Applied Fruit Science (2025) 67:163
https://doi.org/10.1007/s10341-025-01353-3

ORIGINAL ARTICLE

Physico-chemical Changes and Optimal Harvest Determination of 'Zeferan' Peach (*Prunus Persica* L.) Cultivar Throughout the Fruit Ripening Period

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Received: 24 October 2024 / Accepted: 15 April 2025 / Published online: 6 June 2025
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Abstract

'Zeferan' peach cultivar, which grows in the Iğdır region of Türkiye, is known for its sweet taste, attractive red color, high yield, and good adaptation to local growing conditions. This study aimed to investigate the physical and chemical changes of the peach cultivar 'Zeferan' during the ripening period. The study was conducted from the third week of May to the second week of September, spanning approximately 16 weeks, and fruit samples were harvested every 2 weeks (total of nine harvests). The color values (L*, a*, b*, C* and h*), physical properties (weight, size, firmness, elasticity), and chemical properties (pH, soluble solids content, organic acids and phenolic compounds) were measured every 2 weeks. The results showed that the color parameters of the fruit significantly changed during the ripening process. The fruit weight increased from 9.68 to 136.01 g, the fruit width from 27.36 to 61.90 mm, and the fruit length from 40.28 to 75.80 mm. The firmness of the fruit increased in the first four pickings and then decreased. The soluble solids content increased continuously and reached 12.40% in the last harvest. The concentrations of organic acids and phenolic compounds fluctuated throughout the ripening process. The optimum harvest date for 'Zeferan' was around 16 weeks after full bloom.

Keywords Fruit development · Quality characteristics · Phenolic content · Organic acids · Iğdır

Introduction

The peach belongs to the genus *Prunus*, part of the subfamily Prunoideae within the Rosaceae family in the order Rosales (Rieger 2007). Originally from China, the peach is cultivated in many temperate climate zones around the world, as it can quickly adapt to different climatic conditions (Özdemir and Mısırlı 2012). With a peach production of 1,000,008 tons, Türkiye is one of the largest peach-producing countries after China and Italy (FAO 2024).

As Iğdır is Türkiye's gateway to the East and lies on the old trade routes, the genetic diversity of the peach cultivar has developed over date with some fruit species from temperate climates. The peaches, which have been grown from seed in the region for many years, have a unique taste, smell, and aroma, as well as characteristics that can compete with commercial varieties in terms of fruit size. One of these specific cultivars is called 'Zeferan' (Altay et al. 2022).

The quality and shelf life of fruit can be determined by measuring various physical and biochemical changes occurring during the fruit's growth, development, and ripening. Harvesting at the correct date of ripening is an important factor influencing both the quality of the fruit and the rate of quality change during post-harvest processing (Patel et al. 2014).

Fruit ripening is the final stage of fruit development and involves a series of physiological and biochemical changes that make the fruit look more attractive with a better flavor.

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Fig. 1 The different development stages of the physical properties of the cv. 'Zeferan'

In general, significant physical changes can be observed in ripened fruit, which can be reflected in the fruit skin's color and the fruit's firmness (Kader 2002).

'Zeferan' is a local and famous peach cultivar grown in the Iğdır province of Türkiye (Altay 2016). This cultivar has an important place among the region's agricultural products thanks to the microclimate of Iğdır. Iğdır is located in a climate zone that experiences hot summers and cold winters due to the influence of the Aras Valley, which allows fruits such as peaches to grow in high quality (Şimşek et al. 2018). Therefore, this study was carried out to determine the physico-chemical characteristics of 'Zeferan' peach harvested at different stages of ripening throughout a 16-week period, aiming to identify the optimal harvest date for achieving the best quality attributes and enhancing its commercial value. The study's results will help producers, traders, and consumers determine the optimal harvest date when the peach cultivar 'Zeferan' has the best quality characteristics.

