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Research Article

The Pomological and Morphological Characterization of Different Foreign Almond Cultivars and the Local Type Grown under Ecological Conditions of Çanakkale

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Abstract

The present study aims to investigate the pomological and morphological characteristics of different foreign almond [*Prunus dulcis* (Miller) D.A. Webb] cultivars and local type cultivated in Çanakkale ecological conditions. Within the scope of the study, Ferragnes, Ferraduel, Texas, Laurenne and Nonpareil were used as foreing almond cultivars, while Alçıtepe was selected as local type. Two-year data were used in the study. In 2023 and 2024, fruit characteristics of the cultivars and local type harvested in August-September, shelled and ushelled measurements, leaf and petiole characteristics and SPAD values indicating photosynthetic capacity were compared to obtain in-depth information about the production potential and quality parameters of different cultivars and local type. With regard to shelled and unshelled characteristics, the Ferraduel cultivar exhibited the longest shell width (23.32 mm), the Nonpareil cultivar demonstrated the longest shell length (38.99 mm), while the Ferragnes and Texas cultivars exhibited shorter shell characteristics. The highest unshelled fruit weight was found in cultivar Laurenne (2.46 g), while local type Alçıtepe had the lowest unshelled weight (1.30 g). Regarding the unshelled yield ratio, the cultivars Texas (40.31%) and Ferragnes (33.23%) had the highest yield ratios. These results show that there is a large variation in shelled yield ratio between cultivars. When leaf and petiole characteristics were analysed, Ferraduel cultivar had the largest leaf (32.80 mm), while Alçıtepe local type and Texas cultivar had smaller leaves. In terms of SPAD value, Laurenne (42.16) and Alçıtepe (41.60) had the highest values, while Texas (37.38) and Ferragnes (38.56) had lower SPAD values. This shows that there are significant differences in the photosynthetic capacity of different cultivars and this is an important factor in terms of productivity. In conclusion, this study revealed significant differences in pomological and morphological characteristics of some important almond cultivars and local type and highlighted that some cultivars provide larger fruits and higher yields. It is predicted that the results obtained will be an important guide for the selection of productive cultivars in almond production and the improvement of production techniques for almond local type.
Keywords: Local type, standart cultivars, pomological traits, morphological traits.

Çanakkale Ekolojik Koşullarında Yetiştirilen Farklı Yabancı Badem Çeşitleri ve Yerel Tipin Pomolojik ve Morfolojik Karakterizasyonu

Öz

Bu çalışma, Çanakkale ekolojik koşullarında yetiştirilen farklı yabancı badem [*Prunus dulcis* (Miller) D.A. Webb] çeşitlerinin ve yerel tipinin pomolojik ve morfolojik özelliklerini incelemeyi amaçlamaktadır. Çalışma kapsamında Ferragnes, Ferraduel, Texas, Laurenne ve Nonpareil olmak üzere yabancı badem çeşitleri ile Alçıtepe yerel tipi kullanılmıştır. Çalışmada iki yıllık veriler elde edilerek, 2023 ve 2024 yıllarında, Ağustos-Eylül döneminde hasat edilen çeşitlerin ve yerel tipin meyve özellikleri, kabuklu ve kabuksuz ölçümleri, yaprak ve petiol özellikleri ile fotosentetik kapasiteyi belirten SPAD değerleri karşılaştırılarak, farklı çeşitlerin ve yerel tipin üretim potansiyeli ve kalite parametreleri hakkında derinlemesine bilgi elde edilmiştir. Kabuklu ve kabuksuz özellikler açısından Ferraduel çeşidi en geniş kabuk genişliğine (23,32 mm) sahipken, Nonpareil çeşidi en uzun kabuk uzunluğunu (38,99 mm) göstermiştir. Buna ek olarak, Ferragnes ve Texas çeşitleri daha kısa kabuk özelliklere sahip olduğu belirlenmiştir. En yüksek iç badem ağırlığı Laurenne çeşidinde (2,46 g) bulunurken, Alçıtepe yerel tipinin en düşük kabuksuz ağırlığa (1,30 g) sahip olduğu tespit edilmiştir. İç randıman oranı açısından Texas (40,31%) ve Ferragnes (33,23%) çeşitleri en yüksek verim oranlarına sahip olduğu belirlenmiştir. Bu sonuçlar, çeşitler arasında iç randıman oranında büyük bir varyasyon olduğunu göstermektedir. Yaprak ve petiol özellikleri

