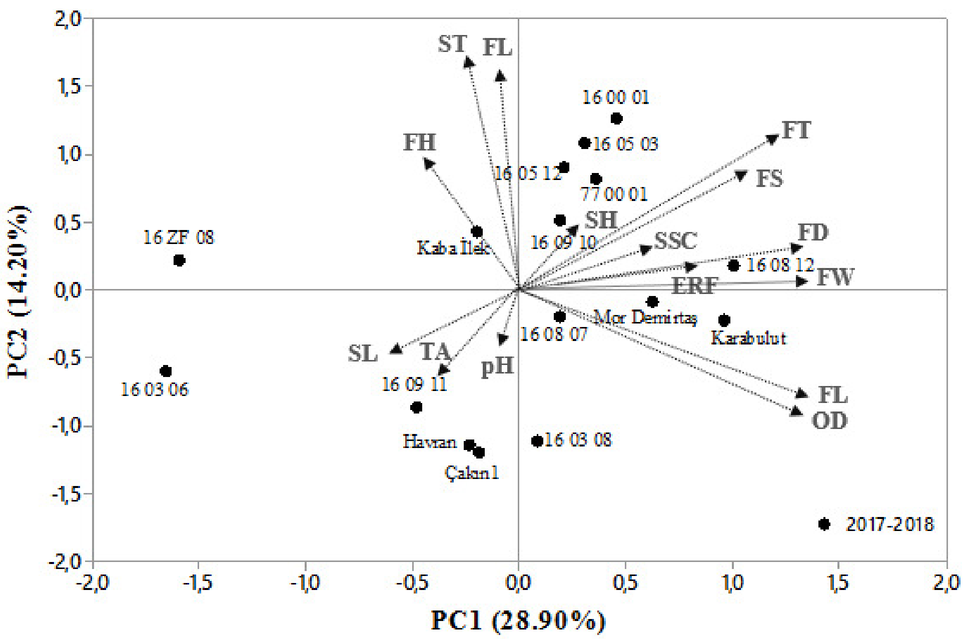

Figure 3. The scatter plot of the variables of the first two factors shows the distribution of different pollen sources used in the pollination of the 'Bursa Siyahı' cultivar average in 2017 and 2018

*Flesh l^* value (Fl), Skin Hue value (SH), Flesh thickness (FT), Fruit set (FS), Early ripening Fruit (ERF), Fruit diameter (FD), Fruit weight (FW), fruit length (FL), ostiole diameter (OD), skin l^* value (SL), flesh H value (FH), skin thickness (ST)

Discussion

Fruit set and early ripening fruit percentage

According to the present study, the fruit setting of 'Bursa Siyahı' was significantly affected by pollen sources, and it differed between years depending on ecological and environmental conditions. The highest fruit set above 60% was achieved in '16 05 03', '16 09 10', 'Mor Demirtaş', and '16 08 07' in both years. Westwood (1988) stated that the fruit set should have been at least 50% for sufficient yield in fig. When the mentioned pollen sources were used, a sufficient yield was achieved, while '16 03 06', '16 09 11', and '16 ZF 08' were used; the fruit set was below 50% in both years. Gaaliche *et al*. (2011a) reported that Smyrna-type figs' fruit set was affected by pollen sources. Zare (2008) reported that pollen sources affect the fruit set, and 'Daneh-Sefid' caprifig had fewer abscised syconia. Çalışkan *et al*. (2017) stated that the low pollen production in some caprifigs negatively affects fruit sets by causing insufficient pollination. Also, the inadequacy of the caprifig types used in the caprification process regarding pollen quality and amount of fig wasp affects the edible fig fruit set (Ilgın *et al*., 2007; Çalışkan *et al*., 2016). Marcotuli *et al*. (2020) reported important characteristics of the caprifigs (profichi crop) that can affect the fruit set and quality of edible fruits; thus, caprification with different pollen sources gives different results regarding fruit set, yield, and quality. When the 'Kaba İlek' cultivar was used as a pollen source, the fruit set was higher in 2018 and lower in 2017. This situation may arise from the interruption of the Blastophaga life cycle due to a problem in the fruit set of three crops in the 'Kaba İlek' cultivar (personal observation). The setting of all three crops is a desirable trait because these consecutive crops continue the Blastophaga life cycle, and these caprifigs should be used in caprification as a pollen source (Çalışkan *et al*., 2017). Also, the fruit set differed between years depending on the changing temperature and humidity (Figure 1). Çalışkan and Bayazit (2012) stated that female fig yield depends on sufficient and high-quality caprifigs and that caprifig quality was affected by high temperatures, so fruit set in the female fig. Sharma *et al*. (2018) found that during high temperature and dry stress conditions, a decrease in the internal content of IAA causes the sterilization of flowers.

