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FULL ARTICLE

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Aroma and soluble solid contents of the uvaia—a native Atlantic rainforest fruit—are negatively affected by early harvest

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Abstract

The uvaia (*Eugenia pyriformis* Cambess) is a native Atlantic Rainforest Myrtaceae that produces acidic yellow-orange fruit with a peculiar aroma. Its postharvest conservation poses a challenge, due to high perishability. This study investigated the postharvest quality of uvaia fruit during three ripening stages stored at 22°C. The quality attributes were evaluated: skin color, soluble solids, titratable acidity, flavonoids, carotenoids, phenolic compounds, antioxidant capacity, and volatile compounds at the beginning and end of the fruit's shelf life. Respiration (CO_2) and C_2H_4 production were determined daily. No relationship between ripening stage and respiration was observed, but C_2H_4 production increased with ripening stage. Green fruit reached the same skin color, titratable acidity, flavonoids, carotenoids phenolic compounds, and antioxidant activity of mature fruit, also displaying increased shelf life. Green fruit also presented lower soluble solids. The volatile compounds that give green fruit characteristic aroma were persistent.

Practical applications

Aroma and soluble solids content are important factors in determining the fruit quality. This work identified how these factors are affected by early uvaia fruit harvesting. Such information assists in determining the uvaia ideal harvesting point, providing better sensory quality, and increasing the fruit acceptance. Early harvesting at different ripening stages, in addition to prolonging the shelf life of the harvested fruit, is also a tool for understanding physiological processes.
This study disseminates unpublished knowledge about uvaia, arousing interest in this native fruit and facilitating its commercialization.

KEYWORDS

Eugenia pyriformis Cambess, physiology, quality, volatile compounds

1 | INTRODUCTION

The uvaia tree (*Eugenia pyriformis* Cambess) is a native Atlantic Rainforest Myrtaceae that produces acidic yellow-orange fruit with a peculiar aroma. Uvaia fruit serve as raw material for edible products such as jellies, ice cream, yogurts, juices, liqueurs, and cosmetic products like shampoos, soaps, and moisturizers (Andrade; Ferreira, 2000).

Although still scarce, recent studies have addressed aspects related to the physicochemical characterization, germination, antiinflammatory, and antioxidant capacity of uvaia fruit, and have demonstrated that, besides being adequate for processing in the food industry, uvaia fruit are also a natural source of bioactive compounds important for human health maintenance (Haminiuk et al., 2011; Pereira et al., 2012; Ramirez et al., 2012; Rufino et al., 2010).

In spite of their potential benefits and uses, uvaia fruit are not known by most of the Brazilian population, as they present seasonal production and are restricted to their occurrence areas, which include backyards, fruit collectors, research centers, and germplasm banks. In addition, these fruit present a very short shelf life, displaying quick quality loss, making them difficult to market and consume fresh (Sartori et al., 2010).

The uvaia fruit physiological ripening process has not yet been elucidated. Early harvesting at different ripening stages, in addition to prolonging the useful life of the harvested fruit, is also an important tool in the understanding of this physiological process. In this context, this study evaluated how harvesting during different ripening stages affects fruit quality attributes during the postharvest period.

2 | MATERIAL AND METHODS

2.1 | Fruit harvesting and experiments

Uvaias in three different ripening stages were obtained from the experimental area at the Federal Institute of Minas Gerais, latitude 22°19′1″S, longitude 46°19′40″ W and 869 m elevation. The local climate is of the Cwb type, presenting a temperate humid climate with dry winters and temperate summers, average annual rainfall of 1.500 mm, and average annual temperature of 19°C (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). Ripening stages were defined according to fruit skin color as stage 1 = green skin, stage 2 = yellow skin, and stage 3 = orange skin (Figure 1).

The fruit, selected in order to obtain uniform batches, were then transported in cool isothermal boxes containing ice sheets to the vegetable postharvesting laboratory (LPV-ESALQ/USP) and stored at 22°C ± 1°C and at RH of 90% ± 5%.