incelendiğinde, Ferraduel çeşidi en büyük yaprağa (32,80 mm) sahipken, Alçıtepe yerel tipi ve Texas çeşidi daha küçük yapraklara sahip olduğu gözlenmiştir. SPAD değeri açısından Laurenne (42,16) ve Alçıtepe (41,60) en yüksek değerlere sahipken, Texas (37,38) ve Ferragnes (38,56) daha düşük SPAD değerlerine sahip olduğu tespit edilmiştir. Bu durum, farklı çeşitlerin fotosentetik kapasitesinde önemli farklılıklar olduğunu ve bunun üretkenlik açısından önemli bir faktör olduğunu göstermektedir. Sonuç olarak, bu çalışma, bazı yabancı badem çeşitleri ve yerel tipinin pomolojik ve morfolojik özelliklerinde önemli farklılıklar ortaya koymuş ve bazı çeşitlerin daha büyük meyveler ve daha yüksek verimler sağladığını vurgulamıştır. Elde edilen sonuçların, badem üretiminde verimli çeşitlerin seçimi yerel badem tiplerinin üretim tekniklerinin geliştirilmesi için bir referans kaynak teşkil edeceği öngörülmektedir.
Anahtar Kelimeler: Yerel tip, standart çeşitler, pomolojik özellikler, morfolojik özellikler.

Introduction

Almond [*Prunus dulcis* (Miller) D.A. Webb L.] is a hard-shelled fruit species that has been cultivated since ancient times. It belongs to the genus *Prunus*, subgenus *Amygdalus*, subfamily *Prunoidea*, family *Rosaceae*, order *Rosales* (Mitra, 2020). The cultivation of almonds, originating from Central and Western Asia and occupying a significant position in global hard-shelled fruit production, has witnessed a notable increase in its prevalence within our nation (Ladizinsky, 1999). Globally, almond production is estimated to be 3.630.427 tons, cultivated across an area of 2.357.075 hectares. Turkey is the fourth-largest producer, with an annual yield of 190.000 tons and an area dedicated to almond cultivation of 63.266 hectares (FAO, 2023). A notable escalation in almond production was observed within the country between 2010 and 2023, accompanied by the establishment of a substantial number of new almond orchards (April, 2024). The key factors contributing to almonds' growing appeal include their remarkable adaptability to diverse soil conditions, their numerous health benefits, and their status as a highly lucrative fruit species (Reisman, 2020).

Almond consumption has been demonstrated to provide significant nutritional benefits, attributable to their high mineral and vitamin content (Chukwuma et al., 2024). Almonds are notable for their abundance of healthy monounsaturated fats, protein, vitamin E, B vitamins, and minerals such as magnesium, potassium, calcium, and phosphorus. A 100-gram serving of almonds contains approximately 579 calories, 49 grams of fat, 21 grams of protein, and 12 grams of fibre (El Bernoussi et al., 2024). The aforementioned nutrients contribute to the promotion of cardiovascular health, the regulation of blood sugar levels, antioxidant properties, and the facilitation of digestive processes.Notably, almonds, which are abundant in vitamin E and phenolic compounds, provide antioxidant support to the body, thereby potentially mitigating cellular damage (Singar et al., 2024).

Pomological traits encompass physical characteristics such as fruit size, shape, weight and peel thickness, while morphological traits comprise structural elements of the plant and adaptability to environmental factors (Uzun et al., 2024). The present study aims to provide a detailed comparison of the morphological and pomological characteristics of almond local type and cultivars. The analysis of these differences offers a more comprehensive understanding of the factors influencing the cultivation of each cultivar, including suitable environmental conditions, water requirements and climate tolerance. In the context of almond cultivation, the variation in productivity among local type, along with their capacity to withstand environmental stresses, offers significant economic insights. Furthermore, the undertaking of pomological and morphological characterisation studies will facilitate the development of marketing strategies, quality control measures and farming practices for almond species.

The results of this study are expected to contribute to the determination of suitable cultivars for more efficient and quality production in almond cultivation. Furthermore, such comparisons provide essential information for the selection of cultivars that are particularly resistant to environmental stresses such as drought and temperature (Rahemi and Gradziel, 2024). Consequently, it will be possible to develop productive almond cultivars that are resistant to the effects of environmental changes such as climate change.

Materials and Methods

Materials

The present study was conducted in the 2023 and 2024 production season at a producer orchard located in Umurbey Village, Lapseki District, Çanakkale Province (parcel 285/19). Cultivation of almond cultivars was undertaken under optimal conditions, with harvesting occurring at the commercial maturity stage.The present study focuses on the pomological and morphological traits of the following almond cultivars grafted onto GF677 rootstock: The cultivars included in the study were Ferraduel, Ferragnes, Texas, Laurenne, Nonpareil, and the local almond type, Alçıtepe (Figure 1). The trees were 11 years old, spaced 1 metre apart within each row, with a 3-metre distance between each row. The dates of harvest for the almond cultivars and local type are provided in Table 1.

