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The Performance of Some Walnut (*Juglans regia*) Cultivars in the Conditions of Bursa, Turkey

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ABSTRACT

The present study aimed to evaluate the pomological and phenological traits, as well as yield potential and incidence of external defects of some local ('Bilecik', 'Maraş 12', 'Maraş 18', 'Şebin', 'Şen 1') and foreign ('Chandler', 'Fernette', 'Fernor', 'Howard', 'Pedro', 'Serr') walnut cultivars grown in Bursa (north-west in Turkey) conditions between 2014 and 2020. The first leafing was observed in Maraş 12, Serr, Şebin, and Maraş 18 cultivars, while Fernette and Fernor were the last leafing cultivars. The female blooming period of the cultivars was recorded to be the longest in Maraş 18 (15 days) and Şebin (16 days) and that was the shortest in Bilecik and Serr (10 days). The male blooming period was recorded as the longest in Chandler, Fernette, Bilecik, and Şebin (16-18 days) and that was the shortest in Maraş 12 and Serr (10 days). The average yield per tree of cultivars ranged between 1.87 kg (Şebin) and 14.21 kg (Pedro). Walnut blight was observed on average in 15.85%, sunburn in 10.21%, codling moth in 5.11%, anthracnose in 3.23%, and bird damage in 2.35% of the fruits. The healthy nut percentage ranged from 40.06% (Şen 1) to 76.50% (Chandler). The nut weight of cultivars was between 9.91 g (Maraş 12) and 16.27 g (Şen 1). Kernel percentage varied from 36.31% (Şen 1) to 53.56% (Maraş 12). The principal component analysis conducted to distinguish the cultivars suggests that the most important factors could be reduced to five components. The results showed that Maraş 12, Chandler, Fernor, and Howard were suitable cultivars for commercial cultivation in Bursa conditions.

Keywords: Phenology, Yield, Fruit characteristics, External defects, Leafing, Blooming

1. Introduction

Anatolia is the center of origin and one of the oldest cultivation areas of walnut. *Juglans regia* is the most commonly grown walnut species for fruit production in Turkey (Akça 2005; Şen 2011; Akça 2012; Vahdati 2014). Turkey is the fourth walnut producer globally after China, United States of America (USA), and Iran, with 286 thousand tons of production (FA0STAT 2020). However, Turkey's current production quantity does not meet its consumption. Walnuts are imported from other countries, especially USA, Chile, and China. New walnut orchards have been recently established with standard high-yielding foreign and selected cultivars for increased production (Ercisli et al. 2012; Ertürk et al. 2014). Since there is a lack of knowledge about those cultivars' adaptation to different ecological regions (Kaşka & Sütyemez, 2001; Aktuğ Tahtacı et al. 2014; Erturk et al. 2014), the orchards established without adaptation trials have failed. It has been reported that low yield is obtained in the case of selecting walnut cultivars without considering the ecological factors (Pezikoğlu et al. 2012; Bilgin et al. 2018). Also, Cosmulescu et al. (2010) cited that ecological factors significantly affect walnut production as much as a cultivar and that the influence of the weather can be of a very local issue.

The favorable ecological conditions for walnut cultivation in Bursa, one of the important walnut cultivation areas in the Marmara region (north-west in Turkey), and the fact that walnut is prominent nutrition and economic value indicate that this region creates opportunities

for walnut cultivation in Turkey. This region, where spring frosts are sometimes seen, has a humid climate that encourages the spread of rain-related disease problems; therefore, selecting suitable cultivars is essential. There is a difference in cultivars' susceptibility to pests and diseases, which cause a significant yield loss under favorable conditions, and their susceptibility is greatly affected by environmental conditions (Woeste et al. 1992). Using late-leafing cultivars is an effective strategy to mitigate the severe damage caused by late-spring frost (Akça & Ozongun 2004; Fallah et al. 2022). In addition, late-leafing walnut cultivars are resistant to walnut blight *(Xanthomonas arboricola pv. juglandis*) (Bernard et al. 2018). Also, pollen shedding, which does not coincide with pistillate bloom, is the reason for the low yield of walnuts (Akça & Sen 1997; Cosmulescu et al. 2010). Obtaining sufficient yield from orchards depends on determining suitable cultivars that can overlap the appropriate walnut cultivars for the regions during blooming time. High yield, late leafing, tolerance to plant diseases/pests, and high nut quality are favorable traits in a good walnut cultivar (Aslantaş 2006; Bujdoso et al. 2016; Hassankhah et al. 2017; Mahmoudian et al. 2021; Sütyemez et al. 2021). The adaptation of standard foreign and local walnut cultivars has been reported in countries such as Romania (Botu et al. 2007; Botu et al. 2014), Australia (Vanhanen 2010), Serbia (Mitrovic et al. 2011), Bulgaria (Gandev & Dzhuvinov 2014; Gandev 2017), Georgia (Bobokasvili et al. 2017), Hungary (Bujdoso et al. 2020) and Iran (Mahmoodi et al. 2016*;* Hassani et al. 2020a; Toolir et al. 2021). Also, the phenological and pomological characteristics of walnut cultivars have been determined in Turkey's Southeastern Anatolia (Aktuğ Tahtacı et al. 2014), Marmara (Ertürk et al. 2014), Aegean (Bilgin et al. 2018; Yıldız & Sümer 2019), Eastern Anatolia (Karlıdağ et al. 2019), Central Black Sea (Akça et al. 2014; Akça et al. 2018), and Mediterranean regions (Sütyemez 2016; Türemiş et al. 2017; Sütyemez et al. 2021; Özcan et al. 2022). However, in Bursa, Marmara region, no long-term data consisting of all long-term yield potential, phenology, pomology, and incidence of fruit external defect observations have been published to determine the adaptation of cultivars. The present study aims to determine the performances of some local and foreign walnut cultivars in terms of yield, phenological and pomological characteristics, and incidence of fruit external defect observations based on long-term data.

2. Material and Methods

The study was carried out in in the Agricultural Application and Research Center of Bursa Uludağ University between 2014 and 2020. The orchard was established in 2008 with a planting distance of 7x7 m, and the plants were trained as a modified leader system. The experimental plantation is located at an altitude of 105 m, with geographic coordinates of 40°14' north latitude and 28°51' east longitude in Bursa. 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 soil is clay with a content of 38% $CaCO_3$ and a pH of 7.1-7.5.

