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Evaluation of Phenological and Pomological Characteristics of Walnut Cultivars in the Ecology of Tavas (Denizli)

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Abstract
This study seeks to assess aims to evaluate the performance of walnut cultivars namely; 'Bilecik', 'Chandler', 'Pedro', 'Şebin', and 'Yalova-1' under the ecological conditions of Tavas (Denizli) based on climate data by analyzing their phenological and pomological characteristics in detail. Phenological observations revealed that the 'Bilecik' cultivar is the earliest to leaf and flower, while the 'Chandler' cultivar is the latest. In terms of pomological characteristics, the 'Yalova-1' cultivar has the highest fruit weight at 18.64 g, whereas the 'Chandler' cultivar has the highest kernel ratio at 50.41%. Color analyses indicate that the 'Chandler' cultivar has the lightest (L*:56.48, a*:7.76) kernel color and performs best in terms of kernel blackening. PCA analysis provides a good summary of the data, with the first two components explaining 88.3% of the total variation. PC1 explains 61.4% of the variance and shows a strong association with size-related traits such as fruit weight, shell thickness, and kernel weight. PC2 explains 26.9% of the variance and is associated with color characteristics. Correlation analysis shows a strong positive relationship between fruit weight and kernel weight (r:0.94), and a negative relationship with kernel ratio (r:-0.41). In conclusion, the 'Chandler' is suggested for its superior kernel quality and high yield, 'Yalova-1' for its ability to produce large nuts, and 'Bilecik' for its early harvest potential and marketing benefits.

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1. Introduction

Turkey, with its ancient and deep-rooted fruit cultivation culture, is among the native lands of walnuts, as it is for many other fruit species (Şen, 2009; Bayazit et al., 2016; Karadeniz et al., 2017; Güvenç and Kazankaya, 2019). The walnut is part of the natural flora of a vast region extending from the Carpathian Mountains to Turkey, Iraq, Iran, Afghanistan, Southern Russia, India, Manchuria, and Korea (Şen, 2009). Among the 18 walnut species identified with certain characteristics, only *Juglans regia* L. is cultivated in Turkey (Şen, 2009). Increasing consumer demands and rising prices each year have led to the expansion of walnut orchards and production areas.

Walnut is a type of hard-shelled fruit that has strategic importance in the global food economy and has an economic volume exceeding two billion dollars in world trade annually. Walnut, which has a wide range of uses from the food industry to the cosmetics sector, from the furniture industry to the pharmaceutical industry, has reached an important position in the functional food market, especially with the increase in healthy nutrition trends in recent years (Gülsoy et al. 2016; Salık and Çakmakçı, 2023). It draws attention with its contribution to the sustainable agricultural economy, the employment opportunities it creates at local and regional levels, and its role in rural development (Jahanban-Esfahlan et al., 2019; Salık and Çakmakçı, 2023). Walnut, which is a high value-added agricultural product due to its high nutritional value, versatile areas of use, and increasing consumer demand, stands out as an agricultural product that will continue to increase its economic importance in the future with its production potential and new product development opportunities.

Turkey's rich climatic diversity offers extensive opportunities for walnut cultivation (Kırca et al., 2014). Walnuts are known for their ability to adapt to different ecological conditions and can therefore be successfully cultivated in various regions of Turkey. However, fruit cultivation is often a costly and challenging process. Therefore, it is crucial to carefully evaluate the performance of walnut cultivars to be used in new cultivation areas (Bilgin et al., 2023). Walnut trees require between 400 and 1800 chilling hours and can grow at altitudes ranging from 0 to 1700 meters. These characteristics provide a wide geographical area for walnut cultivation. As with many fruit species, cultural practices in walnut cultivation affect yield and quality, but the primary impact comes from ecological conditions (Miletić et al., 2009). Temperature is one of the most critical factors directly affecting the quality of walnut fruit (Akça and Yılmaz, 2016).

Support from the Ministry of Agriculture and Forestry contributes to the increase in production areas by encouraging the establishment of walnut orchards. Certified sapling and grant support make walnut cultivation attractive, while special afforestation projects on treasury and forest lands that have lost their quality positively influence the establishment of new orchards. Innovative methods such as modern agricultural techniques, drip irrigation systems, and precision farming applications increase the productivity of walnut orchards. Additionally, walnut processing and packaging facilities enhance the added value of products, contributing to the local economy. Plantations established with walnut cultivars suitable for ecological conditions can provide high yield and quality, increasing competitiveness in international trade. Moreover, walnut trees reduce carbon emissions, prevent soil erosion, and support biodiversity. Therefore, walnut cultivation holds strategic importance in the agricultural sector, providing both economic and environmental benefits.

Walnuts, with high economic value, are an essential part of dietary programs. Walnuts contain 52-70% oil and are rich in essential fatty acids, particularly oleic, linoleic (~60%), and linolenic acids. The high polyunsaturated fatty acid content suggests that walnut consumption can help prevent cardiovascular diseases by lowering total and LDL cholesterol. The nutritional and economic value of walnuts varies according to cultivar and growing conditions, depending on oil content and fatty acid distribution (Şen, 2009; Şen et al., 2011; Şen et al., 2006).

Economic efficiency in fruit cultivation can be achieved through the establishment of monoculture orchards. One of the critical factors in orchard establishment is selecting cultivars or types by considering their phenological, pomological, and vegetative characteristics (Bayazit, 2011).

This study aims to determine walnut cultivars suitable for the ecological conditions of the Tavas (Denizli) district by examining the leafing, female and male flowering periods, harvest time, and fruit characteristics of walnut cultivars over two years in light of climate data.

2. Material and Methods

2.1. Plant material

This study was carried out in a commercial orchard located in Tavas district of Denizli province, at an altitude of 910-960 m for two years in 2022 and 2023. 'Bilecik', 'Chandler', 'Pedro', 'Şebin' and 'Yalova-1' walnut cultivars grafted onto seedling rootstock were used as plant material. The trees are 16 (Bilecik), 10 (Chandler), 12 (Pedro), 16 (Şebin) and 16 (Yalova-1) years old, and the planting distances are 9x9. Cultural practices such as pruning and spraying were carried out in the garden on time. Among the cultural practices, irrigation and fertilization were given in the form of drip irrigation.