Materials and Methods

Plant Material

This study was carried out on the peach cultivar 'Zeferan' during the 2017 growing season. Fruit samples were obtained from a local grower's orchard located in Iğdır, Türkiye. The study period continued for approximately 16 weeks, from May to September. The first fruit samples were collected in the third week of May, 2 weeks after full bloom, and subsequent samples were harvested at 2-week intervals until the second week of September, resulting in a total of nine harvests (Fig. 1). Every 2 weeks, samples were randomly taken from three different trees and kept in plastic bags. At least 10 fruits were taken from each tree from different sides and a total of at least 30 fruits were picked for each period. The fruits were analyzed for physical, sensory, and pomological properties before being stored at –18 °C for further analysis. In study, environmental conditions such as temperature, soil conditions, irrigation, and pest control were not specifically controlled. However, samples were consistently collected from the same orchard and trees at 2-week intervals to minimize environmental variations. Additionally, the study did not include other peach varieties for comparison purposes.

Color Measurement

The color of the peach skin was measured at three different points on the fruit skin using a colorimeter (Minolta, CR 410, Osaka, Japan), according to Karabulut et al. (2007). The measurements were expressed as CIE L*, a* and b* values. C* (chroma), and h° (color angle), were calculated using the following equation:

$$C^* = \sqrt{(a^2 + b^2)}$$
$$h^\circ = \arctan b^*/a^*$$

Physical and Pomological Analyses

Fruit sizes, such as the length and width of the fruit samples, were measured with a digital caliper. The weight of the fruit was determined with a digital precision scale with an accuracy of 0.01 g. The fruits' geometric mean diameter (Dg) and sphericity (S) values were calculated using the following equations:

$$Dg = (lwt)^{1/3}$$
$$s = \left(\left((lwt)^{1/3}\right)/l\right) \times 100$$

where Dg is the geometric mean diameter (mm), and s (%) is the sphericity, l (mm), w (mm), and t (mm) are the length, width, and thickness, respectively.

Mechanical Analysis

The firmness and elasticity of the fruit were measured using a texture analyzer (model TA-XT2, Stable Microsystems, Surrey, UK) with a 2-mm diameter cylindrical stainless-steel probe and a 30-kg load cell. The test parameters were: initial and final velocity of 5 mm/s, test velocity of 1 mm/s, and penetration depth of 3 mm (Cui et al. 2008).

Chemical Properties

Soluble Solid Content and pH Measurements

The soluble solids content (SSC) of filtered peach juice was measured using a refractometer (Boeco Digital Abbe Refractometer, BOE 32400, Germany), and the result was expressed in °Brix. The pH value of the filtered sample juice was determined using a multiparameter analyzer with a pH electrode (Consort, C3040, Belgium) (SP10B, Consort, Belgium).

Sample Extraction

The peach samples were extracted using a modified version of the method described by Alwazeer and Örs (2019). A 5-g portion of the fruit sample was mixed with 10 ml of 50% methanol (v/v) containing 0.1% HCl and homogenized using an IKA Ultra Turrax T18 (Korea) at 1300 rpm for 1 min. The homogenate was then kept in the dark at room temperature for 2 h. The extract was then centrifuged at 10,000 × g and 10 °C for 15 min, and the supernatant was filtered through Whatman No. 4 filter paper followed by a 0.45-μm filter. The resulting filtrate was stored at –80 °C until further analysis.

High-Performance Liquid Chromatography Analysis of Organic Acids and Phenolic Content