Five local ('Bilecik', 'Maraş 12', 'Maraş 18', 'Şebin', and 'Şen 1') and six foreign ('Chandler', 'Fernor', 'Fernette', 'Howard', 'Pedro' and 'Serr') walnut cultivars grafted on *J. regia* L. were used in the present study. To determine the performance of the cultivars, the observations on various traits were recorded as follows:

2.1 Phenological traits

Phenological stages such as bud break, leafing and first, peak, and last male and female blooming were recorded according to UPOV (1999). The degree of dichogamy was calculated according to the formula suggested by Solar et al. (1997).

$$\text{Degree of dichogamy (\%)} = \frac{\text{1-No.of days when male and female blooming coincides}}{\text{Number of days of female blooming}} \text{ x100}$$

The time of defoliation was defined as when the tree lost over 50% of its leaves (UPOV 1999). All phenological observations were performed in comparison with Chandler cultivar.

The external defects as walnut blight (*Xanthomonas arboricola* pv. *juglandis*), anthracnose (*Gnomonia leptostyla*), codling moth (*Cydia pomonella*), sunburn, and bird damage were examined after harvest in four replicates of 50 fruits each. The presence or absence of damage was recorded and calculated as a percentage (Aleta et al. 2001; Hassan et al. 2017; Khasanov et al. 2019).

2.2. Pomological traits

The yield per tree (kg) was recorded in each cultivar's maturity time, and the average and total yield per decare (kg/da) were calculated. After harvest, walnut fruits were dried in natural conditions and stored until the analysis. Fruit traits were evaluated in terms of the weight (g), length (mm), thickness (mm), width of nuts (mm), kernel weight (g), shell thickness (mm), and kernel ratio (%) on 90 nut samples. Kernel rottenness and shrinkage (%) were recorded. The kernel color was classified as amber, light amber, light, and extra light (IPGRI 1994; Khadivi et al. 2019; Akça et al. 2020).

Statistical analysis

The data were statistically analyzed by ANOVA using the Statistical Package for the Social Sciences (SPSS) version 23.0. The mean values were compared with Duncan's multiple range test ($p<0.05$). Minitab (Software Version 17, Minitab) was employed to perform principal component analysis (PCA) and to create scatter plots of the first two factors.

3. Results and Discussion

Five years (2014-2018) of phenological observations are presented in Table 1. All cultivars' bud break, leafing, male and female blooming, except Fernor and Fernette, occurred before Chandler cultivar. Leafing dates of Maraş 18, Şebin, Serr, and Maraş 12 cultivars occurred 13, 16, 20, and 21 days before Chandler cultivar, respectively, while Fernette and Fernor leafed out 8 and 9 days after Chandler. The evaluated cultivars, Fernor and Fernette, were relatively late-leafing and blooming. In contrast, Serr, Maraş 12, Şebin, and Maraş 18 were early leafing compared to Chandler. Similarly, Aktuğ Tahtacı et al. (2014) reported that Maraş 12, Maraş 18, and Serr cultivars leafing was about 17 days earlier than Chandler. Gandev (2017) reported that the first beginning of bud break, male and female blooming occurred in Serr, while the latest was the Fernor cultivar. Also, in Tokat, Turkey, Fernette and Fernor leafing were 8 and 9 days later, whereas Maraş 18 and Maraş 12 cultivars were 20 and 22 days before Chandler (Akça et al. 2018). Among the walnut characteristics, late leafing is crucial in places with a risk of late frost in spring (Akça & Ozongun 2004).

Male and female blooming occurred from early April to May (Figure 1) and lasted 10 to 16 days, depending on the cultivar. Şebin, Chandler, Howard, and Fernette cultivar had the longest (10-11 days) pollen shedding period. Hassani et al. (2020a) stated that Chaldoran's leafing date was early to moderate, but it had a long male blooming period (15 days). The longest peak female blooming was seen in Bilecik, Pedro, Chandler, Fernette, and Howard cultivars, with 10 days. Therefore, Fernor and Fernette's peak of blooming (receptivity) of males and females occurred after Chandler. Besides, leaf defoliation of cultivars was observed to occur 2 to 18 days before Chandler. The results obtained in the present study were compatible when compared to results of previous studies conducted in other regions such as Argentina (Iannamico et al. 2006), Romania (Botu et al. 2007), Bulgaria (Gandev 2017), India (Bobokasvili et al. 2017), Iran (Hassani et al. 2020a) and Turkey (Sütyemez 2016; Akça et al. 2018; Yildiz & Sumer 2019; Sütyemez et al. 2019).

Botu et al. (2007) reported that Fernor, and Fernette cultivar's bud break and male blooming occurred later than Chandler. The first male blooming receptivity was observed in Serr. Akça et al. (2018) stated that the earliest and latest male and female blooming cultivars were Maraş 18, Maraş 12, and Fernor. Yildiz & Sumer (2019) found that the local walnut cultivars, except for Baikal genotype, leafed out earlier than the foreign walnut cultivars. Sütyemez et al. (2021) reported that new released walnut cultivar, Helete Güneşi, leafed out 2 and 10 days later than Chandler and Maraş 18, respectively. Hassani et al. (2020a) reported that, among the new four walnut cultivars, except for Caspian cultivar, leafed out before Chandler. Özcan et al. (2022) stated that the leafing date of the Kurtulus 100 cultivar was 5 days earlier than Chandler. Similar to the results of the present study, it has been found that compared to Chandler, leafing occurred 2 and 3 weeks before in Maraş 18 and Maraş 12, respectively (Sütyemez 2016; Sütyemez et al. 2019).

The degree of dichogamy of cultivars varied from one year to another. According to an average of five years of data, all the cultivars were recorded as protandrous (Table 1). Şen 1, Fernette, Howard, and Pedro (100%) had the highest dichogamy degree, followed by the cultivars of Chandler (88.89%), Fernor (66.67%), Maraş 18 (62.50%), Bilecik (60.00%) and Şebin (54.33%) in decreasing order. Our results, in accordance with those of Sütyemez (2016), indicated that Maraş 18 and Chandler cultivars' overlapping with staminate bloom was around 10%, and these cultivars showed protandry.

Özcan et al. (2022) reported that Chandler showed protandry; however, Kurtulus 100 cultivar was homogamous. Also, Bujdoso et al. (2020) and Hassani et al. (2020a) confirmed that Chandler's overlapping with staminate bloom was around 10%, and it was protandrous. Akça (2014) stated that male and female flowers' receptivity in the Şebin cultivar was not overlapping. The Bilecik cultivar has been recommended as a pollinator for Şebin (Akça 2014); however, the Bilecik cultivar could not fill this gap in the present study. Serr (37.50%) and Maraş 12 (33.33%) cultivars were slightly protandry. Sütyemez et al. (2019) stated that Maraş 12 showed homogamy in Kahramanmaraş, Turkey, whereas Akça et al. (2018) reported that the cultivar was protandrous in Tokat, Turkey.