2.2. Phenological and pomological measurements

Phenological observations recorded included leafing, male and female flowering, and harvest time. Leafing was defined as the period when terminal buds reached approximately 2.5 cm in length on 80-90% of the tree (Koyuncu et al., 2005). Male flowering was defined as the period when male catkins actively produced pollen (Akça, 1999; Asma et al., 1999). Female flowering was considered the period when 80-90% of the female flowers had receptive stigmas (when the stigma turns from yellow to brown) (Akça, 1999). Walnut harvest was conducted when the outer green husk began to turn brown and showed cracks, allowing easy separation from the inner hard shell (Şen et al., 2011).

Thirty harvested fruits were separated from their green husks, washed, and dried in the shade. Analyses were conducted in the laboratory of the Department of Horticulture at Pamukkale University. Average walnut and kernel weights were determined using a precision balance (0.0001 g), and the kernel ratio (%) was calculated. The width, height, length, and shell thickness of the walnuts were measured with a digital caliper with 0.01 mm precision. Fruit color values (L*, a*, b*, Chroma, Hue^{o}) were measured using a PCE-CSM1 model colorimeter (PCE Instruments, Germany) (Kırca et al., 2014).

2.3. Tavas climate data

When comparing the years 2022 and 2023, relative humidity was higher in March, April, and May of 2023 (%72.3, %72.3, %76.9) compared to 2022 (%67.7, %51.3, %58.4). Wind speed was similar in both years, but lower in May 2023 (2.1 m s^{-1}). In terms of temperature, March 2022 was notably colder (2.3 °C) than March 2023 (7.9 °C). In April and May, temperatures were higher in 2022 (13.3 °C and 16.3 °C) compared to 2023 (9.6 °C and 14.5 °C). Regarding precipitation, May 2023 recorded significantly more rainfall (105.6 mm) than May 2022 (23.4 mm). These data indicate that 2023 was wetter and more humid, but cooler compared to 2022 (Figure 1) (Anonymous, 2023).

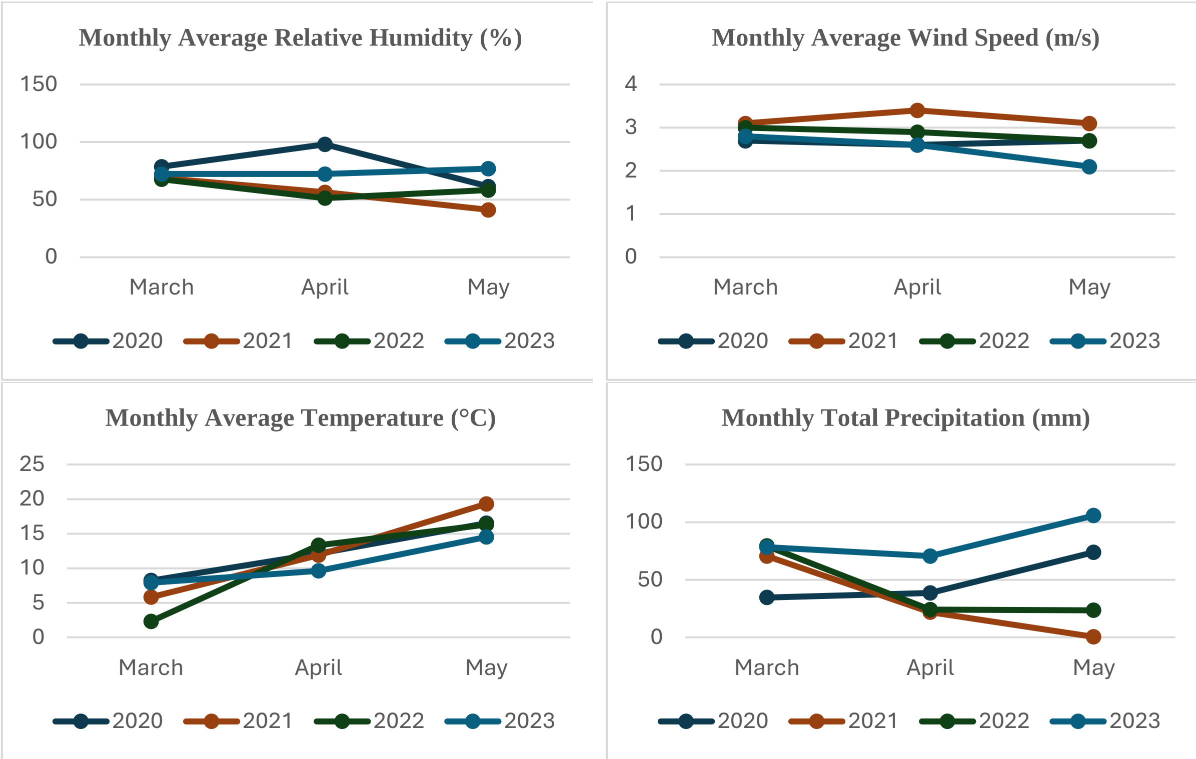

Figure 1. Monthly average relative humidity, monthly average wind speed, monthly average temperature, and monthly total precipitation in Tavas district from 2019 to 2023.

2.4. Statistical analyses

The research was designed according to a completely randomized design with three replications and five trees per replication. The JMP software package was used to evaluate the results obtained from the experiment. The variability of traits according to cultivars was subjected to one-way analysis of variance, and differences were determined using Tukey's Multiple Comparison Test ($p<0.05$). Correlation analysis was performed to determine the relationships between the traits examined, and principal component analysis was used to assess the distribution of traits according to cultivars.

3. Results and Discussion

The phenological observations recorded over two years for walnut cultivars, including leafing, male and female flowering, and harvest dates, are presented in Table 1. These phenological characteristics are crucial for understanding how walnut cultivars respond to ecological conditions and the timing of their developmental stages, which is important for economic efficiency and adaptation to the environment.

