

Determination of Morphological and Biochemical Properties of Almond (*Prunus amygdalus*) Genotypes in Denizli-Çivril

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Abstract

In this study, morphological and biochemical properties of 22 almond genotypes and 'Nonpareil' cultivar were examined. Nut weight, kernel weight, kernel ratio, shell thickness, nut and kernel dimensions, as well as oil, protein, ash, moisture, and total carbohydrate contents were determined. Nut weight ranged from 2.54 to 4.61 g, kernel weight from 0.67 to 1.38 g, kernel ratio from 19.69% to 32.26%, and shell thickness from 2.43 to 3.41 mm. Biochemical analyses revealed oil content between 45.40-55.65%, protein content between 17.22-19.50%, ash content between 2.90-3.69%, moisture content between 3.59-4.55%, and total carbohydrate content between 16.67-30.06%. Principal Component Analysis (PCA) showed a strong negative correlation ($r=-0.970$) between oil content and carbohydrate in the first two components, which explained 57.27% of the total variance. The 20CVRL22 genotype had the highest kernel ratio (32.26%), 20CVRL13 and 20CVRL18 genotypes had the highest oil content (51.47% and 51.60%, respectively), and the 20CVRL15 genotype had the highest protein content (19.50%). The results reveal the richness of almond genetic resources in the Çivril region while providing important information for genotype selection and breeding studies for different usage purposes.

Key words: Morphological properties, Biochemical properties, PCA analysis, Correlation, Variance analysis

Denizli-Çivril'deki Badem (*Prunus amygdalus*) Genotiplerinin Morfolojik ve Biyokimyasal Özelliklerinin Belirlenmesi

Özet

Bu çalışmada, 22 badem genotipi ve 'Nonpareil' çeşidinin morfolojik ve biyokimyasal özellikleri incelenmiştir. Meyve ağırlığı, iç ağırlığı, iç oranı, kabuk kalınlığı, kabuklu ve iç meyve boyutları ile yağ, protein, kül, nem ve toplam karbonhidrat içerikleri belirlenmiştir. Meyve ağırlığı 2.54-4.61 g, iç ağırlığı 0.67-1.38 g, iç oranı %19.69-32.26 ve kabuk kalınlığı 2.43-3.41 mm arasında değişmiştir. Biyokimyasal analizlerde yağ içeriği %45.40-55.65, protein içeriği %17.22-19.50, kül içeriği %2.90-3.69, nem içeriği %3.59-4.55 ve toplam karbonhidrat içeriği %16.67-30.06 arasında tespit edilmiştir. Temel Bileşenler Analizi (PCA), toplam varyansın %57.27'sini açıklayan ilk iki bileşende, yağ içeriği ile karbonhidrat arasında güçlü negatif korelasyon ($r=-0.970$) göstermiştir. 20CVRL22 genotipi en yüksek iç oranına (%32.26), 20CVRL13 ve 20CVRL18 genotipleri en yüksek yağ içeriğine (sırasıyla %51.47 ve %51.60), 20CVRL15 genotipi en yüksek protein içeriğine (%19.50) sahip olmuştur. Sonuçlar, Çivril yöresindeki badem genetik kaynaklarının zenginliğini ortaya koyarken, farklı kullanım amaçlarına yönelik genotip seçimi ve ıslah çalışmaları için önemli bilgiler sunmaktadır.

Anahtar Kelimeler: Morfolojik özellikler, Biyokimyasal özellikler, PCA analizi, Korelasyon, Varyans analizi

Introduction

Almond (*Prunus amygdalus*) is a significant fruit species belonging to the genus *Amygdalus* of the Prunoideae subfamily within the Rosaceae family, order Rosales. It originates from western and central Asia, with a wide geographical distribution encompassing the Mediterranean region, Türkiye, Northern Iran, India, and China. Its sensitivity to low temperatures and heavy precipitation during the flowering period limits its cultivation distribution worldwide (Kester et al. 1990; Kester and Gradziel, 1996). Currently, major almond-producing countries include the United States, Australia, and Mediterranean countries with suitable ecological conditions such as Spain, Türkiye, Morocco, and Italy.

Türkiye holds special significance due to its location within the Mediterranean and Near East gene centers, which are among the eight gene centers

identified worldwide (Demir, 1990; Ağaoglu et al., 1995), and it serves as the homeland of almond along with many other cultivated plants. The suitability of Türkiye's ecological conditions for horticultural crop cultivation, its position on migration routes, and its history as a region inhabited by numerous civilizations since ancient times are the most important factors contributing to its rich diversity of species and cultivars. Almond cultivation has gained particular importance especially in the Aegean Region (Kırca, 2024). Almond kernels are rich in protein, monounsaturated and polyunsaturated fatty acids, vitamin E, ash, riboflavin, phytosterols, and polyphenols, which are considered valuable for human health and nutrition. Additionally, they are important for health due to their ability to reduce cholesterol absorption and lower LDL-cholesterol levels in the blood. This information has increased

interest in almond consumption (Richardson et al., 2009; Kirca and Karadeniz, 2022; Özcan, 2023). Morphological characterization is highly useful for preliminary evaluation of almond and other fruit species genetic resources due to its rapidity and ease of assessment, and it can also be used to reveal genetic variation among morphologically distinguishable accessions. For this purpose, morphological traits combined with multivariate analyses such as principal component analysis (PCA) and cluster analysis are frequently used to screen accessions in different fruit species (Čolić et al., 2012; Sepahvand et al., 2015; Bak and Karadeniz, 2021; Güler et al., 2021; Kirca et al., 2023; Gürcan et al., 2024; Şenlik and Mertoğlu, 2024; Bak et al., 2024). Morphological characteristics of almond genotypes such as fruit weight, fruit width, fruit length, fruit thickness, shell thickness, kernel weight, width, length, thickness, kernel ratio, kernel width index, and kernel thickness index are important parameters for identification and classification of genotypes.

The biochemical properties of almond, particularly its fat, protein, ash, moisture, and total carbohydrate content, are of great importance for both nutritional value and industrial applications. High fat content is a significant factor in the confectionery industry, as higher fat content causes almond paste to absorb less water (Sze-Tao and Sathe, 2000; Gomez et al., 2008; Kirca and Karadeniz, 2022). In this context, the strategic role of high fat content in confectionery production contributes to improving production processes and consumer satisfaction. Protein content is an important factor determining the nutritional value of almonds and can show significant variations among cultivars (Kodad et al., 2023).