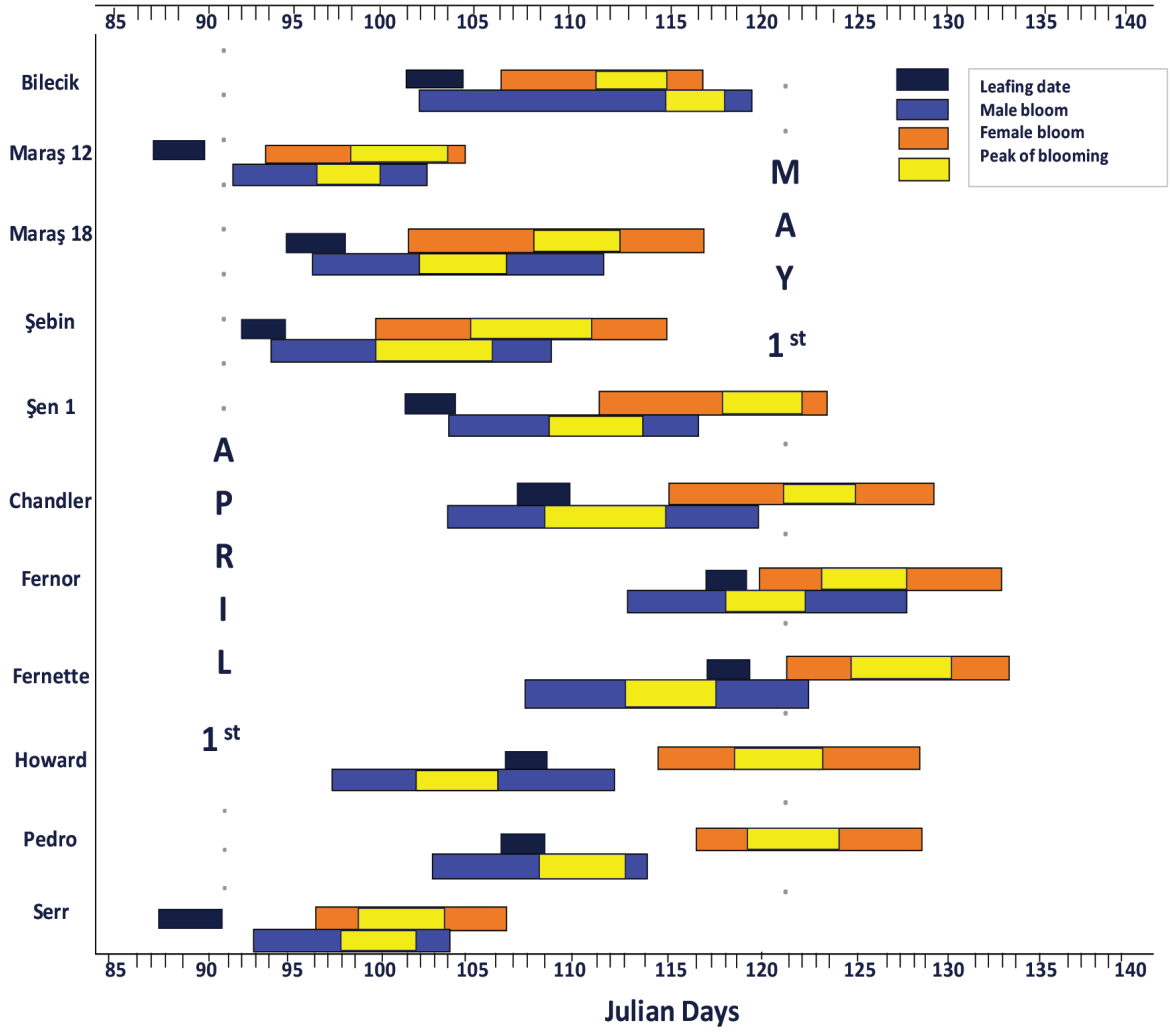

Figure 1- Leafing and blooming dates of the walnut cultivars (2014-2018)

The yield of cultivars for 2014-2020 is presented in Table 2. The average yield of cultivars varied between 1.87 kg and 14.21 kg. The highest average yield per tree was obtained from Pedro (14.21 kg) and Chandler (13.46 kg), followed by Fernor (9.30 kg), Howard (8.70 kg), and Maraş 12 (7.80 kg), while the lowest was Şebin (1.87 kg). The average yield of cultivars per decare was between 38.89 kg (Şebin) and 280.29 kg (Pedro).

The highest total yield was obtained from Pedro (2,030.14 kg) and Chandler (1,923.65 kg). The lowest total yield was obtained from Şebin (267.14 kg). There have been fluctuations in the yield in some cultivars (Figure 2).

In particular, the spring frost incident in Bursa in 2016 damaged the male flowers. This year, the lowest yield was recorded in the local cultivars except for Şebin and Şen 1. This situation may be related to damage that occurred in male flowers of Chandler and Pedro cultivars when female flowers were receptive (Figure 1). The fact that there was no fluctuation in the yield of Şen 1 may be due to its pollination with Fernette and Franquette cultivars, which were less damaged than the other foreign cultivars (Figure 1). In 2016, the highest yield was obtained from Şebin, which may have shown how sensitive this cultivar was to excessive pollen. Akça (2014) stated that Şebin's low yield problem was due to a higher female flower abortion ratio.