For the 'Chandler' cultivar, leafing, male, and female flowering dates in 2023 were delayed by a few days compared to 2022. This delay can be attributed to the lower average temperature in April 2023 (9.6 °C) compared to 2022 (13.3 °C) and the higher precipitation in April 2023 (70.5 mm). Lower temperatures and increased precipitation may have slowed tree development. For the 'Pedro' cultivar, leafing and flowering dates in 2023 were slightly later than in 2022. The higher relative humidity in April 2023 (72.3%) compared to 2022 (51.3%) may have affected plant water status and transpiration rates, altering the timing of phenological events. Additionally, the lower temperatures in 2023 may have contributed to this delay. For the 'Şebin' cultivar, leafing and flowering dates in 2023 were delayed by a few days compared to 2022. This delay can be linked to the lower temperatures (9.6 °C) and higher precipitation (70.5 mm) in April 2023. Increased humidity and precipitation may have slowed tree development. For the 'Yalova-1' cultivar, leafing and flowering dates in 2023 were later than in 2022. The lower temperatures and higher precipitation in April 2023 may have caused the delay in phenological events, leading to slower development under cooler and wetter conditions. For the 'Bilecik' cultivar, the leafing date in 2023 was earlier than in 2022. This early leafing can be associated with the higher temperatures in March 2023 (7.9 °C). The lower precipitation in March (78.1 mm) may have contributed to earlier phenological events by creating drier conditions. However, male and female flowering dates in April occurred slightly earlier, indicating the influence of the temperature increase in March.

Leafing dates varied among cultivars. The 'Bilecik' cultivar showed the earliest development, leafing on March 25 in 2022 and March 21 in 2023, suggesting that this cultivar might be more vulnerable to early frost risk but could offer the advantage of early harvest under Tavas conditions. Other cultivars, such as 'Pedro', 'Şebin', and 'Yalova-1', generally leafed in mid-April, while 'Chandler' was the latest to leaf. 'Chandler' leafed on April 16 in 2022 and April 20 in 2023, indicating that it might perform better in cooler climates and be more resistant to late spring frost.

The 'Bilecik' cultivar flowered with male flowers on April 10 in 2022 and April 8 in 2023, flowering within a similar timeframe as other cultivars. The 'Chandler' flowered with male flowers on April 10 in 2022 and April 14 in 2023, showing slightly later flowering compared to other cultivars. The 'Pedro' and 'Şebin' flowered relatively early, on April 6 and 7 in 2022, and April 10 and 9 in 2023, respectively. The 'Yalova-1' was the earliest to flower with male flowers, on April 5 in 2022 and April 8 in 2023. These male flowering dates are important for planning pollination timing and evaluating the adaptation of cultivars to suitable ecological conditions.

The 'Bilecik' cultivar was the earliest to flower with female flowers, on April 5 in 2022 and April 1 in 2023. This early flowering suggests that 'Bilecik' might be more vulnerable to early frost risk but could offer the advantage of early pollination. The 'Chandler' flowered with female flowers on April 21 in 2022 and April 25 in 2023, showing later flowering compared to other cultivars, suggesting that it might perform better in cooler climates. The 'Pedro' and 'Şebin' flowered in mid-April, on April 19 and 17 in 2022, and both on April 20 in 2023. The 'Yalova-1' also flowered with female flowers on April 17 in 2022 and April 20 in 2023.

The 'Bilecik' was the earliest to be harvested, from October 3 to 5, indicating a rapid maturation process and the advantage of early market availability. The 'Yalova-1' was harvested from October 20 to 25, suggesting a shorter maturation process. The 'Şebin' and 'Pedro' were harvested towards the end of October. The 'Chandler' was the latest to be harvested, from October 27 to 30.

Bilgin et al. (2023) reported in their study on the performance of walnut cultivars in the Kale district of Denizli that leafing dates ranged from April 10 to 20, male flowers opened in the first half of April, female flowers opened 1-2 weeks after male flowers, and the 'Chandler' flowered about a week later than other cultivars. The researchers also found that the harvest period ranged from October 20 to 28. The findings obtained are similar to those of Bilgin et al. (2023) and other studies conducted with different walnut cultivars and genotypes (Gerçekcioğlu et al., 2019; Güller, 2020; Oruç, 2020; Sütyemez et al., 2021; Sütyemez et al., 2022).

The impact of ecological conditions on walnut quality shows significant variations among different species and cultivars. This highlights the need to identify the most suitable walnut cultivars for the ecosystem and recommend these cultivars to growers to increase the number of trees and production volume in walnut cultivation. Regional adaptation studies play a strategic role in evaluating the ability of these cultivars to adapt to local climate and soil conditions, thereby enhancing production efficiency. These studies are critically important for ensuring sustainable growth in walnut cultivation and optimizing quality.

Table 1. Phenological observations of leafing, male and female flowering, and harvest dates for walnut cultivars

Cultivars	Years	Leafing	Male flowering	Female hlowering	Harvest
Chandler	**2022**	16 April	10 April	21 April	27 October
	2023	20 April	14 April	25 April	30 October
Pedro	**2022**	12 April	06 April	19 April	25 October
	2023	17 April	10 April	20 April	27 October
Şebin	**2022**	12 April	07 April	17 April	23 October
	2023	16 April	09 April	20 April	26 October
Yalova-1	**2022**	12 April	05 April	17 April	20 October
	2023	17 April	08 April	20 April	25 October
Bilecik	**2022**	25 March	10 April	05 April	03 October
	2023	21 March	08 April	01 April	05 October