Figure 1. Images of almond cultivars/local type used in the study

Table 1. The harvest dates of the almond cultivars and local type

Cultivar/Local Type Name	Harvest Dates-2023	Harvest Dates-2024
Ferraduel	13 August 2023	15 August 2024
Ferragnes	12 August 2023	15 August 2024
Texas	16 August 2023	18 August 2024
Laurenne	8 September 2023	10 September 2024
Nonpareil	13 August 2023	15 August 2024
Alçıtepe	22 August 2023	20 August 2024

Methods

Collection of Leaf Samples

The collection of leaf samples was conducted in accordance with the following methodology, which is outlined in detail below. Leaves that had reached full development were collected from the four cardinal points of the tree. A total of 100 leaves were taken from each tree, along with their petioles (Figure 2). The sampling method was an X-shape in the relevant orchard, with one tree skipped. The leaf samples were placed in aluminium foils and placed in an ice box. The label information included the name of the sample, the name of the orchard where the sample was taken, the date the sample was taken and the age of the tree. The leaf samples were transferred to the laboratory as soon as possible under cold chain conditions.

Collection of Fruit Samples

Fruits were randomly selected from all four sides of the tree (X-shaped) to represent the production orchard. A total of 30 fruit samples were taken from each tree. The measurements performed on the fruits were determined in three replicates, with 10 fruits in each replicate.

Figure 2. An image of collected leaves (front and rear view)

Measurements Performed in the Study

Shelled width (mm): The harvested shelled almonds were measured with a caliper in three replicates, with 10 almonds in each, between the dorsal part of the almond and the abdominal line, as well as between the cheek parts of the almonds to the right and left of the abdominal line. The measurements were averaged to obtain a single value for each replicate.

Shelled length (mm): The length between the almond tip and the stem pit was measured with a caliper in the harvested shelled almonds, with three replicates comprising 10 fruits each.

Shelled weigth (g): The weight of each shelled almond was determined by weighing it individually on a precision balance with a precision of ±0.01 g.

Shell thickness (mm): The average values of the inner shell were measured using a caliper gauge, with 3 replicates and 10 almonds in each replicate.

Unshelled width (mm): The harvested unshelled almonds were measured with a caliper in three replicates, with 10 almonds in each, between the dorsal part of the almond and the abdominal line, as well as between the cheek parts of the almonds to the right and left of the abdominal line. The measurements were averaged to obtain a single value for each replicate.

Unshelled length (mm): The length between the almond tip and the stem pit was measured with a caliper in the harvested unshelled almonds, with three replicates comprising 10 fruits each.

Unshelled weigth (g): The weight of each unshelled almond was determined by weighing it individually on a precision balance with a precision of ±0.01 g.

Unshelled yield (%): It was obtained by dividing the average inner almond weight by the shelled fruit weight. Expressed as %.

Unshelled L, a*, b*: The CIE L, a*, and b* values were determined on both cheeks using a Minolta colorimeter (CR-400, Minolta Co., Tokyo, Japan) in triplicate and 10 unshelled almonds from each replicate.

Leaf width (mm): It was measured using a ruler over the widest part of the leaf. It was determined with 3 replicates and by averaging the values of 10 randomly selected leaves in each replicate.

Leaf length (mm): The distance from the base of the leaf (i.e. the beginning of the petiole) to the tip of the leaf. It was determined in 3 replicates and by averaging the values of 10 randomly selected leaves in each replicate.

Petiol width (mm): The two ends of the callipers were placed at the widest point of the stem and measured as such. The measurement was recorded as the distance from the fixed part of the caliper to the other end of the caliper and expressed in millimetres. Calculated in 3 replicates and averaged over 10 randomly selected leaf samples in each replicate.

Petiol length (mm): It was calculated using callipers by averaging the petioles of 10 randomly selected leaves in 3 replicates and in each replicate.

Leaf area (mm^2): Average leaf areas were calculated using the Leaf Area Measurement Program version 1.3 (The University of Sheffield, 2003).

SPAD: The data was recorded as the mean of three measurements taken from the leaf situated at the apex of the shoots. For this purpose, 10 randomly selected leaves were used. The measurements were taken with a SPAD device.

Statistical Analyses

The results obtained in the study were evaluated by analysis of variance using the "SAS 9.1.3 Portable" statistical package. The differences between cultivars and local type in the parameters studied were evaluated by the LSD multiple comparison test at the p<0.05 level. For morphological data, the criteria developed by the International Union for the Protection of New Varieties of Plants (UPOV-TG/56/4 Corr. Rev.) for the almond species were taken into account.

Results and Discussion

The highest unshelled width was recorded in the Ferraduel cultivar at 12.56 mm, while the lowest value was observed in the Alçıtepe local type at 10.94 mm. This indicates that the Alçıtepe local type has a narrower shell structure compared to the cultivars. The longest unshelled length was measured in the Laurenne cultivar at 29.86 mm, whereas the shortest was found in the Alçıtepe local type at 21.26 mm. This suggests that the Alçıtepe local type exhibits a shorter shell length relative to the other cultivars (Table 2).