Almond genetic resources propagated from seeds show great variation in terms of resistance to diseases and pests, adaptation to ecological conditions, and tree and fruit characteristics (Čolić et al., 2012; Battle et al., 2017). The presence of numerous seed-propagated almond trees in Türkiye provides significant advantages to almond breeders in selecting genotypes with desired traits. The conservation and characterization of local almond genotypes are important to prevent the loss of genetic diversity and to serve as a potential source of genetic diversity for future almond breeding programs.

In Türkiye, many researchers have conducted selection studies to identify almond genotypes with superior characteristics (Kalyoncu, 1990; Aslantas, 1993; Karadeniz and Erman, 1996; Karadeniz et al., 1996; Balta, 2002; Ağlar, 2005; Yıldırım, 2007; Şimşek, 2008; Sümbül, 2009; Şimşek, 2011; Köse, 2013; Bozkurt, 2017; Acar et al., 2018; Genç, 2024; Işık, 2025). In these selection studies, many promising genotypes have been selected that

possess the qualities desired by almond breeding programs, particularly those that flower late and show superior characteristics in terms of fruit and tree properties. In this study, the morphological (fruit weight, fruit width, fruit length, fruit thickness, shell thickness, kernel weight, width, length, thickness, kernel ratio, kernel width index, kernel thickness index) and biochemical (fat, protein, ash, moisture, total carbohydrate) characteristics of 22 almond genotypes grown in the Çivril district of Denizli and the 'Nonpareil' almond cultivar were examined. The aim of the research is to determine the pomological, morphological, and biochemical characteristics of these genotypes and to reveal their potential for commercial production and as genetic resources.

Materials and Methods

Plant material and characteristics of the region

The study was conducted in 2023 on 22 almond genotypes grown from seed without any irrigation, fertilization, or other cultural practices, along with the 'Nonpareil' almond cultivar in the Çivril district of Denizli province. Çivril is a district located in the northeast of Denizli province with an area of 1,570 km². Situated at an altitude of 840 meters above sea level, Çivril has a transitional climate between the Aegean Region and the Central Anatolia Region. It is characterized by hot and dry summers, and cold and rainy winters (Anonymous, 2025).

When examining the 15-year climate data for monthly average relative humidity, precipitation, temperature, and wind speed in Çivril district between 2009-2023 (Figure 1), continental climate characteristics with distinct seasonal variations are observed. Temperature values reach an average of 25°C during summer months (July-August), while dropping to around 3-5°C during winter months (January-February). This indicates a temperature difference of approximately 22°C throughout the year. Analysis of the region's precipitation regime shows that the annual total precipitation is approximately 442 mm with significant differences in seasonal distribution. The rainiest period occurs during winter and spring months (January-May), while summer months (especially July-September) are distinctly dry. July stands out as the month with the least precipitation, averaging 4.91 mm. Relative humidity levels reach 74-75% during winter months (December-January) and drop to 42-43% during summer months (July-August). This pattern parallels the low precipitation amounts during summer months. Wind speed data varies between 1.96-2.67 m sec⁻¹ throughout the year without showing significant seasonal differences (TSMS, 2025).

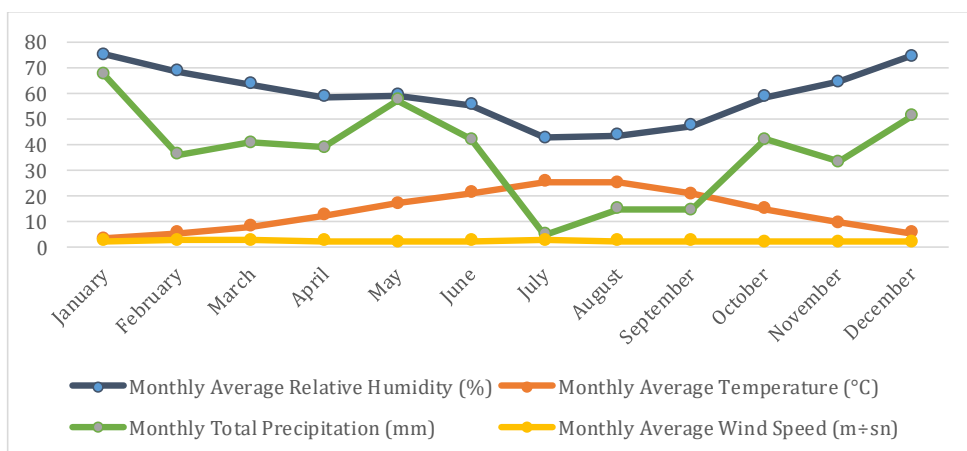


Figure 1. Distribution of monthly average temperature ($^{\circ}\text{C}$), relative humidity (%), total precipitation (mm), and wind speed (m sec^{-1}) values in Çivril district between 2009-2023

Şekil 1. 2009-2023 yılları arasında Çivril ilçesinde aylık ortalama sıcaklık ($^{\circ}\text{C}$), bağıl nem (%), toplam yağış (mm) ve rüzgar hızı (m sn^{-1}) değerlerinin dağılımı

Morphological and biochemical analyses

Morphological and biochemical measurements were performed on 20 randomly selected fruits from each genotype. Fruit analyses were conducted at Pamukkale University Tavas Vocational School, Department of Plant and Animal Production. Fruit weight and kernel weight were measured using an electronic scale with 0.0001 g sensitivity, while the dimensional properties of the fruit with shell and kernel, as well as shell thickness, were measured using a digital caliper with 0.01 mm sensitivity. Kernel ratio was calculated as a percentage. Kernel width index was calculated as the percentage ratio of kernel width to kernel length; kernel thickness index was calculated as the percentage ratio of kernel thickness to kernel width.

Protein content was determined using the micro Kjeldahl method, with total nitrogen amount multiplied by a factor of 6.38 (Cemeroğlu, 2015). Moisture content was determined by the weight loss method after drying ground samples in an oven at 105°C (Uylaşer and Başoğlu, 2016). Fat analysis was performed using the Soxhlet extraction method with Hexane solvent using a behr EF Solvent Extractors device (Cemeroğlu, 2015). Ash content was determined by incinerating samples in an ash furnace at 550°C . Total carbohydrate value was calculated by subtracting the sum of ash, moisture, fat, and protein amounts from 100 (Gibson, 1990).