The averages of two-year measurements for fruit weight, kernel weight, kernel ratio, fruit width, fruit length, fruit height, and shell thickness of the walnut cultivars studied are presented in Table 2. These traits were found to be statistically significant among the walnut cultivars. Among the cultivars, Yalova-1' had the highest fruit weight at 18.64 g, which was statistically significant compared to the other cultivars. 'Bilecik' (12.39 g), 'Chandler' (12.55 g), and 'Şebin' (12.35 g) were similar in terms of fruit weight, while the lowest fruit weight was found in 'Pedro' at 11.57 g. Bilgin et al. (2023) reported that in the Kale district of Denizli, the heaviest walnuts were from the 'Yalova-1' at 16.50 g, and the lightest were from the 'Pedro' at 4.98 g. Çoban (2020) reported a walnut weight of 10.27 g for the 'Chandler' in a two-year study in the Kaman district of Kırşehir; Büyüksolak et al. (2020) reported a range of 8.77-13.35 g for the same cultivar in Uşak; Bilgin et al. (2018) reported fruit weights of 10.98 g, 11.32 g, and 10.42 g for 'Chandler', 'Pedro', and 'Şebin', respectively, in Menemen, İzmir; and Bayazit et al. (2019) reported fruit weights of 16.66 g and 12.83 g for 'Bilecik' and 'Şebin', respectively, in Mucur, Kırşehir. The findings from this study are generally higher than those from previous studies, which may be attributed to cultural practices and ecological conditions. In terms of kernel weight, Yalova-1' had the highest kernel weight at 8.16 g among the cultivars studied. 'Bilecik' (6.07 g), 'Chandler' (6.32 g), and 'Şebin' (5.96 g) were statistically in the same group with similar kernel weights, while 'Pedro' had the lowest kernel weight at 4.99 g. Bilgin et al. (2023) reported kernel weights of 6.34 g for 'Chandler', 4.98 g for 'Pedro', 5.69 g for 'Şebin', and 8.14 g for 'Yalova-1'; Çoban (2020) reported 4.51 g for 'Chandler'; Büyüksolak et al. (2020) reported a range of 4.14-5.40 g; Bilgin et al. (2018) reported 4.47 g, 5.32 g, and 3.65 g for 'Chandler', 'Pedro', and 'Şebin', respectively; and Bayazit et al. (2019) reported kernel weights of 7.67 g for 'Bilecik' and 6.28 g for 'Şebin'. The findings for the cultivars studied are consistent with previous studies. The kernel ratio is an economically important parameter in walnuts, as in other hard-shelled fruits. Significant differences in kernel ratio were found among the cultivars. The highest kernel ratios were found in 'Chandler' (50.41%), 'Bilecik' (49.03%), and 'Şebin' (48.41%), while the lowest were in 'Yalova-1' (43.80%) and 'Pedro' (43.17%). Bilgin et al. (2023) reported kernel ratios of 49.66% for 'Chandler', 46.92% for 'Pedro', 46.79% for 'Şebin', and 49.96% for 'Yalova-1'; Çoban (2020) reported 44% for 'Chandler'; Büyüksolak et al. (2020) reported a range of 42.16-47.58% for 'Chandler' at different altitudes; Bilgin et al. (2018) reported 40.70% for 'Chandler', 47.00% for 'Pedro', and 35.00% for 'Şebin'; and Bayazit et al. (2019) reported 46.07% for 'Bilecik' and 48.93% for 'Şebin'. The kernel ratio values obtained in this study are higher for some cultivars and lower for others compared to other studies. These differences may be due to cultural practices, cultivation techniques, climate, and soil characteristics. The high kernel ratios obtained for 'Chandler' and 'Bilecik' suggest that these cultivars may be more economically advantageous under Tavas conditions. The findings are generally consistent with other studies, although significant differences were observed for some cultivars. Significant differences were found among the cultivars in terms of fruit width, length, and height. The ‘Yalova-1’ had the widest fruit width at 34.60 mm. ‘Chandler’ (32.81 mm) and ‘Şebin’ (31.87 mm) were statistically in the same group, producing fruits of similar width, while ‘Bilecik’ (29.84 mm) and ‘Pedro’ (29.14 mm) had narrower fruits. Similarly, the longest fruits were found in ‘Yalova-1’ (34.23 mm) and ‘Chandler’ (34.04 mm), while ‘Bilecik’ (29.78 mm) and ‘Pedro’ (29.91 mm) had shorter fruits. The tallest fruits were found in ‘Yalova-1’ (44.07 mm), while the shortest were in ‘Bilecik’ (32.46 mm) and ‘Pedro’ (33.54 mm). Bilgin et al. (2023) reported fruit widths of 32.72 mm, 29.51 mm, 30.93 mm, and 34.87 mm, fruit lengths of 34.56 mm, 29.86 mm, 32.31 mm, and 34.73 mm, and fruit heights of 41.88 mm, 33.72 mm, 38.74 mm, and 43.56 mm for ‘Chandler’, ‘Pedro’, ‘Şebin’, and ‘Yalova-1’, respectively; Çoban (2020) reported 31.95 mm fruit thickness, 31.63 mm fruit width, and 38.74 mm fruit height for ‘Chandler’; Büyüksolak et al. (2020) reported a range of 30.56-33.48 mm for fruit width, 39.73-43.70 mm for fruit length, and 31.92-34.96 mm for fruit height for ‘Chandler’ at different altitudes; Bilgin et al. (2018) reported fruit widths of 34.61 mm, 33.26 mm, and 32.52 mm, fruit lengths of 37.74 mm, 40.09 mm, and 38.97 mm, and fruit heights of 32.44 mm, 34.75 mm, and 35.58 mm for ‘Şebin’, ‘Chandler’, and ‘Pedro’, respectively; and Bayazit et al. (2019) reported fruit widths of 34.11 mm and 35.40 mm, fruit lengths of 44.44 mm and 45.42 mm, and fruit heights of 35.31 mm and 35.85 mm for ‘Şebin’ and ‘Bilecik’, respectively. Some consistencies and differences are observed between the findings and previous studies. These differences may be due to climate and soil characteristics, altitude, or cultural practices. The width, length, and height of walnut fruits are important for commercial value and quality. Large and symmetrical walnuts are generally sold at higher prices due to consumer preferences and market standards. These physical characteristics affect the kernel fill ratio and shell thickness, determining quality and serving as important criteria for evaluating the suitability of cultivation conditions. In terms of shell thickness, Yalova-1’ had the thickest shell at 1.95 mm, while ‘Bilecik’ had the thinnest shell at 1.21 mm, significantly distinguishing them from other cultivars. There was no significant difference in shell thickness among ‘Chandler’ (1.62 mm), ‘Pedro’ (1.61 mm), and ‘Şebin’ (1.52 mm). Bilgin et al. (2023) reported shell thicknesses of 1.58 mm, 1.59 mm, 1.54 mm, and 1.65 mm for ‘Chandler’, ‘Pedro’, ‘Şebin’, and ‘Yalova-1’, respectively; Çoban (2020) reported 1.05 mm for ‘Chandler’; Büyüksolak et al. (2020) reported a range of 1.50-1.97 mm for ‘Chandler’; Bilgin et al. (2018) reported shell thicknesses of 1.32 mm, 1.42 mm, and 1.40 mm for ‘Şebin’, ‘Chandler’, and ‘Pedro’, respectively; and Bayazit et al. (2019) reported shell thicknesses of 1.83 mm and 1.42 mm for ‘Şebin’ and ‘Bilecik’, respectively. Shell thickness in walnuts is an important parameter for consumer preferences and production processes. Thin-shelled walnuts are more easily cracked and have a higher kernel fill ratio, making them more preferred by consumers and thus increasing their commercial value. Additionally, thin shells reduce processing costs, while thick shells can protect walnuts from external factors but may increase transportation and storage costs. Therefore, shell thickness is an important feature to consider in walnut production and marketing. Similarities and differences are observed between the findings and previous studies. The significant differences for ‘Yalova-1’ and ‘Bilecik’ may be due to genetic diversity, environmental effects, soil characteristics, or altitude. While there is general consistency for ‘Chandler’, ‘Pedro’, and ‘Şebin’, significant differences are found in some studies. Büyüksolak et al. (2020) reported that fruit size and shell thickness are affected by altitude, with values increasing as altitude increases.