The Alçıtepe local type displayed the lowest unshelled weight at 1.30 g, whereas the highest weight was recorded in the Laurenne cultivar at 2.46 g. This finding highlights that the Alçıtepe local type possesses a lighter shell structure compared to the cultivars. The Ferraduel cultivar exhibited the widest shelled width at 23.32 mm, while the narrowest was observed in the Texas cultivar at 17.96 mm.

Table 2. The pomological traits of almond cultivars and local type

Cultivar/ Local Type	Shelled width (mm)	Shelled length (mm)	Unshelled width (mm)	Unshelled length (mm)	Shelled weigth (g)	Unshelled weigth (g)	Unshelled yield (%)	Shell thickness (mm)
Ferraduel	23.32±0.77^{a}	36.66±1.96^{a}	12.56±0.40^{a}	26.63±1.39^{cd}	8.32±0.69^{a}	2.04±0.18^{c}	24.66±3.51^{c}	1.68±0.15^{a}
Ferragnes	18.88±0.79^{dc}	33.23±1.26^{b}	11.51±0.50^{dc}	25.42±0.33^{d}	5.39±0.53^{c}	1.78±0.08^{d}	33.23±1.80^{b}	1.20±0.18^{c}
Texas	17.96±0.66^{d}	36.72±2.06^{a}	11.70±0.27^{bc}	27.66±1.03^{cb}	5.35±0.26^{c}	2.15±0.10^{bc}	40.31±2.34^{a}	1.56±0.06^{a}
Laurenne	19.70±0.36^{c}	38.48±1.31^{a}	12.36±0.13^{ba}	29.86±0.42^{a}	7.64±0.35^{ba}	2.46±0.11^{a}	32.24±1.98^{b}	1.56±0.06^{a}
Nonpareil	20.92±0.46^{b}	38.99±0.49^{a}	12.35±0.34^{ba}	28.38±0.51^{b}	6.93±0.54^{b}	2.27±0.09^{ba}	32.93±2.96^{b}	1.36±0.06^{bc}
Alçıtepe	21.16±0.39^{b}	32.74±1.14^{b}	10.94±0.53^{d}	21.26±0.45^{e}	5.86±0.10^{c}	1.30±0.14^{e}	22.26±2.30^{c}	1.50±0.07^{ba}
LSD$_{(0.05)}$	1.0653 **	2.612 **	0.6876 **	1.4048 **	0.8117 **	0.2163 **	4.5395 **	0.1951 **

** There are statistically significant differences among cultivars/local type in terms of the related trait (p<0.05)

The Alçıtepe local type, with a shelled width of 21.16 mm, positioned itself at an intermediate level among the cultivars. The Nonpareil cultivar had the longest shelled length at 38.99 mm. In contrast, the Alçıtepe local type demonstrated a shorter shelled length at 32.74 mm. The highest shelled weight was recorded in the Ferraduel cultivar at 8.32 g, while the Alçıtepe local type had a moderate shelled weight of 5.86 g. The thinnest shell was observed in the Ferragnes cultivar at 1.20 mm, while the thickest shell was recorded in the Ferraduel cultivar at 1.68 mm. The Alçıtepe local type exhibited a shell thickness of 1.50 mm, which was comparable to most cultivars. The highest unshelled yield was observed in the Texas cultivar at 40.31%, while the lowest yield was recorded in the Alçıtepe local type at 22.26%. This suggests that the shell weight may negatively influence the kernel yield of the Alçıtepe local type (Table 2).

In this study, Ferraduel exhibited the widest unshelled width 12.56 mm, while Alçıtepe had the narrowest 10.94 mm. Previous research by Khadivi-Khub and Etemadi-Khah (2015), also found considerable differences in unshelled width among almond cultivars, with cultivars like Tuono and Ferraduel showing significantly wider shells. The narrower shell of Alçıtepe in this study aligns with findings from Li et al. (2018), who observed that local type with narrower shells often exhibit higher kernel proportions. However, this study indicates that Alçıtepe's smaller shell does not necessarily translate to higher unshelled yields, as it showed the lowest yield among the tested local type. This is consistent with observations by Calle et al. (2024), who suggested that while narrower shells may reduce processing costs, they can sometimes lead to lower kernel yields due to a higher proportion of empty or smaller kernels.

The Laurenne cultivar, with the longest unshelled length 29.86 mm, contrasts with the findings of Gouta et al. (2021), who reported that cultivars with longer shells tend to have better resistance to mechanical damage during harvesting. This suggests that while Alçıtepe exhibits a shorter shell, its overall yield is negatively impacted, possibly due to its lighter shell weight and other physiological factors. The unshelled weight was significantly lighter in Alçıtepe 1.30 g compared to Laurenne 2.46 g, which corroborates the results of Aktas et al. (2007), who observed that lighter shells do not always correlate with higher kernel yields, highlighting the complexity of yield determination in almond breeding.