Statistical analysis

Descriptive statistics (minimum, maximum, mean) of the data obtained in the study were calculated. Analysis of variance (ANOVA) was applied for statistical evaluation, and differences between means were determined using Tukey's multiple comparison test at $p < 0.05$ significance level. These

analyses were performed using R statistical software (version 4.4.1) (R Core Team, 2024) with the 'agricolae' package (de Mendiburu, 2023) and the 'psych' package (Revelle, 2025) for descriptive statistics. Pearson correlation analysis was conducted to determine relationships between variables, and correlation coefficients were evaluated at $p < 0.05$, $p < 0.01$, and $p < 0.001$ significance levels. The correlation matrix was visualized using the "corrplot" package (Wei and Simko, 2021). Principal Component Analysis (PCA) was used for multivariate analysis of morphological and biochemical characteristics of genotypes. PCA analysis and biplot graph were created using 'FactoMineR' (Lê et al., 2008) and 'factoextra' (Kassambara and Mundt, 2020) packages. The correlation table was prepared using the "ggcorrplot" package (Kassambara, 2023). All graphs were arranged using the "ggplot2" package (Wickham, 2016).

Results and Discussion

Analysis of variance

Morphological characteristics

When examining the fruit weight, kernel weight, kernel ratio, and shell thickness characteristics of almond genotypes, significant differences were detected (Table 1). In terms of fruit weight, genotypes 20CVRL16 (4.47 g), 20CVRL14 (4.36 g), and 20CVRL08 (4.34 g) stood out with high values and were in the same statistical group as the commercial cultivar 'Nonpareil' (4.61 g). The lowest fruit weight was recorded in genotype 20CVRL04 (2.54 g). These values show similarity with the fruit weights of 'Ferragnes' (4.53 g) and 'Ferraduel' (4.83

g) cultivars grown in Yeşilyurt district of Malatya (910 m) as reported by Yıldırım et al. (2023). Additionally, they are consistent with the fruit weights ranging from 3.38-5.24 g in 'Umutlu' almond types selected by Kalyoncu (1990) in Konya and the values reported to range from 1.57-5.26 g in

almond types selected from Çınar district by Şimşek (2011). In Parlakçı's (2008) study, the fruit weight of the 'Bertina' cultivar (6.66 g) was found to be higher than other cultivars.

Table 1. Results regarding fruit weight, kernel weight, kernel ratio and shell thickness traits of almond genotypes

Çizelge 1. Badem genotiplerinin meyve ağırlığı, çekirdek ağırlığı, çekirdek oranı ve kabuk kalınlığı özelliklerine ilişkin sonuçlar

Genotype	Nut weight (g)	Kernel weight (g)	Kernel rate (%)	Shell thickness (mm)
20CVRL01	3.90±0.09 c-e	1.08±0.01 bc	27.61±0.47 a-d	3.41±0.03 a
20CVRL02	3.92±0.13 cd	1.02±0.01 b-e	26.07±0.89 b-e	3.03±0.08 c-g
20CVRL03	3.55±0.11 e-g	0.85±0.03 e-ı	23.95±0.04 c-f	2.86±0.11 d-h
20CVRL04	2.54±0.02 j	0.67±0.03 ı	26.44±1.34 b-e	3.21±0.11 a-d
20CVRL05	3.88±0.06 c-e	0.94±0.01 b-h	24.26±0.04 c-f	3.03±0.11 b-g
20CVRL06	3.56±0.1 e-g	1.01±0.04 b-f	28.23±0.21 a-c	2.43±0.12 j
20CVRL07	3.87±0.16 c-e	0.90±0.07 c-h	23.27±0.85 c-f	2.81±0.05 f-h
20CVRL08	4.34±0.03 a	1.01±0.05 b-f	23.16±1.29 d-f	2.78±0.02 f-ı
20CVRL09	4.31±0.04 ab	1.12±0.06 b	25.90±1.27 b-e	3.40±0.10 a
20CVRL10	4.27±0.03 ab	0.98±0.11 b-g	22.95±2.50 d-f	3.24±0.10 a-c
20CVRL11	3.61±0.11 d-f	0.83±0.05 f-ı	22.88±0.70 d-f	2.85±0.11 e-h
20CVRL12	3.97±0.13 bc	0.95±0.10 b-h	23.98±3.27 c-f	2.83±0.06 f-h
20CVRL13	2.88±0.01 ij	0.77±0.04 hı	26.61±1.17 b-e	3.38±0.12 ab
20CVRL14	4.36±0.07 a	0.97±0.01 b-g	22.25±0.04 ef	3.08±0.06 a-f
20CVRL15	3.42±0.06 f-h	0.95±0.02 b-h	27.68±0.11 a-d	2.46±0.09 ij
20CVRL16	4.47±0.06 a	0.88±0.01 d-h	19.69±0.06 f	2.84±0.07 e-h
20CVRL17	3.76±0.16 c-f	0.94±0.01 b-h	24.89±1.22 c-e	3.18±0.04 a-e
20CVRL18	3.12±0.12 hi	0.85±0.01 e-ı	27.15±1.27 b-e	3.18±0.10 a-e
20CVRL19	2.89±0.06 ı	0.77±0.07 hı	26.63±1.93 b-e	2.60±0.08 h-j
20CVRL20	3.85±0.01 c-e	1.05±0.01 b-d	27.31±0.32 a-d	2.61±0.10 h-j
20CVRL21	3.25±0.05 gh	0.80±0.03 g-ı	24.67±1.25 c-f	3.01±0.10 c-g
20CVRL22	3.44±0.06 f-h	1.11±0.04 b	32.26±0.71 a	2.83±0.04 f-h
Nonpareil	4.61±0.05 a	1.38±0.01 a	29.97±0.01 ab	2.72±0.04 g-j
Minimum	2.54	0.67	19.69	2.43
Maximum	4.61	1.38	32.26	3.41
Mean	3.73	0.95	25.56	2.95

When evaluating kernel weight, the 'Nonpareil' cultivar (1.38 g) was found to be significantly higher than all genotypes. Among the examined genotypes, 20CVRL09 (1.12 g) and 20CVRL22 (1.11 g) were determined to have the highest kernel weights. The lowest kernel weight was observed in genotype 20CVRL04 (0.67 g). These findings are consistent with kernel weights ranging from 0.66-1.34 g in almond types selected from Kahramanmaraş by Beyhan and Şimşek (2007). Additionally, in another study mentioned by Şimşek (2011), kernel weight in selected almond types was reported to vary between 1.01 g and 1.80 g. In Parlakçı's (2008) study, the kernel weight of the 'Bertina' cultivar

(1.79 g) was found to be higher than other cultivars. Gülsoy and Balta (2014) reported that kernel weight in almond genotypes in Aydın province varied between 0.67-1.56 g.