Table 2. Some pomological characteristics of the walnut cultivars studied.

Cultivars	Fruit weight	Kernel weight	Kernel ratio	Fruit width	Fruit length	Fruit height	Shell thickness
Bilecik	12.39±0.01 b	6.07±0.13 b	49.03±1.04 a	29.84±0.29 c	29.78±0.57 c	32.46±0.30 d	1.21±0.06 c
Chandler	12.55±0.35 b	6.32±0.08 b	50.41±0.62 a	32.81±0.05 b	34.04±0.04 a	42.60±0.54 b	1.62±0.01 b
Pedro	11.57±0.01 c	4.99±0.01 c	43.17±0.03 b	29.14±0.15 c	29.91±0.23 bc	33.54±0.05 d	1.61±0.01 b
Şebin	12.35±0.13 b	5.96±0.35 b	48.41±2.05 a	31.87±0.20 b	31.48±0.70 b	38.52±0.13 c	1.52±0.11 b
Yalova-1	18.64±0.11 a	8.16±0.09 a	43.80±0.73 b	34.60±0.59 a	34.23±0.11 a	44.07±0.33 a	1.95±0.01 a
LSD	0.174	0.177	1.113	0.314	0.420	0.319	0.058

Values in the same column marked with different superscript letters are statistically different from each other ($p<0.05$).

The color values of the walnut cultivars were examined, and statistically significant differences were found among L*, a*, b*, chroma, and Hue^o values (Table 3). The L* value is a color parameter that indicates the lightness and darkness of the fruit. Among the cultivars studied, 'Chandler' had the highest L* value (56.48), indicating that it has the lightest kernel color, a feature generally preferred by consumers. 'Bilecik' (41.56) and 'Pedro' (42.09) had lower L* values, indicating darker colors. The a* value among color values is considered an indicator of kernel blackening, and thus, a lower value is desirable. 'Chandler' showed the best performance in terms of kernel blackening with the lowest a* value (7.76), while 'Bilecik' (11.64), 'Pedro' (12.81), 'Şebin' (12.42), and 'Yalova-1' (11.91) had similar a* values. The b* value is an indicator of the yellow color, and a higher value is desirable. 'Chandler' had the highest b* value (28.77), indicating it has the most yellowish color. 'Bilecik' (23.74) and 'Pedro' (23.93) had lower b* values, indicating they are less yellowish compared to 'Chandler'. Chroma value indicates the saturation of the color, with a higher chroma value indicating a more vivid color. 'Chandler' (29.77), 'Şebin' (29.16), and 'Yalova-1' (28.87) had high chroma values, indicating more saturated colors, while 'Bilecik' (26.74) and 'Pedro' (26.81) had lower chroma values. The Hue^o value indicates the tone of the color, with a higher Hue^o value indicating a more yellowish tone. 'Chandler' had the highest Hue^o value (74.92), indicating the most distinct color tone, while 'Bilecik' had a lower Hue^o value (60.78). Bilgin et al. (2023) reported that L* values ranged from 40.04 (Bursa-95) to 55.32 (Chandler), with a* values being low in Bursa-95 (13.52) and high in Chandler (7.76). They found that 'Chandler' had a high b* value (28.84), and the decrease in chroma value in 'Bursa-95' (26.76) compared to 'Chandler' (29.86) indicated a decrease in saturation, with the highest Hue^o found in 'Chandler'. Bayazit et al. (2019) reported L*, a*, b*, chroma, and Hue^o values for 'Şebin' as 59.71, 10.25, 16.35, 19.31, and 57.78, respectively, and for 'Bilecik' as 56.05, 10.57, 17.36, 20.34, and 58.56. The findings indicate that 'Chandler' generally stands out with lighter, more yellowish, and more saturated colors, while 'Bilecik' and 'Pedro' have darker and less saturated colors. Kernel color is an important quality parameter resulting from both cultivar characteristics and post-harvest processes (Bilgin et al., 2023). Overall, the findings from the walnut cultivars studied in the Tavas ecology are consistent with previous studies conducted in other ecologies.

Table 3. Color values of the walnut cultivars studied

Cultivars	L*	a*	b*	Chroma	Hue^o	Kernel color
Bilecik	41.56±0.11 c	11.64±0.33 a	23.74±0.23 d	26.74±0.05 b	60.78±0.59 d	Dark
Chandler	56.48±0.76 a	7.76±0.02 b	28.77±0.01 a	29.77±0.03 a	74.92±0.07 a	Light
Pedro	42.09±2.21 c	12.81±0.75 a	23.93±0.13 d	26.81±0.36 b	61.80±1.73 cd	Dark
Şebin	45.02±0.04 bc	12.42±0.06 a	27.36±0.21 b	29.16±0.22 a	67.33±0.32 b	Medium
Yalova-1	49.29±1.17 b	11.91±0.16 a	25.36±0.10 c	28.87±0.45 a	64.76±0.40 bc	Light
LSD	1.170	0.374	0.158	0.278	0.851	

Values in the same column marked with different superscript letters are statistically different from each other ($p<0.05$).