Akça et al. (2018) reported that the highest yield was obtained from Chandler, Pedro, and Midland cultivars. Also, Iannamico et al. (2006) stated that Tulare, Fernor, and Chandler walnut cultivars were most productive. In the conditions of the Cacak region of Serbia, high yields were obtained from Fernor (15.0 kg) followed by Fernette (13.7 kg) (Mitrovic et al. 2011). Botu et al. (2010) determined that Fernor, Fernette, and Pedro's average yields were 11.2, 11.2, and 10.0 kg, respectively. Our results, in accordance with those of Akça et al. (2014), Iannamico et al. (2006), Mitrovic et al. (2011), and Botu et al. (2010), confirmed that Chandler, Pedro, and Fernor are the most productive cultivars. Hassani et al. (2020a) reported that, in Iran, the yield of four newly released walnut cultivars was

Table 1- Phenological characteristics of the walnut cultivars (2014-2018)

Cultivar	*Bud break*		*Leafing*		*Female blooming*				*Male blooming*								*Dichogamy degree (%)*	*Nature of dichogamy*	*Defoliation*	
	B	*ND**	*B*	*ND*	*B*	*ND*	*PB*	*ND*	*EB*	*ND*	*B*	*ND*	*PB*	*ND*	*EB*	*ND*			*DD*	*ND*
Bilecik	05.04	-5	09. 04	-8	15. 04	-10	19. 04	-10	24. 04	-14	11. 04	-2	23. 04	+5	29. 04	0	60.00	Protandrous	18.11	0
Maraş 12	22.03	-18	27. 03	-21	03. 04	-22	07. 04	-22	13. 04	-26	30 .03	-13	04. 04	-13	11. 04	-18	33.33	Slightly protandry	03.11	-15
Maraş 18	30.03	-10	04. 04	-13	10. 04	-15	16. 04	-13	25. 04	-14	05. 04	-8	10. 04	-7	20. 04	-8	62.50	Protandrous	05.11	-13
Şebin	27.03	-14	01. 04	-16	08. 04	-17	14. 04	-16	24. 04	-15	03. 04	-10	08. 04	-9	19. 04	-9	54.33	Protandrous	13.11	-5
Şen 1	05.04	-5	09. 04	-8	21. 04	-4	27. 04	-3	02. 05	-7	12. 04	0	18. 04	0	25. 04	-4	100.00	Protandrous	03.11	-15
Chandler	10.04	0	17. 04	0	25. 04	0	30. 04	0	09. 05	0	12. 04	0	18. 04	0	28. 04	0	88.89	Protandrous	18.11	0
Fernor	19.04	+9	26. 04	+9	29. 04	+4	03. 05	+3	12. 05	+3	20. 04	+8	27. 04	+9	05. 05	+7	66.67	Protandrous	11.11	-7
Fernette	18.04	+8	25. 04	+8	30. 04	+5	04. 05	+4	12. 05	+4	15. 04	+3	22. 04	+4	01. 05	+3	100.00	Protandrous	10.11	-8
Howard	09.04	-1	16. 04	-1	23. 04	-1	28. 04	-2	07. 05	-2	06. 04	-7	10. 04	-7	21. 04	-8	100.00	Protandrous	14.11	-4
Pedro	09.04	-1	14. 04	-3	24. 04	0	28. 04	-1	08. 05	-1	12. 04	-1	17. 04	0	22. 04	-6	100.00	Protandrous	16.11	-2
Serr	22. 03	-18	28. 03	-20	05. 04	-20	08. 04	-21	14. 04	-24	01. 04	-11	07. 04	-11	13. 04	-16	37.50	Protandrous	13.11	-5

*ND: Number of days compared to 'Chandler' B: Beginning of blooming, PB: Peak of blooming, EB: End of blooming, DD: Defoliation date

high and very similar to that of 'Chandler'. On the other hand, Sütyemez et al. (2021) reported that in the Kahramanmaraş region of Turkey, Helete Güneşi, Chandler, and Maraş 18 cultivars' 7th, 8th, and 9th year yields were 9.36 kg, 7.03 kg, and 4.14 kg respectively. In the present study, the average yield of Maraş 18 and Chandler cultivars in these years was 5.43 kg and 13.20 kg, respectively. The reason for the differences can be the effect of ecological conditions on the cultivar. Also, in Romania (Botu et al. 2007) and Bulgaria (Gandev 2017), high yields have been obtained in Serr (12.54; 22.01 kg) except for Fernor. The differences between these studies may not be because of the lack of pollination in Serr because it has overlapping male and female blooms in the region (Figure 1, Table 1). However, this may be due to the pistillate flower abscission, observed mainly in Serr cultivar (Catlin & Olson 1990; McGranahan et al. 1994; Rovira & Aleta 1997). Pistillate flower abscission varies according to the location, and high abscission occurs yearly in some regions (Catlin et al. 1987; Gonzalez et al. 2008).

Table 2- The yield (kg/tree) and average yield (kg/tree), (kg/da) of the walnut cultivars

Cultivar	*Average yield (kg/tree)*							*Average yield (2014-2020)*	
	2014	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*(kg/tree)*	*(kg/da)*
Bilecik	4.06 cd*	6.60 b	4.52 efg	5.82 efg	3.38 d	9.90 bcd	4.87 d	5.59 de	116.64 c
Maraş 12	5.90bc	6.49 b	4.14 efg	14.33 b	7.96 bc	11.48 bc	4.28 de	7.80 bc	171.13 b
Maraş 18	1.54ef	4.9 bc	1.96 g	9.47 de	6.51 c	8.54 d	6.69 cd	5.66 de	112.08 c
Şebin	1.48 ef	2.01 c	2.98 f	1.36 H	1.83 d	2.16 e	1.27 ef	1.87 f	38.89 d
Şen 1	2.80 de	5.21bc	6.19 de	5.67 efg	1.72 d	8.96 cd	0.71 f	4.46 e	103.31 c
Chandler	6.1 b	13.17a	12.72 ab	13.71 bc	16.24 a	17.77 a	14.51 b	13.46 a	264.51 a
Fernor	1.27 f	3.31 bc	10.42 bc	10.36 cd	13.78 a	16.60 a	9.39 c	9.30 b	189.62 b
Fernette	0.79 f	3.47 bc	5.62 def	5.01 gh	8.31 bc	12.59 b	8.73 c	6.36 cd	121.13 c
Howard	1.49 ef	11.80 a	7.96 cd	9.13 def	9.32 b	11.43 bc	9.80 c	8.70 b	173.30 b
Pedro	9.39 a	13.85 a	14.36 a	18.59 a	9.87 b	16.32 a	17.07 a	14.21 a	280.29 a
Serr	0.87 f	3.40 bc	5.30 def	5.44 Fg	2.44 d	7.85 d	4.78 d	4.29 e	85.79 c

*Different letters represent statistically different groups ($p<0.05$)

In the present study, the yields of the foreign walnut cultivars were higher than those of the local cultivars (Table 2, Figure 2). Maraş 12 and Şebin were the cultivars with the highest and lowest yield among the local cultivars, respectively. The low yield problem of the Şebin cultivar may be related to a higher female flower abortion ratio (Akça 2014). Sütyemez et al. (2019) confirmed that a cluster-bearing habit of Maraş 12 resulted in a high estimated yield. On the contrary, Akça et al. (2018) in Tokat, Turkey reported that the yield of Maraş 12, Maraş 18, and Şebin cultivars was low. However, the present study obtained higher yields from Maraş 12 and Maraş 18 among local cultivars. Also, Sütyemez (2016) and Sütyemez et al. (2019) confirmed that in Kahramanmaraş, Turkey, Maraş 18 and Maraş 12 have a intermediate and high yield, respectively. The results are consistent with those of Sütyemez (2016) and Sütyemez et al. (2019) since the climate of the Kahramanmaraş region, where the cultivars were selected, is similar to the climate in which the study was conducted, as contrasted to the climate of the Tokat region.

