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Investigation of pomological and biochemical properties of peach cultivars with different ripening periods

Samira Maatallah [a,b,*,1], Monia Guizani [a,b,2], Giuseppe Montevecchi [c,d,3], Giulia Santunione [c,4], Guido Flamini [e,f,5], Samia Dabbou [g,h,6]

[a] Institution of Research and Higher Education Agriculture (IRESA), Regional Center for Agricultural Research Sidi Bouzid (CRRA), Sidi Bouzid 9100, Tunisia
[b] University of Carthage, National Research Institute for Rural Engineering, Water, and Forestry (INRGREF), Non-Conventional Water Valuation Research Laboratory (LR VENC), Hedi EL Karray Street, El Menzah IV, Tunis 1004, Tunisia
[c] Department of Life Science (Agri-Food Science Area), University of Modena and Reggio Emilia, Via Amendola 2 (pad. Besta), Reggio Emilia 42122, Italy
[d] BIOGEST - SITEIA Interdepartmental Center, University of Modena and Reggio Emilia, Piazzale Europa 1A, Reggio Emilia 42124, Italy
[e] Dipartimento di Farmacia, University of Pisa, Via Bonanno 6, Pisa 56126, Italy
[f] Centro Interdipartimentale di Ricerca "Nutraceutica e Alimentazione per la Salute" University of Pisa, Via del Borghetto 80, Pisa 56124, Italy
[g] University of Monastir, Faculty of Dental Medicine of Monastir, Unit of Bioactive and Natural Substances and Biotechnology UR17ES49, Avicenne Street, Monastir 5019, Tunisia
[h] University of Monastir, Faculty of Dental Medicine of Monastir, Tunisia

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ABSTRACT

Peaches are highly nutritious summer fruits that are valued for their flavor and richness in phytochemical compounds. The aim of this study was to investigate the effect of maturing genotypes on the pomological properties and biochemical content (sugars, organic acids, phenolic and volatile compounds) of three peach cultivars grown in the Regueb region and characterized by different ripening dates: extra-early (Nectarine), early (Blanvio 10) and mid-season (UFO3). The results showed that Nectarine had the highest fruit weight (107.78 g) and firmness (6.49 kg cm^{-2}). In addition, the fruits of this cultivar were the richest in flavan-3-ols and hydroxycinnamic acids (1061.36 mg100 g^{-1}), while the mesocarps of Blanvio 10 showed the lowest contents. Sugar content varied significantly between cultivars. In fact, UFO3 fruits had the highest sucrose content, followed by Nectarine, while those of Blanvio 10 were the least sweet. The analysis of the aroma and volatile compounds exhibited that all studied cultivars were rich in aromatic substances. In conclusion, the differences found in fruit composition are crucial for different consumer preferences and processing purposes. Understanding these attributes is essential for optimizing their use in food and targeting breeding programs aimed at enhancing desirable traits for both consumer and industry needs.

1. Introduction

Peaches (*Prunus persica*) are the third most widely produced fruit species in temperate climates worldwide, after apples and pears. *P. persica* is a diploid species that naturally self-pollinates. Giving it a broad production potential, its production has expanded worldwide, and there are numerous cultivars that ripen from very-early to very-late (Çetinbaş, 2024; Montevecchi et al., 2013). Peach is a popular fruit on

* Corresponding author at: Institution of Research and Higher Education Agriculture (IRESA), Regional Center for Agricultural Research Sidi Bouzid (CRRA), Sidi Bouzid 9100, Tunisia.
E-mail addresses: samira.maatallah@iresa.agrinet.tn (S. Maatallah), guizanimonia2018@gmail.com (M. Guizani), giuseppe.montevecchi@unimore.it (G. Montevecchi), giulia.santunione@unimore.it (G. Santunione), guido.flamini@farm.unipi.it (G. Flamini), dabbou_samia@yahoo.fr, samia.dabbou@fmdm.u-monastir.tn (S. Dabbou).
[1] orcid.org/0000-0002-4508-2260
[2] orcid.org/0000-0001-5580-7328
[3] orcid.org/0000-0002-2483-7134
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the market, appreciated by consumers for its thick, juicy flesh, rich aroma, and high nutritional value (Montero-Prado et al., 2009; Williamson et al., 2018). It is rich in a cultivar of primary and secondary nutrients including carbohydrates, vitamins, minerals, organic acids, antioxidant compounds (pigments, phenolics), volatiles, and small amounts of proteins and lipids (Alipasandi et al., 2013; Fernández et al., 2017).

Peach fruit maturity, a key marketing factor, varies widely across peaches. The fruit development period (FDP), which typically lasts two to nine months, corresponds to the period between full bloom and harvest (Elsadr et al., 2019) . Peaches may be classified as early (90 days), mid (91–125 days), or late (beyond 125 days) maturing genotypes based on their FDP (Veerappan et al., 2021). There is a wide variety of peaches with a maturation period ranging from 55 days to 270 days after full bloom thanks to the breeding initiatives and the introduction of very early and very late cultivars (Bassi et al., 2023; Layne and Bassi, 2008). Peach ripening is greatly influenced by environmental conditions, even if heredity plays a major role. As a result, in a particular growing zone, ripening takes place at various times of the year, but the order in which it happens across cultivars is mostly constant (Bassi et al., 2023; Layne and Bassi, 2008).

Actually, modern breeding programs aim to satisfy the preferences of both producers and consumers. Producers favor cultivars that are highly productive, disease-resistant, capable of extending the harvest season through varied ripening periods and had less water requirement, while consumers focus primarily on fruit quality (Byrne, 2005). In fact, comparative studies of pomological and biochemical properties between cultivars with different ripening period are scarce, despite their importance for optimizing breeding programs, postharvest preservation, and marketing.

Traditionally, the key factors evaluating peach fruit quality is based on external appearance, sugar content, and acidity. However, peaches also contain a wide range of phytochemicals that, even in low concentrations, play a crucial role in determining overall quality (Santos et al., 2018). Many of these compounds contribute significantly to the color and aroma of the fruit (Lara et al., 2020), with aroma being a key factor in consumer preference(Aubert et al., 2003). Over 100 volatile compounds have been identified in peach aroma, including C6 compounds, lactones, C13 norisoprenoids, aldehydes, alcohols, esters, ketones, and terpenes (Dabbou et al., 2016; Li et al., 2015; Zhang et al., 2010). The interaction between these volatiles and the consumer's perception influences the sensory properties, nutritional value, and emotional experience associated with fruit consumption (Braga and Belo, 2016; Fan et al., 2021; Koroch et al., 2007; Liang et al., 2022).

In recent decades, the growing awareness of food security has led to an increasing market demand for high-quality fruits with enhanced biochemical properties (Farooq et al., 2020). However, the high perishability of fruit crops limits their availability and market presence over extended periods. In addition, climate change, particularly in regions such as central Tunisia, has impacted water resources, leading to a decline in fruit tree cultivation in favor of more drought-resistant species such as olive trees(Dabbou et al., 2015, 2011; Sdiri et al., 2020) and prickly pears (Bouazizi et al., 2022; Terki et al., 2025). In the Regueb region, for example, peach production dropped from 20.150 tonnes in 2021 to 11.450 tonnes in 2024 ("DGPA," 2024). Given these challenges, growing extra-early cultivars with shorter growth cycles and lower water requirements is a viable strategy for farmers to maintain peach production at reduced costs. Known the limited information about the nutritional and biochemical properties of extra-early, early, and mid-season peach cultivars grown in central Tunisia. This study aims to conduct a comparative analysis of three peach cultivars—Nectarine, Blanvio, and UFO3 characterized by different maturation period by evaluating their pomological, biochemical and phytochemical traits, that provide insights into how ripening period influences peach fruit quality, enabling informed decision-making for growers and industry stakeholders.

2. Materials and methods

2.1. Plant material and field characteristics

The current study was conducted on three commercial orchards in the mid-western Tunisia exactly in Regueb region (35°2'0''N, 9°30'0''E). This region, characterized by a semi-arid climate, had a mean annual evapotranspiration and precipitation of 1550 mm and 252 mm, respectively, and a mean temperature between 12.5 °C and 25.3 °C.

In the selected commercial orchards, seven-year-old trees of three peach cultivars – namely Nactarine, Blanvio 10, and UFO3 characterized by different ripening dates: extra-early (Nectarine) early (Blanvio 10) and mid-season (UFO3) and received conventional farmer N-P-K supply practices (Table1). The cultivars were all grafted onto the GF-677 hybrid rootstock, widely used for peach. In each orchard, the trees were planted, in randomized blocks, at a spacing of 4 × 5 m (500 trees ha^{-1}) and irrigated with a drip irrigation of 8 L h^{-1}.

The Nectarine is an extra-early cultivar (the last week of April) (Table 2), with a semi-dwarf form as shown in Fig. 1. Its fruit has a stone that does not adhere to its yellow mesocarp, it is characterized by a very pronounced sweet and slightly sour. Its exocarp is smooth and shiny and has an orange color that tends towards red. The mesocarp is yellow.

The Blanvio 10 cultivar is a flat peach with an early ripening period (mid May); the trees are vigorous and have a standard form. The fruit has a white mesocarp with not overly sweet but it is distinguished by its flavor. It has an attractive flat shape with a velvety exocarp that is greenish red in color (Fig. 1). Eventually, UFO3 is a flat peach, mid-saison cultivar (mid June) (Table 2) and the trees are very vigorous and have a standard form. The fruits are firm, sweet, with a white mesocarp and fleshy, making UFO3 a popular cultivar. Furthermore, it is caracterised byan intense red exocarp (Fig. 1).

2.2. Fruit quality parameters

For each cultivar, ten fruits were collected per tree according to their ripening date and the standard commercial procedure, using three trees with three replicates. Afterwards, immediately after harvest, fruit weight, diameter, firmness and skin color were determined. The width (mm) and height (mm) of each fruit were measured using a caliper (Mitutoyo, UK), while the fresh weight was determined using a precision balance (AXIS-AGN 100 C, Poland). The mesocarp firmness was measured on a partially peeled fruit using a penetrometer (FT 327, Italy).

The color was determined through a reflectance chromameter by a Minolta colorimeter CR-300 (Konica Minolta Sensing, Inc., Japan)that gives CIE (International Commission on Illumination) coordinates (L*, a*, and b*). Three measurements were carried out on the exocarp of the fruit as ground and over color. L* measures brightness, while a* and b* measure green-red color and blue-yellow, respectively (Musetti et al., 2015).

2.3. Soluble sugars and organic acids determination

After fruit sampling, three fruits from each replicate were spared to exocarp and mesocarp, frozen with liquid N2 then lyophilized by a freeze drier (BK-FD10PT, BioBase, Shandong, China) and finally stored

Table 1
Farmer's N-P-K programs (Kg ha^{-1}).

Cultivars	Total N (kg ha^{-1})	Total P (kg ha^{-1})	Total K (kg ha^{-1})	Total NPK (kg ha^{-1})
Nectarine	131.58	63.75	71.32	266.65
Blanvio 10	95.99	67.50	92.20	255.69
UFO3	92.72	56.00	68.00	216.72

Table 2
Ripening dates of the three studied cultivars.

Cultivars	Ripening date
Nectarine (extra-early cultivar)	25/04
Blanvio 10 (early cultivar)	15/05
UFO3 (mid saison cultivar)	15/06

at − 80 °C till the analysis of sugar, organic acids, phenolic compounds and volatiles compounds.