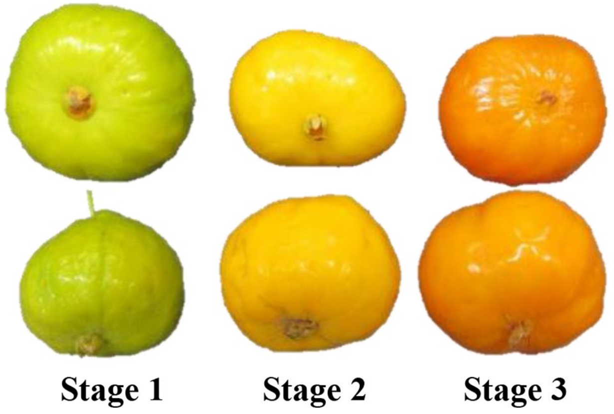

FIGURE 1 Uvaia fruit in the three maturing stages defined by skin color at the moment of their harvest, where 1 = stage 1—green, 2 = stage 2—yellow, 3 = stage 3—orange

2.2 | Analyses

Skin color and soluble solids were determined in the fresh fruit. Titratable acidity, phenolic compounds, carotenoids, flavonoids, antioxidant capacity, and volatile compounds were determined in pulp processed along with the skin, frozen in liquid nitrogen, and stored at −18°C ± 1°C at both the beginning and the end of the uvaia fruit shelf life. The beginning of the shelf life was determined as the day the fruit were harvested, while the end of the shelf life indicated the last day of storage. The final working day varied for each maturation stage, namely stage 1 = 5 days, stage 2 = 4 days, and stage 3 = 3 days.

2.2.1 | Skin color

Skin color of the fruit is determined by two reading taken from two sides of each of the 10 fruits from each ripening stage at the beginning and end of the storage period using a Minolta model CR-300 colorimeter. Values were expressed as luminosity *(L)* (ranging from black to white) and as coordinates *b** (ranging from yellow to blue) and *a** (ranging from red to green).

2.2.2 | Soluble solids

Soluble solids are quantified by direct readings using an Atago Palette PR-101 digital refractometer (AOAC, 2012). Ten samples were collected with the aid of a Pasteur pipette, gauze filtered, homogenized, and then analyzed. Results were expressed as % Brix.

2.2.3 | Titratable acidity

Titratable acidity is determined by neutralization titration using 5.0 g of the fresh fruit mass extracts of 10 fruits, homogenized in 45 ml of distilled water. The extracts were filtered through filter paper and titrated with standard 1 N sodium hydroxide solution (NaOH) until reaching pH 8.1. Results were expressed as % of equivalents of citric acid in the fresh mass (Carvalho, Mantovani, Carvalho, & Moraes, 1990).

2.2.4 | Carotenoids

Two grams of the fresh mass of 10 fruits were homogenized in 18 ml of 80% acetone. Readings were carried out on a spectrophotometer at 663 nm, 646 nm, and 470 nm (Lichtenthaler, 1987). Carotenoid content was expressed as g kg^{-1} of the samples.

2.2.5 | Flavonoids

The extracts were prepared from 1 g of fresh fruit mass homogenized in 50 ml of 1.5 N hydrochloric acid using a Turrax homogenizer (Ika, model: T25 digital) for 2 min. The contents were transferred to a glass vial, wrapped in aluminum foil, and stored for 12 hr in a fridge. The extracts were then filtered and readings were carried out on a spectrophotometer at 374 nm. Total flavonoid contents were calculated using the formula: (Absorbance × dilution factor)/98.2 and, expressed as g kg^{-1} (Francis, 1982).

2.2.6 | Phenolic compounds

Determined by the Folin–Ciocalteau spectrophotometric method (Woisky & Salatino, 1998). Briefly, extracts were prepared with 1 g of fresh mass diluted in 50 ml of distilled water. Then, 0.5 ml of the extracts and 2.5 ml of Folin–Ciocalteau reagent (1:10) were mixed in a test tube, and left standing for 3 min. Subsequently, 2 ml of 4% sodium carbonate were added and the tubes were homogenized and sheltered from light for 2 hr prior to the spectrophotometer readings, taken at 740 nm. Results were expressed as gallic acid equivalent (g kg^{-1}), according to the calibration curve.

2.2.7 | Antioxidant activity

Antioxidant activity is determined by oxygen radical absorbance capacity (ORAC) method or absorption capacity of oxygenated radicals according to Ou, Hampsch-Woodill, and Prior (2001) adapted for microplate reading. A total of 20 mg of homogenized lyophilized fruit pulp were added to 1 ml of phosphate buffer, followed by a 1/50 dilution in phosphate buffer preparation. A total of 30 l of the prepared dilution (1/50), 60 µl of fluorescein and 110 µl of a 76 mM AAPH solution were pipetted onto a microplate. The samples were then allowed to stand for 2 hr in the dark and then analyzed at 528 nm using a spectrophotometer. Antioxidant activity results were expressed as mol kg^{-1} (extract trolox), according to the calibration curve.

