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ORIGINAL ARTICLE

Determination of Phenological, Pomological, and Phytochemical Properties of Some Apricot Varieties Grown in the Mut (Mersin) Region

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Abstract

Turkiye has a rich apricot flora and a production potential capable of affecting global markets. In order to emphasize this potential, phenological characteristics, fruit quality, and some phytochemical properties of selected apricot varieties grown in the Mut district of the Mersin region were evaluated in the study. The results showed that the lowest fruit weight (25.64 g) was recorded for the 'Precoce de Tyrinthe' variety, while the highest (49.34 g) was observed for 'Flopria'. Stone weight ranged from the lowest (1.76 g) in 'Precoce de Tyrinthe' to the highest (2.32 g) in 'Domino'. Fruit flesh firmness was found to be lowest (76.25 kg/cm^2) in the 'Çağatay Bey' variety and highest (94.00 kg/cm^2) in 'Orange Ruby'. Soluble solids content varied between 12.90% in 'Rubista' and 18.46% in 'Çağatay Bey'; pH value measured between 3.21 in 'Rubista' and 3.83 in the 'Domino' variety. Titratable acidity was found to be lowest (1.32%) in the 'Domino' variety and highest (2.42%) in 'Orange Ruby'. In terms of antioxidant activity (measured by 2,2-diphenyl-1-picrylhydrazyl [DPPH] and ferric reducing antioxidant power [FRAP] methods), 'Orange Ruby' demonstrated the highest antioxidant capacity in both analyses. The lowest total phenolic content value (10.16 mg GAE/100 g) was recorded in 'Flopria', while the highest (120.47 mg GAE/100 g) was observed in the 'Orange Ruby' variety. Total anthocyanin content varied from 0.82 mg/g in the 'Çağatay Bey' variety to (1.58 mg/g) in 'Domino'. The findings indicated that the most suitable apricot varieties for cultivation in the Mut district are 'Flopria', 'Domino', and 'Çağatay Bey', with 'Orange Ruby' standing out due to its high antioxidant capacity and phenolic content.

Keywords Stone fruit · Biochemical · Fruit quality · Phenology · Pomology

Introduction

Apricot (*Prunus armeniaca* L.) is a stone fruit belonging to the Rosaceae family and has 2n = 16 chromosomes (Mehlanbacher et al. 1991; Hormaza et al. 2007). Its origin is believed to be in the northern and northeastern regions of China, extending to the Tien Shan and Altai Mountains, Central Asia, and the Near East (Janick and Moore 1975; Durgac 2001). Turkiye, located in a region rich in plant genetic resources, is particularly prominent in fruit production (Pinar et al. 2013). While there are various theories about the introduction of apricot to Anatolia, it is widely accepted that it was brought by Silk Road traders or during the campaigns of Alexander the Great (Bailey and Hough 1979). Türkiye's favorable climate and soil conditions have made apricot cultivation possible across a wide geographic area. Except for the high plateaus of the Eastern Black Sea and Eastern Anatolia regions, apricot production is carried out in many parts of the country. The Mediterranean climate regions, in particular, provide favorable conditions for apricot

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cultivation. Although apricot is a widespread fruit worldwide, its production is concentrated in a few countries with significant economic importance. European countries such as Italy, Spain, and France, as well as North African countries like Egypt, Algeria, and Morocco, play a crucial role in apricot production. In recent years, Central Asia and Near Eastern countries (Uzbekistan, Iran, Pakistan) have shown an increase in apricot production (FAO 2023). In 2023, the global apricot production was recorded at 3,728,155,89 t, with Turkiye leading the world with a 20.4% share of production. Turkiye is followed by Uzbekistan (11.5%), Iran (7.8%), and Italy (5.9%) (FAO 2023). In Turkiye, Malatya is the leading province for apricot production, accounting for 61.5% of the production areas, followed by Kahramanmaraş, Elazığ, and Mersin (TUIK 2023). In the Mediterranean region, the cultivation of apricots for fresh consumption has become increasingly important, with the Mut district of Mersin gaining prominence for early apricot production. Apricots grown in this region are delivered to large consumption centers such as Ankara and Istanbul, contributing to the economy. Apricots are rich in beneficial compounds for human health, including phenolic compounds, antioxidants, vitamins, and dietary fibers. Their antioxidant properties provide protective effects against free radicals, playing a role in delaying aging and preventing diseases (Moure et al. 2001). It is particularly noted that Turkish apricots have higher antioxidant capacity compared to those from other countries. To meet the daily vitamin A requirement, 250 g of fresh apricot or 30 g of dried apricot is sufficient (Kan 2009). Apricots are not only consumed fresh but are also processed into products such as dried apricots, marmalade, jam, pulp, and fruit juice. Their kernels are used in the cosmetics and pharmaceutical industries to obtain by products such as almond oil, edible oil, benzaldehyde, and activated carbon (Asma 2000). However, apricot production faces several challenges. Issues such as late spring frosts, ecological adaptation deficiencies, and short shelf life negatively affect production. Additionally, the increase in dried apricot production in countries like Uzbekistan is putting pressure on Turkiye's global competitiveness. This situation calls for the development of new apricot varieties that are resistant to diseases and pests, as well as the improvement of agricultural practices (Asma et al. 2017). The early apricots produced in the Mediterranean region being offered to the European market 15–20 days earlier than other countries provides Turkiye with a significant advantage in exports. Properly utilizing this potential could position Turkiye as a leader in fresh apricot exports. In this context, researching the phenological, pomological, and some phytochemical properties of apricots, particularly in regions like the Mut district in Mersin, is of great importance for developing production strategies.