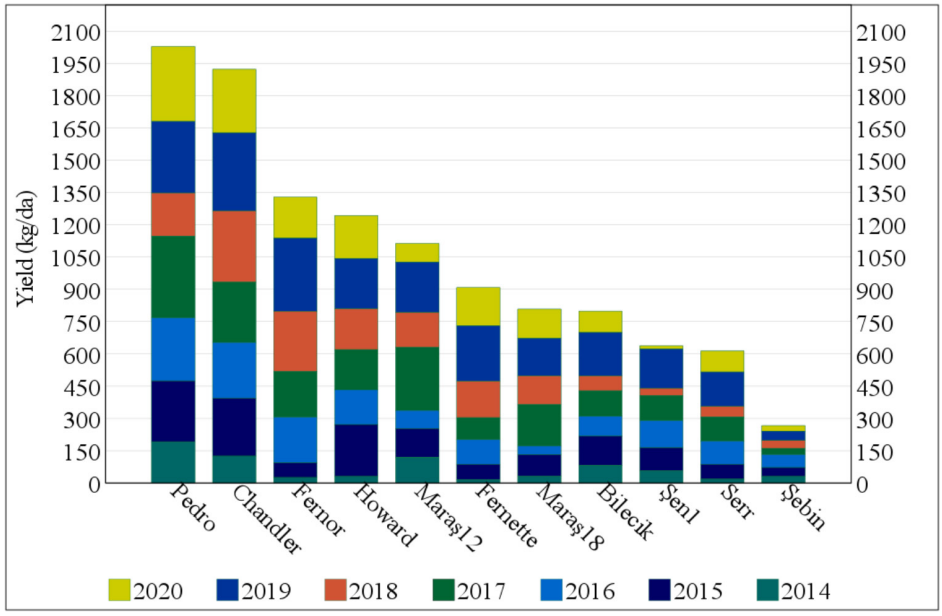

Figure 2- Total yield (kg/da) of the walnut cultivars (2014-2020)

According to the five-year data (Table 3), the highest walnut blight incidence was observed in Şen 1 (31.20%), followed by Şebin (23.81%), while the lowest was in Howard (7.83%). Anthracnose incidence was between 0.50% (Chandler) and 13.64% (Serr); codling moth ranged from 1.37% (Pedro) to 17.37% (Şen 1), and bird damage was between 0.80% (Howard) and 5.52% (Şebin). Sunburn incidence of cultivars ranged from 4.81% (Fernette) to 16.75% (Bilecik). The highest sunburn damage was seen in Bilecik (16.75%) and Howard (15.16%), whereas the lowest in Serr (6.68%), Fernor (5.62%), and Fernette (4.81%). Chandler (76.50%), Fernette (74.93%), and Howard (72.66%) cultivars were identified as having healthy nuts with a low incidence of anthracnose, bird damage codling moth, walnut blight, and sunburn. On the other hand, Şen 1 (40.06%) and Şebin (42.28%) were the cultivars with the least healthy fruit and more external defects. The present study mainly observed the walnut blight damage among the fruit's external defects.

Table 3- Incidence of external defects on walnut cultivars (2014-2018)

Cultivar	*Walnut blight damage (%)*	*Anthracnose damage (%)*	*Codling moth damage (%)*	*Sunburn damage (%)*	*Bird damage (%)*	*Healthy nuts (%)*
Bilecik	12.56 ef*	2.36 cd	1.81 cd	16.75 a	2.67 bc	65.10 d
Maraş 12	11.06 fg	3.77 c	2.54 cd	9.12 de	4.05 b	70.20 c
Maraş 18	15.00 de	3.25 c	4.12 c	10.87 cd	3.17 bc	64.75 d
Şebin	23.81 b	6.72 b	9.15 b	12.59 bc	5.52 a	42.28 f
Şen 1	31.20 a	2.00 cd	17.37 a	9.34 de	0.98 de	40.06 f
Chandler	9.43 gh	0.50 d	1.62 d	11.06 cd	1.22 de	76.50 a
Fernor	17.70 c	0.53 d	2.82 cd	5.62 f	0.43 e	73.04 abc
Fernette	15.06 de	0.75 d	3.12 cd	4.81 f	1.78 cde	74.93 ab
Howard	7.83 h	0.70 d	3.50 cd	15.16 ab	0.80 e	72.66 abc
Pedro	14.12 de	1.25 d	1.37 d	10.37 cd	2.28 cd	71.12 bc
Serr	16.54 cd	13.64 a	8.84 b	6.68 ef	2.98 bc	52.92 e

*Different letters represent statistically different groups ($p<0.05$)

Aleta et al. (2001) noted Chandler's blight incidence on fully developed nuts to be 10-14% and reported that the cultivar showed low susceptibility in field conditions. Aktuğ Tahtacı et al. (2014) stated that walnut blight was observed in all cultivars except Chandler. Bujdoso et al. (2020) reported that Chandler was moderately susceptible to walnut blight. Our results are in accordance with these reports, where Chandler has a lower walnut blight incidence (9.43%). On the contrary, Moragrega et al. (2011) and Jelev & Marinov (2016) reported that Chandler fruit was affected by walnut blight, and the blight incidence in fruit were 42.7% and 67.9%, respectively.

Some of our results agree with other studies conducted about the local cultivar's walnut blight incidence. Özaktan et al. (2007) stated that Şebin was highly susceptible, Bilecik, Şen 1, and Chandler were moderately susceptible, and Pedro was tolerant. Saracoğlu (2015) found that Chandler, Hartley, and local cultivar Şebin were highly susceptible to blight, while Pedro was classified as less susceptible. Also, in Tokat, Turkey, Chandler, Maraş 12, Şebin and Şen 1 have been found more susceptible to walnut blight than other cultivars (Akça 2018). Botu et al. (2010) indicated that Fernor, Fernette and Serr were moderately susceptible to blight. In the present study, blight incidence was lower in Bilecik, Chandler, and Maraş 12 cultivars whereas moderate in Pedro, Fernette, and Fernor.