Organic acid measurements were performed isocratically, with slight modifications according to Akin et al. (2008), using an Agilent 1260 series high-performance liquid chromatography (HPLC) system equipped with a diode array detector (DAD) and an ACE GENERIX 5 C18 column (5 μm, 4.6 mm × 250 mm). HPLC elution was performed at 30 °C with 98% Na_2HPO_4 (adjusted to pH 2.4 with H_3PO_4) as the mobile phase, and the flow rate was 1 ml min^{-1}. The chromatograms were detected at 210 nm for citric acid and at 400 nm for ascorbic acid. The separation of phenolics (gallic acid and catechin) was performed using the method described by Hussain et al. (2013), with slight modifications, using an Agilent 1260 series HPLC system equipped with a DAD and a Poroshell 120 EC-C18 column (2.7 μm, 4.6 mm × 150 mm). A gradient mobile phase consisting of 83% phosphoric acid and 17% acetonitrile was used as mobile phase B at a 1 ml/min flow rate, and the injection volume was adjusted to 20 μl. The gradient used was as follows: A = 83% for 1 min, A = 70% for 2 min, A = 60% for 4 min, and A = 83% for 10 min. Operating conditions were as follows: detector wavelengths at 210 and 300 nm, injection volume of 20 μL, and column temperature at 20 °C.

Statistical Analysis

Data were statistically analyzed using one-way analysis of variance (ANOVA) along with Duncan's multiple range tests ($P < 0.05$) using SPSS version 18 statistical software (SPSS Inc., Armonk, NY, USA), and results are presented as mean ± standard deviation.

Results and Discussion

Color

Color is a crucial indicator of some fruits' ripeness and harvest date. The color of the fruit reflects the chemical changes during the ripening process and helps to determine the degree of ripeness and the harvest date (Köksal and Büyükkartal 2011). The color values (L*, a*, b*, C* and h*) together with the color indices for the peach cultivar 'Zeferan' throughout nine fruit pickings (from the 3rd picking in May to the 1st picking in September) are listed in Table 1. The L* value showed a general increase from the 1st to the 9th picking date, but fluctuations in L* value were shown during picking dates. The highest value was

Table 1 Color values (L*, a*, b*, C* and h*) of 'Zeferan' peach cultivar

No.	Harvesting date	L*	a*	b*	h*	C*
1	16.05.2017	34.87 ± 0.65	2.58 ± 4.21	15.18 ± 9.90	80.35 ± 16.90	15.40 ± 12.64
2	30.05.2017	51.38 ± 1.25	–4.71 ± 1.58	15.05 ± 0.60	107.38 ± 5.04	15.77 ± 1.10
3	13.06.2017	49.28 ± 2.32	–6.38 ± 4.51	22.04 ± 2.37	106.14 ± 8.96	22.94 ± 3.93
4	27.06.2017	56.49 ± 3.26	–5.64 ± 2.45	25.06 ± 1.77	102.68 ± 5.42	25.69 ± 2.70
5	11.07.2017	55.32 ± 1.59	–8.86 ± 1.35	24.63 ± 1.14	109.78 ± 2.37	26.18 ± 1.87
6	25.07.2017	58.76 ± 3.75	–8.39 ± 1.07	24.91 ± 1.44	108.61 ± 1.48	26.28 ± 2.09
7	08.08.2017	54.03 ± 0.27	–6.70 ± 0.75	25.16 ± 0.10	104.91 ± 2.00	26.04 ± 0.13
8	22.08.2017	65.31 ± 3.09	–10.75 ± 1.82	31.67 ± 1.18	108.75 ± 2.81	33.44 ± 2.07
9	05.09.2017	57.24 ± 0.85	19.11 ± 0.15	34.04 ± 0.15	60.69 ± 0.14	39.04 ± 0.08
Significance[++]		0.000	0.000	0.000	0.000	0.000

[+]Color values are the mean of two replicate experiments with three samples analyzed per replicate ($n = 6$)
[++] $P < 0.001$

recorded for the 8th picking date. The a* value showed a positive value on the first picking date, but from the 2nd picking date the value became negative and showed a continuous downward trend until the 7th picking date. On the 9th picking date, the a* value jumped to 19.11. This indicates that the color of the fruit changes from green to red on one axis. Although there were generally small fluctuations in the L* value, a continuous increase was observed, with the highest increase in the last three picking dates. b* is a parameter that expresses the yellow-blue hue of a color. Positive b* stands for the yellow hue, while negative b* stands for the blue hue (Wyszecki and Stiles 2000). The b* value increased gradually from the 1st picking to the 9th picking date (except the 2nd picking date).