The shell thickness in this study ranged from 1.20 mm in Ferragnes to 1.68 mm in Ferraduel, with Alçıtepe having a shell thickness of 1.50 mm. The thicker shells in Ferraduel were similar to those reported by Du and Tan (2021), who found that thicker shells were more resistant to cracking during mechanical harvesting, but this also increased the energy requirements for shelling. On the other hand, the thinner shell of Ferragnes in this study aligns with the results of Lipan et al. (2024), who found that thinner shells may be advantageous in terms of easier cracking, but this can result in lower protection for the kernel, affecting its overall quality. The moderate shell thickness in Alçıtepe 1.50 mm suggests that it strikes a balance between the advantages of shell protection and the disadvantages of requiring more energy for cracking.

The most striking finding of this study was the significant difference in unshelled yield between the cultivars. Texas exhibited the highest unshelled yield at 40.31%, while Alçıtepe showed the lowest yield at 22.26%. This trend is consistent with previous studies such as Khadivi et al. (2019), which indicated that cultivars with heavier shells tend to yield higher percentages of kernel. The higher unshelled yield in Texas may be linked to its shell-to-kernel ratio, as heavier and more robust shells may protect the kernels more effectively during processing, resulting in higher kernel quality and yield.

In contrast, the Alçıtepe local type's lower unshelled yield supports the findings of Ledbetter (2008), who concluded that local type with smaller or lighter shells often produce lower kernel yields due to reduced kernel size or density. This study suggests that the shell weight may negatively influence kernel yield in Alçıtepe, likely due to a higher proportion of non-commercial kernels or a lower overall kernel weight. This observation highlights the importance of considering both shell weight and kernel characteristics when selecting almond cultivars for high yield.

The Ferraduel and Ferragnes cultivars, which exhibited higher unshelled yields and wider shells, align with the findings of Wang et al. (2020) and Khojand et al. (2024), who suggested that larger, heavier shells are often associated with higher kernel yields, likely due to the protective benefits they offer. Texas, similarly, exhibited high kernel yields, though it had a narrower shell compared to Ferraduel. This suggests that other factors, such as genetic makeup and internal kernel quality, play a role in determining kernel yield, beyond just shell characteristics.

Conversely, Alçıtepe, despite its small shell, showed lower kernel yields, possibly due to its lighter shell structure. This aligns with the findings of Sideli et al. (2023), who indicated that lighter, narrower shells can sometimes be less efficient in protecting the kernel, which may result in lower overall yield in terms of marketable kernels.

The highest unshelled yield was observed in the Texas cultivar at 40.31%, while the lowest yield was recorded in the Alçıtepe local type at 22.26%. This suggests that the shell weight may negatively impact the kernel yield of the Alçıtepe local type (Table 2).

In terms of leaf width, the widest leaves were found in Ferraduel 32.80 mm, while the narrowest were observed in Alçıtepe 21.24 mm. For leaf length, the longest leaves were recorded in Laurenne 98.53 mm, while the shortest were found in Alçıtepe 78.30 mm. Regarding petiole width, Ferragnes exhibited the widest petioles 1.20 mm, while Alçıtepe had the narrowest 0.74 mm. The longest petiole was observed in Ferragnes 17.60 mm, and the shortest in Laurenne 13.73 mm (Table 3).

Table 3. The pomological and morphological traits of almond cultivars and local type

Cultivar/ Local Type	Unshelled L*	Unshelled a*	Unshelled b*	Leaf width (mm)	Leaf length (mm)	Petiol width (mm)	Petiol length (mm)	Leaf area (mm^2)	SPAD
Ferraduel	$58.03±2.48^{b}$	$12.05±1.28^{ba}$	$45.76±1.76^{c}$	$32.80±1.00^{a}$	$96.60±1.00^{b}$	$1.15±1.00^{a}$	$16.00±1.00^{a}$	$2501.6±2.00^{a}$	$41.50±1.00^{a}$
Ferragnes	$63.84±2.64^{b}$	$7.23±1.56^{c}$	$42.85±0.68^{d}$	$31.60±1.00^{a}$	$98.20±1.00^{ba}$	$1.20±1.00^{a}$	$17.60±1.00^{a}$	$2469.6±2.00^{a}$	$38.56±1.00^{b}$
Texas	$59.65±2.91^{b}$	$11.21±2.61^{ba}$	$50.59±0.56^{ba}$	$23.00±1.00^{c}$	$89.40±1.00^{c}$	$1.04±0.05^{a}$	$13.80±1.00^{b}$	$1340.6±2.00^{cb}$	$37.38±1.00^{b}$
Laurenne	$61.54±2.18^{ba}$	$11.09±1.97^{ba}$	$52.67±2.39^{a}$	$27.93±0.58^{b}$	$98.53±0.58^{a}$	$1.12±1.00^{a}$	$13.73±0.58^{b}$	$1739.9±2.00^{b}$	$42.16±1.00^{a}$
Nonpareil	$63.82±0.23^{a}$	$9.35±0.45^{bc}$	$50.13±0.34^{b}$	$23.20±1.00^{c}$	$83.40±1.00^{d}$	$1.16±1.00^{a}$	$16.00±1.00^{a}$	$1708.4±2.00^{cb}$	$41.24±1.00^{a}$
Alçıtepe	$46.21±0.38^{c}$	$12.83±0.50^{a}$	$35.58±0.83^{e}$	$21.24±1.00^{d}$	$78.30±1.00^{e}$	$0.74±0.01^{a}$	$16.02±1.00^{a}$	$1230.9±2.00^{c}$	$41.60±1.18^{a}$
$LSD_{(0.05)}$	3.739 **	2.8316 **	2.3397 **	1.6773 **	1.6773 **	N.S.*	1.6773 **	480.01 **	1.8378 **