Early ripening fruit percent was affected by pollen sources. In both years, the percent of early ripening fruit was higher when 'Karabulut' and '16 03 08' were used as pollinators for the 'Bursa Siyahı' cultivar and lower when '16 ZF 08' and '16 08 07' were used. Al-Khalifah (2006) reported that due to date palm pollen grain's metaxenia features, pollen grains affected fruits' quality and ripening time. Also, Jafari (2004) and Zare (2008) confirmed that the caprifig cultivar affected the early ripening of fig fruits of 'Sabz' figs. While the percent of early ripening fruit of the 'Bursa Siyahı' pollinated with '16 03 06', 'Havran' and 'Kaba İlek' pollen was low in 2017 but higher in 2018. Similarly, the percent of early ripening fruit of the 'Bursa Siyahı' pollinated with 'Çakın1' pollen was high in 2017 and low in 2018. It can be explained by the earlier ripening of the fruits on the lower parts of the marked branches, as the fruits on the shoot ripen gradually from the lower part of the shoot to the tip. Also, cultural processes, temperature, humidity, and soil properties are other factors that affect the beginning and period of ripening.

Fruit characteristics

Pollen sources affected Bursa Siyahı's fruit weight, diameter, and length in both years. Pollen of '16 00 01', '16 08 12', and 'Karabulut' produced larger and heavier fruits than other pollen sources. 'Bursa Siyahı' fruits were smaller when pollinated with '16 ZF 08' and '16 03 06'. Fruits were within the reference range determined by TPTI (2018) for 'Bursa Siyahı' fruits (fruit diameter: 55.00-65.00 mm; fruit length 45.00-55.00 mm) in pollination with all pollen sources except '16 ZF 08' and '16 03 06'. Our findings consistent with Tunisia's reports that pollen sources affected fruit weight considerably (Gaaliche *et al*., 2011a, b). Rahemi and Jafari (2008) and Pourghayoumi *et al*. (2012) confirmed that the fruit length was considerably affected by pollen sources. Pollen source affects the growth of ovarian tissues by stimulating hormone production and exerts a specific effect on fruit growth (Shafique *et al*., 2011; Pourghayoumi *et al*., 2012). Farag *et al*. (2012) noted that some pollinators increased the production of GA hormone in the fruit, increasing weight and size of the fruit. Shahsavar and Shahhosseini (2021) cited that the pollen grains of some cultivars had higher amounts of the desired hormones, triggering the production of the highest amount of these hormones in different stages of growth and development of date fruit. In the present study, the fruit weight, diameter, and length differed between years depending on the ecological factors. The findings suggest that the maximum temperatures and high humidity during the fruit ripening period in 2017 may cause the fruits to be smaller (Figure 1). Similarly, Polat and Çalışkan (2017), in the study to determine the effects of two different environments on fruit characteristics in figs in the Eastern Mediterranean region of Turkey, obtained the highest fruit weight values from an environment where the maximum temperature does not exceed 37 °C during the ripening period. Moreover, fruit numbers in branches and various cultural practices, as well as pollen sources or these combinations, might affect fruit sizes.