2.2.8 | Respiration and ethylene production

For the respiration analysis (carbon dioxide production—CO_2) and C_2H_4 production, 12 glass bottles with a mean volume of 586.69 ml were used, containing a mean of 146.04 g of fruit stored at room temperature (22°C ± 1°C) and at a relative humidity of 90% ± 5%. The vials remained closed for 1 hr followed by 1-ml sample removal through a lid septum using a syringe for subsequent injection in a Trace 2000 GC gas chromatograph (Thermo Finnigan) comprising a flame ionization detector (FID), using nitrogen as the flow gas at 33.3 ml/min and a column temperature of 200°C. CO_2 production results were expressed as nmol kg s^{-1}.

2.2.9 | Volatile compounds

Volatile compounds analyzed in triplicate, according to the solid-phase microextraction (SPME) method. The extracts were prepared with the pulp and skins of 10 fruits, chopped with a stainless-steel blade, frozen in liquid nitrogen, and stored at −18°C. A total of 3 g of the processed fruit were weighed into 20-ml amber vials, followed by the addition of 7 ml of a 30% (w/v) NaCl solution. The vials were sealed with silicone lids and frozen at −20°C. For volatile compound extraction, vials were thawed in a water bath at 40 °C under constant stirring with magnetic bars for 10 min in order to accumulate the volatile compounds in the headspace (Pesis et al., 2009). Then, the SPME fiber (divinylbenzene, carboxene, and 50/30 µm polydimethylsiloxane, Supelco, Inc.) was introduced into the vial headspace and exposed for 50 min. Once captured, the volatile compounds were desorbed from the fiber by exposure to the heat of the chromatograph injector (200°C) for 5 min.

A Hewlett-Packard (HP) chromatograph 6890 coupled to an HP mass spectrometer model 5973 was used. The employed chromatographic column was a Supelcowax 10 (30 m, 0.25 mm internal diameter, 0.25 µm film thickness). The temperature program was set as follows: 2°C. minimum temperature range from 40 to 150°C. The temperature of the interface between the chromatograph and the selective mass detector was of 230°C and ionization was carried out by electron impact (70 eV) with the ion source maintained at 150°C. The mass spectra obtained were compared to the NIST version 2011 library.

2.2.10 | Statistical analyses

The experimental design was completely randomized, arranged in a 3 × 5 factorial scheme, comprising three treatments composed by maturation stages 1, 2, and 3, evaluated during 5, 4, or 3 days—depending on the fruit shelf life—with four replicates consisting of 10 fruits each. The results were evaluated by an analysis of variance followed by Scott-Knott's test at 5%, except for CO_2 and C_2H_4 production data, that were graphically compared with the aid of vertical bars representing the standard error of the means ($p < 0.05$). For volatile compound data, a principal component multivariate analysis and hierarchical grouping (Heatmap) were used, the latter carried out using the Metaboanalyst 3.0 software (Xia, Wishart, Xia, & Wishart, 2016).

3 | RESULTS AND DISCUSSION

During the storage period, 1-, 2-, and 3-stage fruits remained of satisfactory quality for 5, 4, and 3 days, which were, thus, considered the shelf lives of each stage.

3.1 | Respiration and ethylene production

Regarding the Stage 3 fruit, no significant variations were observed in CO_2 production (Figure 2). However, an increase in respiration was observed from the fourth day of storage for the other stages, reaching a CO_2 production equivalent of 1.05 nmol kg s^{-1}, similar to the value reported for mangoes (1.13 nmol kg s^{-1}) at 20°C. Thus, uvaia production can be classified as moderate, according to (Saltveit, 2016). Increases in respiration are a reflection of the physiological processes related to stages 1 and 2 ripening. Despite increasing throughout the storage period, no significant difference was observed for CO_2 production between the three stages.