** There are statistically significant differences among cultivars/local type in terms of the related trait ($p<0.05$)
*N.S. There are not statistically significant differences among cultivars/local type in terms of the related trait ($p<0.05$)

The largest leaf area was found in Ferraduel 2501.6 mm², while the smallest was observed in Alçıtepe 1230.9 mm². In terms of chlorophyll content (SPAD), the highest value was recorded in Ferraduel 41.50, while the lowest was observed in Texas 37.38. These results indicate that the Alçıtepe local type generally exhibits lower yield and leaf characteristics, while cultivars like Ferraduel and Ferragnes demonstrate higher yield and better leaf traits (Table 3).

The widest leaves were found in the Ferraduel cultivar 32.80 mm, while the narrowest were observed in the Alçıtepe local type 21.24 mm. This result indicates that Ferraduel has larger and broader leaves, which may contribute to higher photosynthetic capacity, thus enabling more energy production. Nortes et al. (2009) reported that broader leaves allow for more light capture, which could enhance overall plant productivity. The narrow leaves of the Alçıtepe local type, as observed in this study, have been similarly noted in other research, where narrow leaves typically correlate with lower photosynthetic activity and potentially reduced yield (Ranjbar et al., 2021).

In terms of leaf length, the longest leaves were recorded in Ferragnes 98.20 mm, while the shortest were found in Texas 89.40 mm. Ferragnes's longer leaves may contribute to more efficient use of water and nutrients, which could positively affect yield. Moldero et al. (2021) highlighted that longer leaves provide a larger surface area, thereby increasing photosynthetic efficiency. In contrast, Texas's shorter leaves, which offer less surface area, might limit photosynthetic capacity and result in lower yields.

Regarding petiole width, Ferragnes exhibited the widest petioles 1.20 mm, while Alçıtepe had the narrowest 0.74 mm. The wider petioles in Ferragnes might facilitate more efficient transport of water and nutrients. Alçıtepe's narrower petioles could be associated with a lower capacity for transporting these substances. Egea et al. (2012) emphasized that petiole width plays a crucial role in nutrient and water transport, affecting overall plant health and growth.

As for petiole length, the longest petiole was observed in Ferragnes 17.60 mm, and the shortest in Texas 13.80 mm. Longer petioles support better leaf positioning, which may increase the leaf's exposure to sunlight, aiding in photosynthesis. Trainin et al. (2022) suggested that longer petioles could result in more favorable light interception, thereby enhancing photosynthesis and growth.

The largest leaf area was found in Ferraduel 2501.6 mm², while the smallest was observed in Alçıtepe 1230.9 mm². The larger leaf area of Ferraduel likely contributes to its higher photosynthetic capacity, enabling better growth and yield. Gohari et al. (2023) noted that larger leaf areas correspond to higher photosynthetic activity, which can promote plant growth and yield. The smaller leaf area in Alçıtepe is indicative of reduced photosynthetic potential and may contribute to lower yields.

In terms of chlorophyll content (SPAD), the highest value was recorded in Ferraduel 41.50, while the lowest was found in Texas 37.38. Chlorophyll content is a key indicator of photosynthetic efficiency, and Ferraduel's higher chlorophyll content suggests that it has a better capacity for photosynthesis, leading to higher yield potential. Prgomet et al. (2020) stated that higher chlorophyll levels are associated with better growth and productivity. The lower chlorophyll content in Texas may suggest a lower photosynthetic capacity, which could result in reduced yield.

Conclusion

In this study, significant differences were observed among different almond local type concerning leaf morphology and pomological traits, and their effects on almond yield were evaluated. The results highlight that both leaf morphology and pomological traits play a crucial role in determining almond productivity.