The foreign cultivars, except for Serr, showed the lowest anthracnose incidence. Serr and Şebin cultivar had the highest anthracnose incidence among the foreign and local cultivars, respectively. In Uzbekistan, Chandler has been noted as the most resistant cultivar, with an anthracnose disease incidence of 0%. (Khasanov et al. 2019). In Bulgaria, the highest infestation index in the fruits has been observed in Serr (7.7%), while it was low in the rest of the cultivars (Fernette, Fernor, and Chandler) (Arnaudov et al. 2014). In Romania, Franquette, Fernor, and Fernette have shown very low susceptibility (Botu et al. 2010). In addition, Arnaudov and Gandev (2009) recorded that Chandler was resistant, whereas Serr was highly susceptible. These studies are consistent with the results obtained in the present study. However, Salahi & Jamshidi (2009) reported that Serr had moderate resistance, and Pedro was susceptible to the disease.

Concerning codling moth damage, the highest incidence was observed in Şen 1, Şebin, and Serr, whereas the lowest was in Chandler and Pedro. Coates (2008) reported that Serr was susceptible to codling moth, walnut blight, and sunburn. Besides, Chandler is a recommended cultivar due to the relatively low incidence of codling moth and walnut blight. Akça (2014) stated that Şebin was susceptible to codling moths. Sütyemez (2016) reported that Maraş 18 was resistant to codling moths. These studies are consistent with the obtained results.

In the present study, sunburn damage incidence was higher in Bilecik, Howard, and Şebin cultivars than the others. These results agree with Lampinen et al. (2006), who indicated sunburn occurred in Howard, followed by Chandler. Howard trees are generally smaller and, therefore, more likely to be exposed to photosynthetically active radiation conditions that can cause sunburn (Lampinen et al. 2006). Akça (2014) stated that Şebin was sensitive to sunburn and water stress, reducing kernel quality. Also, Mahmoudi et al. (2021) stated that Chandler's sunburn damage incidence was higher than the Franquette and reported that it was related to the thickness of the fruit husk of the Franquette cultivar. In the present study, the reason why less sunburn was observed on the fruits of Fernor and Fernette cultivars may be the thicker husk of these French origin cultivars such as Franquette. Early leafing cultivars experienced more external damage than late leafing cultivars (Mills et al. 2000; Bernard et al. 2018). Our results are in accordance with these reports where late leafing cultivars have lower external damage incidence. Except for Maraş 12, the ratio of healthy fruit was lower in early leafing cultivars.

The results of nut traits of the walnut cultivars are shown in Table 4. Nut weight ranged from 9.81 g (Şebin) to 16.27 g (Şen 1). Kernel weight ranged from 5.18 g (Pedro) to 7.52 g (Maraş 18), and kernel percentage varied between 36.31% (Şen 1) and 53.56% (Maraş 12). Kernel percentage was high in Şebin, Maraş 18, Maraş 12, moderate in Bilecik, low in Fernette, Serr, Howard, and Chandler, and very low in the others (Table 4). Desirable nut and kernel weight should range from 12 g to 18 g, and 6 g to 10 g, respectively, or kernel percentage should be at least 50% (McGranahan & Leslie 1990). Maraş 18 was the cultivar that had these kernel traits. Akça et al. (2014) reported that the nut weight of the evaluated 13 cultivars ranged from 12.79 g (Fernor) to 15.35 g (Midland), kernel weight from 5.80 g (Fernor) to 7.22 g (Fernette), and kernel percentage from 42.80% (Pedro) to 47.33% (Fernette). Bobokashvili et al. (2017) reported that the kernel weight of Fernette and Howard was 7.68 g and 7.80 g, and kernel percentage was 50.31% and 52.57%, respectively. In Australia, Chandler, Fernette, and Fernor's nut weights were 10.6, 11.0, and 11.4 g, respectively (Vanhanen 2010). In Iran, nut weights varied between 8.5 and 11.5 g in Serr, 11.5 and 13.5 g in Pedro, 8.5 and 11.5 g in Fernor, and 8.5 and 11.5 g in Chandler (Toolir 2021). The differences between studies in terms of nut and kernel weights can be due to the effect of environmental factors. Also, Özcan et al. (2022) reported that Kurtulus 100 obtained from a KSÜ00M5× Pedro crossing was superior to Chandler in terms of fruit quality; its nut weight, kernel weight, and kernel percentage were calculated to be 13.48 g, 7.52 g, 55.78% respectively. Similarly, Hassani et al. (2020a) stated that new cultivar Persia has a greater kernel percentage (63%) when compared to that of Chandler.

Nut width, thickness, and length significantly varied in the cultivars evaluated in the study. Nut width varied from 29.34 mm (Maraş 12) to 42.30 mm (Şen 1), nut thickness was between 30.62 mm (Maraş 12) and 42.65 mm (Şen 1), nut length ranged from 34.23 mm (Maraş 12) to 43.36 mm (Şen 1). Shell thickness, kernel rottenness, and shrinkage were also significantly affected by the cultivars. The cultivars' shell thickness was between 1.11 mm (Şebin) and 2.30 mm (Fernor). In other words, the shell strength of Şebin and Maraş 12 was comparatively weak, whereas Şen 1, Howard, and Fernor were strong. The cultivars were also assessed for kernel shrinkage and

rottenness, which are important factors that affect kernel quality. The least kernel shrinkage was observed in Maraş 12 (1.46%), Maraş 18 (1.52%), and Howard (1.84%), while the highest was observed in Pedro (15.63%). Sütyemez (2016) stated that there was no kernel shrinkage in Chandler and Maraş 18 cultivars. Kernel rottenness varied from 3.12% (Bilecik) to 21.71% (Serr).