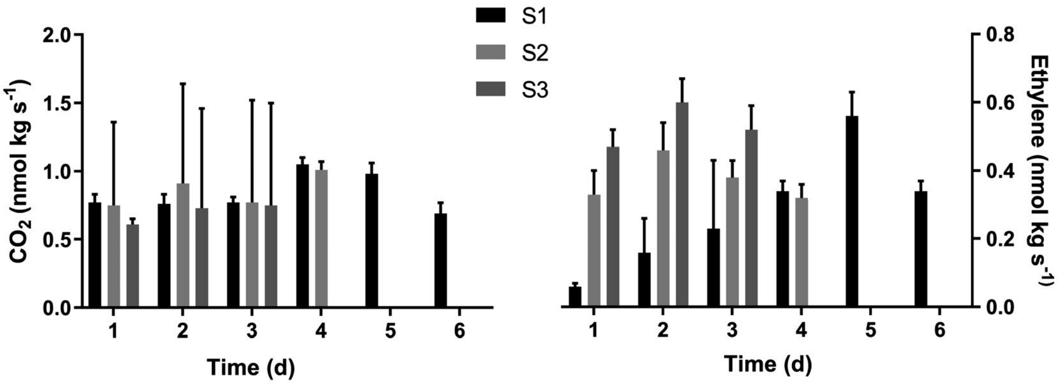

FIGURE 2 Uvaia fruit respiratory rates (CO_2) and ethylene (C_2H_4) production in the evaluated three ripening stages of fruit stored at 22 ± 1°C and 90 ± 5% RH. Vertical bars represent standard error ($n = 12$)

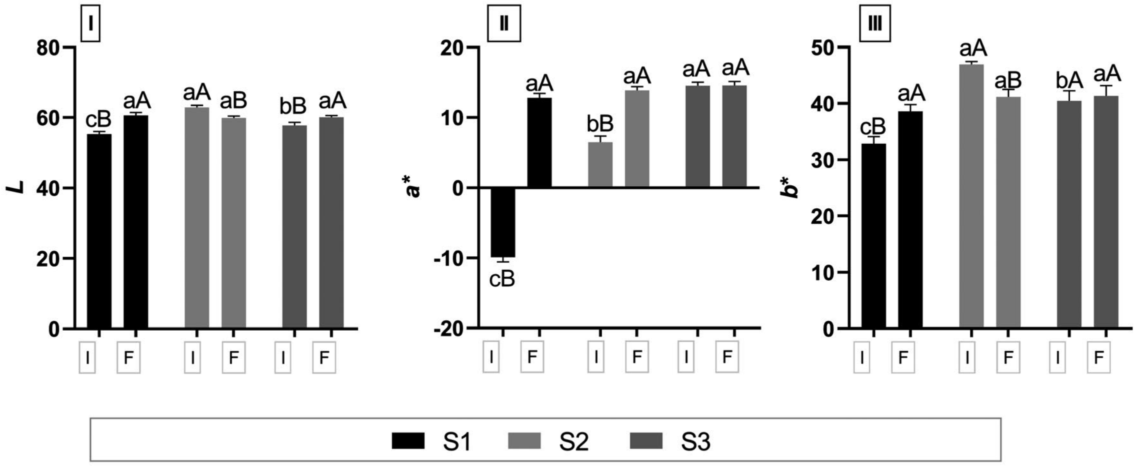

FIGURE 3 Uvaia fruit skin color stored at 22 ± 1°C and 90 ± 5% RH. Means of the three stages: I—Luminosity. II—Coordinate *a**, representing yellow to blue variations. II—Coordinate *b**, representing green to red variations, where: I = initial, on the harvest day and *F* = final, on the last day of storage. Vertical bars represent standard error ($n = 10$). Means followed by the same letter do not differ from each other, while lower case letters refer to the comparison between the stages and capital letters refer to the comparison at each stage ($p < 0.01$)

Ethylene (C_2H_4) production increased during the postharvest period and was directly proportional to the ripening progress of each stage. C_2H_4 production during stage 1 in the first three days of storage ranged from 0.06 to 0.22 nmol kg s^{-1}, while in stage 2 values ranged from 0.33 to 0.46 nmol kg s^{-1}, and from 0.47 to 0.60 nmol kg s^{-1} in stage 3 (Figure 2b).

At the end of their shelf lives, C_2H_4 production in uvaias harvested during stage 1 was equivalent to fruit harvested in stages 2 and 3, indicating that the C_2H_4 synthesis was not affected by the anticipated harvest.

The significant increase in C_2H_4 production in green fruit is related to ripening physiology, where the synthesis and degradation of organic acids, carbohydrates, phenolic compounds, pigments, and volatile compounds directly reflect changes in fruit flavor, color, and aroma (Defilippi, Manríquez, Luengwilai, & González-Agüero, 2009).

3.2 | Quality attributes at the harvest

Skin color was the main attribute used to identify ripening stages at the harvest moment (Figure 3).

During storage, the skin color of fruit harvested with a green skin (Stage 1) evolved from yellowish green to orange. This transformation is supported by the variations detected in *L* data (55.33–60.65), *a** (−9.88–12.83), and *b** (12.83–38.60) at the beginning and at the end of the storage period (Figure 3).