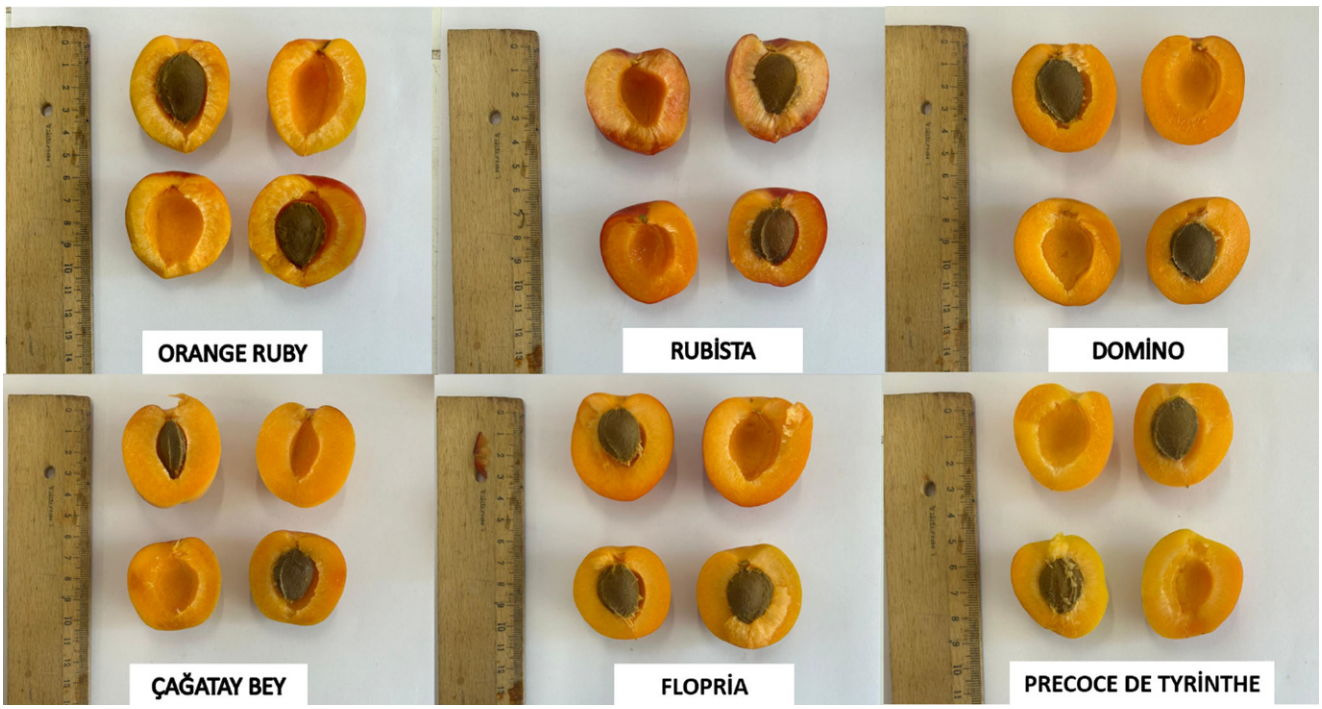


Fig. 1 Fruit appearance of six apricot varieties selected for the study

Materials and Method

Materials

In the study, six different 15-year-old apricot varieties—'Precoce de Tyrinthe', 'Rubista', 'Domino', 'Flopria', 'Orange Ruby', and 'Çağatay Bey'—grown in the Mut district of Mersin Province were used (Fig. 1). Fruit harvest was carried out based on fruit flesh firmness and skin color (yellowish-green) as maturity indicators according to UPOV (2021) criteria. After harvest, pomological measurements were initially performed. Subsequently, the fruits were homogenized using a homogenizer to obtain fruit juices, which were then stored at –20 °C.

Pomological analyses were conducted with four repetitions, using 10 fruit samples per repetition for each variety, meaning a total of 40 fruit samples were analyzed. The data obtained in this way allowed for a detailed examination of the various characteristics of the apricot varieties.

Methods

Phenological Characteristics

Bud swelling: Dark brown scales turn yellow-green and begin to swell and the buds start to swell by 70–80% (UPOV 2021).

Bud breaking: This is the stage at which the buds open and leaf tips are visible (UPOV 2021).

First blooming: Approximately 5–10% of the flower buds on the tree open, designated as a period (UPOV 2021).

Full blooming: Approximately 70% of the flower buds on the tree open, accepted as a period (UPOV 2021).

End of flowering: Approximately 90–95% of the flowers on the tree have petals, considered to be the period when the flowers fall (UPOV 2021).

Harvest date: Based on flesh firmness and fruit color (yellowish-green) was accepted as the commercially ripening stage which it was made (UPOV 2021).

Pomological Characteristics

Fruit weight and stone weight: The weight of fruits randomly selected from each variety was measured using a precision scale with 0.01-g sensitivity (Della Strada et al. 1989).

Flesh firmness (kg cm^{-2}): A thin section of the fruit peel was thinly cut with a knife and measured with a hand penetrometer with 11-mm tip.

Fruit dimensions: Fruit width, length, height (suture length) were determined with a digital caliper sensitive to 0.01 mm. The average values were recorded.

Fruit flesh thickness: This was determined by cutting the fruit in half and measuring with a digital caliper sensitive to 0.01 mm. Average values were recorded.

Stone shape in lateral view: triangular, ovate, oblong, elliptic, circular, oblate, obovate, oblique rhombic; color of fruit flesh: whitish green cream, light orange, medium orange, dark orange; stone adherence to flesh: absent or very weak, weak, medium, strong (UPOV 2021).

Fruit flesh/stone ratio: This was obtained by subtracting the stone weights from the fruit weights and dividing by the stone weight.