The findings indicated that the ostiole diameter was significantly affected by pollen sources. 'Mor Demirtaş', 'Karabulut', and '16 08 12' increased it as parallel with weight and size of the fruit in both years. The ostiole diameter was lower when 'Bursa Siyahı' was pollinated with '16 ZF 08', '16 05 03', and '16 05 12'. For '16 ZF 08' and '16 03 06' pollen sources, ostiole diameter was lower in parallel with having small fruits. Fertilized seeds producing a large amount of auxin stimulate ethylene production within the tissue (Ryugo, 1988). Therefore, many fertilized seeds may cause ostiole cracking (Crisosto *et al*., 2010). However, pollen of '16 05 03' increased the fruit set and size of the 'Bursa Siyahı' cultivar, but it did not increase ostiole opening. A large ostiole in the fig is an undesirable feature that causes pests and pathogens into the fruit easily, such as endosepsis that spreads to healthy fruits (Michailides and Morgan, 1998; Çalışkan and Polat, 2008; Crisosto *et al*., 2011). Zare (2008) stated that using 'Daneh-Sefid' as a caprifig to pollinate the Iranian cultivar increased the number and diameter of seeds and caused a rapid ostiole-tip cracking before the fruits ripened. In research conducted in Iran and Tunisia, it has been reported that the diameter of the ostiole is affected by the pollen source (Rahemi and Jafari, 2008; Gaaliche *et al*., 2011a, b). In contrast, Pourghayomi *et al*. (2012) stated that it was insignificant. The ostiole diameter also differed between years. The larger ostiole in 2018 could be attributed to larger fruit sizes and cracking of the fruit caused by rainfall during the harvest period (Figure 1).

The fruit flesh and skin thickness were affected by pollen sources. In table fig cultivation, the thin, thick, or too juicy skin reduces fruit quality (Göçmez and Seferoğlu, 2014). The skin thickness values of other fruits are below the reference range (5.20-6.00 mm) determined for the cultivar except for the skin thickness values of the 'Bursa Siyahı' fruits pollinated with 'Çakın1' and '16 09 11' pollen in 2017 and '16 08 12' and '16 00 00' pollen in 2018. In figs, the fruit's quality is also attributed to the fruit's flesh thickness (Göçmez and Seferoğlu, 2014). In both years, pollen of '77 00 01' increased the flesh thickness compared to other pollen, while 'Karabulut' pollens decreased it. Gaaliche *et al*. (2011a) cited the significant effect of pollen sources on fruit skin and flesh thickness. Also, Trad *et al*. (2013) indicated that pollen sources significantly affected flesh thickness.

Fruit's skin and flesh color

Bursa Siyahı fruit's skin color (H° value) was significantly affected by pollen sources. Also, l^* a^* and b^* values were significantly affected by pollen sources. Hue angle value is a parameter that has been widely used to predict visual color appearance (Ma *et al*., 2009). The H angle value of 'Bursa Siyahı' fruits pollinated with all caprifigs corresponds to the color between yellow and red-purple. Similarly, Solomon *et al*. (2006) reported a 'Bursa Siyahı' cultivars skin color between yellow and red-purple (20.7°), whereas Çalışkan and Polat (2012) reported cultivars hue angle (H°) indicated a color between blue and red-purple (278.98°). When 'Bursa Siyahı' was pollinated with '16 03 08', '16 03 06' and '16 ZF 08' pollens, fruit's $H^°$ values decreased, and fruits were darker red-purple. In contrast, pollinated with '16 09 11', '16 05 03', and '77 00 01', fruit's H° values increased, and fruits were lighter red-purple. These results, which showed that pollen sources had a significant effect on the skin color of fig fruit, concur with those of Bose and Mitra (1990), and Rahemi and Jafari (2008). Also, Pourghayoumi *et al*. (2012) revealed that the H° value was significantly affected by pollen sources; other parameters (l^*, a^*, b^*, C) were not affected by pollen sources. Pollen sources considerably affected fruit flesh color (H° value). Also, b^* values were significantly affected by pollen sources; however, there was no effect on l^*, a^*, and C values. The lowest values of H° were obtained from 'Çakın1' and '16 03 08', and those fruit flesh were redder than others.