At the end of the storage period, the fruit harvested with a green skin reached a similar skin color as those harvested in more mature stages (2 and 3). In turn, *a** and *b** confirm what was visually observed, indicating that the fruit turned orange. Only luminosity varied in stage 3 (57.78–60.09) between the beginning and the end of the experiment, respectively, while *a** and *b** remained stable (Figure 3).

A positive relationship between soluble solids and ripening progress was noted on the harvest day. The highest levels of soluble solids content were observed in fruit harvested at stage 3 (8.5%) and the lowest in stage 1 (4.9%) (Figure 4II).

Fruit in stages 1 and 2 did not reach similar soluble solid contents compared to the initial ripening of stage 3 during the postharvest period. Reserve consumption was observed in all stages, higher in stage 3, given by soluble solids values for the beginning and end of

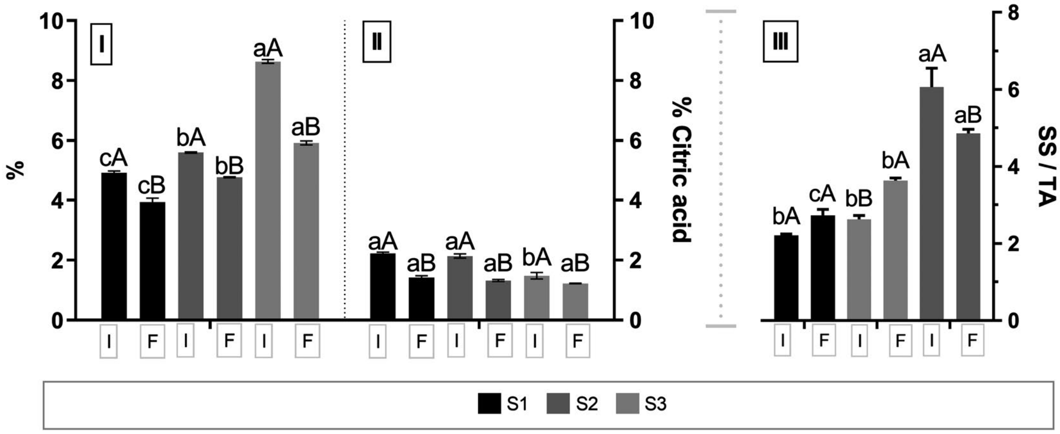

FIGURE 4 I—Soluble solids content % Brix ($n = 10$), II—Titratable acidity in citric acid equivalents ($n = 6$), III—Ratio ($n = 6$), and in fresh uvaia fruit from three ripening stages, stored at 22 ± 1°C and 90 ± 5% RH, where: I = initial, harvest day and *F* = final, last day of the storage period. Vertical bars represent standard error. Means followed by the same letter do not differ from each other, while lower case letters refer to the comparison between the stages and capital letters refer to the comparison at each stage ($p < 0.01$)

storage period. In this context, the late uvaia harvesting is more adequate when the aim is to obtain fruit with high sugar content, as fruit in stages 1 and 2 did not reach the soluble solids contents of fruit in stage 3. This is a relevant parameter, especially for fruit that will be consumed *in natura*, since the difference between stages reached 3.72%.

Uvaias in stages 1 and 2 contained more organic acids (2.23% eq. of citric acid and 2.14% eq. of citric acid, respectively) compared to stage 3 (1.48% eq. of citric acid) (Figure 4I), with acidity level decreases noted in all stages. At the end of the storage period, the green uvaias reached the same titratable acidity as the uvaias in later ripening stages, and therefore had the same sensory quality.

The biochemical transformations observed during uvaia storage led to decreased SS and TA content, resulting in the increase of the ratio in all stages (Figure 4III). However, green uvaias presented lower soluble solid content than uvaias harvested at more advanced ripening stages (2 and 3). Thus, it affected negatively the sensorial quality of fruit harvested during stage 1—lower compared to the other stages.

3.3 | Bioactive compounds

Flavonoids, phenolic compounds, and carotenoids at the end of storage period were not statistically different between the three evaluated stages (Figure 5I, II, III).