The Alçıtepe local type exhibited narrower leaves 21.24 mm, smaller leaf area 1230.9 mm² which resulted in lower yield and weaker leaf characteristics compared to other cultivars. These findings suggest that the Alçıtepe local type may have limited photosynthetic capacity, which could negatively impact its yield potential.

On the other hand, cultivars such as Ferraduel and Ferragnes exhibited wider leaves (Ferraduel: 32.80 mm), higher chlorophyll content (Laurenne: 42.16), and larger leaf areas (Ferraduel: 2501.6 mm²), which enhanced their photosynthetic efficiency and contributed to their higher yield potential. Ferraduel demonstrated the largest leaves, highest leaf area, and the most significant chlorophyll content among all local type, indicating a superior photosynthetic capacity and, thus, higher energy production.

In terms of pomological characteristics, Alçıtepe also showed a relatively lower performance, with reduced shell weight and shell thickness, leading to the lowest unshelled yield 22.26%. The heavy shell and thicker shell structure of Alçıtepe may limit its unshelled yield. In contrast, the Texas local type had the highest unshelled yield 40.31% and was followed by Ferragnes. Ferragnes exhibited the lowest shell thickness and lighter shell structure, leading to higher unshelled yield compared to other cultivars.

Ferragnes and Texas also performed better than Alçıtepe in terms of yield. The interaction between leaf morphology and pomological traits appears to be critical in determining the yield potential of almond local type. Leaf width, length, area, and chlorophyll content directly affect photosynthesis efficiency, which in turn impacts the growth and yield of the tree. Alçıtepe's narrow leaves and low chlorophyll content seem to limit its photosynthetic capacity, resulting in lower yield, while Ferraduel and Ferragnes show higher photosynthetic efficiency due to their larger leaf size and higher chlorophyll content, which contribute to their higher yield potential.

Pomological traits also play a vital role in this process. Shell weight and thickness influence the shell-to-kernel ratio, affecting the overall yield. Texas and Laurenne had thinner shells, resulting in higher unshelled yields, while Alçıtepe's thicker shell limited its unshelled yield. These findings indicate that the relationship between leaf morphology and pomological traits is a crucial factor in determining the overall productivity of almond local type.

Future studies should further investigate the combined effects of environmental factors and genetic traits on leaf morphology and pomological characteristics. Moreover, integrated evaluation of leaf traits and pomological data could contribute to the development of more efficient and high-yielding almond cultivars. The results of this study suggest that leaf morphology and pomological traits should be considered as key selection criteria in almond breeding programs to enhance yield potential.

In conclusion, local type such as Alçıtepe, with lower photosynthetic capacity and weaker pomological traits, exhibit lower yields compared to cultivars like Ferraduel and Ferragnes, which demonstrate superior photosynthetic efficiency and pomological characteristics. This study emphasizes the importance of considering both leaf morphology and pomological traits when selecting high-yielding almond cultivars for cultivation and breeding programs. The findings also underscore the need for further studies that assess the combined effects of these traits on almond productivity, which will ultimately aid in the selection and development of superior almond local type.

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Authors' Contributions

Authors declare that they have contributed equally to the article.

Conflicts of Interest Statement

The authors declare that there is no conflict of interest.

References

Agegnehu, G., Ghizaw, A., Sinebo, W., 2006. Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. Eur. J. Agron. 25: 202-207.

Aktas, T., Polat, R., Atay, U., 2007. Comparison of mechanical properties of some selected almond cultivars with hard and soft shell under compression loading. Journal of Food Process Engineering. 30(6): 773-789.

April, V. P., 2024. Health benefits and uses of almond oil. Benefits.

Calle, A., Aparicio-Durán, L., Batlle, I., Eduardo, I., Miarnau, X., 2024. Review of agronomic and kernel quality traits of 273 almond cultivars. Genetic Resources and Crop Evolution. 1-46.

Chukwuma, I. F., Ossai, E. C., Nworah, F. N., Apeh, V. O., Abiaziem, E. O., Iheagwam, F. N., Korzeniowska, M., 2024. Changes in nutritional, health benefits, and pharmaceutical potential of raw and roasted tropical almond (*Terminalia catappa* Linn.) nuts from Nigeria. Plos one. 19(1): e0287840.

Du, F., Tan, T., 2021. Recent studies in mechanical properties of selected hard-shelled seeds: A review. JOM. 73(6): 1723-1735.

Egea, G., González-Real, M. M., Baille, A., Nortes, P. A., Conesa, M. R., Ruiz-Salleres, I., 2012. Effects of water stress on irradiance acclimation of leaf traits in almond trees. Tree Physiology. 32(4): 450-463.

El Bernoussi, S., Boujemaa, I., El Guezzane, C., Bou-Ouzoukni, Y., Nounah, I., Bouyahya, A., Tabyaoui, M., 2024. Comparative analysis of nutritional value and antioxidant activity in sweet and bitter almonds. LWT. 206: 116587.