Soluble sugar and organic acids were determined according to the method described by (Chinnici et al., 2005) and modified by (Guizani et al., 2019). Briefly, the aqueous extracts were prepared by suspending 1 g of freeze-dried samples in 10 mL of deionized water, subjected to homogenization by an ultra-Turrax (T25D, IKA Labortechnik, Janke & Kunkel, Staufen, Germany)than centrifugation at 15,000 × *g* for 15 min at 4 °C and, finally, filtration through a cellulose nitrate membrane filter (0.45 μm pore size). The obtained extracts were analyzed in a HPLC system (PU 4180, Jasco Europe Srl, Cremella, LC) equipped with a Rezex™ RCM Monosaccharide Ca^{+2} (8 %), LC Column 300 × 7.8 mm, Ea column. The isocratic separation of sugars and organic acids was performed at 30 °C, using a mobile phase of 0.1 % phosphoric acid pumped into the column with a flow rate of 0.5 mL min^{-1}. The quantification of sugars was carried out with a refractive index detector (RI 4030) whereas the organic acids were quantified using a UV/Vis detector (UV4070, Jasco) at a wavelength of 210 nm. The identification of the analytes was performed by comparing the retention times of the obtained peaks with pure reference standards. Sugar and organic acid standards were supplied by Supelco analysis (Bellefonte, PA, USA). The three sugars had a purity of not ≥ 99 %; the four organic acids had a purity ≥ 99 %. Quantification was carried out through the external standard calibration method (Table S1). Results were expressed as g$100g^{-1}$on a dry weight basis (DW).

2.4. Extraction and analysis of phenolic compounds

The individual phenolic compounds and anthocyanins were determined as previously described (Martínez-Esplá et al., 2014). An aliquot of 1 g of freeze-dried fruit sample and 10 mL of methanol-water (80:20) containing NaF (0.0839 g L^{-1}) were homogenized for 1 min using an Ultra-Turrax (T25D, IKA Labortechnik, Janke & Kunkel, Staufen, Germany). After centrifugation (7500 × *g* at 4 °C), the extract was collected and filtered through a cellulose nitrate membrane filter (0.45 μm) into 2-mL black glass vials. The quantification was carried out through an HPLC system (PU 4180, Jasco Europe Srl, Cremella, Italy) equipped with a Luna C_{18} column (25 cm × 0.46 cm i.d., 5 μm particle size; Phenomenex, Macclesfield, UK) supplied with a C_{18} security guard (4.0 mm × 3.0 mm) cartridge system (Phenomenex, Macclesfield, UK). Chromatograms were recorded at 280, 320, 360, and 520 nm using a UV/VIS detector (PU 4180, Jasco Europe Srl). Hydroxycinnamic derivatives, *p*-coumaroylquinic and hydroxybenzoic acids were characterized using pure analytical standards through chromatographic comparison and according to previous reports based on retention time and 280-nm wavelength (Tomas-Barberan et al., 2001). Anthocyanins (cyanidin-3-*O*-glucoside) were detected at 520 nm and quantified by comparison with pure standards (Polyphenols SA, Sandnes, Norway). Hydroxycinnamic acids were quantified as 5-*O*-caffeoylquinic acid (neochlorogenic acid) at 320 nm, and flavonols as quercetin 3-*O*-rutinoside (rutin) at 360 nm. 5-*O*-caffeoylquinic acid (neochlorogenic acid) had a purity ≥ 95 %; catechin had a purity ≥ 97 %; quercetin 3-*O*-rutinoside (rutin) had a purity ≥ 95 %. Cyanidin-3-*O*-glucoside were purchased from Polyphenols AS (Sandnes, Norway) with a purity ≥ 97 % (Table S1). Quantification was carried out using an external standard calibration and the concentrations were expressed as mg 100 kg^{-1}DW (Table S1).

All standards were purchased from Sigma-Aldrich-Supelco now under the Merck KGaA brand (Darmstadt, Germany).

2.5. Volatile compounds analysis

For volatile compounds analysis, Supelco (Bellefonte, PA) polydimethylsiloxane (PDMS, 100 μm) coated SPME devices were used to sample the headspace of dry plant material placed in a 15 mL glass vial and held at equilibrium for 30 min. Then, after the equilibration time, the fiber was exposed to the headspace for 35 min at room temperature. Once sampling was complete, the fiber was withdrawn into the needle and transported to the injection port of the GC–MS system. The SPME sampling and desorption conditions were identical for all samples. In addition, blank samples were run before each initial SPME extraction and repeated randomly during each series.

GC-EI-MS analyses were performed using a Varian (Palo Alto, CA) CP3800 gas chromatograph equipped with a DB-5 capillary column (30 m × 0.25 mm × 0.25 μm; Agilent) and a Varian Saturn 2000 ion trap mass detector. The analytical settings were as follows: Injector and transfer line temperatures were 250 and 240 °C, respectively; oven temperature was programmed from 60 to 240 °C with an increasing rate of 3 °C min^{-1}; carrier gas was helium at 1 mL min^{-1}; splitless injection. Component identification was based primarily on comparison of retention times with those of authentic samples, comparison of their linear retention indices with respect to the range of n-hydrocarbons (C_7-C_{28}) and computer matching with commercial (Adams, 2007) and (NIST 2014) and home-made libraries of mass spectra, aa well as MS literature

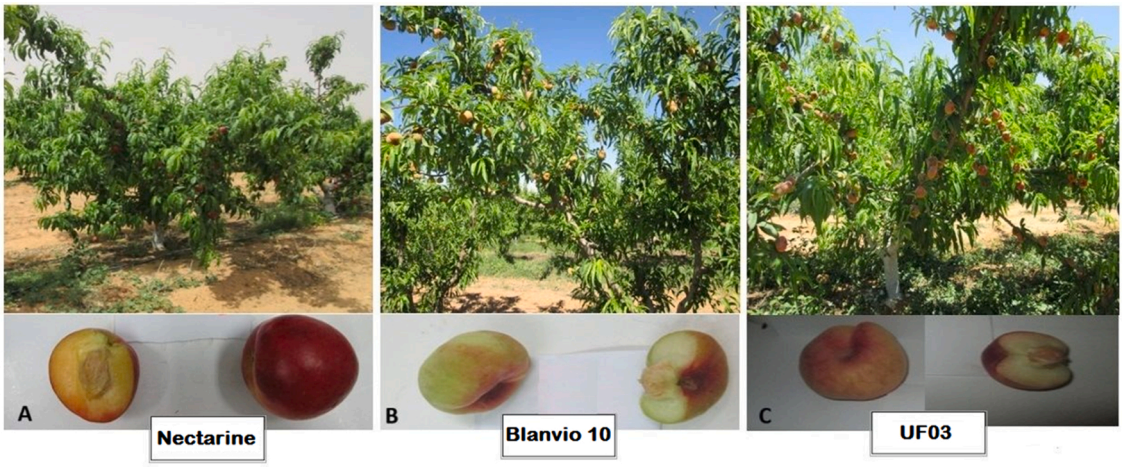

Fig. 1. Tree shape and fruit morphology of tree studied cultivars Nectarine, Blanvio and UFO3.

data (Adams, 1995; Davies, 1990; Jennings and Shibamoto, 1980; Stenhagen et al., 1974; Swigar and Silverstein, 1981). Quantitative comparisons were made of the relative areas of the peaks between the same chemicals in the different samples. The results were expressed as percentages of the individual areas over the total areas analysed.

2.6. Statistical analysis

Statistical analyses of the samples studied were performed using SPSS software (release 17.0 for Windows, SPSS, Chicago, IL, USA). An analysis of variance (ANOVA) was employed. Duncan test and Student-t test were used to compare means between cultivars. The values were represented as the mean ± the standard deviation. Statistically significant differences between groups were considered when *p-value*< 0.05.

The relationships among the cultivars, the various parts of the fruit, and their composition were highlighted using principal component analysis (PCA) using Statistica v8.0 software (formerly Stat Soft Inc., now TIBCO Software Inc., Palo Alto, USA).

3. Results

3.1. Pomological quality and exocarp color

The determination of the average fresh weight of the fruit (Table 3) showed that there was a significant difference between the fruit samples of the three studied peach cultivars. Nectarine cultivar had the highest fruit weight (107.78 g), followed by the fruits of UFO3 (94.82 g), while the fruits of Blanvio 10cultivarshowed the lowest weight (52.85 g). The fruit diameter of the different cultivars also varied significantly ($p < 0.05$). Nectarine fruits had the largest diameter (66.42 mm), while for UFO3 and Blanvio10, the diameters were 55.65 mm and 51.49 mm, respectively.

The results revealed that the fruits of UFO3 cultivar had a significantly higher firmness (6.49 kg cm^{-2}) than those of the other cultivars, whose firmness was approximately the same (4.80 and 4.63, for Nectarine and Blanvio 10, respectively).

The color analysis carried out in the epicarp of the peach cultivars (Table 3) showed that Blanvio 10 had the highest brightness (L* = 54.31), the lowest value for a* (16.61), and the highest for b* (30.02). On the other hand, the fruits of UFO3 and Nectarine exhibited the highest values for a* (34.51 and 31.56, respectively), and the lowest values for b*.

Table 3 shows general data on the whole fruit. The data based on one-way ANOVA revealed significant differences in weight, height, diameter, firmness, and color parameters between Nectarine, Blanvio 10, and UFO3 fruits. In terms of weight, UFO3 was the heaviest, followed by Nectarine, while Blanvio 10 was significantly lighter. The extremely low *p-value* (7.89 E^{-11}) confirmed that these differences were highly significant. Similarly, when examining fruit height, Nectarine standed out as the highest, whereas UFO3 was intermediate, and Blanvio 10was the shortest. The statistical data clearly indicated considerable variation in fruit height among the three cultivars. In terms of diameter, UFO3 had the largest fruit size, while Nectarine was marginally smaller, and Blanvio 10 had the smallest diameter.

Regarding consistency, Nectarine was markedly firmer than UFO3 and Blanvio 10 cultivars, which display comparable softness. This indicates that the harder texture of nectarines may significantly influence its shelf life and consumer preference. The reduced firmness of Blanvio 10 and UFO3 could render them more susceptible to bruising or softer in texture.

The determination of color parameters showed that Nectarine is the darkest while Blanvio 10fruit is the lightest, as indicated by the high L* value. Both Nectarine and UFO3 exhibit a higher red pigmentation (a*) than Blanvio 10, which seems to have a lower red intensity.

Furthermore, Blanvio 10 is distinguished from the other cultivars by its more noticeable yellow hue (b*). The statistical analysis confirms that these differences in color attributes are highly significant, which may have implications for consumer appeal and market selection.

3.2. Phenolic compounds

The results obtained from the phenolic profiles (Fig. 2) show that the exocarp tissues were the richest in phenolic compounds, especially, flavonols, hydroxycinnamic acids and anthocyanins. In addition, the exocarp of the extra-early nectarine cultivar had the highest levels offlavonols, hydroxycinnamic acids, and anthocyanins (2498,51; 2249.21 and 1443.62 mg kg^{-1}, respectively). Furthermore, the analysis revealed that all the varieties studied contained relevant levels of flavanols, and lower contents of hydroxycinnamic acids at the mesocarp level as shown in Fig. 2. Similarly, the mesocarps of the Nectarine cultivar were the richest in flavan-3-ols (1432.59 mg kg^{-1}DW) and hydroxycinnamic acids (1061.36 mg kg^{-1}100 g^{-1}DW), followed by the fruits of the UFO3 cultivar, while the mesocarps of the Blanvio 10 fruits cultivar showed the lowest levels (Fig. 2). The analysis of phenolic profile of both tissues (Tables 4 and 5) showed the richness of exocarp tissue with twelve different phenolic compounds(3-*O*-caffeoylquinic acid, 4-*O*-caffeoylquinic acid, 5-*O*-caffeoylquinic acid, cyandin-3-*O*-glucoside, quercetin-di-*O*-glucoside, quercetin-3-*O*-rutinoside, quercetin-3-*O*-glucoside, kaempferol-3-*O*-rutinoside, isorhamnetin-3-*O*-galactoside, isorhamnetin-3-*O*-rutinoside, isorhamnetin-3-*O*-glucoside and quercetin) in comparison to mesocarp having only 4 compounds (catechin, 3-*O*-caffeoylquinic acid, 4-*O*-caffeoylquinic acid and 5-*O*-caffeoylquinic acid).