Chroma indicates how intense or bright a color is. A more saturated color has a high chroma value, while a paler color has a lower chroma value (Granato and Masson 2010). In 'Zeferan', the lowest and highest C* values were observed for the first and last fruit picking dates. In general, the C* value increased continuously from the first to the last picking (except the 7th picking date). Hue angle (h*) indicates the degree of intensity of color and in degrees: 0 (red), 60 (yellow), 120 (green), 180 (cyan), 240 (blue), and 300 (magenta) (Wyszecki and Stiles 2000). Although the h* value fluctuated from the 1st to the 8th picking date, it generally showed an upward trend, while at the last harvest it decreased sharply and reached a value of 60.69.

In general, the color of peach cultivars ranges from yellow to orange, but shades of pink and red can also be observed due to the pubescence on the outer surface (Fallahi et al. 2009; USDA 2024). Carotenoids, anthocyanins, chlorophyll, and phenolic compounds play an important role in the formation of peach color. The interaction of these chemicals determines the cultivar of peach colors and the changes that occur during the ripening process (Zhao et al. 2022; Bento et al. 2022).

Physical and Pomological Properties

The weight and size of the fruit are among the quality criteria that significantly influence consumer preferences. These characteristics directly influence the sale and acceptance of fruit (Kelley et al. 2016). The changes in the physical properties of cv. 'Zeferan' during the ripening process is shown in Fig. 2. There were significant differences in the physical properties of the 'Zeferan' samples collected at 2-week intervals ($P < 0.05$). In the period from the first picking date to the last one (harvest), the fruit weight increased from 9.68 to 136.01 g, the fruit width from 27.36 to 61.90 mm, and the fruit length from 40.28 to 75.80 mm. The sphericity