Color determination: Skin base color (L, a, b) of five fruits randomly selected from 10 repetitions was measured using a colorimeter (Minolta Co., model CR-400, Tokyo, Japan). The colorimeter was calibrated with a standard white plate before measurements. From the a* and b* values, chroma (C*) representing color saturation/vividness and hue angle (ho) representing the basic color tone were calculated:

$$C* = (a*2 + b*2)1/2, ho = \tan -1(b*/a*)$$

Chemical Analyses

Soluble solids content (SSC): The SSC of representative fruit samples was measured as °Brix using a digital refractometer (Atago, Japan). A drop of fruit juice was placed on the screen, and the displayed value was recorded as percent SSC.

Titratable acidity (TA): A 1-ml sample of fruit juice was titrated with 0.1 N NaOH solution until the pH reached 8.1. The acidity was expressed as a percentage of malic acid (Cemeroğlu 2007).

Sugar/acid ratio: Calculated by dividing the SSC value by TA.

pH determination: A 10-ml sample of fruit juice was analyzed using a digital pH meter. The pH meter electrode was immersed in the juice, and the value was recorded once stabilized.

Phytochemical Analyses

Determination of Total Phenol The total phenolic content (TPC) of pulp was determined colorimetrically using Folin–Ciocalteu reagent (Spanos and Wrolstad 1990). Results were described as milligram gallic acid equivalent/100 g of weight (mg/GAE 100 g).

Determination of Total Antioxidant Capacity The total antioxidant capacity was assessed using two key methods:

- Ferric reducing antioxidant power (FRAP): This method measures the reducing antioxidant power of iron and was conducted following the protocol described by Benzie and Strain (1996).
- Radical scavenging activity of 2,2-diphenyl-1-picrylhydrazyl (DPPH): The procedure was performed as outlined by Brand-Williams et al. (1995) with slight modifications as detailed by Polat et al. (2022).

Total Monomeric Anthocyanin Content Determination For total anthocyanin analysis, the method described by Giusti and Wrolstad (2001) was used with some modifications. Total anthocyanin determination was read at 510 and 700 nm in a spectrophotometer and calculation was made according to the following formula:

$$\text{Absorbance} = X = (510\,\text{nm pH1} - 700\,\text{nm pH 1}) - (510\,\text{nm pH4.5} - 700\,\text{nm pH4.5})$$

$$\text{Anthocyanin content(mg/L)} = (\text{absorbance}/29600 \times 1) \text{x}1000 \times 445 \times 20$$

Statistical Analysis

Descriptive statistics were expressed as mean and standard deviation. Analysis of variance (ANOVA) was used to determine whether there was a difference between the mean scores of the varieties with respect to these traits. Following the analysis of variance, Duncan's multiple comparison test was used to determine the differences. The calculations were based on a statistical significance level of 5% and the calculations were performed using the statistical package IBM SPSS Statistics 22 (Düzgüneş et al. 1987). Correlation analysis was performed in the IBM SPSS Statistics 22 statistical program to determine the relationships between the pomological characteristics examined in apricot (Düzgüneş et al. 1987). In addition, principal component analysis (PCA) was performed to explore the relationship between varieties' pomological and biochemical traits. The ggbiplot package, which is based on the ggplot2 visualization framework (Wickham and Wickham 2016), was used to create biplots for better visualization of the PCA results.

Results

Phenological Observations

In the study, phenological observations conducted in 2024 revealed that the 'Precoce de Tyrinthe' variety exhibited the earliest development stages, while the 'Çağatay Bey' variety showed the latest. Bud swelling occurred earliest on February 15 in 'Precoce de Tyrinthe' and latest on March 10 in 'Çağatay Bey'. Bud breaking was observed between February 19 for 'Precoce de Tyrinthe' and March 12 for 'Çağatay Bey'. First blooming started on February 22 for 'Precoce de Tyrinthe' and on March 15 for 'Çağatay Bey'. Full bloom periods ranged from March 1 for 'Precoce de Tyrinthe' to March 21 for 'Çağatay Bey'. The end of flowering was recorded earliest on March 5 and latest on March 25. Harvest dates varied between May 11 for 'Precoce de Tyrinthe' and May 28 for 'Çağatay Bey'. It was also noted that in the winter of 2023, phenological phases began 4–5 days earlier compared to 2024 due to higher than average air temperatures. These findings indicate significant differences in phenological development durations among varieties and emphasize the influence of environmental conditions, especially temperature and altitude, on the timing of phenological events (Tab. 1).

Pomological Analyses

The average physical characteristics of the apricot varieties for the years 2023 and 2024 are presented in Table 2. Statistically significant differences ($p < 0.05$) were observed among the varieties in terms of pomological traits.

Regarding fruit size measurements:

Fruit weight ranged from 25.64 g in 'Precoce de Tyrinthe' to 49.34 g in 'Flopria'.

Fruit length varied between 34.32 mm in 'Precoce de Tyrinthe' and 42.78 mm in 'Domino'.

Fruit width ranged from 35.04 mm in 'Precoce de Tyrinthe' to 42.49 mm in 'Domino'.

Fruit height was measured between 36.42 mm in 'Precoce de Tyrinthe' and 47.27 mm in 'Orange Ruby'.