In terms of kernel ratio, genotype 20CVRL22 reached the highest value with 32.26% and was in a statistically similar group with 'Nonpareil' (29.97%). Genotypes 20CVRL06 (28.23%), 20CVRL15 (27.68%), and 20CVRL01 (27.61%) also stood out with high kernel ratios. The lowest kernel ratio was determined in genotype 20CVRL16 (19.69%). These values are consistent with previous studies. Indeed, they align with the kernel ratio (30.24-32.49%) of the 'Ferragnes' cultivar reported

by Yıldırım et al. (2023). However, in the same study, it was noted that as altitude increased, the kernel ratio of the 'Ferraduel' cultivar decreased (from 26.59% to 23.56%). Types selected from Çınar district reported by Şimşek (2011) showed a wider range of kernel ratios varying between 23.52-48.30%. In Parlakçı's (2008) study, while the 'Felisia' cultivar (38.09%) had the highest kernel ratio, the 'Bertina' cultivar (24.46%) showed the lowest value.

When examining shell thickness, genotypes 20CVRL01 (3.41 mm) and 20CVRL09 (3.40 mm) were identified as having the thickest shells. The thinnest shells were measured in genotypes 20CVRL06 (2.43 mm) and 20CVRL15 (2.46 mm). The 'Nonpareil' cultivar (2.72 mm) was in the medium-low shell thickness group. Gülsoy and Balta (2014) reported that shell thickness in almond genotypes in Aydın province varied between 2.08-4.79 mm.

When examining fruit and kernel dimensions of almond genotypes, significant differences were observed between genotypes (Table 2). In terms of fruit width, genotypes 20CVRL18 (23.85 mm), 20CVRL13 (23.78 mm), and 20CVRL22 (23.49 mm) had the highest values and were in the same statistical group as the 'Nonpareil' cultivar (23.41 mm). The lowest fruit widths were recorded in genotypes 20CVRL21 (18.01 mm) and 20CVRL19 (18.37 mm). These values are consistent with the range of in-shell fruit width (17.25-27.14 mm) reported by Gülsoy and Balta (2014) in almond genotypes in Aydın province.

When evaluating fruit length, the 'Nonpareil' cultivar (36.01 mm) was found to be significantly higher than all genotypes. Among the examined genotypes, 20CVRL10 (34.88 mm) and 20CVRL04 (33.55 mm) were identified as having the longest fruits. The shortest fruits were measured in genotype 20CVRL12 (19.62 mm). These results show similarity with the fruit length values of the 'Ferragnes' cultivar at 910 m altitude reported by Yıldırım et al. (2023). Additionally, they are consistent with the fruit dimensions reported by Pérez-Sánchez and Morales-Corts (2021) in traditional almond cultivars in the Iberian Peninsula.

In terms of fruit thickness, the 'Nonpareil' cultivar (15.15 mm) and genotype 20CVRL11 (14.80 mm) reached the highest values and were in the same statistical group. Genotype 20CVRL18 (14.07 mm) also stood out with high fruit thickness. The lowest fruit thickness was determined in genotypes 20CVRL08 (12.17 mm) and 20CVRL10 (12.28 mm). The findings of the present study are consistent with the range reported by Gülsoy and Balta (2014), who reported in-shell fruit thickness between 13.42 mm (AYD-124) and 18.68 mm (AYD-49).

When examining kernel width, genotype 20CVRL13 (13.32 mm) was determined to have a similar value to 'Nonpareil' (13.12 mm). Genotypes 20CVRL01 (12.85 mm) and 20CVRL17 (12.41 mm) also stood out with large kernel measurements. The narrowest kernel measurements were observed in genotypes 20CVRL10 (9.55 mm) and 20CVRL03 (9.99 mm). These values fall within the kernel width range (8.19-14.81 mm) reported by Gerçekçioğlu and Güneş (1999) in a study conducted in Tokat. These values, which are consistent with the kernel length range (16.41-28.20 mm) reported by Kaşka et al. (1993), demonstrate the commercial potential of the examined genotypes.

In terms of kernel length, the 'Nonpareil' cultivar (27.75 mm) was found to be significantly longer than all genotypes. Genotypes 20CVRL04 (25.33 mm) and 20CVRL07 (25.23 mm) were recorded as having the longest kernel measurements. The shortest kernels were measured in genotypes 20CVRL11 (15.16 mm) and 20CVRL12 (15.18 mm). The findings of the present study are consistent with the kernel fruit length range (19.52-28.80 mm) reported by Gülsoy and Balta (2014) in almond genotypes.

When evaluating kernel thickness, the 'Nonpareil' cultivar (7.15 mm) was found to have the highest value. Genotypes 20CVRL19 (6.66 mm) and 20CVRL01 (6.60 mm) stood out with thick kernel measurements. The thinnest kernels were detected in genotypes 20CVRL05 (5.38 mm) and 20CVRL04 (5.44 mm). Gülsoy and Balta (2014), in their study with almond genotypes, reported kernel thickness between 5.18 mm (AYD-122) and 9.04 mm.