Regarding phenolic content of mesocarp, Nectarine consistently exhibited the highest concentrations across all measured compounds, particularly in 3-*O*-caffeoylquinic acid, catechin, and 4-*O*-caffeoylquinic acid, where its values were significantly greater than those of Blanvio 10 and UFO3. Blanvio 10, while displaying moderate levels, still maintained notably higher concentrations than UFO3, which had the lowest phenolic content. The statistical significance of these differences, supported by very low *p-values*, suggested a strong varietal effect on phenolic accumulation, potentially influencing antioxidant properties and health benefits.

Furthermore, peach exocarps demonstrated significant differences in phenolic compounds, as confirmed by the one-way ANOVA (Table 5). Nectarine exhibited the highest levels in most measured compounds,

Table 3
Peach fruit quality main traits. Values are the means of three different peach samples ($n = 12$) ± standard deviation. One way ANOVA was shown as *p-values*. Letters (a > b > c) indicate significant differences (*p-values* < 0.05), obtained through post hoc Duncan test.

	Nectarine	Blanvio 10	UFO3	ANOVA
Weight (g)	94.83 ± 12.46 b	52.85 ± 13.43 c	107.78 ± 15.67 a	7.89E−11
Height (mm)	54.61 ± 2.32 a	26.55 ± 1.73 c	37.85 ± 2.32 b	1.01E−17
Diameter (mm)	55.66 ± 2.77 b	51.49 ± 3.61 c	66.43 ± 3.64 a	5.41E−12
Firmness (kg cm^{-2})	6.49 ± 1.65 a	4.63 ± 1.18 b	4.80 ± 0.99 b	2.09E−03
L*	33.80 ± 7.29 c	54.31 ± 6.07 a	41.91 ± 5.04 b	1.22E−08
a*	34.51 ± 6.76 a	16.61 ± 4.19 b	31.56 ± 4.68 a	2.04E−09
b*	14.54 ± 3.70 b	30.20 ± 7.30 a	17.48 ± 3.00 b	1.44E−08

One way ANOVA was shown as *p-values*. Letters (a > b > c) indicate significant differences (*p-values* < 0.05), obtained through post hoc Duncan test.

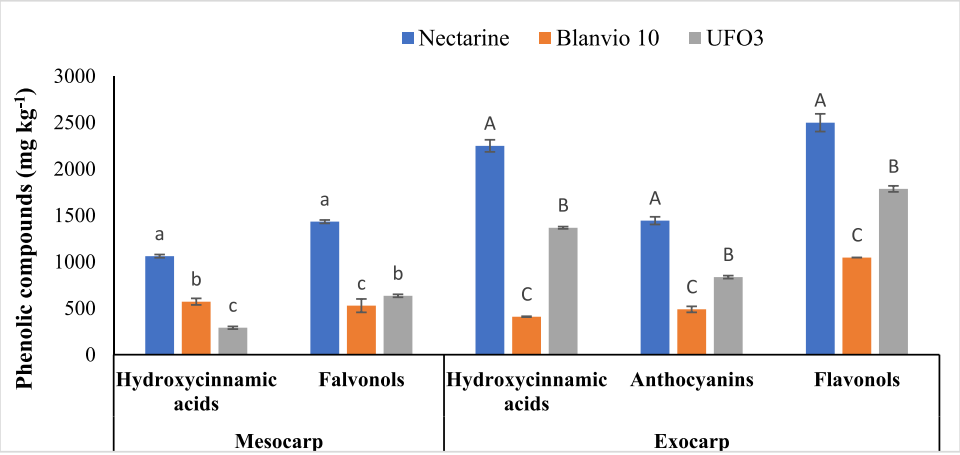

Fig. 2. Total phenolic compounds variation in the mesocarp and exocarp of the three studied cultivars. Values are the means of three different peach samples ($n = 3$) ± standard deviation. One way ANOVA was shown as *p-values*. Letters (a > b > c) indicate significant differences (*p-values* < 0.05), obtained through post-hoc Duncan test.

Table 4
Peach mesocarp phenolic, sugar, and organic acid content. Values are the means of three different peach samples ($n = 3$) ± standard deviation.

Phenols (mg kg^{-1} D.W)	**Nectarine**	**Blanvio 10**	**UFO3**	**ANOVA**
3-*O*-Caffeoylquinic acid	268.22 ± 18.23 a	205.12 ± 3.75 b	84.53 ± 40.89 c	7.07E−04
Catechin	1432.60 ± 72.17 a	528.04 ± 159.20 b	640.97 ± 152.25 b	7.68E−04
4-*O*-Caffeoylquinic acid	704.74 ± 16.05 a	294.19 ± 8.88 b	216.27 ± 95.82 b	1.06E−04
5-*O*-Caffeoylquinic acid	88.40 ± 2.94 a	71.95 ± 2.16 c	80.70 ± 2.06 b	9.28E−04
Sugars (g 100 g^{-1} D.W)				
Sucrose	35.84 ± 0.71 b	34.43 ± 0.15 c	40.53 ± 2.96 a	8.35E−04
Glucose	11.97 ± 0.73 a	12.55 ± 0.08 a	1.72 ± 0.55 b	5.91E−06
Fructose	7.22 ± 0.39 a	7.50 ± 0.10 a	1.84 ± 0.52 b	1.64E−05
Total sugars	55.02 ± 1.80 a	54.48 ± 0.28 a	44.10 ± 2.34 b	3.44E−04
***Organic acids* (g 100 g^{-1} D.W)**				
Malic acid	3.35 ± 0.16 a	3.40 ± 0.14 a	2.44 ± 0.25 b	7.41E−04
Citric acid	8.11 ± 0.14 a	4.49 ± 0.01 b	0.36 ± 0.02 c	7.05E−09
Succinic acid	2.52 ± 0.15 b	2.21 ± 0.03 b	3.66 ± 0.30 a	1.85E−04
Fumaric acid	0.0032 ± 0.0003 b	0.0033 ± 0.0001 b	0.0083 ± 0.0009 a	2.11E−05
Total acids	13.98 ± 0.43 a	10.11 ± 0.15 b	6.47 ± 0.10 c	3.16E−06

One way ANOVA was shown as p-values. Letters (a > b > c) indicate significant differences (p-values < 0.05), obtained through post-hoc Duncan test.

particularly 3-*O*-caffeoylquinic acid, 4-*O*-caffeoylquinic acid, and cyanidin-3-*O*-glucoside, while Blanvio 10 consistently showed the lowest values. UFO3 generally falls between the two, except for specific flavonoids such as quercetin-di-*O*-glucoside and isorhamnetin-3-*O*-rutinoside, where it surpassed the other cultivars. Statistical analysis confirmed these differences as highly significant, highlighting clear varietal effects on exocarp phenolic accumulation.

3.3. Sugar and organic acids variation

According to results presented in Tables 4 and 5, three sugar components were identified in both the exocarp and mesocarp of the studied peach fruits, sucrose, glucose and fructose. A considerable variation in total sugar content among the cultivars studied was observed. Sucrose was the predominant sugar in both tissues, followed by glucose and fructose. Total sugar content in mesocarp samples ranged from 42.92 g100 g^{-1}DW in the mid-season cultivar UFO3 to 55.02 g100 g^{-1}DW in the extra-early cultivar Nectarine. In addition, Nectarine and Blanvio 10 showed relatively similar levels of total sugars, while UFO3 contained significantly less in the mesocarp. Although sucrose levels were highest in UFO3, it exhibited drastically lower concentrations of glucose and fructose compared to the other two cultivars. The statistical results indicated that these differences are highly significant, highlighting potential variations in sweetness perception and carbohydrate metabolism between the cultivars.

Concerning exocarp samples, sugar content varied significantly between cultivars (Table 5). Despite these variations, total sugar content remains highest in UFO3 and Nectarine (54.65 and 51.65 g 100 g^{-1}DW, respectively), while Blanvio 10 exhibited the lowest sugar concentrations (46.13 g100 g^{-1}DW). Indeed, sucrose is highest in UFO3, followed by Nectarine, with Blanvio 10 containing the lowest amount. Glucose levels were similar between Nectarine and UFO3 but significantly lower in Blanvio 10, whereas fructose was notably reduced in UFO3 compared to the other two cultivars.

In addition, Tables 4 and 5 showed four organic acids identified in both the exocarp and mesocarp of the studied peach cultivars, namely malic (1.37–3.40 g 100 g^{-1}DW), citric (0.32–8.11 g 100 g^{-1}DW), succinic (2.21–3.66 g 100 g^{-1}DW), and fumaric (0.0025–0.0083 g 100 g^{-1}DW) acids. The mesocarp of the extra-early cultivar Nectarine had the highest concentration of total organic acids (13.98 g 100 g^{-1}DW), while the mid-season cultivar had the lowest concentrations in both the exocarp (6.57 g 100 g^{-1}DW) and mesocarp (6.48 g 100g^{-1}DW).

Organic acid composition further differentiates these peach cultivars (Tables 4 and 5). In both tissues, malic acid content didn't significantly differ between Nectarine and Blanvio 10, but it was markedly lower in UFO3. Citric acid concentration was minimal in UFO3 compared to the other cultivars. On the other hand, UFO3 stood out with the highest succinic and fumaric acid concentrations, significantly surpassing the levels found in Blanvio 10 and Nectarine. In general, total acid content was highest in Blanvio 10 and Nectarine, and was significantly lower in

Table 5
Peach exocarp phenolic, sugar, and organic acid content. Values are the means of three different peach samples ($n = 3$) ± standard deviation.

Phenols (mg 100 kg^{-1}D.W)	Nectarine	Blanvio 10	UFO3	ANOVA
3-*O*-Caffeoylquinic acid	229.91 ± 0.47 a	89.21 ± 11.51c	199.50 ± 9.39 b	2.33E−06
4-*O*-Caffeoylquinic acid	1965.58 ± 0.47 a	299.41 ± 11.00c	1101.18 ± 52.65 b	2.72E−09
5-*O*-Caffeoylquinic acid	53.72 ± 0.49 a	20.65 ± 12.18 b	66.61 ± 3.50 a	6.59E−04
Cyandin−3-*O*-glucoside	1443.62 ±012 a	488.22 ± 15.95 c	835.53 ± 41.24 b	7.67E−08
Quercetin-di-*O*-glucoside	6.58 ± 0.13 c	50.97 ± 1.56 b	96.11 ± 5.82 a	2.16E−07
Quercetin−3-*O*-rutinoside	908.69 ± 1.92 a	274.36 ± 8.87 c	510.06 ± 26.42 b	1.61E−08
Quercetin−3-*O*-glucoside	1158.21 ± 2.54 a	383.72 ± 12.26 c	703.82 ± 36.53 b	3.50E−08
Kaempferol−3-*O*-rutinoside	294.97 ± 0.86 a	50.46 ± 1.17c	112.89 ± 6.56 b	8.09E−10
Isorhamnetin−3-*O*-galactoside	17.13 ± 0.13 c	38.13 ± 1.33 b	53.80 ± 3.10 a	1.37E−06
Isorhamnetin−3-*O*-rutinoside	21.97 ± 0.07c	114.62 ± 4.88 b	175.29 ± 11.90 a	7.68E−07
Isorhamnetin−3-*O*-glucoside	90.95 ± 6.22 a	49.53 ± 1.36 b	45.18 ± 1.85 b	1.13E−05
Quercetin	n.d.	84.46 ± 2.78 a	88.62 ± 5.04 a	8.52E−08
Sugars (g 100 g^{-1}D.W)				
Sucrose	34.22 ± 1.35 b	30.55 ± 1.04 c	38.86 ± 1.49 a	7.26E−04
Glucose	9.97 ± 0.06 a	7.96 ± 1.03 b	9.99 ± 0.45 a	1.30E−02
Fructose	7.46 ± 0.10 a	7.62 ± 0.84 a	5.80 ± 0.19 b	7.75E−03
Total sugars	51.65 ± 1.25 a	46.13 ± 2.55 b	54.65 ± 2.11 a	6.07E−03
***Organic acids* (g 100 g^{-1} D.W)**				
Malic acid	1.98 ± 0.12 a	1.79 ± 0.10 a	1.37 ± 0.12 b	1.66E−03
Citric acid	4.14 ± 0.36 a	4.26 ± 0.24 a	0.32 ± 0.02 b	1.96E−06
Succinic acid	2.93 ± 0.56 b	4.44 ± 0.28 a	4.86 ± 0.19 a	1.78E−03
Fumaric acid	0.0026 ± 0.0006 b	0.0025 ± 0.0002 b	0.0128 ± 0.0004 a	1.19E−07
Total acids	9.05 ± 0.81 b	10.49 ± 0.62 a	6.57 ± 0.21 c	6.00E−04

One way ANOVA was shown as p-values. Letters (a > b > c) indicate significant differences (p-values < 0.05), obtained through post-hoc Duncan test.