In the present study, the nut dimension of the cultivars was similar to the results published by Akça et al. (2014) and Akça et al. (2018). Akça et al. (2014) evaluated 13 walnut cultivars grown in Tokat, Turkey, and found nut width of about 35.24 mm (Fernor) - 38.47 mm (Fernette); nut length of 40.62 mm (Fernor) - 43.50 mm (Pedro) and nut thickness of 33.73 mm (Fernor) - 36.86 mm (Fernette). Akça et al. (2018) reported that the nut width of cultivars ranged between 30.55 mm (Maraş 12) and 39.97 mm (Şen 1), and nut length varied from 32.58 mm (Şen 1) to 42.53 mm (Şen 1). In Argentina, the average nut widths of 34.10-40.80 mm, nut thickness of 33.70-40.50 mm, and nut length of 36.70-45.20 mm have been reported (Iannamico et al. 2006). Ercisli et al. (2012) in Yalova, Turkey, found nut widths of Şebin, Şen 1, Chandler, Pedro, and Serr as 33.98 mm,46.38 mm, 36.55 mm, 37.51 mm, and 37.10 mm, respectively. Türemiş et al. (2017) evaluated 10 walnut cultivars in Adana, Turkey, and nut width varied between 31.70 mm (Maraş 12) and 42.91 mm (Şen 1), nut thickness ranged from 30.19 mm (Maraş 12) to 39.59 mm (Şen 1). Karlıdağ et al. (2019) reported that the nut width of Maraş 18, Chandler, and Bilecik cultivars was 35.81, 36.24, and 38.82 mm, and nut thickness was 34.41, 34.91, and 37.19 mm, respectively. In the present study, the nut dimension of the cultivars was found larger than those determined by Ercisli et al. (2012). These differences can be due to environmental conditions on the cultivar (Vanhanen 2010). In addition to nut weight, kernel weight, kernel percentage, shell thickness, kernel color is also an important parameter in walnut cultivar, and light kernel colors are among the important objectives of walnut breeding (Vahdati et al. 2019; Hassani et al. 2020b; Sütyemez et al. 2021). In the present study the kernels of Chandler and Fernor were extra light, Şen 1 light amber and the other cultivars were light color (Figure 3).

PCA was applied to evaluate the data set and detect the most important variables for determining the data structure. The analysis showed that the eigenvalues of the first five principal components were greater than 1.0, explaining 85.20% of the total variance. The first five principal components accounted for 28.30%, 19.60%, 18.00%, 11.30%, and 8.00% of the variation.

The PC1 represented the maximum variation of the data set (Table 5). It was positively associated with nut weight, nut thickness, nut length, nut width, and shell thickness, while negatively associated with kernel percentage and bird damage values. The PC2 was negatively correlated with healthy nut ratio and yield, whereas positively connected with walnut blight damage and codling moth damage.

Yield and healthy nut ratio increased with decreasing walnut blight and codling moth damage. The negatively correlated variables with the PC3 were leafing, male and female flower blooming, on the other hand anthracnose value was determined to be positively correlated. These data reveal that the increase in anthracnose damage occurs with early leafing and flowering. The PC4 was positively correlated with kernel shrinkage and defoliation and negatively correlated with kernel weight. Besides, sunburn damage and kernel rottenness were the leading indicators for the PC5.

The plot of the PC1 versus PC2 (Figure 4) identified Şen 1 and Şebin located some distance away from the others, indicating that Şen 1's fruit weight was higher, while its yield and healthy nut ratio were lower. Also, Şebin was located on the negative side of the PC1 and the positive side of the PC2, which showed that its fruit size was smaller, while its yield and healthy nut ratio were lower than the others, similar to Şen 1. The cultivars located on the positive side of the PC1 and the negative side of the PC2, Fernor, Fernette, Pedro, Maraş 18, Chandler, and Howard, had higher yield and lower walnut blight and codling moth damage, especially Chandler and Howard.

Table 4- Some nut traits of the walnut cultivars (2014-2018)

Cultivar	*Nut weight (g)*	*Nut width (mm)*	*Nut thickness (mm)*	*Nut length (mm)*	*Kernel weight (g)*	*Kernel percent (%)*	*Shell thickness (mm)*	*Shell strength*	*Kernel color*	*Kernel rottenness (%)*	*Kernel shrinkage (%)*
Bilecik	11.12±0.07 f*	33.50±0.50 e	33.18±0.46 fg	38.92±0.62 b	5.38±0.06 hi	46.06±0.50 c	1.68±0.01 c	Intermediate	Light	3.12±0.40 i	4.15±0.49 cd
Maraş 12	9.91±0.06 g	29.34±0.19 h	30.62±0.11 h	34.23±0.16 f	5.49±0.11 ghi	53.56±0.94 a	1.40±0.02 d	Weak	Light	8.99±0.77 cef	1.46±0.24 f
Maraş 18	14.41±0.22 b	34.10±0.09 cd	35.53±0.16 b	39.15±0.12 b	7.52±0.12 a	50.89±0.31 b	1.69±0.01 c	Intermediate	Light	3.24±0.60 hi	1.52±0.37 f
Şebin	9.81±0.17 g	30.73±0.09 g	32.66±0.11 g	34.58±0.21 f	5.94±0.25 ef	50.82±2.23 b	1.11±0.02 e	Weak	Light	14.62±.48 c	2.89±0.30 de
Şen 1	16.27±0.23 a	42.30±0.12 a	42.65±0.04 a	45.36±0.18 a	6.82±0.20 b	36.31±1.16 g	2.20±0.05 a	Strong	Light amber	18.70±1.48 b	4.93±0.60 bc
Chandler	12.36±0.05 d	33.67±0.07 de	35.11±0.13 bc	39.08±0.16 b	5.73±0.02 fgh	43.92±0.14 cd	1.98±0.02 b	Intermediate	Extra light	5.84±0.51 gh	4.64±0.54 c
Fernor	13.43±0.09 c	34.00±0.13cde	35.11±0.17 bc	38.77±0.17 bc	5.84±0.04 efg	39.25±0.03 f	2.30±0.04 a	Strong	Extra light	9.34±0.66 de	2.37±0.46 ef
Fernette	13.96±0.25 b	36.16±0.04 b	35.75±0.34 b	38.02±0.08 cd	6.53±0.07 bc	40.80±0.73 ef	1.88±0.01 b	Intermediate	Light	11.50±0.55 d	4.71±0.39 c
Howard	13.17±0.29 c	34.31±0.09 c	34.04±0.27 de	36.93±0.16 e	6.14±0.16 de	43.66±0.28 cd	2.23±0.01 a	Strong	Light	6.76±0.63 efg	1.84±0.08 ef
Pedro	11.93±0.08 de	33.45±0.17 e	33.59±0.16 ef	38.08±0.25 c	5.18±0.06 i	39.60±0.40 f	1.73±002 c	Intermediate	Light	6.50±1.02 fg	15.63±0.64 a
Serr	11.66±0.13 e	32.23±0.06 f	34.60±0.09 cd	37.27±0.08 de	6.41±0.10 cd	43.14±0.47 de	1.88±0.09 b	Intermediate	Light	21.71±0.85 a	6.12±0.81 b