These results highlight considerable variations in fruit dimensions among the varieties. 'Flopria' was identified as

Table 1 Phenological observation dates of apricot varieties in 2024 (days/month)

Periods	'Precoce de Tyrinthe'	'Rubista'	'Orange Ruby	''Çağatay Bey'	'Domino'	'Flopria'
Bud swelling	15 February	5 March	28 February	10 March	20 February	25 February
Bud breaking	19 February	8 March	1 March	12 March	22 February	28 February
First blooming	22 February	13 March	3 March	15 March	24 February	2 March
Full blooming	1 March	18 March	6 March	21 March	1 March	5 March
End of flowering	5 March	22 March	9 March	25 March	3 March	8 March
Harvest date	11 May	13 May	25 May	28 May	10 May	16 May

Table 2 Average pomological analysis results for 2023–2024

Varieties	Fruit weight (g)	Fruit length (mm)	Fruit width (mm)	Fruit height (mm)
'Precoce de Tyrinthe'	25.64 ± 3.24e	34.32 ± 0.67c	35.04 ± 0.36c	36.42 ± 1.12d
'Rubista'	35.16 ± 1.48c	40.38 ± 0.16ab	39.38 ± 0.13b	42.74 ± 0.08b
'Orange Ruby'	37.09 ± 2.21c	38.78 ± 0.32b	39.21 ± 0.46b	47.27 ± 0.84a
'Çağatay Bey'	41.50 ± 2.43b	41.61 ± 0.94ab	36.64 ± 0.59c	39.16 ± 0.58c
'Domino'	41.72 ± 4.53b	42.78 ± 1.40a	42.49 ± 1.35a	39.55 ± 0.00c
'Flopria'	49.34 ± 3.24a	39.63 ± 0.56b	40.55 ± 0.45ab	43.64 ± 0.16b

Different superscript letters in the same column indicate significant difference between values at the $p \leq 0.05$ level

Table 3 Average pomological analysis results for 2023–2024

Varieties	Stone adherence to flesh	Stone shape	Stone weight (g)
'Precoce de Tyrinthe'	Weak	Circular	1.76 ± 0.18e
'Rubista'	Weak	Circular	1.79 ± 0.22e
'Orange Ruby'	Weak	Circular	2.09 ± 0.13d
'Çağatay Bey'	Weak	Circular	2.15 ± 0.11c
'Domino'	Weak	Circular	2.32 ± 0.16a
'Flopria'	Weak	Circular	2.21 ± 0.07b

Different superscript letters in the same column indicate significant difference between values at the $p \leq 0.05$ level

the variety with the largest fruits, followed by 'Domino' and 'Çağatay Bey'.

Table 3 presents additional pomological traits of the six apricot varieties studied. It was determined that the attachment of the flesh to the stone was "weak" in all varieties. All varieties displayed circular stone shapes. Stone weight differed significantly among the varieties, ranging from 1.76 g in 'Precoce de Tyrinthe' to 2.32 g in 'Domino'.

Fruit flesh firmness, a critical parameter for storage and transport, ranged from 76.25 kg/cm^2 in 'Çağatay Bey' to 94.00 kg/cm^2 in 'Orange Ruby'. Flesh thickness was lowest in 'Precoce de Tyrinthe' 8.68 mm and highest in 'Flopria' (10.57 mm). Flesh to stone ratio varied from 13.61% in 'Precoce de Tyrinthe' to 21.33% in 'Flopria'. The flesh color of the varieties was also assessed. 'Precoce de Tyrinthe', 'Çağatay Bey', and 'Domino' were characterized by medium orange flesh, 'Flopria' by light orange, and 'Rubista' and 'Orange Ruby' by dark orange (Table 4).

Color Characteristics of Apricot Varieties

Many researchers around the world have stated that there are significant changes in the color of fruits as the altitude above sea level increases (Akkuş 2017). In addition, studies conducted on some fruit species (apple, fig and apricot) have shown that during fruit ripening periods, in addition to the day night temperature difference, annual temperature changes are also important in fruit coloration (Çalışkan and Polat 2012). The most widely used color system to express color in fruits and vegetables is CIE (L*a*b*), where L* has a brightness value between 0 (black) and 100 (white), a*, red (+)-green (–), b*, yellow (+)-blue (–) color values (Güler and Yıldırım 2016). The color parameters of the apricot varieties are presented in Table 5. The results are summarized as follows: L* ranged from 32.16 to 65.20 in 'Flopria', a* ranged from 24.84 in 'Çağatay Bey' to 39.30 in 'Orange Ruby', and b* ranged from 13.41 in 'Rubista' to 53.59 in 'Flopria'. Chroma* varied between 31.81 in 'Rubista' and 61.69 in 'Flopria', while hue * ranged from 24.92 in 'Rubista' to 60.30 in 'Flopria'.

Chemical Analysis Results

The average chemical properties of the apricot varieties evaluated in 2023 and 2024 are presented in Table 6. Statistically significant differences ($p < 0.05$) were observed among the varieties in terms of their chemical composition. The results are summarized as follows: SSC: The lowest SSC value was recorded in the 'Rubista' variety (12.90%), whereas the highest value was found in the 'Çağatay Bey' variety (18.46%). pH: The 'Rubista' variety exhibited the lowest pH value (3.21), while the highest pH was measured in the 'Domino' variety (3.83). TA: The lowest TA was ob-

Table 4 Average pomological analysis results for 2023–2024

Varieties	Firmness of flesh (kg/cm^2)	Flesh to stone ratio (%)	Color of flesh	Fruit flesh thickness (mm)
'Precoce de Tyrinthe'	90.15 ± 2.05a	13.61 ± 0.06d	Medium orange	8.68 ± 0.08c
'Rubista'	78.75 ± 0.65b	18.69 ± 0.18b	Dark orange	9.08 ± 0.06bc
'Orange Ruby'	94.00 ± 1.00a	16.71 ± 0.13c	Dark orange	10.44 ± 0.11a
'Çağatay Bey'	76.25 ± 3.25b	18.30 ± 0.02b	Medium orange	9.39 ± 0.15b
'Domino'	80.15 ± 4.55b	16.95 ± 0.31c	Medium orange	10.48 ± 0.27a
'Flopria'	92.65 ± 0.05a	21.33 ± 0.04a	Light orange	10.57 ± 0.07a

Different superscript letters in the same column indicate significant difference between values at the $p \leq 0.05$ level