UFO3, with highly significant *p-values* confirming these variations.

The strong statistical significance of these differences suggested that acid composition in the exocarp contributed to distinct flavor profiles, with Blanvio 10 potentially having a sourer taste compared to the milder UFO3. Overall, the ANOVA results highlighted clear compositional differences among the three peach cultivars.

3.4. Volatile compounds

The main classes of volatile compounds in both mesocarp and exocarp tissues of the three studied cultivars are presented in Fig. 3 (A) and (B). The results allowed us to identify seven major classes which are alcohol, aldehyde, esters, terpenes, lactones, alkanes and ketone. These compounds vary significantly among cultivars. Indeed, in the mesocarp tissue, Blanvio 10 had the highest amounts of alcohol (51.5 %), Nectarine fruit was richest in Ester (39), while UFO3 had the elevated concentration of ketone (35.1 %) (Fig. 3A). The results also showed that the exocarp of Blanvio 10 contains an important concentration of Aldehyde (50.17 %) followed by the fruits of UFO 3 (34.1 %), however the exocarp of Nectarine was marked by a higher amount of Terpene (34 %) (Fig. 3B). In addition, the analysis of volatile compounds allowed us to characterize 44 compounds in the mesocarp and exocarp of peach fruit (Table 6). GC-MS analysis revealed that non-terpene compounds were detected as the main volatile components in both peach fruit tissues. The other major compounds are apocarotenoids and monoterpene hydrocarbons. Similarly, the results showed the presence of oxygenated monoterpenes only in Blanvio 10 fruits in the exocarp (8.2 %) and mesocarp (42.5 %).

Statistical analysis showed significant differences ($p < 0.05$) for almost all volatile compounds in the mesocarp and exocarp of the peach fruit samples (Table 6), indicating distinct aromatic profiles in the peach samples. The exocarp generally had higher concentrations of volatile compounds than the mesocarp, especially terpenes (e.g., limonene in Nectarine) and aldehydes (e.g., hexanal, nonanal).

(*E*)-2-hexenal, 1-hexanol, and (*E*)-2-hexenyl acetate were more abundant in the mesocarp of

Nectarine and Blanvio 10, contributing to fruity and green notes. In particular, (*E*)-2-hexenal showed higher levels in the exocarp of Nectarine. Benzaldehyde, hotrienol, and terpenediol I were particularly high in the exocarp of the Blanvio 10 and contributed to floral and almond-like aromas (Table 6).

Hexanal, nonanal, and 3-nonanone were prominent in the exocarp of UFO 3, contributing to fresh, green, and slightly fatty notes. Nonanal was also significant in the mesocarp of UFO3, adding a more floral, citrusy note.

Furfural was more abundant in Nectarine and Blanvio 10 exocarps, while it was absent in UFO3, indicating a more oxidized, toasted characteristic in these cultivars. On the other hand, Limonene was concentrated in the exocarp of Nectarine, contributing to a sweet citrus aroma, while (*E*)-β-Ionone was higher in Blanvio 10, which commonly might bring in green, fruity, floral and peach-like aromas to both yellow- and white-fleshed types

3.5. Principal component analysis

PCA was performed separately on the autoscaled mesocarp (Fig. 4A) and exocarp (Fig. 5A) data of the three peach cultivars. In both cases, the first two principal components (PCs) had eigenvalues > 1, meeting the Kaiser criterion (Kaiser, 1958).

Regarding mesocarp PCA, PC1 (59.06 % variance) primarily captures the distinction between sugar/acid-rich and aromatic-rich cultivars. PC1negative loadings (Fig. 4B) for total sugars, glucose, fructose, malic acid, citric acid, total acids, and all phenolic compounds indicate that samples with lower PC1 scores (Nectarine) have higher sugar and acid content (Fig. 4A). In contrast, positive loadings for volatiles like (*E*)-2-penten-1-ol, hexanal, (*Z*)-2-heptenal, benzaldehyde, 1-octen-3-ol, 6-methyl-5-hepten-2-one, 3-octen-2-one, γ-caprolactone, 3,5-octadien-2-one (isomer 1), 3,5-octadien-2-one (isomer 2), and 3-nonanone suggest that samples with higher PC1 scores (UFO3) contain greater concentrations of these aromatic compounds (Fig. 2 A).

PC1 also captures pomological parameters, with diameter (0.75) and weight (0.33) positively correlated, while firmness (-0.58) is negatively correlated. This means larger, softer fruits (UFO3) score higher on PC1, whereas firmer, smaller ones (Nectarine) score lower.

PC2 (37.30 % variance) reflects size and specific volatiles, helping to classify the three peach types based on their physicochemical and sensory attributes.PC2 negative loadings for weight (-0.92) and height (-0.88) indicate that fruits with lower PC2 scores are larger. PC2 also separates volatiles, with furfural (0.98), limonene (0.98), and hotrienol (1.00) linked to positive values, which characterize Blanvio 10 fruits'

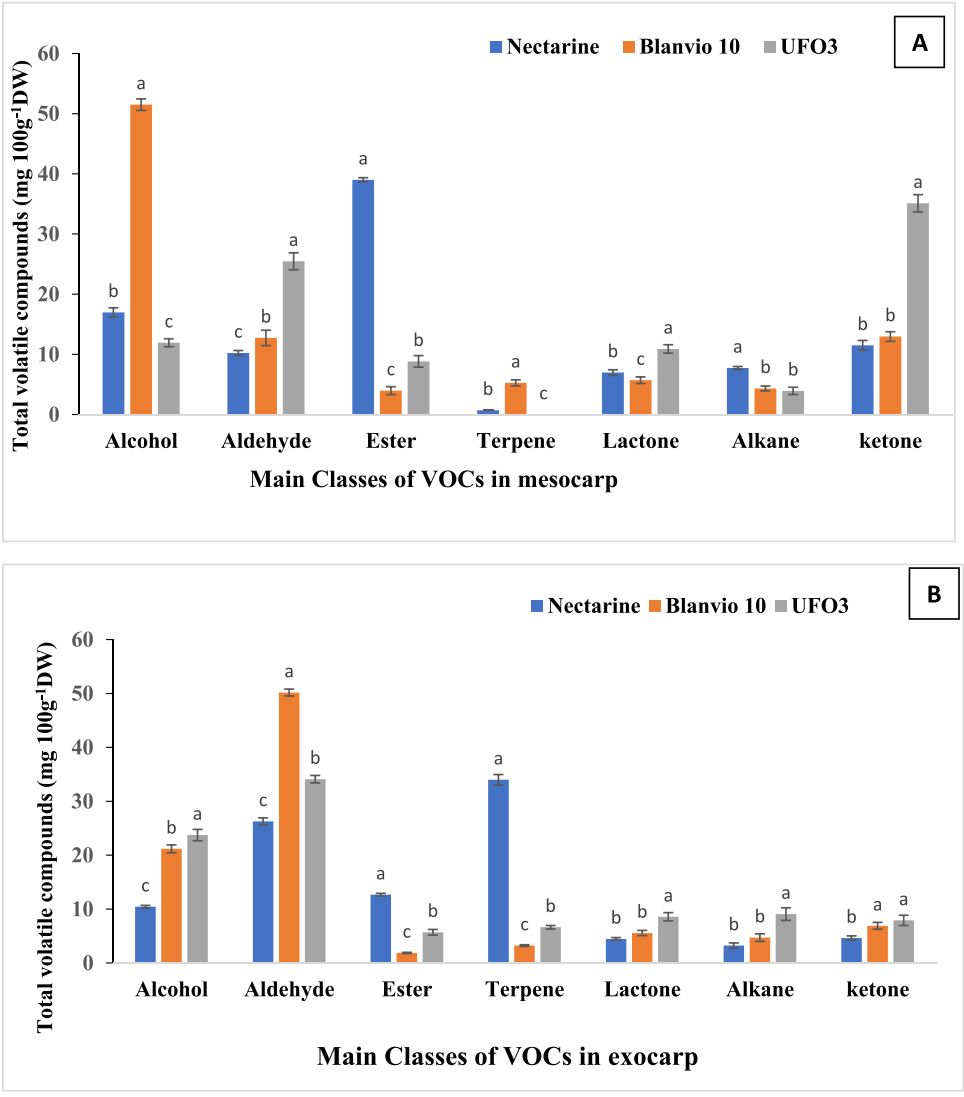

Fig. 3. Main classes of volatile compounds in the mesocarp (A) and exocarp (B) of the three studied cultivars. Values are the means of three different peach samples ($n = 3$) ± standard deviation. One way ANOVA was shown as *p-values*. Letters (a > b > c) indicate significant differences (*p-values* < 0.05), obtained through post-hoc Duncan test.

bouquet, while (*Z*)-3-hexenyl acetate (-0.98), hexanal (-0.62), and 1-hexanol (-0.59) are associated with negative PC2 values. To summarize the position on the PC1 vs PC2 plan of the three cultivars, Nectarine mesocarps have negative PC1 and PC2 scores, Blanvio 10 mesocarps score positively on PC2 and near zero on PC1, while UFO3 mesocarps have positive PC1 and negative PC2 scores.

The PCA loading values for the exocarp samples of the three peach cultivars reveal distinct patterns in their physical, chemical, and volatile composition (Fig. 5B). Fig. 5A shows that the score plot positions Nectarine on the positive PC1 axis, Blanvio 10 on the negative side of PC1 and positive side of PC2, and UFO3 on the negative side of both PC1 and PC2 axes, indicating that these components effectively separate the three cultivars.

PC1, explaining the largest variance (54.00 %), primarily correlates with phenolic compounds and volatiles. High positive loadings for compounds like quercetin-3-*O*-rutinoside (0.89), kaempferol-3-*O*-rutinoside (0.94), and cyanidin-3-*O*-glucoside (0.90) suggest that samples with positive PC1 scores (Nectarine) are richer in anthocyanins and flavonoids. Conversely, UFO3 and Blanvio 10, on the negative PC1 side, are associated with higher concentrations of C_6 and C_7 volatiles, such as hexanal, (*Z*)-2-heptenal, which contribute to fruity and green aromas, while nonanal and 3-nonanone provide citrusy, slightly creamy, waxy, and slightly earthy characters, adding subtle complexity to fruity profiles. The C_9 volatiles enhance a well-rounded, warm, and rich bouquet, complementing both fresh and ripe fruit characteristics. γ-caprolactone and β-cyclocitral (an apocarotenoid, derived from carotenoids by oxidative cleavage) also contribute to the placement of UFO3 in the score plot.

PC2 (40.16 % of the variance) differentiates samples based on color, sugars, acids, and certain volatiles. The positive correlation of L* (0.63) and b* (0.74) suggests that lighter-colored samples, such as Blanvio 10, are positioned towards the positive PC2 axis. In addition, total acids (0.93) and citric acid (0.83) are positively associated with PC2, while total sugars (-0.91) and sucrose (-0.95) are negatively correlated, indicating that samples with high PC2 scores (Blanvio 10) have a more acidic and less sweet profile.(*E*)-2-hexenal, 1-hexanol, benzaldehyde, hotrienol, terpenediol I, (*E*)-ß-ionone with high positive loadings on PC2 and negative on PC1 characterized Blanvio 10.

These results confirm that Nectarine is distinguished by high phenolic content and intense pigmentation, UFO3 by elevated volatiles linked to fruity and green aromas, and Blanvio 10 by lighter color and a more acidic profile, and a sophisticated, multi-layered peach aroma, both fresh and floral, fruity and nutty, with a lingering woody-violet elegance. As a whole. PCA highlights the distinct compositional and

Table 6
Peach volatile compounds (% on total volatile compounds) evaluated in fruits of three studied cultivars. Values are the means of three different peach samples ($n = 3$) ± standard deviation.