*Different letters represent statistically different groups ($p<0.05$)

Figure 3- Shell and kernel photos of the walnut cultivars

4. Conclusions

Late leafing was observed in Chandler, Fernor, and Fernette cultivars, while local cultivars were leafing relatively early. While the disease incidence rate was lower in foreign cultivars except for Serr, healthier fruits were obtained from Maraş 12 among local cultivars. The yields of Chandler, Pedro, Howard, Fernor, and Maraş 12 cultivars were higher, and no yield fluctuations depending on the years were observed. Yield fluctuations were detected mainly in Şebin, Serr, and partially Şen 1 cultivars. Kernel percentage was generally higher in local cultivars, and excellent result was obtained from Maraş 12, Maraş 18, and Şebin. Besides, a considerable amount of kernel shrinkage and rottenness was not seen on Maraş 18 nuts. These were followed by foreign cultivars Chandler and Howard. Pedro cultivar, which has a high yield potential, attracted attention with its high kernel shrinkage rate.

In conclusion, considering the region is affected by spring late frost, Chandler, Howard, and Fernor cultivars with late leafing, high yield potential, lower disease incidence rate, and relatively high-quality fruit may be recommended. Among the local cultivars, if the early leafing trait is ignored, Maraş 12 can be a preferable cultivar in terms of all factors. Alternatively, Maraş 18 cultivar can be recommended with lower yield potential but larger nut dimension and kernel percentage.

Table 5- Eigenvalues and cumulative variance for five factors resulted from PCA

Parameter	*1*	*2*	*3*	*4*	*5*
Nut weight	0.893	0.021	-0.246	-0.308	-0.084
Nut thickness	0.881	0.395	-0.126	-0.106	-0.080
Nut length	0.880	0.264	-0.195	0.004	0.145
Nut width	0.877	0.285	-0.297	-0.057	0.030
Shell thickness	0.773	-0.271	-0.238	0.063	-0,251
Kernel percent	-0.700	-0.048	0.354	-0.515	0.298
Bird damage	-0.677	0.351	0.341	-0.211	0.059
Healthy nut	-0.057	-0.916	-0.347	0.023	-0.051
Walnut blight damage	0.210	0.911	-0.096	-0.119	-0.149
Codling moth damage	0.348	0.811	0.235	-0.086	-0.108
Yield	0.216	-0.730	-0.207	0.224	0.057
Blooming of male flower	0.309	-0.027	-0.859	0.182	-0.040
Leafing	0.340	-0.274	-0.841	0.152	-0.167
Blooming of female flower	0.480	-0.211	-0.785	0.194	-0.084
Anthracnose damage	-0.226	0.331	0.744	0.078	-0.329
Kernel shrinkage	0,160	-0.010	0.026	0.785	-0.003
Defoliation	-0.160	-0.267	-0.208	0.720	0.106
Kernel weight	0.468	0.160	0.205	-0.663	-0.154
Sunburn damage	-0.080	-0.049	0.135	0.221	0.901
Kernel rottenness	0.141	0.463	0.392	0.199	-0.612
Eigen value	5.665	3.910	3.600	2.258	1.596
% of variance	28.300	19.600	18.000	11.300	8.000
Cumulative variance %	28.300	47.900	65.900	77.200	85.200

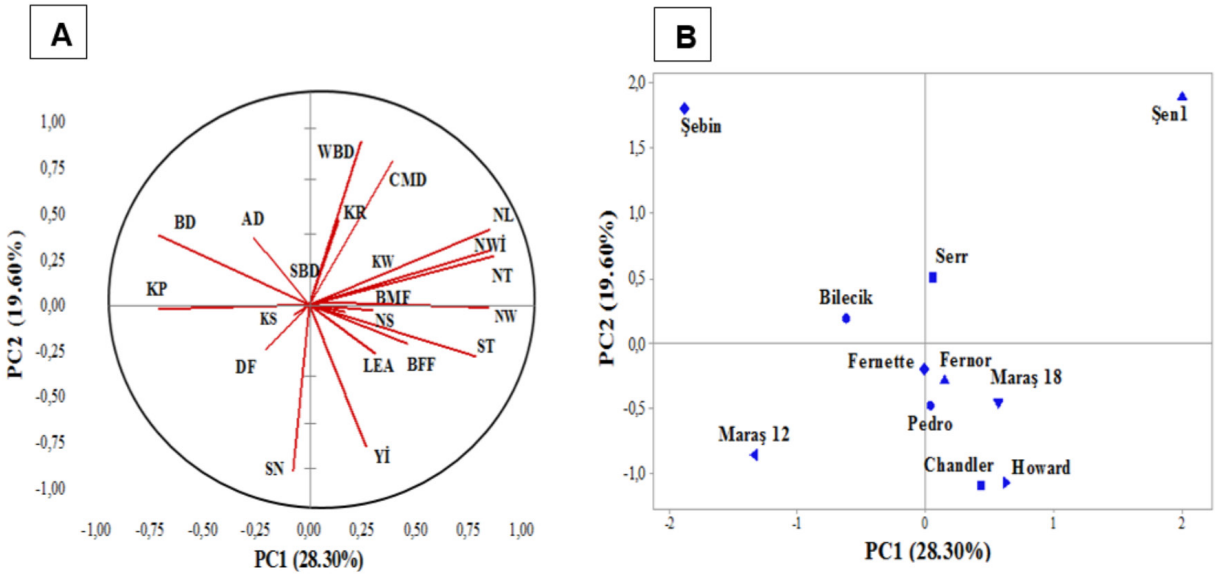

Figure 4- (A) The scatter plot of the variables of the first two principal components; (B) The scat-ter plot of cultivars YI: Yield, LEA: Leafing, BFF: Blooming of female flower, ST: Shell thickness, NW: Nut weight, BMF: Blooming of male flower, NT: Nut thickness, NWI: Nut width, NL: Nut length, KW: Ker-nel weight, CMD: Codling moth damage, KR: Kernel rottenness, WBD: Walnut blight damage, SBD: Sunburn damage, AD: Anthracnose damage, BD: Bird damage, KP: Kernel percentage, KS: Kernel shrinkage, DF: Defoliation, SN: Healthy nut ratio

Data availability: Data are available on request due to privacy or other restrictions.

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