Table 5 Average L*, a*, and b* color value results of the varieties in 2023–2024

Varieties	L*	a*	b*	Chroma*	Hue*
'Precoce de Tyrinthe'	56.63 ± 1.40bc	32.92 ± 1.11ab	38.13 ± 1.43b	50.45 ± 1.43b	49.11 ± 3.07b
'Rubista'	32.16 ± 1.16 d	28.85 ± 3.14b	13.41 ± 1.50c	31.81 ± 3.44c	24.92 ± 0.09c
'Orange Ruby'	54.07 ± 1.50c	39.30 ± 0.34a	39.22 ± 1.49b	55.54 ± 0.81ab	44.93 ± 1.33b
'Çağatay'	59.39 ± 0.24b	24.84 ± 2.86b	42.50 ± 0.14b	49.29 ± 1.56b	59.79 ± 2.79a
'Domino'	54.06 ± 1.90c	29.17 ± 5.02b	39.32 ± 1.23b	49.19 ± 1.99b	53.66 ± 5.57ab
'Flopria'	65.20 ± 0.12a	30.56 ± 0.36ab	53.59 ± 1.38a	61.69 ± 1.38a	60.30 ± 0.34a

Different superscript letters in the same column indicate significant difference between values at the $p \leq 0.05$ level

Table 6 Average chemical analysis results of the varieties in 2023–2024

Varieties	Soluble solids content (%)	Titratable acidity (%)	pH
'Precoce de Tyrinthe'	13.88 ± 0.12 d	1.90 ± 0.02c	3.42 ± 0.04c
'Rubista'	12.90 ± 0.10e	1.68 ± 0.06 d	3.21 ± 0.05 d
'Orange Ruby'	17.15 ± 0.15b	2.42 ± 0.04a	3.62 ± 0.08b
'Çağatay Bey'	18.46 ± 0.04a	1.58 ± 0.10 d	3.70 ± 0.02b
'Domino'	13.24 ± 0.04e	1.32 ± 0.04e	3.83 ± 0.04a
'Flopria'	14.50 ± 0.20c	2.17 ± 0.02b	3.37 ± 0.02c

Different superscript letters in the same column indicate significant difference between values at the $p \leq 0.05$ level

served in the 'Domino' variety (1.32%), and the highest in the 'Orange Ruby' variety (2.42%).

Phytochemical Properties and Antioxidant Activity

In recent years, the role of phytochemicals, especially those with anticancer potential, has gained increasing attention in human nutrition, alongside traditional physical attributes that determine fruit quality. This trend has significantly elevated consumer demand and scientific interest in functional foods. In the current report, a total of six apricot varieties were evaluated in terms of phytochemical properties and antioxidant activity. The phytochemical parameters including TPC, antioxidant activity, and total monomeric anthocyanin content were assessed (Table 7). Statistically significant differences ($p < 0.05$) were observed among the apricot varieties for all measured phytochemical traits.

TPC: The lowest TPC was found in the 'Flopria' variety 10.16 mg GAE/100 g, whereas the highest was observed in 'Orange Ruby' 120.47 mg GAE/100 g.

Antioxidant activity (DPPH method): Antioxidant activity ranged from 25.29% in 'Domino' to 29.47% in 'Orange Ruby'.

Ferric reducing antioxidant power (FRAP assay): Antioxidant capacity ranged from 0.44 mg TE/g FW in 'Domino' to 2.47 mg TE/g FW in 'Orange Ruby', indicating that 'Orange Ruby' possessed the highest antioxidant potential by both methods.

Total monomeric anthocyanins: The lowest anthocyanin content was recorded in the 'Çağatay Bey' variety (0.82 mg/g), while the highest was found in 'Domino' (1.58 mg/g).

These findings highlight the considerable phytochemical diversity among apricot varieties and reinforce the nutritional and functional value of apricots, particularly the 'Orange Ruby' and 'Domino' varieties.

Principal Component Analysis of Pomological and Pyhtochemical Characteristics in Apricot Varieties

The results of the PCA for pomological, chemical and phytochemical characteristics of apricot fruits are presented in

Table 7 Total anthocyanin, phenolic and antioxidant activity values of apricot varieties

Varieties	DPPH (%)	FRAP (mg TE/g FW)	Total phenol (mg/GAE 100 g)	Total monomeric anthocyanin (mg/g)
'Domino'	25.29 ± 0.29 d	0.44 ± 0.01 d	10.30 ± 0.23de	1.58 ± 0.02a
'Çağatay Bey'	25.80 ± 0.36 d	2.19 ± 0.02b	90.67 ± 0.69b	0.82 ± 0.05c
'Flopria'	26.52 ± 1.09cd	1.10 ± 0.29 d	10.16 ± 0.29e	1.21 ± 0.08b
'Rubista'	27.14 ± 0.79bc	1.82 ± 0.08c	30.42 ± 0.70 d	1.21 ± 0.16b
'Precoce de Tyrinthe'	27.77 ± 0.42b	2.01 ± 0.08bc	60.20 ± 0.36c	1.54 ± 0.02a
'Orange Ruby'	29.47 ± 0.80a	2.97 ± 0.05a	120.47 ± 0.54a	0.74 ± 0.02c

Different superscript letters in the same column indicate significant difference between values at the $p \leq 0.05$ level
DPPH 2,2-Diphenyl-1-picrylhydrazyl, *FRAP* Ferric reducing antioxidant power