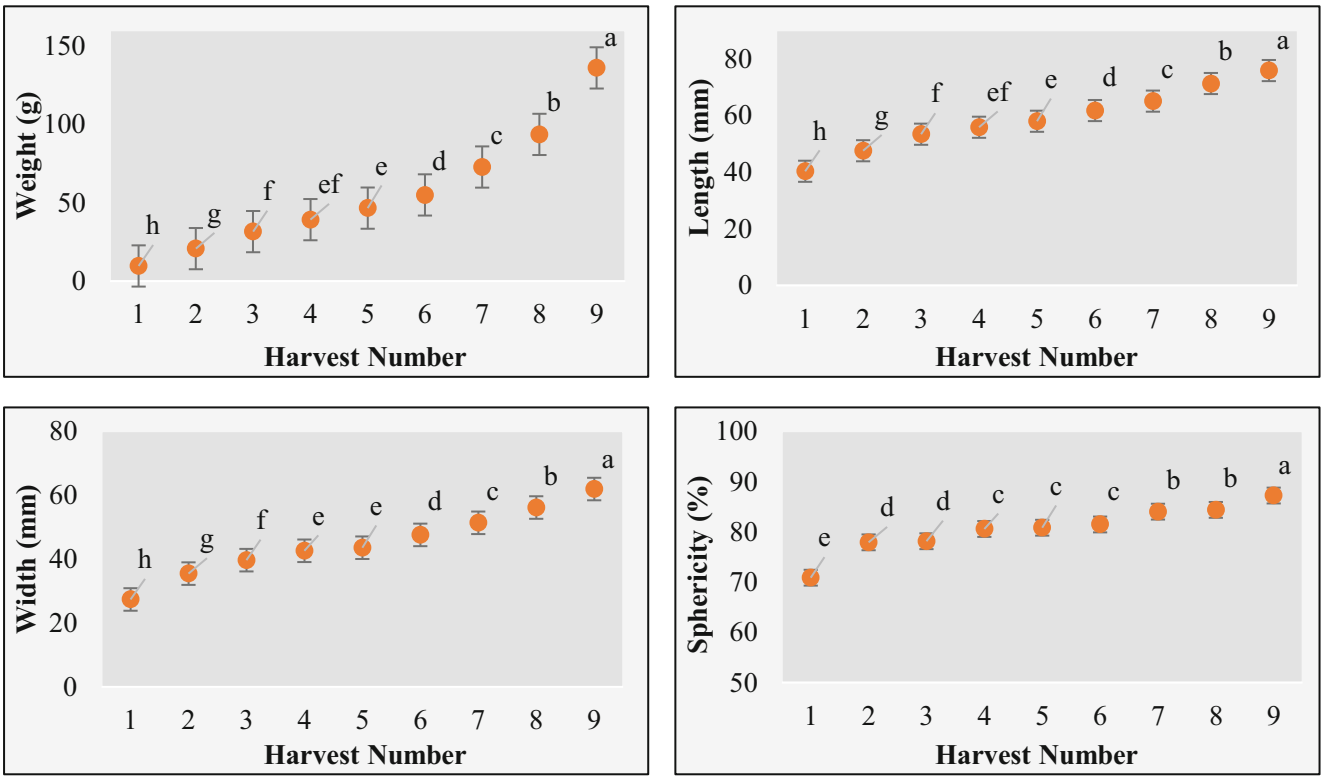


Fig. 2 Changes in weight, length, width, and sphericity of the peach cultivar 'Zeferan' during ripening. The variance analysis results applied to the weight, length, width, and sphericity data were statistically significant ($P < 0.001$)

value continuously increased from the first picking date to the last one (harvest), reaching 87.20%.

In earlier studies, Altay et al. (2022) reported that the fruit weight of cv. 'Zeferan' ranges from 115.22 to 258.4 g, and that the diameter and length range from 67.5 to 78.7 mm and 68.7 to 87.6 mm, respectively. In another study, Koprivica et al. (2022) reported that fruit length in some standard and hybrid peach cultivars ranged from 29.2 to 40.2 mm and from 37.8 to 40.7 mm, respectively, and fruit weight ranged from 27.00 to 81.5 g and from 67.8 to 89.6 g, respectively. In this study, the results for fruit weight and size were lower than those of Altay et al. (2022) and higher than those of Koprivica et al. (2022). These differences may be due to genetic factors, varieties, cultivation and management practices as well as different climatic and soil conditions.

Fruit Firmness and Elasticity

The texture of fruit is a physical property of the fruit that can be felt in the mouth. It is formed by the interplay of components such as cell structure, water content, pectin and fiber content, degree of ripeness, and genetic factors (Harker et al. 2010). According to Fig. 3, the fruit firmness of 'Zeferan' generally increased on the first four fruit picking dates and reached its highest value on the 4th date. After that, it fell below the initial value and showed a continuous downward trend in the following five fruit pickings (Fig. 3). The increase in firmness observed during the first 4 weeks is thought to result from cell wall thickening and strengthening due to cellulose, hemicellulose, and pectin accumulation, which is later thought to be broken down by enzymes like pectinase and cellulase, reducing firmness (Wakabayashi 2000; Chen et al. 2015). On the other hand, the elasticity showed a general downward trend for the period of nine picking dates, but a slight increase was observed on the last two picking dates. The elasticity of fruit is important for resistance to impact, freshness, the right degree of ripeness, and a longer shelf life (Paliyath et al. 2009). The softening of the fruit occurs chemically through the breakdown of pectin, the decomposition of cell wall components, and the effect of the hormone ethylene (Tucker et al. 2017).