The relationships between the pomological characteristics and color values of the walnut cultivars studied are illustrated in Figure 2. A very strong positive relationship (0.943) was found between fruit weight and kernel weight, while a negative relationship (-0.414) was identified with the kernel ratio. Fruit width showed a strong positive correlation with both fruit weight (0.796) and kernel weight (0.883). Similarly, fruit length and height were positively related to fruit weight and kernel weight (0.657 and 0.679; 0.756 and 0.756, respectively). Shell thickness was positively correlated with fruit weight (0.732) and kernel weight (0.586), but negatively correlated with the kernel ratio (-0.590). Among the color parameters, the L* value was positively related to fruit width (0.711) and height (0.830). The a* value was negatively related to the kernel ratio (-0.629) and L* (-0.835). The b* value showed a positive relationship with the kernel ratio (0.574) and L* (0.813). Chroma value exhibited a strong positive correlation with fruit width (0.815) and height (0.876), but a negative correlation with the a* value (-0.586). The Hue° was positively related to L* (0.912) and b* (0.956), but negatively related to a* (-0.820). Soleimani et al. (2024) found a significant relationship between fruit shape and kernel percentage in different Iranian walnut cultivars, indicating that fruit shape is an important factor affecting the kernel ratio. Einollahi and Khadivi (2024) reported positive relationships between walnut weight and walnut dimensions, as well as between shell thickness and walnut weight, and generally positive relationships between kernel weight and fruit dimensions. Bernard et al. (2021) and Rezaei et al. (2018) reported a positive correlation between kernel weight and walnut weight. Kabiri et al. (2018), in their study on the morphological and pomological characteristics of walnut genotypes in the Moroccan ecology, found strong negative correlations between kernel weight and fruit length, fruit weight, and kernel color. Conversely, they found a strong positive correlation between kernel weight and kernel ratio. They also reported that fruit weight was positively and strongly related to fruit length and kernel color. Amiri et al. (2010) reported that kernel weight, walnut weight, shell thickness, and ease of kernel extraction from the walnut are the main variables determining kernel percentage and should be considered together in breeding studies. Examining the correlations between traits facilitates breeding programs (Amiri et al. 2010). Strong correlations, especially between size, shape, and weight parameters, can be important for walnut quality and classification.

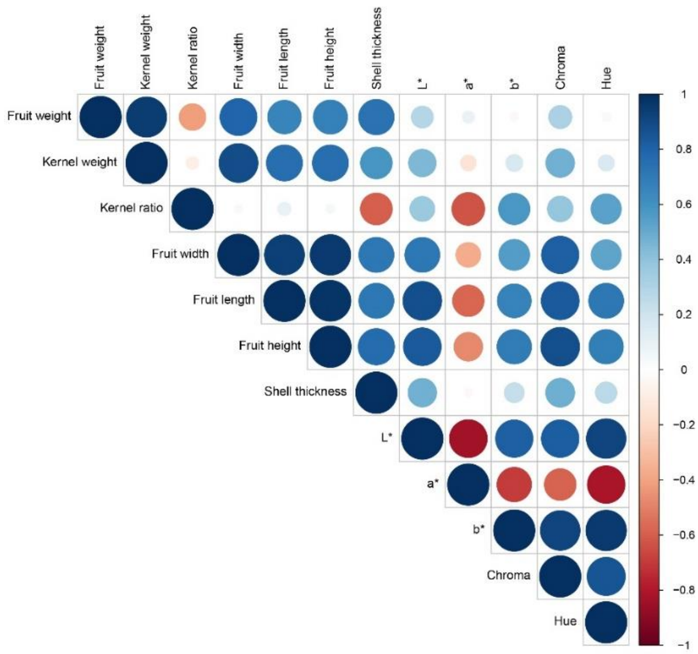

Figure 2. Correlation Analysis Among the Studied Traits in Walnut Cultivars

Principal Component Analysis (PCA) is a widely used statistical technique that reduces the dimensionality of a dataset while preserving as much data variation as possible (Jolliffe and Cadima, 2016). The PCA plot in Figure 3 shows the distribution of walnut cultivars based on their physical and color characteristics. The first two components (PC1 and PC2) explain 88.3% of the total variation, indicating a good summary of the data. PC1 accounts for 61.4% of the total variance and shows a strong relationship with size-related traits such as fruit weight, shell thickness, and kernel weight. The ‘Yalova-1’ cultivar has the highest positive value on PC1, standing out with its large and plump fruit characteristics. PC2 explains 26.9% of the variance and is associated with color traits such as the a* value. The ‘Pedro’ cultivar has a high positive value on PC2, differentiating itself in terms of color characteristics. ‘Chandler’ exhibits a balanced profile, occupying an average position in terms of both size and color traits, while ‘Bilecik’ and ‘Şebin’ are more centrally located, indicating more average characteristics compared to other cultivars. The kernel ratio shows a negative relationship with PC1, indicating an inverse relationship with size. This analysis provides important insights into how walnut cultivars differ based on phenotypic characteristics. Einollahi and Khadivi (2024) reported in their study on walnut genotypes that they included morphological traits in 14 principal components with eigenvalues greater than 1, explaining 72.64% of the total variance. Kabiri et al. (2018) found that the first two components explained 71.29% of the total variation in their study on the relationships between morphological and pomological traits of walnut genotypes. They reported that PC1 had a negative impact on fruit weight and length and kernel color, while it had a positive impact on kernel weight and kernel ratio. Bernard et al. (2020) found that the first two components (PC1 and PC2) explained 75.5% of the total variance in their study with 161 walnut types and cultivars. They reported that fruit weight, kernel weight, and fruit dimensions contributed highly to PC1, while shape index and shell strength were prominent in PC2. Sallom et al. (2023) reported that the PCA analysis summarized 26 traits into eight principal components, explaining 75.37% of the total variance in their study on the morphological and pomological characteristics of walnut genotypes. They also reported that the first component (PC1) explained 22.92% of the variance and included four important traits such as fruit length, width, weight, and kernel weight, while the second component (PC2) included traits such as leafing date, first female and male flowering, and harvest date, explaining 13.36% of the variance. Bükücü (2023) reported that seven independent components explained 72.51% of the total variation in his study on the pomological diversity of F1 walnuts (*Juglans regia* L.) and the differences between their parents. He reported that the first component (PC1) was defined by factors such as fruit weight, kernel weight, and shell thickness, explaining 26.82% of the variance, while the second component (PC2) was highlighted by factors such as ease of kernel extraction, explaining 13.55% of the variance. According to the findings, size-related traits such as fruit weight, kernel weight, and shell thickness generally contribute highly to the first component, while other traits such as color and shape are prominent in the second component. PCA analysis also provides valuable insights into how walnut cultivars differ in terms of marketability and consumer preferences. Similar results obtained in previous studies demonstrate that PCA can be used as a consistent and reliable method for evaluating walnut cultivars and genotypes.