When examining the shape indices of almond genotypes, significant differences were detected between genotypes (Table 2). Significant differences were observed among genotypes in terms of kernel width and thickness indices. The highest values for kernel width index were recorded in genotypes 20CVRL12 (81.06%) and 20CVRL17 (80.63%). These genotypes were followed by 20CVRL11 (70.64%), 20CVRL18 (69.86%), 20CVRL09 (69.07%), 20CVRL13 (67.52%), and 20CVRL19 (67.46%). The lowest kernel width index value was determined in genotype 20CVRL10 (38.31%). In terms of kernel thickness index, genotypes 20CVRL19 (43.32%) and 20CVRL11 (43.16%) had the highest values, followed by genotypes 20CVRL12 (40.19%) and 20CVRL18 (36.74%). The lowest kernel thickness index was detected in genotype 20CVRL04 (21.49%). The 'Nonpareil' cultivar used as a standard (47.27%; 25.76%) has medium-low values for both indices. These results indicate a wide variation in kernel shape among the examined almond genotypes. Genotypes with high index values have a more rounded and plump kernel structure, while genotypes with low index values exhibit a longer

and thinner kernel structure. Bayazit and Çalışkan (2021), in their study with *Amygdalus orientalis* and *Amygdalus turcomanica* species, reported kernel width index as 42.44-80.16% and kernel thickness index as 34.81-66.02%. Şimşek and Küden (2007), in their study in Hilvan, reported that the width

index varied between 52.05-60.30%. Shape indices are important parameters in morphological characterization of almond fruits and determination of marketing categories (Gradziel, 2008).

Table 2. Results regarding dimensional properties (width, length, thickness) and shape indices of in-shell and kernel almonds

Çizelge 2. Kabuklu ve iç bademlerin boyutsal özellikleri (en, boy, kalınlık) ve şekil indekslerine ilişkin sonuçlar

Genotype	Nut width (mm)	Nut length (mm)	Nut thickness (mm)	Kernel width (mm)	Kernel length (mm)	Kernel thickness (mm)	Kernel width index	Kernel thickness index
20CVRL01	22.12±0.34bc	32.96±0.28cd	13.55±0.10c-f	12.85±0.11ab	23.48±0.44cd	6.60±0.04ab	54.74±1.50de	28.09±0.68e-j
20CVRL02	20.87±0.16d-f	29.87±0.08g	12.90±0.06g	11.69±0.08d-f	23.06±0.26d	6.12±0.21a	50.68±0.24ef	26.55±1.22e-j
20CVRL03	19.37±0.18gh	22.64±0.23l	13.54±0.06c-f	9.99±0.01jk	17.24±0.45hk	5.72±0.24b	57.97±1.60cd	33.17±0.52b-f
20CVRL04	22.30±0.13bc	33.55±0.18c	13.17±0.01e-g	11.34±0.24f-h	25.33±0.50b	5.44±0.01b	44.80±1.84g-ı	21.49±0.48j
20CVRL05	22.44±0.25b	31.42±0.13ef	12.39±0.08h	11.53±0.17e-g	23.39±0.25d	5.38±0.59b	49.29±0.19f	22.97±2.26ij
20CVRL06	21.72±0.12b-d	32.20±0.23de	13.23±0.18c-g	10.90±0.03g-ı	24.56±0.40bc	6.09±0.30ab	44.39±0.83hı	24.79±1.64g-j
20CVRL07	19.06±0.18hı	31.69±0.06e	13.69±0.08bc	10.78±0.3hı	25.23±0.09b	5.92±0.17ab	42.72±1.36ı	23.47±0.76h-j
20CVRL08	19.50±0.20gh	24.31±0.21jk	12.17±0.04h	11.24±0.29f-h	18.38±0.05g	5.76±0.26b	61.14±1.41c	31.32±1.34c-g
20CVRL09	21.90±0.28bc	24.22±0.10jk	13.59±0.15c-e	12.25±0.25b-d	17.74±0.32gh	5.92±0.20ab	69.07±0.20b	33.38±0.52b-e
20CVRL10	19.12±0.06hı	34.88±0.14b	12.28±0.17h	9.55±0.08k	24.93±0.07bk	5.74±0.38b	38.31±0.45j	23.03±1.60ij
20CVRL11	20.72±0.08ef	21.43±0.01m	14.80±0.14a	10.71±0.27hı	15.16±0.17ı	6.54±0.58ab	70.64±0.98b	43.16±4.31a
20CVRL12	20.84±0.11ef	19.62±0.33n	12.90±0.08g	12.31±0.04b-d	15.18±0.13ı	6.10±0.20ab	81.06±0.91a	40.19±1.64ab
20CVRL13	23.78±0.15a	27.67±0.32h	13.62±0.18b-e	13.32±0.19a	19.72±0.06f	6.05±0.03ab	67.52±0.77b	30.68±0.06c-h
20CVRL14	21.52±0.07c-e	26.30±0.17ı	13.40±0.01c-f	11.34±0.25f-h	20.74±0.25ef	5.54±0.01b	54.69±1.90de	26.71±0.26e-j
20CVRL15	21.97±0.13bc	28.13±0.35h	13.11±0.13fg	11.29±0.08f-h	20.59±0.13ef	6.10±0.52ab	54.85±0.77d	29.63±2.35c-ı
20CVRL16	20.02±0.34fg	24.52±0.03j	12.91±0.14g	10.94±0.03g-ı	18.21±0.23gh	5.85±0.50ab	60.10±0.93c	32.09±2.35c-g
20CVRL17	20.78±0.19ef	21.63±0.30m	13.60±0.05c-e	12.41±0.06bc	15.39±0.09ı	5.48±0.01b	80.63±0.07a	35.62±0.30b-d
20CVRL18	23.85±0.02a	23.60±0.23k	14.07±0.15b	12.13±0.06c-e	17.37±0.25gh	6.38±0.66ab	69.86±0.67b	36.74±4.31a-c
20CVRL19	18.37±0.25ij	21.15±0.13m	13.64±0.13b-d	10.38±0.20j	15.39±0.48ı	6.66±0.21ab	67.46±0.82b	43.32±2.73a
20CVRL20	22.47±0.32b	26.00±0.18ı	13.49±0.19c-f	12.40±0.11bc	20.48±0.29ef	5.83±0.01b	60.56±0.30c	28.45±0.37d-j
20CVRL21	18.01±0.18j	30.64±0.24fg	13.22±0.05d-g	10.49±0.16j	21.59±0.21e	5.62±0.42b	48.56±0.28fg	26.00±1.68e-j
20CVRL22	23.49±0.19a	27.97±0.06h	12.94±0.01g	12.09±0.11c-e	20.17±0.08f	5.91±0.04ab	59.93±0.76c	29.31±0.10c-ı
Nonpareil	23.41±0.40a	36.01±0.16a	15.15±0.04a	13.12±0.11a	27.75±0.26a	7.15±0.16a	47.27±0.83f-h	25.76±0.83f-j
Minimum	18.01	19.62	12.17	9.55	15.16	5.38	38.31	21.49
Maximum	23.85	36.01	15.15	13.32	27.75	7.15	81.06	43.32
Mean	21.20	27.50	13.36	11.52	20.48	6.00	58.10	30.26