Soluble Solids Content and PH

The variance analysis results applied to determine the change in soluble solids content (SSC) and pH values depending on different picking dates were statistically significant ($P<0.001$). However, multiple range test results showed that both SSC and pH values were not different on all dates (Fig. 4). The pH value was determined between 3.63 and 4.26, with the highest pH value recorded on the 1st fruit picking date. Slight fluctuations in pH were observed between the 2nd and 9th picking, and a value of 3.91 was recorded on the last picking date. SSC is the amount of soluble substances in the aqueous phase and is usually expressed as a percentage. It includes sugars, organic acids, and minerals (Scalisi and O'Connell 2021). The SSC value of cv. 'Zeferan' showed a continuous increase up to the 5th fruit picking date. From the 6th picking date, it showed slight fluctuations until harvest and finally reached 12.40% on the 9th date (Fig. 4). The increase in SSC value may be related to the degradation of starch and polysaccharides in the cell wall to simple sugars by enzymatic hydrolysis. This process occurs particularly during ripening, where complex carbohydrates are converted into simple sugars, increasing the SSC value (Balaguera-López and Arévalo 2012). SSC provides a suitable mechanism for the accumulation of flavor compounds that significantly influence the taste and aroma of peaches. Studies have shown that peaches must have an SSC value higher than 10 to be

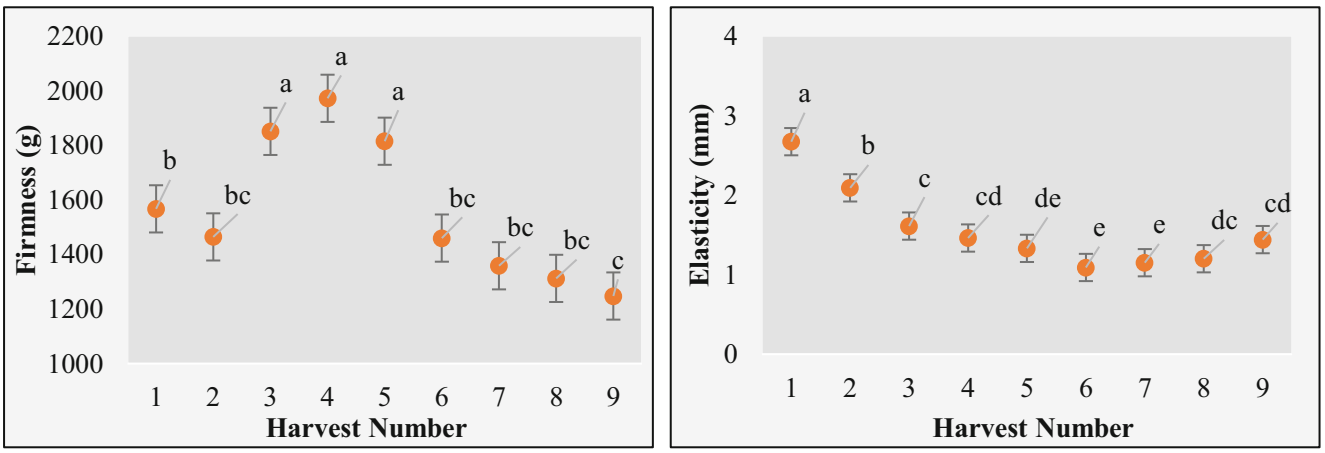


Fig. 3 Changes in firmness (*g*) and elasticity (*mm*) values of 'Zeferan' peach cultivar during the ripening period. The variance analysis results of the data for firmness and elasticity were statistically significant ($P<0.001$)