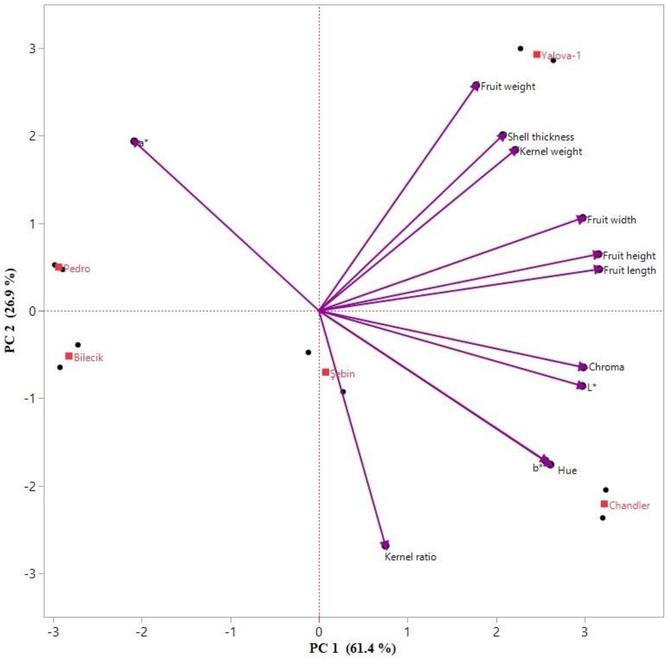

Figure 3. PCA Biplot analysis of the studied walnut cultivars and their traits

4. Conclusion

This study comprehensively evaluated the adaptation capabilities of walnut cultivars studied in the ecology of Tavas (Denizli). Phenological observations indicate that the ‘Bilecik’ cultivar, with its early leafing and flowering characteristics, may be vulnerable to early frost risk but offers the advantage of early harvest. The ‘Chandler’ cultivar, being the latest to leaf and flower, may perform better in the Tavas ecology and be more resistant to late frost risk. The ‘Yalova-1’ cultivar stands out with its large and plump fruit characteristics, while the ‘Chandler’ cultivar exhibits a balanced profile in terms of both size and color traits. ‘Chandler’ also showed the best performance in terms of kernel blackening and yellow color. The ‘Pedro’ and ‘Şebin’ cultivars, displaying more average characteristics, reveal the adaptation capabilities and agricultural productivity potential of the cultivars in the Tavas ecology. As a conclusion, for the region, ‘Chandler’ variety is recommended for high-quality kernel and high kernel ratio, ‘Yalova-1’ for large nut production, and ‘Bilecik’ for early harvest and marketing advantage. These recommendations will enable producers in the region to make selections according to their objectives (early market, kernel quality, nut size, etc.).

References

Akça, Y., 1999. Tokat ekolojik koşullarında bazı standart ceviz çeşitlerinin performanslarının saptanması üzerine bir araştırma (1997-1998 Dilimi), Kongre Bildiriler Kitabı, *Türkiye III. Ulusal Bahçe Bitkileri Kongresi*, 14-17 Eylül, Ankara, 2:41-46.

Akça, Y., Yılmaz, S., 2016. Tüplerde yetiştirilen farklı ceviz (*Juglans regia*) çeşitlerine ait çöğürlerin bazı morfolojik özelliklerinin ve kalitelerinin belirlenmesi. *Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi*, 33(3): 157-166.

Amiri, R., Vahdati, K., Mohsenipoor, S., Mozaffari, M.R., Charles, L., 2010. Correlations between some horticultural traits in walnut. *HortScience*, 45(11): 1690-1694.

Anonymous, 2023. Turkish State Meteorological Service, (https://www.mgm.gov.tr/eng/forecast-cit-ies.aspx), (Access date: 20.06.2024).

Asma, B.M., Öztürk, K., Zengin, Y., 1999. Malatya bölgesine uygun ceviz çeşitlerinin belirlenmesi. Kongre Bildiriler Kitabı, *Türkiye III. Ulusal Bahçe Bitkileri Kongresi*, 14-17 Eylül, Ankara, 27-30.

Bayazit, S., 2011. Bazı ceviz (*Juglans regia* L.) genotiplerinin Yayladağı (Hatay) koşullarındaki fenolojik özellikleri ve yan dal verimliliği. *Atatürk Üniversitesi Ziraat Fakültesi Dergisi*, 42(2): 95-102.

Bayazit, S., Calıskan, O., Kılıc, D., 2019. Pomological and chemical properties of some walnut genotypes in central Anatolia. *Journal of Agricultural Faculty of Gaziosmanpaşa University,* 36(3): 243-249.

Bayazit, S., Tefeki, H., Çalışkan, O., 2016. Türkiye'de ceviz (*Juglans regia* L.) araştırma. *Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi*, 11(1): 169-179.

Bernard, A., Crabier, J., Donkpegan, A., Marrano, A., Lheureux, F., Dirlewanger, E., 2021. Genome-wide association study reveals candidate genes involved in fruit trait variation in persian walnut (*Juglans regia* L.). *Frontiers in Plant Science*, 11.

Bernard, A., Hamdy, S., Le Corre, L., Dirlewanger, E., Lheureux, F., 2020. 3D characterization of walnut morphological traits using X-ray computed tomography. *Plant Methods*, 16: 1-11.

Bilgin, N.A., Üründü, H.E., Mısırlı, A., Mansoor, M., 2023. Performances of Walnut Varieties Produced in Kale/Denizli District. *Anadolu Ege Tarımsal Araştırma Enstitüsü Dergisi*, 33(1): 88-94.

Bilgin, S., Şen, F., Özeker, E., Bilgin, N.A., 2018. Bazı ceviz çeşitlerinin menemen ekolojisinde morfolojik ve pomolojik özelliklerinin belirlenmesi. *Çanakkale Onsekiz Mart Üniversitesi Ziraat Fakültesi Dergisi*, 6(1): 31-39.

Bükücü, Ş.B., 2023. The pomological diversity of F1 walnut (*Juglans regia* L.) progenies and differences between their parents. *Erwerbs-Obstbau*, 65(4): 807-818.