Biochemical characteristics

When examining the biochemical composition of almond genotypes, significant variations emerged in terms of nutritional components (Table 3). Regarding fat content, the ‘Nonpareil’ cultivar (55.65%) was determined to have a significantly higher fat ratio than all genotypes. Among the genotypes, 20CVRL18 (51.60%) and 20CVRL13 (51.47%) stood out with the highest fat content. These genotypes can be evaluated as valuable raw material sources for fat-based products. The lowest fat content was detected in genotypes 20CVRL22 (45.40%) and 20CVRL06 (45.46%). These values are consistent with the range of 45.2-57.8%

determined by Parlakçı (2008) in different almond cultivars. Additionally, the 55.30% fat ratio reported by Ayadi et al. (2006) in the ‘Nonpareil’ cultivar is almost identical to the result in our study.

When evaluating the protein profile, genotype 20CVRL15 (19.50%) stood out as having similar protein content to the ‘Nonpareil’ cultivar (19.46%). Genotypes 20CVRL21 (18.60%) and 20CVRL12 (18.55%) also showed superiority in nutritional value with their high protein contents. The genotypes with the lowest protein content were determined to be 20CVRL22 (17.22%) and 20CVRL18 (17.25%). Kester and Asay (1975) reported that 100 g of fresh almonds contain 19 g of

protein, which aligns with the results in our study. Similarly, Özdemir (2022) determined that protein content varied between 19.36-30.00% in a study with almond fruits. Ahrens et al. (2005) stated that the protein content of 'Carmel', 'Mission', and 'Nonpareil' cultivars grown in California, USA was 20.6%, 23.3%, and 21%, respectively. Erdoğan (2018), in a study conducted in the Eğil district of Diyarbakır, determined the protein content in 'Ferragnes' and 'Ferradual' cultivars as 25.31% and 31.38%, respectively. Gülsoy and Balta (2014) identified the protein range in 'Texas' and 'Ferragnes' cultivars in Aydın province as 22.08-33.01%.

In terms of ash content, which is an indicator of mineral matter, the 'Nonpareil' cultivar (3.69%) and genotype 20CVRL13 (3.67%) were determined to have the richest composition. Genotypes 20CVRL18 (3.54%) and 20CVRL10 (3.53%) were also found to be rich in mineral matter. The lowest ash content was detected in genotypes 20CVRL11 (2.90%) and 20CVRL03 (2.91%). Özdemir (2022), in a study conducted in Mardin and Diyarbakır provinces, reported ash content as 2.83-3.69%. Similarly, Erdoğan (2018) determined the ash content in 'Ferragnes' and 'Ferradual' cultivars from Diyarbakır Eğil district as 2.86% and 4.20%,

respectively. Pérez-Sánchez and Morales-Corts (2021) reported that the ash content of Spanish almond cultivars varied between 3.05-3.45%; the values in our study are at the upper limit of this range or slightly above it.

When examining moisture content, the highest moisture content was detected in the 'Nonpareil' cultivar (4.55%). Genotypes 20CVRL13 (4.34%) and 20CVRL18 (4.27%) also stood out with high moisture content. This characteristic is important in terms of storage stability and texture properties. The lowest moisture content was recorded in genotypes 20CVRL03 (3.59%) and 20CVRL08 (3.60%). In terms of total carbohydrate content, genotypes 20CVRL17 (30.06%), 20CVRL04 (30.02%), and 20CVRL03 (29.90%) were found to have the highest values. These genotypes are thought to offer different characteristic features in terms of energy value and flavor profile. The 'Nonpareil' cultivar (16.67%) was determined to have significantly lower carbohydrate content than all genotypes. Özdemir (2022) reported that the total carbohydrate value was between 14.51% and 19.95%; Erdoğan (2018) reported it as 10.91% and 25.21% in 'Ferragnes' and 'Ferradual' cultivars, respectively.

Table 3. Results regarding biochemical composition (oil, protein, ash, moisture and total carbohydrate) of almond genotypes

Çizelge 3. Badem genotiplerinin biyokimyasal bileşimlerine (yağ, protein, kül, nem ve toplam karbonhidrat) ilişkin sonuçlar