Regarding flavonoids and phenolic compounds, ripening stages did not affect fruit shelf life. In the literature, gallic acid is reported as the main phenolic compound in uvaia pulp, a natural antioxidant that can be used in the food, pharmaceutical, and cosmetic industries (Nayeem, Smb, Salem, & Ahel-Alfqy, 2016; Silva, Rodrigues, Mercadante, & Rosso, 2014). Flavonoids and carotenoids are also associated with beneficial health effects, due to their antioxidant and antiinflammatory activity, and are also important pigments for postharvest quality, contributing to fruit color and aroma (Kaulmann & Bohn, 2014; Simkin, Schwartz, Auldridge, Taylor, & Klee, 2004; Warner et al., 2016).

Carotenoid quantification determined increasing concentrations of this compound and chlorophyll degradation for fruit in stage 1 (Figure 5III), in agreement with the changes noted in skin color and increased C_2H_4 production. The process is similar to the color changes observed in tomato skin, with chlorophyll degradation and carotenoid synthesis occurring at the same time (Hörtensteiner & Kräutler, 2011; Matile, Hortensteiner, Thomas, & Krautler, 1996; Su et al., 2015).

Antioxidant capacity at the end of the storage period did not differ significantly between the three stages, ranging from 0.22 to 0.24 mol/kg trolox in the dry mass (Figure 5IV), suggesting that uvaia can be harvested in the green stage with the same potential of oxidative stress protection as fruit harvested at a more mature maturation stage (Genovese, Da Silva Pinto, De Souza Schmidt Goncalves, & Lajolo, 2008; Haminiuk et al., 2011; Temple, 2000).

3.4 | Aroma

Volatile substance quantification allowed for the identification of changes in the aroma in stages 1 (green), 2 (turning), and 3 (mature). In all, 59 volatile compounds were characterized as comprising uvaia aroma (Table 1).

Sample distribution in the main component analysis plane indicated that each stage displays a distinct volatile profile on their respective harvest day (Figure 6).

The first principal component (PC1) indicated that 44.9% of the total variability was due to the difference between maturation stages. Stages 2 (turning) and 3 (mature) were grouped, indicating a greater number of shared characteristics (Figure 6a).

The identified compounds were separated into two groups, where group A comprised most compounds related to maturation stage 1, whereas group B was composed of the more abundant compounds detected in stages 2 and 3 (Figure 6b). In stage 1, herbal aromatic notes, such as eucalyptol, prevailed. Another relevant volatile compound was hexanol, a medium chain alcohol, whose smell