		Nectarine		Blanvio 10		UFO 3		ANOVA (*p value*)		Standard
Constituents	**l.r.i.**	**Mesocarp**	**Exocarp**	**Mesocarp**	**Exocarp**	**Mesocarp**	**Exocarp**	**Mesocarp**	**Exocarp**	
(*E*)−2-Penten−1-ol	767	0.80 ± 0.10 b	0.40 ± 0.00 c	1.23 ± 0.35 ab	1.00 ± 0.26 b	1.80 ± 0.35 a	4.10 ± 0.36 a	1.59E−02	4.60E−06	*
1,3-Butanediol	788	n.d.	n.d.	n.d.	n.d.	n.d.	2.17 ± 0.15 a		1.21E−07	*
2,3-Butanediol	789	n.d.	n.d.	n.d.	n.d.	n.d.	5.70 ± 0.40 a		1.18E−07	*
Hexanal	802	7.50 ± 0.46 b	6.23 ± 0.32 b	4.40 ± 0.36 a	12.27 ± 0.64 a	17.17 ± 0.78 a	13.00 ± 0.70 a	3.49E−07	1.34E−05	*
Furfural	834	0.57 ± 0.06 b	7.37 ± 0.55 a	4.97 ± 0.57 a	1.30 ± 0.36 b	n.d.	n.d.	3.06E−06	7.93E−07	*
(*E*)−2-Hexenal	856	0.50 ± 0.00 b	097 ± 0.21 b	0.90 ± 0.20 a	2.43 ± 0.47 a	n.d.	n.d.	2.33E−04	1.75E−04	*
1-Hexanol	869	12.63 ± 0.47 a	2.90 ± 0.36 c	3.20 ± 0.53 b	9.37 ± 0.55 a	2.33 ± 0.50 c	5.47 ± 0.51 b	4.51E−07	9.85E−06	*
Heptanal	901	0.30 ± 0.00 a	0.80 ± 0.17 a	n.d.	n.d.	n.d.	n.d.	4.51E−02	8.98E−05	*
Methyl hexanoate	928	n.d.	n.d.	n.d.	n.d.	n.d.	1.27 ± 0.23 a		3.33E−05	*
(*Z*)−2-Heptenal	962	n.d.	n.d.	0.90 ± 0.10 b	1.10 ± 0.26 a	2.00 ± 0.20 a	1.43 ± 0.25 a	4.36E−06	3.92E−04	
Benzaldehyde	963	0.80 ± 0.10 c	1.53 ± 0.21 b	1.57 ± 0.38 b	19.27 ± 0.93 a	4.00 ± 0.44 a	0.20 ± 0.00 c	6.11E−05	1.88E−08	*
1-Octen−3-ol	981	n.d.	n.d.	1.53 ± 0.23 b	n.d.	2.33 ± 0.25 a	n.d.	1.95E−05		*
6-Methyl−5-hepten−2-one	987	2.03 ± 0.12 c	6.70 ± 0.53 a	3.07 ± 0.42 b	1.00 ± 0.20c	5.47 ± 0.51 a	4.80 ± 0.52 b	9.81E−05	1.19E−05	*
Octanal	1002	n.d.	0.50 ± 0.17 a	n.d.	n.d.	n.d.	n.d.		1.23E−03	*
(*Z*)−3-Hexenyl acetate	1008	2.73 ± 0.21 a	0.73 ± 0.06 a	0.30 ± 0.00 c	n.d.	2.07 ± 0.31 b	n.d.	2.20E−05	2.34E−07	*
1-Hexyl acetate	1010	18.57 ± 0.76 a	6.27 ± 0.40 a	2.23 ± 0.32 c	0.97 ± 0.15 c	4.80 ± 0.60 b	2.97 ± 0.38 b	8.87E−08	3.46E−06	*
(*E*)−2-Hexenyl acetate	1017	17.70 ± 0.70 a	4.77 ± 0.32 a	1.43 ± 0.40 b	0.90 ± 0.10 b	1.97 ± 0.29 b	0.20 ± 0.00c	2.36E−08	2.39E−07	*
Limonene	1032	0.70 ± 0.00 b	34.00 ± 0.96 a	5.27 ± 0.50 c	3.23 ± 0.15 c	n.d.	6.63 ± 0.32 b	1.07E−06	1.89E−09	*
3-Octen−2-one	1043	n.d.	n.d.	n.d.	n.d.	2.73 ± 0.49 a	n.d.	3.14E−05		
γ-Caprolactone	1058	6.97 ± 0.47 b	4.47 ± 0.25 c	5.70 ± 0.56 c	5.57 ± 0.49 b	10.90 ± 0.70 a	8.57 ± 0.78 a	8.72E−05	2.51E−04	*
3,5-Octadien−2-one (isomer 1)	1072	5.27 ± 0.42 c	1.93 ± 0.31 b	9.63 ± 0.67 b	1.43 ± 0.38 b	18.90 ± 0.96 a	2.93 ± 0.49 a	1.17E−06	9.97E−03	
3,5-Octadien−2-one (isomer 2)	1093	1.17 ± 0.21 b	n.d.	1.23 ± 0.29 b	n.d.	5.73 ± 0.70 a	n.d.	2.51E−05		
Nonanal	1104	0.57 ± 0.06 b	8.20 ± 0.44 c	n.d.	13.80 ± 0.66 b	2.30 ± 0.36 a	17.13 ± 1.01 a	2.71E−05	1.76E−05	*
Hotrienol	1106	0.73 ± 0.06 b	n.d.	42.47 ± 1.10 a	5.60 ± 0.56 a	n.d.	n.d.	3.23E−10	9.38E−07	
3-Nonanone	1108	n.d.	n.d.	n.d.	3.30 ± 0.44 a	3.93 ± 0.49 a	3.37 ± 0.40 a	3.71E−06	2.92E−05	*
2,6-Dimethyldecane	1111	0.60 ± 0.00 a	1.33 ± 0.32 a	n.d.	n.d.	n.d.	n.d.	3.71E−06	1.66E−04	
Methyl octanoate	1128	n.d.	0.90 ± 0.10 b	n.d.	n.d.	n.d.	1.27 ± 0.38 a		1.24E−03	*
4-Ketoisophorone	1144	n.d.	1.00 ± 0.10 a	n.d.	n.d.	n.d.	n.d.		9.71E−07	*
(*E,Z*)−2,6-Nonadienal	1158	n.d.	0.30 ± 0.00 a	n.d.	n.d.	n.d.	n.d.		9.71E−07	*
Terpenediol I	1194	n.d.	n.d.	n.d.	2.57 ± 0.47 a	n.d.	n.d.		3.53E−05	
Decanal	1204	n.d.	0.37 ± 0.06 a	n.d.	n.d.	n.d.	n.d.		1.42E−05	*
β-Cyclocitral	1222	n.d.	n.d.	n.d.	n.d.	n.d.	2.33 ± 0.25 a		1.52E−06	*
1-Decanol	1271	n.d.	n.d.	n.d.	n.d.	n.d.	1.50 ± 0.26 a		2.75E−05	*
n-Tridecane	1300	n.d.	n.d.	n.d.	n.d.	n.d.	1.20 ± 0.17 a		8.50E−06	*
1-Tetradecene	1393	0.97 ± 0.15 a	0.93 ± 0.15 a	1.07 ± 0.21 a	1.93 ± 0.35 a	n.d.	1.53 ± 0.35 ab	2.18E−04	1.80E−02	*
n-Tetradecane	1400	2.13 ± 0.21 b	1.60 ± 0.17 b	4.33 ± 0.42 a	4.70 ± 0.70 a	3.93 ± 0.61 a	4.83 ± 0.65 a	1.97E−03	6.33E−04	*
2-Dodecanol	1417	0.77 ± 0.06 a	0.43 ± 0.06 b	n.d.	1.63 ± 0.32 a	n.d.	n.d.	1.79E−07	1.06E−04	*
(*E*)-Geranylacetone	1455	3.87 ± 0.31 a	1.33 ± 0.15	1.50 ± 0.20 b	1.30 ± 0.10	3.80 ± 0.26 a	1.60 ± 0.20	4.66E−05		*
4-Methyltetradecane	1456	2.60 ± 0.26 a	0.30 ± 0.00 b	n.d.	n.d.	n.d.	3.03 ± 0.42 a	1.08E−06	8.32E−06	
3-Methyltetradecane	1473	2.40 ± 0.26 a	n.d.	n.d.	n.d.	n.d.	n.d.	1.76E−06		
(*E*)-β-Ionone	1487	1.20 ± 0.10 a	0.37 ± 0.06 b	0.6 ± 0.00 b	0.93 ± 0.06 a	n.d.	n.d.	7.72E−07	9.85E−07	*
Monoterpene hydrocarbons		0.7	34	5.3	3.2	0	6.6			
Oxygenated monoterpenes		0.7	0	42.5	8.2	0	0			
Sesquiterpene hydrocarbons		0	0	0	0	0	0			
Phenylpropanoids		0	0	0	0	0	0			
Apocarotenoids		5.1	2.7	2.1	2.2	3.8	3.9			
Non-terpenes		87.6	59.9	47.6	82	92.3	86.7			
Total identified		94.1	96.6	97.5	95.6	96.1	97.2			
Non-terpene hydrocarbons		**8.6**	**4.1**	**5.4**	**6.6**	**3.9**	**10.5**			
Non-terpene alcohols		**14.2**	**3.7**	**5.9**	**12**	**6.4**	**19**			
Non-terpene ketones/aldehydes		**18.8**	**34.9**	**26.7**	**55.9**	**62.2**	**42.8**			
Non-terpene esters		**46**	**17.2**	**9.6**	**7.5**	**19.8**	**14.4**			

One way ANOVA was shown as *p-values*. Letters (a > b > c) indicate significant differences (*p-values* < 0.05), obtained through post-hoc Duncan test.

* Pure standards purchased from Sigma-Aldrich-Fluka (now all associated with Merck Italia) (Milano, Italy) and their purity varied from 95.5 % to 99.9 %

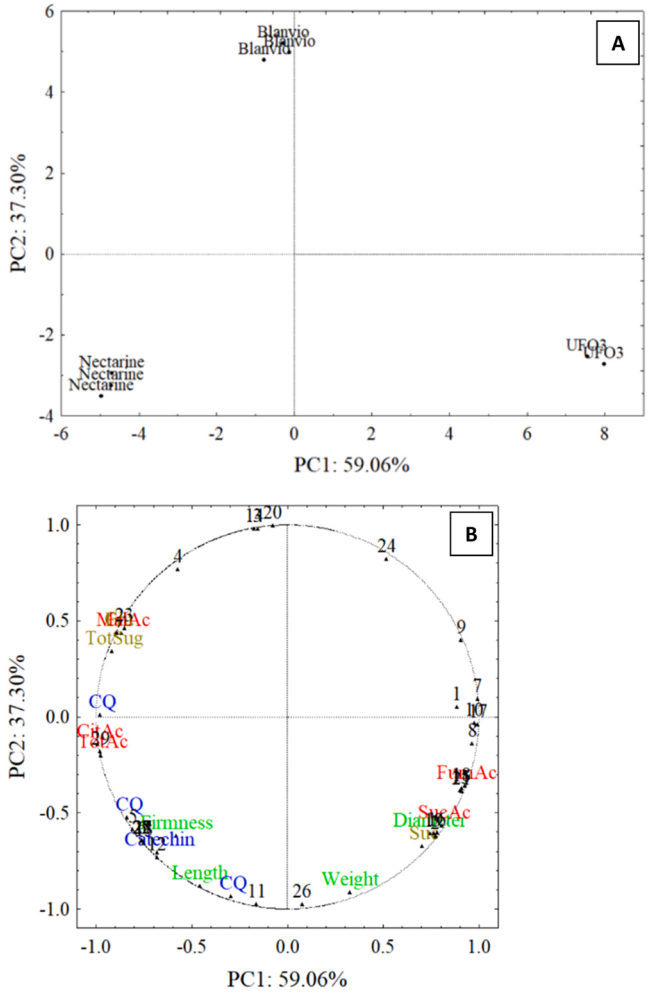

Fig. 4. Mesocarp values PCA. A) score plot of the PC1 versus PC2; B) Loading plot of the PC1 versus PC2. CQ1, 3-*O*-caffeoylquinic acid; CQ2, 4-*O*-caffeoylquinic acid; CQ3, 5-*O*-caffeoylquinic acid; Suc, sucrose; Glu, glucose; Fru, fructose; TotSug, total sugars; MalAc, malic acid; CitAc, citric acid; SucAc, succinic acid; FumAc, fumaric acid; TotAc, total acids; 1, (*E*)-2-penten-1-ol; 2, hexanal; 3, furfural; 4, (*E*)-2-hexenal; 5, 1-hexanol; 6, heptanal; 7, (*Z*)-2-heptenal; 8, benzaldehyde; 9, 1-octen-3-ol; 10, 6-methyl-5-hepten-2-one; 11, (*Z*)-3-hexenyl acetate; 12, 1-hexyl acetate; 13, (*E*)-2-hexenyl acetate; 14, limonene; 15, 3-octen-2-one; 16, γ-caprolactone; 17, 3,5-octadien-2-one (isomer 1); 18, 3,5-octadien-2-one (isomer 2); 19, nonanal; 20, hotrienol; 21, 3-nonanone; 22, 2,6-dimethyldecane; 23, 1-tetradecene; 24, *n*-tetradecane; 25, 2-dodecanol; 26, (*E*)-geranylacetone; 27, 4-methyltetradecane; 28, 3-methyltetradecane; 29, (*E*)-ß-ionone.