Genotype	Oil (%)	Protein (%)	Ash (%)	Humidity (%)	Total Carbohydrate (%)
20CVRL01	48.37±0.35 e-g	17.40±0.24 ef	3.15±0.04 f-h	3.87±0.05 f-i	27.22±0.2 e-g
20CVRL02	50.33±0.76 bc	18.34±0.08 c-e	3.30±0.06 d-f	3.82±0.06 f-j	24.23±0.56 j-l
20CVRL03	46.25±0 hi	17.36±0.15 ef	2.91±0.08 j	3.59±0.05 k	29.9±0.01 ab
20CVRL04	45.7±0.33 i	17.70±0.40 c-f	2.94±0.02 ij	3.66±0.05 i-k	30.02±0.01 a
20CVRL05	50.24±0.6 b-d	18.47±0.41 b-d	3.33±0.04 c-f	4.00±0.06 d-f	23.98±0.29 kl
20CVRL06	45.46±0.42 i	18.51±0.20 a-d	3.20±0.03 e-h	3.88±0.06 f-h	28.95±0.31 a-d
20CVRL07	46.68±0.03 g-i	18.23±0.21 c-f	3.08±0.04 g-j	3.74±0.06 g-k	28.28±0.09 b-f
20CVRL08	46.46±0.01 hi	17.27±0.22 f	3.04±0.12 g-j	3.60±0.05 k	29.65±0.4 a-c
20CVRL09	49.32±0.16 c-f	17.60±0.18 c-f	3.44±0.01 b-d	4.16±0.05 b-e	25.5±0.37 h-k
20CVRL10	48.4±0.09 e-g	18.51±0.06 a-d	3.53±0.04 a-c	4.22±0.06 bc	25.35±0.06 i-k
20CVRL11	46.51±0.54 hi	18.38±0.26 c-e	2.90±0.03 j	3.69±0.06 h-k	28.53±0.72 a-e
20CVRL12	47.64±0.42 f-h	18.55±0.11 a-d	3.00±0.03 h-j	3.74±0.04 g-k	27.08±0.38 e-h
20CVRL13	51.47±0.26 b	18.51±0.24 a-d	3.67±0.03 a	4.34±0.06 ab	22.02±0.01 m
20CVRL14	46.36±0.35 hi	17.27±0.07 f	3.13±0.04 f-i	3.83±0.06 f-j	29.43±0.32 a-c
20CVRL15	45.56±0.26 i	19.50±0.63 a	3.23±0.03 e-g	3.94±0.06 e-g	27.79±0.8 d-f
20CVRL16	49.61±0.35 c-e	17.41±0.04 ef	3.21±0.08 e-h	3.93±0.06 fg	25.85±0.18 g-j
20CVRL17	45.56±0.05 i	17.54±0.13 d-f	3.08±0.04 g-j	3.77±0.04 g-k	30.06±0 a
20CVRL18	51.6±0.18 b	17.25±0.27 f	3.54±0.02 ab	4.27±0.06 b	23.35±0.17 lm
20CVRL19	47.61±0.24 f-h	17.71±0.26 c-f	2.93±0.03 ij	3.63±0.06 jk	28.13±0.06 c-f
20CVRL20	48.50±0.04 d-f	17.31±0.23 f	3.31±0.08 d-f	4.01±0.04 c-f	26.88±0.06 f-i
20CVRL21	45.98±0.01 hi	18.60±0.08 a-c	3.04±0.01 g-j	3.70±0.05 h-k	28.7±0.13 a-e
20CVRL22	45.4±0.16 i	17.22±0.23 f	3.39±0.06 b-e	4.17±0.08 b-d	29.83±0.07 ab
Nonpareil	55.65±1.45 a	19.46±0.25 ab	3.69±0.05 a	4.55±0.02 a	16.67±1.17 n
Minimum	45.40	17.12	2.90	3.59	16.67
Maximum	55.65	19.50	3.69	4.55	30.06
Mean	48.03	18.00	3.22	3.92	26.84

PCA analysis

Multivariate analysis of morphological and biochemical characteristics of almond genotypes is critically important in breeding programs and cultivar development. The Principal Component Analysis (PCA) Biplot graph presented in Figure 2 visualizes the complex relationships between physical and chemical properties of 22 almond genotypes and the 'Nonpareil' (23) cultivar. The first two components (Dim1 and Dim2) explain 57.27% of the total variance. Dim1 (35.3%) is positively correlated with characteristics such as fat, moisture, ash, and kernel dimensions, while negatively correlated with total carbohydrate. Dim2 (21.9%) shows strong positive correlation with kernel thickness and width indices. These findings parallel the study by Güney and Genç (2025) on almond genotypes grown in Yozgat province; their research also identified similar relationships between fatty acid profile and morphological characteristics. Genotypes positioned on the right side of the figure have high fat content and kernel dimensions, while those on the left have higher carbohydrate content. Genotypes in the upper part show superiority in terms of kernel thickness and width indices, while those in the lower part are characterized by kernel and fruit length. Similarly, in the genetic diversity assessment conducted by Bayazit et al. (2025) in the Eastern Mediterranean Region, phenotypic and morpho-physicochemical properties were

emphasized as determinants for almond breeding programs. When examining the relationship of genotypes with characteristics, 'Nonpareil' (23) stands out with high fat, moisture, and ash content, while 20CVRL13 and 20CVRL18 are superior in terms of kernel width and thickness. This is consistent with the fatty acid profiling study by Kumawat et al. (2024) in almond germplasm in the Western Himalaya region; they also showed that genotypes with high fat content are associated with certain morphological characteristics. 20CVRL11, 20CVRL12, 20CVRL17, and 20CVRL19 show strong correlation with kernel thickness and width indices. 20CVRL3, 20CVRL14, 20CVRL16, and 20CVRL21, located on the left side, stand out with high carbohydrate content. 20CVRL4, 20CVRL5, 20CVRL6, 20CVRL7, and 20CVRL10, located in the lower part, are characterized by kernel and fruit length properties. 20CVRL02 and 20CVRL15 are associated with protein content, while 20CVRL08, 20CVRL20, and 20CVRL22 are related to fruit thickness and shell thickness properties. As stated in the genomic study by Khojand et al. (2024) in Iranian almond germplasm, such multivariate analyses are critically important in selecting genotypes with targeted characteristics in almond breeding programs and in preserving genetic diversity.

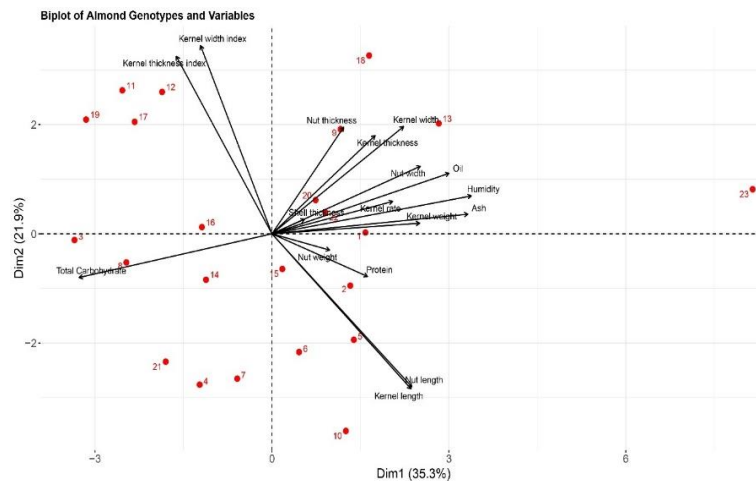


Figure 2. PCA Biplot graph of morphological and biochemical characteristics of almond genotypes. Numbers shown in red in the graph represent genotypes.