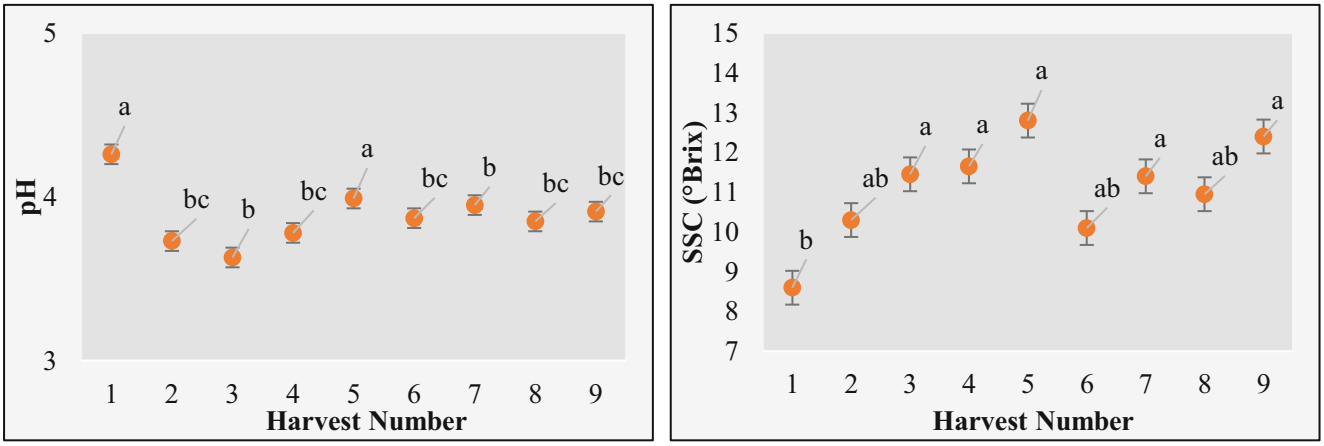


Fig. 4 Changes in soluble solids content (*SSC*) and pH values of 'Zeferan' peach cultivar during ripening period. The variance analysis results of the data of SSC were statistically insignificant ($P > 0.05$), while the variance analysis results of the pH data were statistically significant ($P < 0.05$)

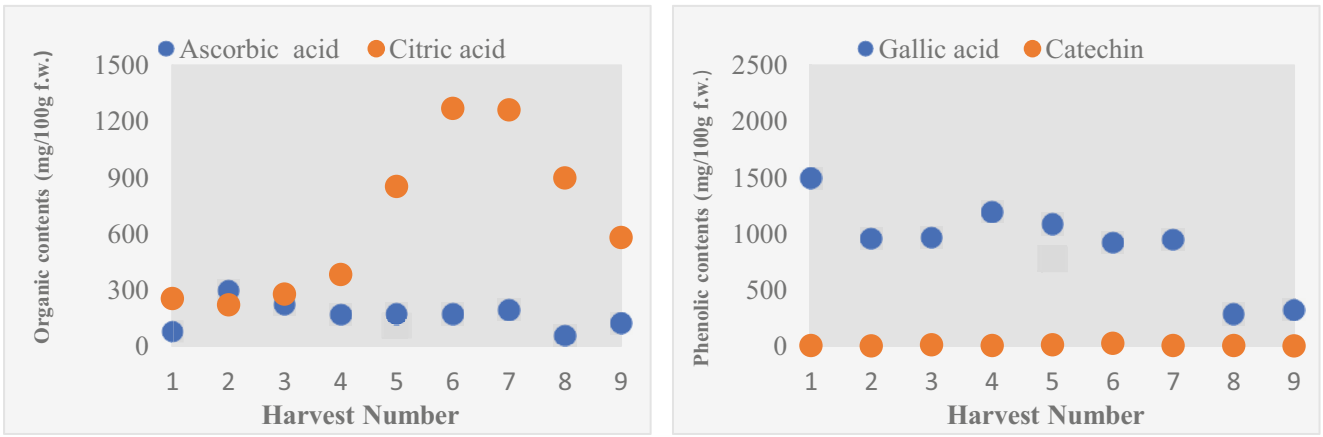


Fig. 5 Changes in phenolic content and organic acids of 'Zeferan' peach cultivar during ripening period

considered sweet and acceptable by consumers (Iglesias and Echeverría 2009).