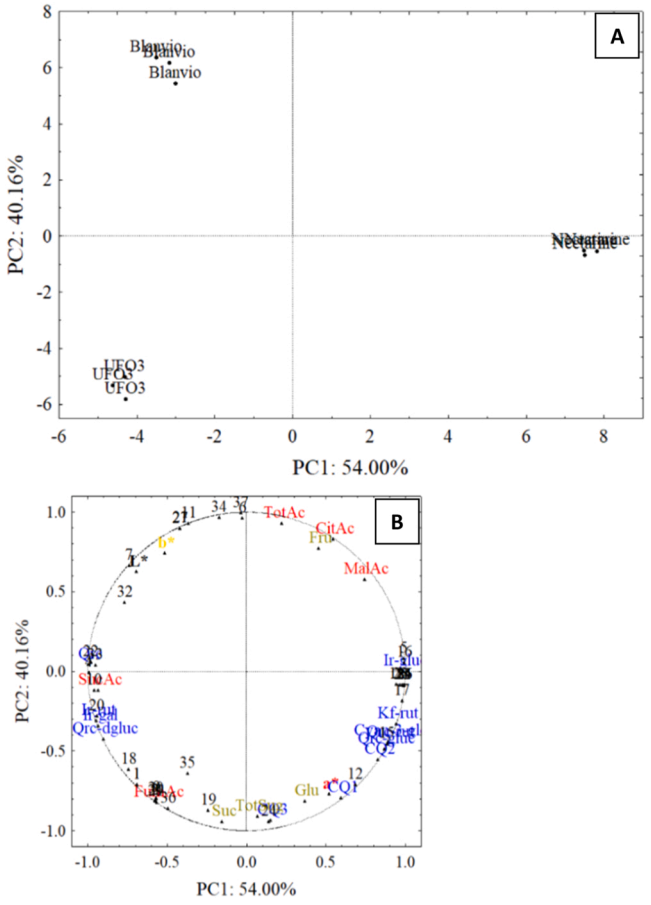

Fig. 5. Exocarp values PCA. A) score plot of the PC1 versus PC2; B) Loading plot of the PC1 versus PC2.L*, a*, and b*, CIELab color coordinates; CQ1, 3-*O*-caffeoylquinic acid; CQ2, 4-*O*-caffeoylquinic acid; CQ3, 5-*O*-caffeoylquinic acid; Cyan-3-glc, cyanidin-3-*O*-glycoside; Qrc-dgluc, quercetin-di-*O*-glucoside; Qrc-rut, quercetin-3-*O*-rutinoside; Qrc-gluc, quercetin-3-*O*-glucoside; Kf-rut, kaempferol-3-*O*-rutinoside; Ir-gal, isorhamnetin-3-*O*-galactoside; Ir-rut, isorhamnetin-3-*O*-rutinoside; Ir-gluc, isorhamnetin-3-*O*-glucoside; Qrc, Quercetin; Suc, sucrose; Glu, glucose; Fru, fructose; TotSug, total sugars; MalAc, malic acid; CitAc, citric acid; SucAc, succinic acid; FumAc, fumaric acid; TotAc, total acids;1, (*E*)-2-penten-1-ol; 2, 1,3-butanediol; 3, 2,3-butanediol; 4, hexanal; 5, furfural; 6, (*E*)-2-hexenal; 7, 1-hexanol; 8, heptanal; 9, methyl hexanoate; 10, (*Z*)-2-heptenal; 11, benzaldehyde; 12, 6-methyl-5-hepten-2-one; 13, octanal; 14, (*Z*)-3-hexenyl acetate; 15, 1-hexyl acetate; 16, (*E*)-2-hexenyl acetate; 17, limonene; 18, γ-caprolactone; 19, 3,5-octadien-2-one (isomer 1); 20, nonanal; 21, hotrienol; 22, 3-nonanone; 23, 2,6-dimethyldecane; 24, methyl octanoate; 25, 4-ketoisophorone; 26, (*E,Z*)-2,6-nonadienal; 27, terpenediolI; 28, decanal; 29, ß-cyclocitral; 30, 1-decanol; 31, *n*-tridecane; 32, 1-tetradecene; 33, *n*-tetradecane; 34, 2-dodecanol; 35, (*E*)-geranylacetone; 36, 4-methyltetradecane; 37, (*E*)-ß-ionone.

aromatic differences between the cultivars.

4. Discussion

The maturation period is an essential indicator to describe and characterize peach cultivars. Maturation as well as fruit development, which follow blossoming for a long time, are mainly genetically determined. However, both can be significantly affected by environmental factors (Szalay et al., 2023).

Some physiological criterion and important features of tree and fruit are often used in cultivar selection programs, such as the maturation period, the weight and size of fruit, the skin color and the sensory quality (Maatallah et al., 2024). The results of the current study showed that the mid-season cultivar (UFO3) had the highest fruit weight and diameter (106.78 g and 66.43 mm, respectively) followed by the extra-early cultivar Nectarine, while Blanvio 10 exhibited the smallest values (52.85 g and 26.55 mm for weight and height, respectively). Previous studies on the effect of peach fruit ripening on these parameters show that fruits from late-ripening peach cultivars are often heavier and larger than those from early and mid-season ripening cultivars (Dabbou et al., 2016; Guizani et al., 2019; Mihaylova et al., 2021). On the other hand, fruit weight and size varied significantly by cultivar characteristics, harvest timing, agricultural practices, and climatic conditions (Nowicka et al., 2016). Foroni et al. (2016) mentioned that color is associated with various attributes such as spoilage, ripeness, and sweetness. According to Maatallah et al. (2024), skin color is among the most determining factors of product quality. Our results indicated that, the extra-early cultivar Nectarine, was characterized by the higher value of a* (34.51) compared to the studied cultivars (31.56 and 61.61 for UFO3 and Blanvio 10, respectively), which may be explain by the fact that

Nectarine initiated fruit skin coloration earlier and then developed a more intense color compared to traditional ones (Iglesias and Echeverría, 2009).

Although the mesocarp, or edible portion, has been the subject of most metabolic research on mature peach fruit (Prinsi et al., 2011; Tosetti et al., 2014), several studies have examined the metabolic composition of the exocarp and mesocarp independently (Guizani et al., 2022; Rodriguez et al., 2019). These investigations demonstrated that the various tissues exhibit distinct metabolic and bioactive substances. In this study, both exocarp and mesocarp tissues of the three studied cultivars were analyzed independently and results confirmed significant variations between both parts.

A fresh peach's overall organoleptic quality is influenced by both its soluble sugars and organic acids contents (Nowicka et al., 2019). The variability in these components and their ratio significantly impacts fruit flavor (Colaric et al., 2004). In the exocarp and mesocarp of the studied peach fruits, sucrose, glucose, and fructose were the primary sugars identified. These findings agree the results previously reported (Guizani et al., 2022; Nowicka et al., 2019) in peach and nectarine cultivars. Our work shows that sucrose was the main sugar in both exocarp (66–71 %) and mesocarp (63–91 %) samples examined, followed by glucose (17–19 % and 3.9–23 %, respectively) and fructose (10–16 % and 4–14 %, respectively). Previous studies found approximately equal amounts for glucose and fructose (Cirilli et al., 2016; Vimolmangkang et al., 2016). In addition to these three soluble sugars, Vimolmangkang et al. (2016) was identified sorbitol, and smaller amounts of inositol in peach.

Moreover, the total sugar content reached 55.03 g100 g^{-1} DW in the studied peach fruits, while total organic acids did not exceed 13.98 g100 g^{-1} DW. Otherwise, Colaric et al. (2004) reported that the organic acid content in peaches is, on average, eightfold lower than the sugar content.

Focusing on organic acids, results showed that among the four acids identified in peach fruits, citric and malic acids were the major ones, followed by succinic and fumaric acids. These results are consistent with earlier research elaborated by Guizani et al. (2019). Even though they are weak acids, they have a big impact on the flavour of the fruit (Wills et al., 1988). A clear correlation exists between fruit flavour and the content of organic acids and sugars. Furthermore, Mihaylova et al. (2021) revealed that peaches with a greater fructose level are often firmer and have a better flavour, whereas those with a higher sucrose and sorbitol content are typically of lower quality.

Phenolic contents from the three peach fruit cultivars were higher in the exocarp than mesocarp tissues. These results confirm the findings of Gil et al. (2002) and Guizani et al. (2022) showing that phenols from peach exocarp are two to three times higher than those from the mesocarp. Additionally, from Fig. 2, it was confirmed that anthocyanins contents were found to be almost exclusively located in the exocarp of the three studied cultivars (1443.62, 835.53 and 488.21 mg kg^{-1} for Nectarine, UFO3 and Blanvio 10, respectively). In fact, anthocyanin pigmentation in the mesocarp was generally very small and mainly found close to the stone. However, it had far fewer flavonols content than the exocarp (Guizani et al., 2022; Tomas-Barberan et al., 2001).

Table 3 reveals that extra-early cultivar Nectarine contained the highest phenolic compounds, while the lowest values were observed in Blanvio 10. According to Mihaylova et al. (2021), extra-early-ripening cultivars generally had higher phenolic acid concentrations than other cultivars. Furthermore, as stated before by previous works (Gil et al., 2002; Tomas-Barberan et al., 2001), white or yellow mesocarp was not a reliable indicator of phenolic content of peach fruit since the determining factor was the individual cultivar. Genetic origin and cultivar are two elements that are responsible for the variability in phenolic distribution (Çetinbaş, 2024).

The genetic background and maturing genotype significantly affect the composition of volatile compounds in peach fruits, which determines the fruit's aroma (Drincovich, 2021; Farcuh and Hopfer, 2023; Li et al., 2023). The type and content of volatile compounds contributing to fruit aroma and flavor are cultivar dependent and varied significantly between the three studied cultivars (Table 6).

There are notable variations in the relative amounts of alcohols, aldehydes, esters, and terpene between both tissues of peach fruits (Fig. 2A and B), besides, they vary depending on the cultivar. These results align with the fundings of Li et al. (2023) carried out on several peach cultivars. The identification of alcohols and aldehydes with higher concentrations in early-season cultivars than in late- and mid-season cultivars has also been mentioned in previous studies (Mohammed et al., 2021). In fact, alcohols and aldehydes are called C6 compounds and are primarily known for their "grassy taste" or "green aroma". Their concentration is high in immature peaches and decreases as the peach ripens (Eduardo et al., 2010). Generally, researchers reported that C6 compounds provide green notes, while esters, lactones, and some terpenoids provide fruity and floral notes of ripe peaches (Liu et al., 2022). According to Seker et al. (2017), aldehydes are among the components that are present at high concentrations in peach fruits, followed by esters and lactones.