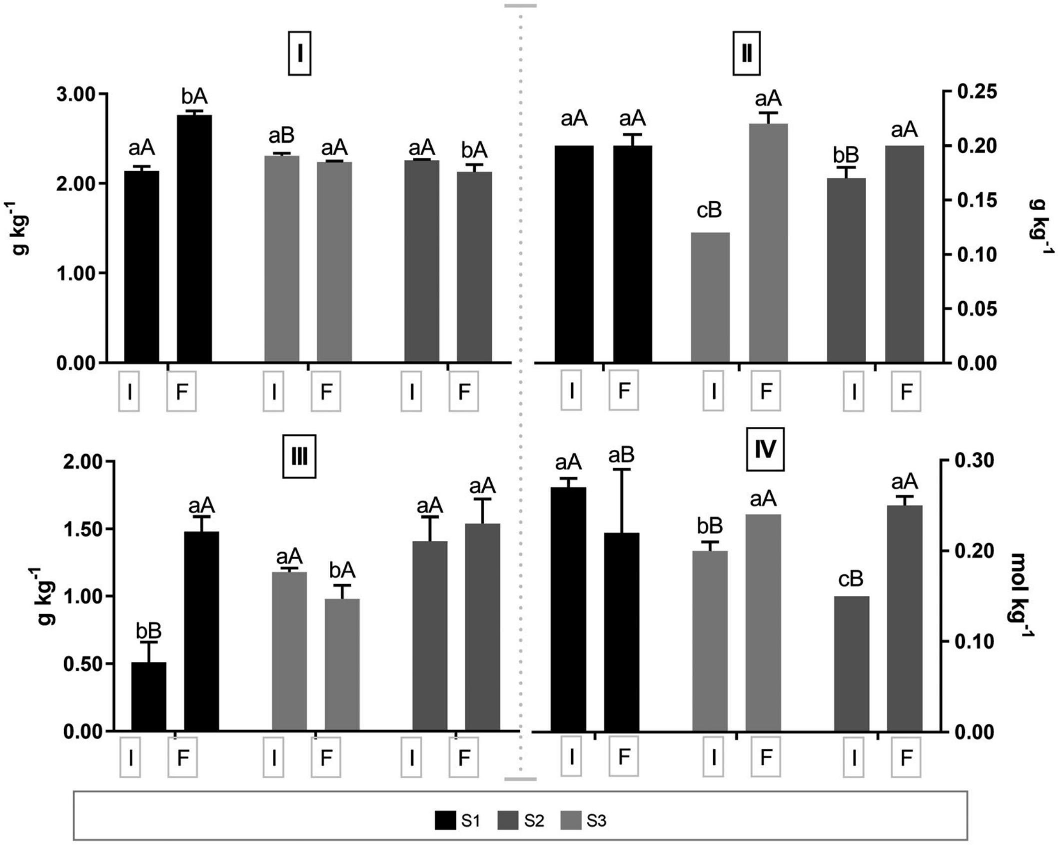

FIGURE 5 I—Phenolic compounds in gallic acid equivalents (*n* = 6), II—flavonoids (*n* = 3), III—carotenoids (*n* = 3), and IV—antioxidant activity in trolox (*n* = 3) in fresh uvaia from three maturity stages, stored at 22 ± 1°C and 90 ± 5% RH, where: I = initial, harvest day and F = final, last day of the storage period. Vertical bars represent standard error. Means followed by the same letter do not differ from each other, while lower case letters refer to the comparison between the stages and capital letters refer to the comparison at each stage ($p < 0.01$)

is associated with freshness (Table 1). Compounds present in higher amounts on the day the fruit were harvested suggest that stage 1 uvaias presented a green fruit aroma.

Sweet and fruity aroma notes were detected in stage 2 (turning), featuring an attractive "ripe fruit" aroma, through the combination of compounds like ethyl butyrate and hexyl acetate. However, compounds such as α-cubebene and viridiflorol were also detected, conferring a herbal aroma (Table 1), characterizing stage 2 as a transition between green and ripe.

Fruit in stage 3 exhibited the greatest diversity and amount of compounds. The most striking difference was the citrus aromatic notes conferred by sulcatone and nonanal (Table 1). Most compounds identified in stage 3 were classified as esters, derived from fatty acids, produced in higher amounts by the degradation of cell membranes or amino acids, in aminotransferase-catalyzed reactions (Hui, 2010).

The diversity of volatile compounds accompanied fruit ripening, resulting from the ripening process that provides substrates—carbohydrates, fatty acids, and proteins—for the formation of more complex aroma molecules (Hewett, 2006; Kader, 1999).

At the end of storage period, the amount of volatile compounds was increased in all stages, leading to similar aromatic profiles in stages 2 and 3. This was explained by 39.4% of the total variability for the first principal component (PC1) (Figure 7). Volatile compounds produced in stage 1 differed significantly from stages 2 and 3, evidenced by sample distribution in opposite quadrants (Figure 7b).

The compounds were clustered into two groups, A and B, creating a contrast between ripening stages (Figure 7b). Group A was represented by volatile compounds with a characteristic ripe fruit aroma, characterized by fruity, citric, and sweet notes—abundant in stages 2 and 3. Regarding group B, compounds contributed to the herbal, woody, fruity, and citric aroma were more abundant in stage 1.

In the most advanced ripening stages (2 and 3), compounds correlated with pleasant and desirable odors were identified, such as octyl butyrate, 1-octanol, and isoamylacetate (fruity) and β-ocimene and nonanal (floral), and others which may indicate loss of quality and senescence onset—such as isoamyl alcohol, pentanal, ethanol, and neryl acetone (fermented-alcoholic).

Fruit in stage 1 exhibited a mixture of volatiles presenting herbal green aromatic (β-bourbonene, 3-hexenol, and 2-transhexenyl acetate) and fruity notes (delta-elemene, hexyl acetate, α-cubebene, alloaromadendrene, ethyl butyrate, ethyl acetate, ethyl hexanoate, (Z)-3-hexenyl butyrate, and hexyl hexanoate) (Table 1).