SSC, TA, and pH

There were significant differences between pollen sources regarding the SSC content of fruits. '16 00 01' pollen source increased the SSC value, and 'Havran' decreased it in both years compared to other pollen sources. These findings are consistent with those of Rahemi and Jafari (2008) and Gaaliche *et al*. (2011a, b), who found that the pollen source had a significant effect on SSC. Also, Pourghami *et al*. (2012) reported that SSC was affected by pollen sources, which might be due to the differences in genetics, growth, health, vigor, and age of caprifig trees. According to TPTI (2018), the 'Bursa Siyahı' cultivar was rich in high sugar content (Brix content between 17.00 and 18.50). In the present study, 'Bursa Siyahı' were below these Brix values when pollinated '16 03 08', '16 05 03', '77 00 01', 'Havran', and 'Kaba İlek', whereas '16 00 01' were used; it was within the reference range both years. The SSC also differed between years, and it was lower in 2017. It has been assumed that the maximum temperatures and high humidity during the fruit ripening period in 2017 may cause lower SSC. The assumption of the present study is consistent with findings in citrus (Hutton *et al*., 2000; Moon *et al*., 2015), and SSC and acidity in fruits are reduced under high-temperature treatment. SSC is also affected by canopy position and cultural practices as well as climatic changes (Koch, 1988; Verreynne *et al*., 2004). Pollen of 'Havran' and '16 08 12' provided the highest acid fruits in both years. The least acid fruits were obtained at '16 ZF 08' in 2017, whereas from '16 05 12', '16 00 01', and '16 09 10' in 2018. Gaaliche *et al*.

(2011b) reported that TA was affected by pollen sources, and using 'Djieba 1' as caprifig to pollinate Tunisian cultivar increased the TA.

Conclusions

The present study was conducted to investigate the suitable pollen sources as the 'Bursa Siyahı' fig cultivar is one of Turkey's most important exported products contributing to the economy. The present study revealed that pollen sources affect the fruit characteristics of 'Bursa Siyahı' (xenia effect). Pollen source significantly affected fruit set, size, early ripening fruit, ostiole diameter, SSC, TA, pH, and skin color, but flesh color was not affected considerably. Based on the caprification results, '16 05 03', '16 09 10', '16 08 07', and 'Mor Demirtaş' pollen sources reduced syconia abscission. While the percent of early ripening fruit of 'Bursa Siyahı' fruits pollinated with 'Karabulut', '16 03 08' and '16 00 01' pollen was higher, those pollinated with '16 ZF 08' and '16 08 07' were lower. '16 00 01', '16 08 12', and '16 09 10' pollen sources improved the Bursa Siyahı cultivar's physical and biochemical characteristics.

Considering the fruit set and other fruit traits, the best pollen sources were identified as '16 09 10' and '16 05 03'. Alternatively, '16 08 07' and 'Mor Demirtaş' pollen source increased the fruit set of the cultivar, and the fruit size was obtained between the average values. Also, '16 08 12' and 'Karabulut' can be recommended because it provides an average fruit set and increased fruit size of the cultivar. In terms of increasing caprification's effectiveness, selecting good-quality pollen sources and testing them in caprification studies are crucial. The current data can be important for producers to use the caprifig suitable for 'Bursa Siyahı' and reduce the loss of quality and yield resulting from low-quality random caprifig.

Authors' Contributions

Conceptualization: UE and DAK; Investigation: ÜE, DAK and RBO; Methodology: ÜE, DAK, and MBK; Formal analysis: AI; Writing-original draft: DAK; and Writing-review and editing: DAK, MBK and RBO. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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