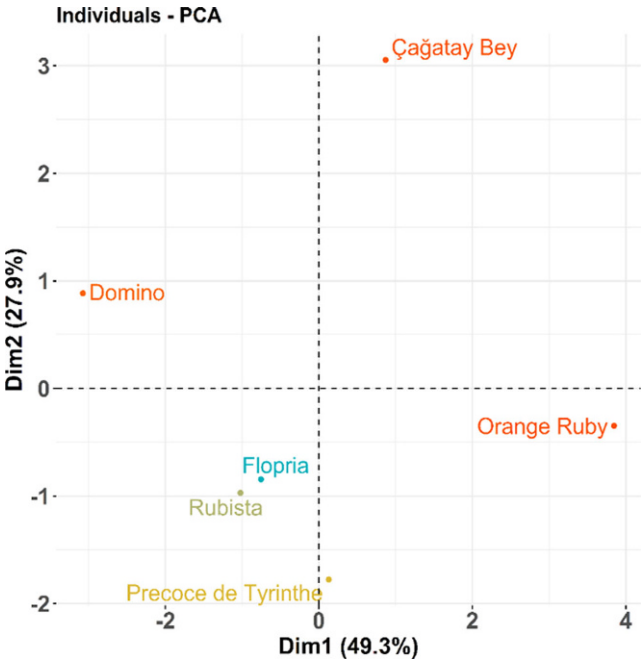


Fig. 2 Identification of the correlation between pomological, chemical, and phytochemical contents of apricot varieties by principal component analysis (*PCA*)

Fig. 2. This analysis explores the correlation between various pomological, chemical and biochemical components in different apricot varieties, and the results are summarized as follows: PC1 (49.3%) and PC2 (27.9%) together account for 77.2% of the total variation, making them critical for understanding the data distribution. This indicates that the majority of the differences among varieties can be represented in a two dimensional space. 'Domino', 'Çağatay Bey' and 'Orange Ruby' are distinctly positioned in the PCA plot, suggesting significant differences in their pomological, chemical and biochemical profiles compared to other varieties. These differences may be due to genetic factors, influencing the biochemical composition and resulting in unique traits. Traits such as fruit weight, total antioxidant capacity, TPC and other bioactive compounds likely contribute to the separation of varieties in the PCA. The findings could guide cultivar selection for specific uses, such as enhancing flavor profiles, optimizing nutrient content, or tailoring for functional food products. Understanding these distinctions is essential for improving apricot breeding programs, marketing strategies and meeting consumer preferences. PCA is a powerful tool for identifying cultivar-specific properties and could support targeted agricultural and industrial applications. The distinct phytochemical and pomological traits of 'Domino', 'Çağatay Bey' and 'Orange Ruby' demonstrate the potential for specialized cultivation and product development.

Correlation Between Pomological and Phytochemical Properties of Apricot Varieties

The study examined the relationships between pomological properties (fruit weight, flesh firmness), chemical properties (pH, SSC, and TA), and phytochemical properties (total antioxidant capacity, TPC, and total monomeric anthocyanin content) in apricot varieties through correlation analysis (Fig. 3). The findings are as follows: Total antioxidant capacity, determined using the DPPH method, exhibited a strong positive correlation with FRAP values (r^2 = 0.70***), TPC (r^2 = 0.51**), and TA (r^2 = 0.69*). These results indicate that higher antioxidant activity is associated with increased phenolic content and acidity. FRAP values were positively correlated with TPC (r^2 = 0.89***), SSC (r^2 = 0.60*) and TA (r^2 = 0.62*). However, a strong negative correlation was observed between FRAP and total monomeric anthocyanin content (r^2 = –0.74***), suggesting an inverse relationship between antioxidant capacity and anthocyanin levels. TPC demonstrated a positive correlation with SSC (r^2 = 0.78**), but a negative correlation with total monomeric anthocyanin content (r^2 = –0.73***). Similarly, total monomeric anthocyanin content showed a significant negative correlation with SSC (r^2 = –0.76**). Fruit flesh firmness was positively correlated with TA (r^2 = 0.83***) emphasizing the influence of acidity on textural properties. Additionally, SSC showed a positive relationship with pH (r^2 = 0.69*), indicating that higher sugar levels are associated with increased pH.

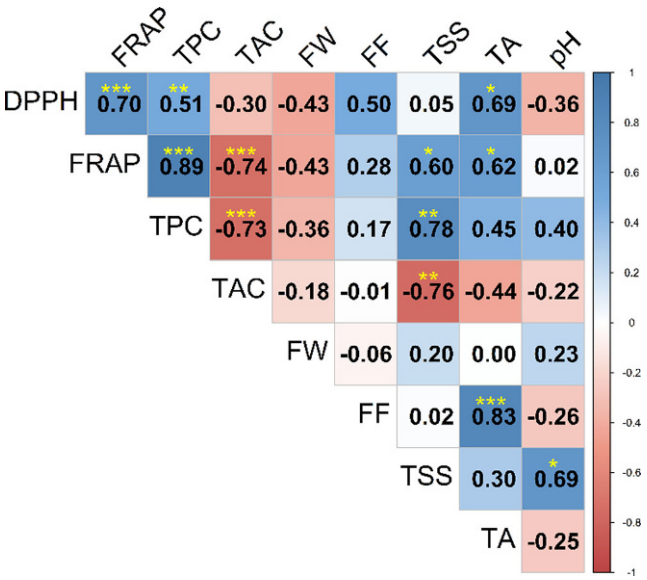


Fig. 3 Correlation graph of the pomological and Phytochemical properties analyzed in the study. (*DPPH* 2,2-Diphenyl-1-picrylhydrazyl, *FRAP* Ferric reducing antioxidant power, *TPC* Total phenolic content, *FW* Fresh weight, *FF* Fruit flesh, *TSS* Total soluble solids, *TA* Titratable acidity, *pH* Acidity level)

Overall, the results highlight the complex interplay between chemical and phytochemical properties in apricot varieties. Positive correlations between antioxidant capacity phenolic content and acidity underline their synergistic role in enhancing fruit quality. In contrast, the inverse relationship between anthocyanin content and other parameters suggests distinct phytochemical pathways influencing apricot composition. These findings contribute to a deeper understanding of the chemical and nutritional attributes of apricots that are vital for breeding programs and consumer preferences.