In fact, the distinct flavors and fragrances of peach fruits are emphasized by the volatile chemical makeup of their mesocarp and exocarp, which makes them appropriate for a variety of consumer tastes and industrial applications (Mihaylova et al., 2022). Indeed, Nectarine's high concentration of esters such 1-hexyl acetate and (*E*)-2-hexenyl acetate. Likewise, Seker et al. (2017) were reported that nectarines were observed to accumulate high levels of esters when compared to the other genotypes, which contribute to its fresh and sweet scent, makes it stand out for having a bright, fruity, and citrus-like aroma. Its green and somewhat floral notes are further enhanced by the substantial amounts of 1-hexanol and (*E*)-2-penten-1-ol. Particularly abundant in limonene, the exocarp has a strong citrus aroma. Due to these characteristics, Nectarine is very desirable when consumed fresh and well-suited for juices and other fruit-based drinks, where its fragrant components can improve the flavor. However, the aromatic makeup of Blanvio 10 is more fascinating and complex. Its exocarp is distinguished by a high amount of benzaldehyde, which contributes to its nutty and almond-like aroma. Blanvio 10 exocarp contains also high concentrations of aldehydes and ketones, such as furfural and hexanal, which imparts a green, slightly woodsy aroma, as well as hotrienol, a compound known for its honey-like and floral aroma. This rich volatile profile of Blanvio 10 fruit makes it valuable for processed products like jams, preserves, and baked goods, where its warm, slightly nutty notes may improve the overall taste. Additionally, its floral characteristics may make it useful for making flavor extracts and possibly for use in perfumery. Moreover, Toumi et al. (2023) reported that Blanvio 10 were the most suitable cultivars recommended for warm and arid Tunisian areas for their precocity degrees.

Concerning UFO3, the aroma profile was dominated by hexanal and γ-caprolactone. These compounds offer fresh, green, and subtly creamy aroma. Legua et al. (2009) mentioned that UFO3 had consistent fruit flesh, lighter and smaller stones. The comparison between the exocarp and mesocarp of this later cultivar showed the presence of *β*-cyclocitral which contributes to citrusy and tea-like note of its overall aroma. Thanks to these qualities, UFO3 seem to be suitable for dairy-based products, where its mild sweetness and creamy nuances may enhance other flavors. For fresh-cut fruit goods, its balanced fruity and green flavour and natural scent and sweetness can boost customer appeal.

According to PCA findings for both exocarp and mesocarp, UFO3, on the positive PC1 side, is linked to larger size, softer texture, and higher concentrations of certain volatiles like (*Z*)-2-heptenal and hexanal, Nectarine cultivar is located on the negative PC1 axis in both analyses, revealing more phenolic content, sugars, and organic acids. Both instances had Blanvio 10 positioned positively on PC2, which is characterized by its lighter color and floral volatiles including benzaldehyde and (*E*)-*β*-ionone. These results emphasize the three cultivars studied unique compositional and aromatic characteristics that affect their

potential market appeal and technological suitability, according to a thorough examination of the mesocarp and exocarp composition of peaches. In fact, while exocarp analysis highlighted colour and volatile variations, mesocarp data point up fruit firmness, sugars, and acids.

5. Conclusions

This study revealed significant variations in the physical, chemical, and aromatic profiles of the three peach cultivars, which may affect consumer preferences as well as technical applications. Due to its intense red coloration, large size, and high firmness, Nectarine cultivar appears to be visually attractive and perfect for fresh consumption and juice production. In addition, its richness in esters and monoterpenes makes its aroma fruity and citrusy. Phenolic compounds, which may have antioxidant and health properties, is found in the highest concentration in this cultivar. However, Blanvio 10 cultivar was distinguished by its high organic acid content, making it suitable for processed applications such as jams, baked goods, and flavor extracts. Despite having reduced sugar and phenolic levels, its moderate sweetness and acidity balance may improve its sensory appeal in processed foods. Regarding the mid-season cultivar UFO3 showing moderate sugar content and lower firmness, seems to be more suitable for fresh consumption as softer-textured fruit. Higher sucrose content might make UFO3 fruits seem sweeter while having less acidity. Both the fresh and processed markets may benefit from their well-balanced character.

The distinct potential of each cultivar for various consumer preferences and processing purposes is highlighted by these variations in the parameters studied.

Consequently, to improve favorable qualities for both consumer and industrial demands as well as guiding breeding programs, it is crucial to consider these attributes.

CRediT authorship contribution statement

Samira Maatallah: Writing – original draft, Methodology. **Guido Flamini:** Methodology, Formal analysis. **Samia Dabbou:** Writing – original draft, Validation, Formal analysis, Conceptualization. **Monia Guizani:** Writing – original draft, Validation, Methodology, Conceptualization. **Giuseppe Montevecchi:** Validation, Software, Methodology. **Giulia Santunione:** Writing – original draft, Software, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2025.108427.

Data availability

The data will be made available upon reasonable request.

References

Adams, R.P., 1995. Identification of Essential Oil Components by Gas Chromatography/ mass Spectrometry. Allured Publishing Corp. Carol Stream.

Adams, R.P., 2007. Identification of Essential Oil Components by Gas Chromatography/ mass Spectrometry. Allured Publishing Corporation, Carol Stream.

Alipasandi, A., Ghaffari, H., Alibeyglu Zohrabi, S., 2013. Classification of three varieties of peach fruit using artificial neural network assisted with image processing techniques. Int. J. Agron. Agric. Res. 2179–2186.

Aubert, C., Ambid, C., Baumes, R., Günata, Z., 2003. Investigation of bound aroma constituents of yellow-fleshed nectarines (Prunus persica L. Cv. Springbright). changes in bound aroma profile during maturation. J. Agric. Food Chem. 51, 6280–6286. https://doi.org/10.1021/jf034613h.

Bassi, D., Cirilli, M., Foschi, S., Iglesias, I., Giovannini, D., Badenes, M.L., Gasic, K., 2023. Cultivars. CABI 92–113. https://doi.org/10.1079/9781789248456.0004.

Bouazizi, S., Montevecchi, G., Masino, F., Antonelli, A., Hamdi, M., 2022. Tunisian opuntia ficus-indica fruit peels: biochemical and microbiological characterization and possible applications. Ann. Univ. Dunarea De. Jos Galati Fascicle VI Food Technol. 46, 67–78. https://doi.org/10.35219/FOODTECHNOLOGY.2022.1.06.

Braga, A., Belo, I., 2016. Biotechnological production of γ-decalactone, a peach like aroma, by yarrowia lipolytica. World J. Microbiol. Biotechnol. https://doi.org/10.1007/s11274-016-2116-2.

Byrne, D.H., 2005. Trends in stone. HortTechnology 15, 494–500.

Çetinbaş, M., 2024. Effects of Pre-harvest applications of aminoethoxyvinylglycine and oxalic acid on biochemical compounds and fruit quality of 'Big Bang' nectarine variety. Appl. Fruit. Sci. 66, 1631–1640. https://doi.org/10.1007/s10341-024-01145-1.

Chinnici, F., Spinabelli, U., Riponi, C., Amati, A., 2005. Optimization of the determination of organic acids and sugars in fruit juices by ion-exclusion liquid chromatography. J. Food Compos. Anal. 18, 121–130. https://doi.org/10.1016/j.jfca.2004.01.005.

Cirilli, M., Bassi, D., Ciacciulli, A., 2016. Sugars in peach fruit: a breeding perspective. Hortic. Res. 3, 15067. https://doi.org/10.1038/hortres.2015.67.

Colaric, M., Stampar, F., Hudina, M., 2004. Contents of sugars and organic acids in the cultivars of peach (Prunus persica L.) and nectarine (Prunus persica var. nucipersica Schneid.). Acta Agric. Slov. 83, 53–61.

Dabbou, S., Dabbou, S., Chehab, H., Brahmi, F., Taticchi, A., Servili, M., Hammami, M., 2011. Chemical composition of virgin olive oils from koroneiki cultivar grown in Tunisia with regard to fruit ripening and irrigation regimes. Int. J. Food Sci. Technol. 46. https://doi.org/10.1111/j.1365-2621.2010.02520.x.

Dabbou, S., Dabbou, S., Chehab, H., Taticchi, A., Servili, M., Hammami, M., 2015. Content of fatty acids and phenolics in coratina olive oil from Tunisia: influence of irrigation and ripening. Chem. Biodivers. 12. https://doi.org/10.1002/cbdv.201400142.

Dabbou, S., Lussiana, C., Maatallah, S., Gasco, L., Hajlaoui, H., Flamini, G., 2016. Changes in biochemical compounds in flesh and peel from prunus persica fruits grown in Tunisia during two maturation stages. Plant Physiol. Biochem. 100, 1–11. https://doi.org/10.1016/j.plaphy.2015.12.015.

Davies, N.W., 1990. Gas chromatographic retention indices of monoterpenes and sesquiterpenes on methyl silicone and c arbowax 20M phases. J. Chromatogr. 503, 1–24.

DGPA [WWW Document], 2024. Direction générale de la production agricole Tunisie. URL ⟨https://catalog.agridata.tn/organization/direction-generale-de-la-production-agricole⟩ (accessed 5.31.25).

Drincovich, M.F., 2021. Identifying sources of metabolomic diversity and reconfiguration in peach fruit: taking notes for quality fruit improvement. FEBS Open Bio 11, 3211–3217. https://doi.org/10.1002/2211-5463.13233.

Elsadr, H., Sherif, S., Banks, T., Somers, D., Jayasankar, S., 2019. Refining the genomic region containing a major locus controlling fruit maturity in peach. Sci. Rep. 9, 7522. https://doi.org/10.1038/s41598-019-44042-4.

Eduardo, I., Chietera, G., Bassi, D., Rossini, L., Vecchietti, A., 2010. Identification of key odor volatile compounds in the essential oil of nine peach accessions. J. Sci. Food Agric. 90, 1146–1154. https://doi.org/10.1002/jsfa.3932.

Fan, Z., Hasing, T., Johnson, T.S., Garner, D.M., Barbey, C.R., Colquhoun, T.A., Sims, C. A., Resende, M.F.R., Whitaker, V.M., 2021. Strawberry sweetness and consumer preference are enhanced by specific volatile compounds. Hortic. Res. 8. https://doi.org/10.1038/s41438-021-00502-5.

Farcuh, M., Hopfer, H., 2023. Aroma volatiles as predictors of chilling injury development during peach (Prunus persica (L) Batsch) cold storage and subsequent shelf-life. Postharvest Biol. Technol. 195, 112137. https://doi.org/10.1016/j.postharvbio.2022.112137.

Farooq, U., Shafi, A., Akram, K., Hayat, Z., 2020. Fruits and nutritional security. Fruit Crops: Diagnosis and Management of Nutrient Constraints. Elsevier, pp. 1–12. https://doi.org/10.1016/B978-0-12-818732-6.00001-0.

Fernández, P., Gabaldón, J.A., Periago, M.J., 2017. Detection and quantification of alicyclobacillus acidoterrestris by electrical impedance in apple juice. Food Microbiol. 68, 34–40. https://doi.org/10.1016/j.fm.2017.06.016.

Foroni, F., Pergola, G., Rumiati, R.I., 2016. Food color is in the eye of the beholder: the role of human trichromatic vision in food evaluation. Sci. Rep. 6. https://doi.org/10.1038/srep37034.

Gil, M.I., Toma-Barberan, F.A., Hess-Pierce, B., Kader, A.A., 2002. Antioxidant capacities, phenolic compounds, carotenoids, and vitamin c contents of nectarine, peach, and plum cultivars from california. J. Agric. Food Chem. 50, 4976–4982.