Organic Acids and Phenolic Content

Figure 5 presents the evolution of organic acids (ascorbic and citric acids) and phenolic compounds (gallic acid and catechin) of cv. 'Zeferan'. Citric acid generally increased throughout the 6th picking date and reached its highest value at that date (1271.68 mg 100 g^{-1} f.w.). However, in the last 3 weeks, the citric acid content decreased continuously. Bae et al. (2014) reported that in peaches during an 8-weekly growing period, citric acid increased until the 6th picking date and then decreased on the following two picking dates. Ascorbic acid reached its highest value (298.01 mg 100 g^{-1} f.w) at the 2nd picking date, decreased between the 2nd and 7th picking dates, increased slightly on the 7th picking date, and then decreased again on the last two picking dates (Fig. 5). While malic, citric, and ascorbic acid are abundant in the flesh of apricots and peaches (Famiani et al. 2016), malic acid is present in much larger quantities in cherries and plums (Moscatello et al. 2019). Ascorbic acid (vitamin C) is essential for various metabolic functions in living organisms. It acts as an antioxidant to protect against oxidative stress and serves as a cofactor for several important enzymes involved in processes such as collagen synthesis and the production of neurotransmitters (Carr and Maggini 2017). Liu et al. (2015) reported that the ascorbic acid content of different peach cultivars harvested at four different dates decreased significantly during the development period, ranging from 59.1 to 79.9%. Some researchers have also noted a decrease in ascorbic acid content during fruit growth (Bashir and Abu-Goukh 2003; Deng et al. 2022). The results obtained by the researcher are consistent with that of the present study.

The contents of gallic acid and catechin in the 'Zeferan' cultivar during the growth period were shown in Fig. 5. While the amount of gallic acid was highest on the first fruit picking date, it decreased on the 2nd and 3rd picking dates. Although there was an increase on the 4th picking date

(1196.25 mg 100 g^{-1} f.w), a general decrease was observed from this picking date until the last one (harvest). During the fruit growth period, the catechin content of the 'Zeferan' cultivar showed fluctuations; the highest value was recorded on the 6th picking date (23.58 mg 100 g^{-1} f.w.), while the lowest value was observed on the 2nd picking date (1.14 mg 100 g^{-1} f.w.). Phenolic compounds are known for their antioxidant, anti-inflammatory, and antimicrobial properties, which have positive effects on human health and nutrition (Shahidi and Ambigaipalan 2015). Liu et al. (2015) found that the gallic acid and catechin content of all five peach cultivars harvested at four different dates during the growing season decreased continuously from the first to the last harvest. Catechin and gallic acid are powerful antioxidants found in many fruits, especially peaches, apples, tea, and other plant sources. The quantities of these compounds can vary depending on the cultivar, genotype, growing region, seasonal changes, light, and altitude (Zhao et al. 2022). The fluctuations in organic acids and phenolic compounds are likely due to enzymatic activities, metabolic pathways, and structural changes occurring during fruit ripening. These variations are believed to result from these physiological processes. Specifically, the decline in phenolic compounds during ripening may have originated from enzymatic degradation, oxidation, and polymerization, which are natural processes associated with fruit maturation.

Conclusions

In this study, the physical and chemical changes of the 'Zeferan' peach cultivar were comprehensively investigated over a 16-week ripening period, with a total of nine fruit pickings conducted at 2-week intervals. During the ripening period, the fruit color changed from green to yellow, while the fruit weight and size increased continuously. The firmness decreased after the 4th fruit picking date, while the elasticity decreased generally. While the soluble solids content increased, the pH values showed fluctuations. Organic acids and phenolic compounds showed a decreasing tendency. The results indicated significant changes in all parameters, and the optimum harvest date for 'Zeferan' peach was determined to be approximately 16 weeks (9th picking) after full bloom when the fruit reached its best quality attributes, including desirable color, size, and sweetness. In summary, this study comprehensively evaluated the ripening process of 'Zeferan' peach, providing useful information for determining the optimal harvest date based on fruit quality parameters. These findings may offer practical benefits for producers, the food industry, and consumers, and could guide various applications. Future research should focus on improving storage methods and processing techniques, as well as enhancing the overall quality of 'Zeferan' peaches.

Funding This research was made possible by funding from The Scientific Research Projects Unit of Iğdır University (Project no: 2019-FBE-A29).

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK).

Conflict of interest E. Gülsoy, E. Kus, B. Tan, D. Alwazeer and K. Tan declare that they have no competing interests.

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