Discussion

Phenological Observations

Phenological observations provide crucial insights into the biological cycles of plants and their interaction with environmental factors. The early phenological development observed in 'Precoce de Tyrinthe' is compatible with previously reported early-maturing varieties (Bilgin and Mısırlı 2016). The later development of the 'Çağatay Bey' variety supports the effect of higher altitude and lower temperature conditions on delaying phenological stages (Balta et al. 2002; Özkarakaş et al. 2008). The observation that phenological stages in the winter of 2023 started 4–5 days earlier than in 2024 highlights the impact of climate change on plant developmental cycles. This underscores the need to consider climate variability in production planning and variety selection (Guo et al. 2015).

Variations in early phenological events such as bud swelling and bud breaking can be attributed to regional climatic differences and genetic factors (Yağmur 2024; Acarsoy 2013). Differences in flowering periods are critical for fruit yield and quality and thus important for ensuring regional adaptation (Yarılgaç and Kazankaya 2002; Guo et al. 2015).

Differences in harvest dates result from regional climatic conditions, genetic diversity, and cultivation practices, providing valuable information for the optimal timing of agricultural activities (Yağmur 2024; Asma 2011).

In conclusion, monitoring phenological stages and understanding the effects of environmental conditions are fundamental for developing sustainable production and climate change adaptation strategies in apricot cultivation.

Pomological Analyses

When studies conducted in various regions of the world and Turkiye are examined, as conducted by Yağmur (2024) in the Bitlis region, seed propagated apricot genotypes exhibited the following pomological characteristics: Fruit weight ranged from 11.04 to 32.66 g, fruit length from 26.97 to 40.39 mm, fruit width from 12.05 to 38.00 mm, and fruit height from 26.00 to 35.38 mm. Çalışkan et al. (2012), in the Mut district of Mersin, reported fruit weights ranging from 26.7 to 78.4 g, fruit lengths from 37.8 to 54 mm, fruit widths from 35.00 to 49.9 mm, and fruit heights from 37.8 to 54 mm. In another study, Çalışkan et al. (2021) examined the 'Mikado' and 'Magador' varieties in Hatay and found that fruit weight ranged from 34.45 to 37.47 g, fruit length from 39.86 to 41.11 mm, fruit height from 40.74 to 40.84 mm, and fruit width from 31.01 to 37.31 mm. Pehluvan et al. (2021) reported the following measurements for 'Şalak' and 'Teberze' varieties—'Şalak': fruit weight 6.72–61.53 g, fruit length 31.38–49.58 mm, fruit width 20.78–45.06 mm, fruit height 18.68–46.43 mm; 'Teberze': fruit weight 4.14–29.29 g, fruit length 24.30–37.41 mm, fruit width 19.27–35.61 mm, fruit height 16.11–37.84 mm. The variations in these results are likely attributable to differences in cultivar regional ecological conditions and cultural practices. In terms of flesh-to-stone attachment. Yarılgaç and Kazankaya (2002) found that 'Precoce de Tyrinthe' exhibited strong flesh to stone adherence in Van, whereas 'Precoce de Colomer Bebeco' and 'Sakit 2' showed weak adherence. Bulut (2023), in a study conducted in Mersin (2021–2022), reported that among hybrids derived from 'Şahinbey' × 'Bebeco', eight had strong and 24 had weak stone attachments. Similarly, Yanar (2016), in a study at the Malatya Apricot Research Institute involving 37 varieties and genotypes, reported that 11 had strong and 26 had weak flesh stone adherence. Regarding stone shape, Yağmur (2024) observed that among genotypes from Bitlis, five had circular stones and 15 had elongated circular stones. Bulut (2023) found two hybrids with elongated-circular stones, while the rest had circular ones. Stone weight values from different studies are as follows: Yağmur (2024), 1.42–3.06 g; Asma et al. (1998), 1.1–3.5 g; Kaska et al. (1997), 1.36–3.74 g; Kaufmane and Lacis (2004) (Latvia), 1.6–2.5 g; Kumar et al. (2015) (India), 2.17–4.34 g; Çalışkan et al. (2021), 'Mikado' (2.48 g) and 'Magador' (2.77 g). The lowest and highest stone weights recorded in our study are consistent with those reported in the literature. Regarding fruit flesh firmness, Naryal et al. (2019) reported a firmness of 2.4 kg/cm^2 in 47 apricot varieties grown in Ladakh, India (elevation: 3006–3346 m). Bartolini et al. (2015) determined a firmness range of 1.6–2.9 kg/cm^2 for the 'Pisana' variety under Mediterranean conditions. Doğru Çokran (2020) found the average flesh thickness in promising clones to range between 15.84 and 16.11 mm in Iğdır, 15.29 and 16.83 mm in Tuzluca, and 15.05 and 15.83 mm in Kağızman. Yanar (2016) reported the flesh-to-stone ratio to be highest in 'Hasanbey' (18.19%) and lowest in 'Erivan' (4.31%).

In comparison, Çalışkan et al. (2021) recorded values of 12.93% ('Mikado') and 15.71% ('Magador').

These findings concur with previous studies, highlighting that pomological traits in apricots are largely influenced by genetic factors, alongside environmental conditions and cultivation practices. As for fruit color, Karaat and Serçe (2019) examined 12 apricot varieties from different regions of Turkiye and found wide variation: L* values, 27.60–70.71; a* values, 7.11–44.72; b* values, 8.61–43.63. Yağmur (2024) measured the L* value between 53.03 and 73.56, the a* value between 4.47 and 18.57, the b* value between 40.29 and 56.37, the chroma* value between 40.57 and 56.61 and the hue value between 71.96 and 87.12.