Büyüksolak, Z., Aşkin, M., Kahramanoglu, I., Okatan, V., 2020. Effects of altitude on the pomological characteristics and chemical properties of 'Chandler' walnuts: A case study in Uşak province. *Acta Agrobotanica*, 73(3).

Çoban, İ., 2020. Chandler, Kaman-1 ve Midland ceviz (*Juglans regia*) çeşitlerinin fonolojik, pomolojik ve biyokimyasal özelliklerin karşılaştırılması. Yüksek Lisans Tezi, Kırşehir Ahi Evran Üniversitesi, Fen Bilimleri Enstitüsü, Kırşehir

Einollahi, F., Khadivi, A., 2024. morphological and pomological assessments of seedling-originated walnut (*Juglans regia* L.) trees to select the promising late-leafing genotypes. *BMC Plant Biology*, 24(1).

Gerçekcioğlu, R., Gültekin, N., Bayındır, Y., Özatasever, Ö., 2019. Hekimhan yöresinde ceviz (*Juglans regia* L.) genotiplerinin seleksiyonu. *Gaziosmanpaşa Bilimsel Araştırma Dergisi*, 8(3): 70-81.

Güller, O., 2020. Sakarya bölgesinde yetiştirilen bazı önemli ceviz genotiplerinin (*Juglans regia* L.) fenolojik ve pomolojik özelliklerinin belirlenmesi. Yüksek Lisans Tezi, Sakarya Üniversitesi Fen Bilimleri Enstitüsü, Sakarya.

Gülsoy, E., Kaya, T., Pehluvan, M., Şimşek, M., 2016. Iğdır ilinden seçilen ceviz (*Juglans regia* L.) genotiplerinin bazı pomolojik ve kimyasal özellikleri. *Anadolu Journal of Agricultural Sciences*, 31(3): 309-314.

Güvenç, İ., Kazankaya, A., 2019. Türkiye'de ceviz üretimi, dış ticareti ve rekabet gücü. *Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi*, 29(3): 418-424.

Jahanban-Esfahlan, A., Ostadrahimi, A., Tabibiazar, M., Amarowicz, R., 2019. A comparative review on the extraction, antioxidant content and antioxidant potential of different parts of walnut (*Juglans regia* L.) fruit and tree. *Molecules*, 24(11): 2133.

Jolliffe, I.T., Cadima, J., 2016. Principal Component Analysis: A review and recent developments. philosophical transactions of the royal cociety a: *Mathematical, Physical and Engineering Sciences*, 374(2065): 20150202.

Kabiri, G., Bouda, S., Elhansali, M., Haddioui, A., 2018. Morphological and pomological variability analysis of walnut (*Juglans regia* L.) genetic resources from the middle and high atlas of Morocco. *Atlas Journal of Biology*, 575-582.

Karadeniz, T., Güler, E., Yazıcı, L., 2017. Artvin yöresinde yetişen cevizlerin meyve özellikleri. *Bahçe*, 46(2): 281-287.

Kırca, S., Yarılgaç, T., Kırca, L., Bak, T., 2014. Study on the selection of walnut (*Juglans regia* L.) in Trabzon. *Türk Tarım ve Doğa Bilimleri Dergisi*, 1(Özel Sayı-1): 835-841.

Koyuncu, M.A., Koyuncu, F., Yıldırım, A., Akıncı, F., Dilmaçünal, T., Vural, E., 2005. Gelincik (Isparta) doğal ceviz genotiplerinin yan dal verimliliği ve meyve özelliklerinin belirlenmesi. *Bahçe*, 34 (1): 73-82.

Miletić, R., Mitrović, M., Rakićević, M., 2009. The effect of meteorological factors on major properties of selected walnut cultivars. *Plant Science*, 46: 219–223.

Oruç, G., 2020. Aydın İli Karacasu ilçesi ceviz (*Juglans regia* L.) genotiplerinin seleksiyonu. Doktora Tezi, Aydın Adnan Menderes Üniversitesi, Fen Bilimleri Enstitüsü, Aydın.

Rezaei, Z., Khadivi, A., Valizadeh Kaji, B., Abbasifar, A., 2018. The selection of superior walnut (*Juglans regia* L.) genotypes as revealed by morphological characterization. *Euphytica*, 214(4).

Salık, M.A., Çakmakçı, S., 2023. Walnut (*Juglans regia* L.) leaves and green husks: their functional properties, health benefits and potential use in foods. *Akademik Gıda*, 21(1): 90-100.

Sallom, A., Fatahi, R., Zamani, Z., 2023. Morphological, phenological, and pomological diversity among 130 seed-propagated walnut (*Juglans regia* L.) trees and apomixis study in some selected genotypes. *Erwerbs-Obstbau*, 65(1): 101-113.

Soleimani, A., Rabiei, V., Hassani, D., Mozaffari, M.R., Dastjerdi, R., 2024. Yield related traits in some Persian walnut cultivars: analysis of genetic and genetic by environment interaction. *Advances in Horticultural Science*, 37(4): 367-376.

Sütyemez, M., Bükücü, Ş.B., Keleş, Ö., Özcan, A., Yıldırım, E., Boyacı, S., 2021. Phenological differences, genetic diversity, and population structure of genotypes obtained from seeds of Kaman-1 walnut cultivar. *Journal of Food Quality*, 1-9.

Sütyemez, M., Özcan, A., Yılmaz, A., Yıldırım, E., Bükücü, Ş.B., 2022. Determining phenological and genetic variation in genotypes obtained from open-pollinated seeds of 'Maraş 12' walnut (*Juglans regia* L.) cultivar. *Genetic Resources and Crop Evolution*, 1-16.

Şen, S.M., 2009. Ceviz yetiştiriciliği, besin değeri, folklorü. Üçüncü Baskı, ÜÇM Yayıncılık. 207s, Ankara.

Şen, S.M., Karadeniz, T., Beyhan, Ö., 2011. Sorularla ceviz yetiştiriciliği. ÜÇM Yayıncılık, 208s, Ankara.

Şen, S.M., Kazankaya, A., Yarılgaç, T., Doğan, A., 2006. Bahçeden mutfağa ceviz. Maji Yayınları, 233s, Ankara.

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