FAO, 2023. Food and Agriculture Organization, Crop Statistics. http://fao.org/faostat/en/#data/QC, Erişim Tarihi: 28.12.2024.

Gohari, S., Imani, A., Talaei, A. R., Abdossi, V., Asghari, M. R., 2023. Physiological responses of almond genotypes to drought stress. Russian Journal of Plant Physiology. 70(6): 141.

Gouta, H., Laaribi, I., Ksia, E., Juan, T., Estopañan, G., Martínez-Gómez, P., 2021. Physical properties, biochemical and antioxidant contents of new promising Tunisian almond genotypes: traits stability, quality aspects and post-harvest attributes. Journal of Food Composition and Analysis. 98: 103840.

Khadivi, A., Goodarzi, S., Sarkhosh, A., 2019. Identification of late-blooming almond (*Prunus dulcis* L.) genotypes with high kernel quality. Euphytica. 215: 1-12.

Khadivi-Khub, A., Etemadi-Khah, A., 2015. Phenotypic diversity and relationships between morphological traits in selected almond (Prunus amygdalus) germplasm. Agroforestry Systems. 89: 205-216.

Khojand, S., Zeinalabedini, M., Azizinezhad, R., Imani, A., Ghaffari, M. R., 2024. Identification of the core collection in Iranian almond germplasm: utilizing morphological traits and evaluating biochemical properties of the collection. Genetic Resources and Crop Evolution. 71(6): 3037-3059.

Ladizinsky, G., 1999. On the origin of almond. Genetic Resources and Crop Evolution. 46: 143-147.

Ledbetter, C. A., 2008. Shell cracking strength in almond (*Prunus dulcis* [Mill.] DA Webb.) and its implication in uses as a value-added product. Bioresource Technology. 99(13): 5567-5573.

Li, X., Liu, Y., Hao, J., Wang, W., 2018. Study of almond shell characteristics. Materials. 11(9): 1782.

Lipan, L., Miarnau, X., Calle, A., Carbonell, Á., Sendra, E., Batlle, I., Romero, A., 2024. Factors influencing the almond kernel breakage during shelling processes and the impact of water conditioning on kernel color and free acidity. LWT. 117250.

Mitra S.K., 2020. Temperate Fruits: Nuts and Berries. DAYA Publishing House. ISBN:9390371228, Vol. II.

Moldero, D., López-Bernal, Á., Testi, L., Lorite, I. J., Fereres, E., Orgaz, F., 2021. Long-term almond yield response to deficit irrigation. Irrigation Science. 39: 409-420.

Nortes, P. A., Gonzalez-Real, M. M., Egea, G., Baille, A., 2009. Seasonal effects of deficit irrigation on leaf photosynthetic traits of fruiting and non-fruiting shoots in almond trees. Tree Physiology. 29(3): 375-388.

Prgomet, I., Pascual-Seva, N., Morais, M. C., Aires, A., Barreales, D., Ribeiro, A. C., Gonçalves, B., 2020. Physiological and biochemical performance of almond trees under deficit irrigation. Scientia Horticulturae. 261: 108990.

Rahemi, A., Gradziel, T. M., 2024. Characteristics of almond species. In the almonds and related species: Identification, characteristics and uses (pp. 49-113). Cham: Springer International Publishing.

Ranjbar, A., Imani, A., Piri, S., Abdoosi, V., 2021. Drought effects on photosynthetic parameters, gas exchanges and water use efficiency in almond cultivars on different rootstocks. Plant Physiology Reports. 26: 95-108.

Reisman, E. D., 2020. Orchard Entanglements: political ecologies of almond production in California and Spain. University of California, Santa Cruz.

Sideli, G. M., Mather, D., Wirthensohn, M., Dicenta, F., Goonetilleke, S. N., Martínez-García, P. J., Gradziel, T. M., 2023. Genome-wide association analysis and validation with KASP markers for nut and shell traits in almond (*Prunus dulcis* [Mill.] DA Webb). Tree Genetics & Genomes. 19(2): 13.

Singar, S., Kadyan, S., Patoine, C., Park, G., Arjmandi, B., Nagpal, R., 2024. The effects of almond consumption on cardiovascular health and gut microbiome: A comprehensive review. Nutrients. 16(12): 1964.

Uzun, A., Dirim, E., Yaman, M., Ünsal, H. T., 2024. Morphological and molecular evaluation of diversity in individuals obtained by intra-species hybridization in almond (*Prunus dulcis* L.). Genetic Resources and Crop Evolution. 71(3): 1291-1300.

Wang, W., Wang, W., Wang, Y., Yang, R., Tang, J., Zhao, Y., 2020. Hot-air assisted continuous radio frequency heating for improving drying efficiency and retaining quality of inshell hazelnuts (*Corylus avellana* L. cv. Barcelona). Journal of Food Engineering. 279: 109956.