The effect of region and altitude is seen in the L*, a*, and b* color values of the fruit peel in apricot fruit. In the study, it is seen that the physical properties of apricot varieties are consistent with the data obtained in previous studies. These results confirm that fruit color in apricot is highly variable and influenced by both genetic factors and environmental conditions, particularly sunlight exposure (Özbek 1978). Moreover, harvest timing is known to be a key factor affecting skin color in table apricots.

Chemical Analysis

When studies from different regions of Turkiye and the world are examined, a considerable variation is observed in the chemical properties of apricot fruits. Yağmur (2024) reported that seed-propagated genotypes from the Bitlis region had SSC values ranging from 9.67 to 25.40%, TA values between 0.29 and 2.49%, and pH values from 3.70 to 5.62. Similarly, Çalışkan et al. (2012), in a study on 14 table apricot varieties in Mut (Mersin), found SSC values between 9.6 and 14.6%, TA from 1.2 to 2.4%, and pH between 3.15 and 3.74. Son (2018), analyzing varieties from Silifke, noted SSC and TA values varying by cultivar; for example, 'Alyanak' had 16.40% SSC and 1.2% TA, while 'Precoce de Tyrinthe' had 10.93% SSC and 1.49% TA. In another study, Pehluvan et al. (2021) found that 'Şalak' and 'Teberze' exhibited SSC values of 5.08–13.09% and 6.01–13.80%, respectively, with TA and pH values also varying widely. Such differences may arise due to genetic diversity, environmental conditions (e.g., climate and soil), harvest timing, and cultural practices. The broad ranges in SSC, pH, and TA indicate substantial potential for targeted breeding programs. For instance, varieties with moderate acidity and high SSC are preferable for fresh consumption, while those with higher acidity and lower SSC may be more suitable for industrial uses like juice production (Mphahlele et al. 2014). Additionally, these parameters can guide the development of varieties tailored to market-specific preferences (Alcaraz-Mármol et al. 2017). Despite observed differences across studies, the results of the present research are generally in concordance with previous findings and in some instances even surpass them. This highlights the economic and nutritional potential of the studied apricot varieties.

Phytochemical Properties and Antioxidant Activity

There is increasing interest in the high levels of bioactive compounds found in fruits and vegetables because they may help protect people against many diseases. These bioactive compounds have been linked to their ability to reduce free radical damage to cells as a result of oxidative stress and to lower the risk of major chronic conditions such as cancer, cardiovascular disease, obesity, and other diseases. When apricot research conducted in the world and in Turkiye is examined, Saridas and Ağcam (2021) reported that the TPC of 'Teberze' and 'Ağerik' apricot varieties grown in the Iğdır region ranged from 8.73 to 43.54 mg GAE/100 g, while antioxidant activity measured by the DPPH method varied between 0.035 and 0.142%. In a study conducted by Sochor et al. (2010) on 21 apricot varieties, antioxidant capacity was measured in the range of 0.015–1.42%, and TPC varied from 41 to 170 mg GAE/100 g. Similarly, Roussos et al. (2011) reported DPPH antioxidant activities of 0.35, 0.498, and 0.938 µmol Trolox equivalents/g FW in the 'Bebeco', 'Nafsika', and 'Niove' varieties, respectively, while FRAP values were 1.68, 1.47, and 2.01 µmol Trolox equivalents/g FW, respectively. Bureau et al. (2009), in their analysis of two apricot varieties ('A3576' and 'A3751') harvested in France, found total monomeric anthocyanin contents of 0.041 and 0.296 mg/g, respectively. Çalışkan et al. (2012) identified phenolic contents ranging from 14.4 to 177.1 mg GAE/100 g and antioxidant activity levels ranging from 20.3 to 120.3 mg Fe^2/g in apricot varieties cultivated in Turkiye's Mediterranean region. The findings concur with previous studies showing significant phytochemical variation among apricot varieties, mainly due to genetic differences. Environmental factors such as climate, soil, and cultivation methods also influence this composition. Hallmann et al. (2019) noted that organic apricots typically have higher levels of phenolics and carotenoids. Varieties with deep orange flesh, often richer in these compounds, are especially recommended for their superior nutritional quality. Overall, apricots stand out as a valuable source of bioactive compounds beneficial to human health.

Conclusion

Turkiye is one of the countries of origin of apricots and possesses a remarkably rich genetic diversity. This study examined the physical, chemical, and phytochemical properties of selected apricot varieties and evaluated the

findings. The key results of the study are summarized as follows—Physical properties: 'Flopria', 'Domino' and 'Çağatay Bey' varieties stood out in terms of fruit weight. 'Orange Ruby' 'Flopria' and 'Precoce de Tyrinthe' varieties, with their high flesh firmness, were found to be more durable for storage and transport. Soluble solid content (SSC), a critical indicator of nutritional value and commercial significance, was highest in the 'Çağatay Bey' variety. The highest total phenolic content was recorded in the 'Orange Ruby' variety. In the antioxidant activity analysis (DPPH and FRAP methods), 'Orange Ruby' exhibited the highest antioxidant capacity. The highest total monomeric anthocyanin content was found in the 'Domino' variety. For consumers aiming for healthy dietary choices, it is recommended to prioritize apricot varieties with high phenolic content and antioxidant capacity. 'Orange Ruby' and 'Domino' varieties particularly stand out with these attributes. Considering productivity and quality criteria, the 'Flopria' variety is identified as the most suitable apricot variety for the Mut district. In conclusion, apricot varieties exhibit significant variations in their physical and chemical properties due to the presence of bioactive compounds beneficial to health. These findings highlight the value of apricot as a nutritious fruit and underline the need for further research in this field.

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Data Availability Statement The data presented in this study are available on request from the authors.

Conflict of interest Y. Polat, G. Nogay, B. Özgören, B. İmrak and N. E. Kafkas declare that they have no competing interests.

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