Şekil 2. Badem genotiplerinin Badem genotiplerinin morfolojik ve biyokimyasal özelliklerinin PCA Biplot grafiği. Grafikte kırmızı ile gösterilen sayılar genotipleri temsil etmektedir.

1:20CVRL01, 2:20CVRL02, 3:20CVRL03, 4:20CVRL04, 5:20CVRL05, 6:20CVRL06 22:20CVRL22, 23:Nonpareil

Correlation analysis

The correlation matrix presented in Figure 3 shows the relationships between morphological and

biochemical characteristics of almond genotypes. The strong positive correlation between kernel weight and fruit weight ($r=0.711, p<0.001$) indicates

that fruit weight largely derives from kernel weight. Similarly, a strong positive correlation was observed between kernel width and fruit width ($r=0.768$, $p<0.001$). The very high correlation between fruit length and kernel length ($r=0.977$, $p<0.001$) shows that these two characteristics change almost completely together. These findings are consistent with the relationships between morphological characteristics identified by Güney and Genç (2025) in almond genotypes grown in Yozgat province; similar correlations between fruit and kernel dimensions were also observed in their study. A significant positive correlation was also found between fruit thickness and kernel thickness ($r=0.664$, $p<0.001$). While a strong positive correlation was observed between kernel width index and kernel thickness index ($r=0.862$, $p<0.001$), strong negative correlations were detected between these indices and fruit length and kernel length ($r=-0.881$, $p<0.001$; $r=-0.882$, $p<0.001$; $r=-0.896$, $p<0.001$; $r=-0.903$, $p<0.001$). These results show that, as emphasized by Bayazit and Alaz (2022), in-shell fruit dimensions can provide important clues about kernel characteristics.

In terms of chemical properties, strong positive correlations were observed between fat content and ash and moisture ($r=0.734$, $p<0.001$; $r=0.729$, $p<0.001$), while a very strong negative correlation was found between fat and total carbohydrate ($r=-0.970$, $p<0.001$). These findings parallel the study by Kumawat et al. (2024) in almond germplasm in the Western Himalaya region; they also identified similar relationships between fat content and other biochemical parameters. Similarly, a very strong positive correlation between moisture and ash ($r=0.967$, $p<0.001$) and strong negative correlations of both with total carbohydrate ($r=-0.794$, $p<0.001$) were detected. Kernel width showed positive correlation with fat content, moisture, and ash ($r=0.498$, $p=0.016$; $r=0.522$, $p=0.011$; $r=0.497$, $p=0.016$), while showing negative correlation with total carbohydrate ($r=-0.477$, $p=0.021$).

Gouta et al. (2021) identified significant relationships between the physical properties and chemical composition of almond kernels. The researchers reported negative correlations between kernel length and weight and oleic/linoleic ratio and oleic acid content ($r=-0.37$), and positive correlation with linoleic acid content ($r=-0.40$). Additionally, they found that fruit thickness and weight showed positive correlation with protein content ($r=0.32$) and linoleic acid ($r=0.26$), while showing negative correlation with fat content ($r=-0.27$) and oleic acid ($r=-0.25$). These findings partially differ from the positive correlation between kernel width and fat content ($r=0.498$, $p=0.016$) detected in the present study. This difference may result from differences in the genetic structures of the studied genotypes and the ecological conditions in which they were grown.

The results of the correlation analysis are consistent with the observation noted by Kodad et al. (2023) in their research on almond genotypes in Spain, that genotypes with high fat content generally have larger kernel dimensions. Additionally, the relationships between morphological and biochemical characteristics detected by Bayazit et al. (2025) in almond genotypes in the Eastern Mediterranean Region support our findings. As stated by Gülcan (1976) and Özbek (1978), the kernel ratio is low in thick-shelled almonds and high in thin-shelled almonds. This observation was also confirmed in the genomic study by Khojand et al. (2024) in Iranian almond germplasm; the negative relationship between shell thickness and kernel ratio is consistently observed in almond populations with different genetic structures. In the study by Göksu and Yıldız (2024), as a result of principal component analysis, it was reported that genotypes with high kernel ratio had thinner shells.

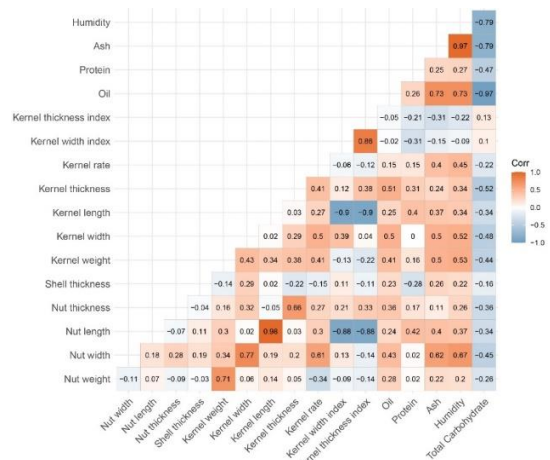


Figure 3. Pearson correlation coefficients and significance levels between morphological and biochemical characteristics of almond genotypes.

Şekil 3. Badem genotiplerinin morfolojik ve biyokimyasal özellikleri arasındaki Pearson korelasyon katsayıları ve anlamlılık düzeyleri.

Conclusion

As a result of the research, genotype 20CVRL22 had the highest kernel ratio with 32.26%, while genotypes 20CVRL13 and 20CVRL18 stood out with fat contents of 51.47% and 51.60%, respectively. Genotype 20CVRL15 drew attention with 19.50% protein content, and genotypes 20CVRL06 and 20CVRL15 with the thinnest shell thickness values of 2.43 mm and 2.46 mm, respectively. Principal Component Analysis showed a strong negative correlation between fat content and carbohydrate. In correlation analysis, strong positive relationships were detected between fruit and kernel dimensions. In conclusion, genotype 20CVRL22 was found

valuable for breeding studies with its high kernel ratio and kernel weight, while genotype 20CVRL13 showed versatile usage potential with high fat, ash, and moisture content similar to 'Nonpareil'. Genotype 20CVRL15 was found suitable for products with high nutritional value due to its high protein content, and genotypes 20CVRL06 and 20CVRL15 were found suitable for in-shell consumption with their thin shell characteristics. These findings reveal the richness of almond genetic resources in the Çivril region while providing valuable information for genotype selection for different usage purposes and future breeding programs.

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