Guizani, M., Dabbou, S., Maatallah, S., Montevecchi, G., 2019. Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in center-west of Tunisia. Agric. Water Manag. 217, 81–97. https://doi.org/10.1016/j.agwat.2019.02.021.

Guizani, M., Dabbou, S., Maatallah, S., Montevecchi, G., Antonelli, A., Serrano, M., Hajlaoui, H., Rezig, M., Kilani-Jaziri, S., 2022. Evaluation of two water deficit models on phenolic profiles and antioxidant activities of different peach fruits parts. Chem. Biodivers. 19. https://doi.org/10.1002/cbdv.202100851.

Iglesias, I., Echeverría, G., 2009. Differential effect of cultivar and harvest date on nectarine colour, quality and consumer acceptance. Sci. Hortic. 120, 41–50. https://doi.org/10.1016/j.scienta.2008.09.011.

Jennings, W., Shibamoto, T., 1980. Qualitative analysis of flavor and fragrance volatiles by glass capillary gas chromatography. Acad. Press Inc. https://doi.org/10.1021/ed058pa381.1.

Kaiser, H.F., 1958. The varimax criterion for analytic rotation in factor analysis. Psychometrika 23, 187–200. https://doi.org/10.1007/BF02289233.
Koroch, A.R., Rodolfo Juliani, H., Zygadlo, J.A., 2007. Bioactivity of essential oils and their components. In: Berger, R.G. (Ed.), Flavours and Fragrances: Chemistry, Bioprocessing and Sustainability. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 87–115. https://doi.org/10.1007/978-3-540-49339-6_5.
Lara, M.V., Bonghi, C., Famiani, F., Vizzotto, G., Walker, R.P., Drincovich, M.F., 2020. Stone fruit as biofactories of phytochemicals with potential roles in human nutrition and health. Front. Plant Sci. https://doi.org/10.3389/fpls.2020.562252.
Layne, D., Bassi, D., 2008. The peach: botany, production and uses. Peach Bot. Prod. Uses 596. https://doi.org/10.1079/9781845933869.0000.
Legua, P., Hernandez, F., Nicolás, J.J., 2009. Agronomic and quality parameters of flat peach UFO3, UFO4 and sweetcap®. Ital. J. Food Sci. 22.
Li, X., Gao, P., Zhang, C., Xiao, X., Chen, C., Song, F., 2023. Aroma of peach fruit: a review on aroma volatile compounds and underlying regulatory mechanisms. Int. J. Food Sci. Technol. https://doi.org/10.1111/ijfs.16621.
Li, X. wei, Jiang, J., Zhang, L. ping, Yu, Y., Ye, Z. wen, Wang, X. min, Zhou, J. yi, Chai, M. liang, Zhang, H. qin, Arús, P., Jia, H. juan, Gao, Z. shan, 2015. Identification of volatile and softening-related genes using digital gene expression profiles in melting peach. Tree Genet. Genomes 11. https://doi.org/10.1007/s11295-015-0891-9.
Liang, Z., Fang, Z., Pai, A., Luo, J., Gan, R., Gao, Y., Lu, J., Zhang, P., 2022. Glycosidically bound aroma precursors in fruits: a comprehensive review. Crit. Rev. Food Sci. Nutr. https://doi.org/10.1080/10408398.2020.1813684.
Liu, H., He, H., Liu, C., Wang, C., Qiao, Y., Zhang, B., 2022. Changes of sensory quality, Flavor-Related metabolites and gene expression in peach fruit treated by controlled atmosphere (CA) under cold storage. Int. J. Mol. Sci. 23, 7141. https://doi.org/10.3390/ijms23137141.
Maatallah, S., Guizani, M., Lahbib, K., Montevecchi, G., Santunione, G., Hessini, K., Dabbou, S., 2024. Physiological traits, fruit morphology and biochemical performance of six old fig genotypes grown in warm climates “Gafsa oasis” in Tunisia. J. Agric. Food Res. 17, 101253. https://doi.org/10.1016/j.jafr.2024.101253.
Martínez-Esplá, A., Zapata, P.J., Castillo, S., Guillén, F., Martínez-Romero, D., Valero, D., Serrano, M., 2014. Preharvest application of methyl jasmonate (MeJA) in two plum cultivars. 1. improvement of fruit growth and quality attributes at harvest. Postharvest Biol. Technol. 98, 98–105. https://doi.org/10.1016/j.postharvbio.2014.07.011.
Mihaylova, D., Popova, A., Desseva, I., Petkova, N., Stoyanova, M., Vrancheva, R., Slavov, A., Slavchev, A., Lante, A., 2021. Comparative study of early-and mid-ripening peach (Prunus persica l.) varieties: biological activity, macro-, and micro-nutrient profile. Foods 10. https://doi.org/10.3390/foods10010164.
Mihaylova, D., Popova, A., Vrancheva, R., Dincheva, I., 2022. HS-SPME-GC–MS volatile profile characterization of peach (Prunus persica L. Batsch) varieties grown in the eastern Balkan peninsula. Plants 11, 166. https://doi.org/10.3390/plants11020166.
Mohammed, J., Belisle, C.E., Wang, S., Itle, R.A., Adhikari, K., Chavez, D.J., 2021. Volatile Profile Characterization of Commercial Peach (Prunus persica) Cultivars Grown in Georgia, USA. Horticulturae 7, 516. https://doi.org/10.3390/horticulturae7120516.
Montero-Prado, P., Sánchez-Jarabo, C., Nerín, C., 2009. Development and application of an active package to increase the shelf-life of “Calanda peach. Ital. J. Food Sci. 94–97.
Montevecchi, G., Simone, G.V., Mellano, M.G., Masino, F., Antonelli, A., 2013. Fruit sensory characterization of four pescabivona, White-fleshed peach [Prunus persica (L.) Batsch], landraces and correlation with physical and chemical parameters. Fruits 68, 195–207. https://doi.org/10.1051/fruits/2013067.
Musetti, A., Tagliazucchi, D., Montevecchi, G., Verzelloni, E., Antonelli, A., Fava, P., 2015. Characterization of a combined treatment with Alpha-Lipoic acid for the control of enzymatic browning in Fresh-Cut golden delicious apples. J. Food Process. Preserv. 39, 681–687. https://doi.org/10.1111/jfpp.12276.
Nowicka, P., Wojdyło, A., Laskowski, P., 2019. Principal component analysis (PCA) of physicochemical compounds’ content in different cultivars of peach fruits, including qualification and quantification of sugars and organic acids by HPLC. Eur. Food Res. Technol. 245, 929–938. https://doi.org/10.1007/s00217-019-03233-z.
Nowicka, P., Wojdyło, A., Samoticha, J., 2016. Evaluation of phytochemicals, antioxidant capacity, and antidiabetic activity of novel smoothies from selected prunus fruits. J. Funct. Foods 25, 397–407. https://doi.org/10.1016/j.jff.2016.06.024.
Prinsi, B., Negri, A.S., Fedeli, C., Morgutti, S., Negrini, N., Cocucci, M., Espen, L., 2011. Peach fruit ripening: a proteomic comparative analysis of the mesocarp of two cultivars with different flesh firmness at two ripening stages. Phytochemistry 72, 1251–1262. https://doi.org/10.1016/j.phytochem.2011.01.012.
Rodriguez, C.E., Bustamante, C.A., Budde, C.O., Müller, G.L., Drincovich, M.F., Lara, M. V., 2019. Peach fruit development: a comparative proteomic study between endocarp and mesocarp at very early stages underpins the main differential biochemical processes between these tissues. Front. Plant Sci. 10, 715. https://doi.org/10.3389/fpls.2019.00715.
Santos, T.C.D., Gomes, T.M., Pinto, B.A.S., Camara, A.L., Paes, A.M.D.A., 2018. Naturally occurring acetylcholinesterase inhibitors and their potential use for Alzheimer’s disease therapy. Front. Pharmacol. https://doi.org/10.3389/fphar.2018.01192.
Sdiri, W., Dabbou, S., Chehab, H., Selvaggini, R., Servili, M., Bella, G.D., Mansour, H.B., 2020. Quality characteristics and chemical evaluation of chemlali olive oil produced under dairy wastewater irrigation. Agric. Water Manag. 236, 106124. https://doi.org/10.1016/j.agwat.2020.106124.
Seker, M., Ekinci, N., Gür, E., 2017. Effects of different rootstocks on aroma volatile constituents in the fruits of peach (Prunus persica L. Batsch cv. ‘Cresthaven’). N. Z. J. Crop Hortic. Sci. 45, 1–13. https://doi.org/10.1080/01140671.2016.1223148.
Stenhagen, E., Abrahamsson, S., McLafferty, F.W., 1974. Registry of Mass Spectral Data, 1st ed. Wiley.
Swigar, A.A., Silverstein, R.M., 1981. Monoterpenes: Infrared, Mass, ^{1}H NMR, and ^{13}C NMR spectra, and Kováts indices. Aldrich Chemical Co.
Szalay, L., Bakos, J.L., Bekefi, S., 2023. Ripening time of peach cultivars in the central part of Hungary in a long-term observation. South West. J. Hortic. Biol. Environ. 14.
Terki, L., Aissaoui, O., Hadjout, L., Calvini, R., Montevecchi, G., Khelouia, L., Baziz, H., Oukhmanou-Bensidhoum, S., Kaci, M., Boulekbache-Makhlouf, L., Kujawski, W., Madani, K., 2025. Mathematical modeling for cactus pear juice concentration kinetics and a study of the physicochemical changes during the concentration process. J. Food Process. Preserv. 2025. https://doi.org/10.1155/jfpp/3124679.
Tomas-Barberan, F.A., Gil, I., Cremin, P., Waterhouse, A.L., Hess-pierce, B., Kader, A.A., 2001. HPLC - DAD - ESIMS Analysis of Phenolic Compounds in Nectarines, Peaches, and Plums 4748–4760.
Tosetti, R., Tardelli, F., Tadiello, A., Zaffalon, V., Giorgi, F.M., Guidi, L., Trainotti, L., Bonghi, C., Tonutti, P., 2014. Postharvest biology and technology molecular and biochemical responses to wounding in mesocarp of ripe peach (Prunus persica L. Batsch) fruit. Postharvest Biology and Technology, pp. 40–51. https://doi.org/10.1016/j.postharvbio.2013.12.001, 90.
Toumi, I., Tlahig, S., Nagaz, K., 2023. Evaluation of low-chill peach (*prunus persica* L.) cultivars suitable for arid climate of Southern Tunisia. Acta Hortic. 57–62. https://doi.org/10.17660/ActaHortic.2023.1372.8.
Veerappan, K., Natarajan, S., Chung, H., Park, J., 2021. Molecular insights of fruit quality traits in peaches, prunus persica. Plants. https://doi.org/10.3390/plants10102191.
Vimolmangkang, S., Zheng, H., Peng, Q., Jiang, Q., Wang, H., Fang, T., Liao, L., Wang, L., He, H., Han, Y., 2016. Assessment of sugar components and genes involved in the regulation of sucrose accumulation in peach fruit. J. Agric. Food Chem. 64, 6723–6729. https://doi.org/10.1021/acs.jafc.6b02159.
Williamson, K., Pao, S., Dormedy, E., Phillips, T., Nikolich, G., Li, L., 2018. Microbial evaluation of automated sorting systems in stone fruit packinghouses during peach packing. Int. J. Food Microbiol. 285, 98–102. https://doi.org/10.1016/j.ijfoodmicro.2018.07.024.
Wills, R., McGlasson, B., Graham, D., Joyce, D., 1988. Postharvest: an Introduction to the Physiology and Handling of Fruit, Vegetables and Ornamentals. HortTechnology, 4th ed. CAB International. https://doi.org/10.21273/horttech.9.2.299.
Zhang, B., Shen, J.Y., Wei, W.W., Xi, W.P., Xu, C.J., Ferguson, I., Chen, K., 2010. Expression of genes associated with aroma formation derived from the fatty acid pathway during peach fruit ripening. J. Agric. Food Chem. 58, 6157–6165. https://doi.org/10.1021/jf100172e.