The increase in volatile compounds in stage 1 may be related to increased C_2H_4, since C_2H_4 production signals genes encoding enzymes

TABLE 1 Description of the volatile compounds emitted by uvaia fruit during the three assessed ripening stages at the initial and at the final of the storage period

CN*	Volatile Compound CAS	Aroma	Classificat ion	Precursor	Stages					
					Initial			Final		
					1	2	3	1	2	3
1	Ethanol 64-17-5	Alcoholic	Alcohol	Carbohydrates						■
2	β-thujene 28634-89-1	NA	Terpene	Carbohydrates	■			■		
3	Ethyl butyrate 105-54-4	Sweet	Ester	Fatty acids		■		■	■	■
4	Hexanal 66-25-1	Fresh	Aldehyde	Fatty acids		■	■	■	■	■
5	Sabinene 3387-41-5	Woody	Terpene	Carbohydrates	■		■	■		■
6	Limonene 138-86-3	Herbal	Terpene	Carbohydrates	■	■	■	■	■	
7	Eucalyptol 470-82-6	Herbal	Terpene	Carbohydrates	■			■	■	
8	(E)-2-Hexenal 6728-26-3	Green	Aldehyde	Fatty acids			■		■	■
9	Ethyl hexanoate 123-66-0	Sweet	Ester	Fatty acids		■		■	■	
10	Trans-β-Ocimene 3779-61-1	Sweetish	Terpene	Carbohydrates	■			■	■	
11	Hexyl acetate 142-92-7	Fruity	Ester	Fatty acids		■	■	■		■
12	4-hexen-1-ol, acetate 72237-36-6	Fresh	Ester	Fatty acids		■	■		■	
13	Sulcatone 110-93-0	Citric	Ester	Fatty acids			■	■		■
14	Hexanol 111-27-3	Herbal	Alcohol	Fatty acids	■			■	■	■
15	3-Hexen-1-ol, (Z) 928-96-1	Green	Alcohol	Fatty acids	■			■	■	■
16	Nonanal 124-19-6	Citric	Aldeído	Fatty acids			■		■	■
17	2-Hexen-1-ol, (E) 928-95-0	Fruity	Ester	Fatty acids	■	■			■	■
18	Hexyl butyrate 2639-63-6	Green	Ester	Fatty acids		■	■		■	■
19	α-cubebene 17699-14-8	Herbal	Terpene	Carbohydrates	■		■	■	■	■
20	(Z)-3- Hexenyl butyrate 16491-36-4	Fresco	Ester	Fatty acids		■	■	■	■	
21	δ-elemene 20307-84-0	Herbal	Terpene	Carbohydrates	■	■		■	■	■
22	α-copaene 3856-25-5	Woody	Terpene	Carbohydrates		■		■	■	
23	β-bourbonene 5208-59-3	Herbal	Terpene	Carbohydrates	■				■	
24	Elixene 3242-08-8	NA	Terpene	Carbohydrates						■
25	Caryophyllene 87-44-5	Spicy	Terpene	Carbohydrates	■			■	■	
26	Valencene 4630-07-3	Citric	Terpene	Carbohydrates	■		■	■	■	
27	Hexyl hexanoate 6378-65-0	Green	Ester	Fatty acids		■	■	■	■	
28	Alloaromadendrene 25246-27-9	Woody	Terpene	Carbohydrates		■	■	■	■	
29	y-cadinene 39029-41-9	Woody	Terpene	Carbohydrates		■	■	■	■	
30	Humulene 6753-98-6	Woody	Terpene	Carbohydrates	■			■	■	
31	(Z)-3-Hexenyl hexanoate 31501-11-8	Green	Ester	Fatty acids		■	■	■	■	

(Continued)

TABLE 1 (Continued)

CN*	Volatile Compound CAS	Aroma	Classification	Precursor	Stages Initial 1	Initial 2	Initial 3	Final 1	Final 2	Final 3
32	y-muurolene 30021-74-0	Woody	Terpene	Carbohydrates	■			■	■	
33	y-elemene 29873-99-2	Green	Terpene	Carbohydrates			■	■	■	
34	δ-cadinene 483-76-1	Herbal	Terpene	Carbohydrates	■			■	■	
35	Neryl acetone 3879-26-3	Rancid	Terpene	Fatty acids		■	■			■
36	Viridiflorol 1000122-17-3	Herbal	Terpene	Carbohydrates		■	■	■	■	
37	Ethyl acetate 141-78-6	Ethereal	Ester	Fatty acids		■	■	■		■
38	β-cubebene 13744-15-5	Citric	Terpene	Carbohydrates			■	■	■	
39	β-ocimene 13877-91-3	Floral	Terpene	Carbohydrates		■			■	
40	3-hexen-1-ol 544-12-7	Green	Alcohol	Fatty acids			■		■	■
41	α-guaiene 3691-12-1	Woody	Terpene	Carbohydrates		■				
42	Viridiflorene 21747-46-6	Woody	Terpene	Carbohydrates		■				
43	1-Octanol 111-87-5	Citric	Alcohol	Fatty acids		■	■		■	■
44	2-Ciclopenten-1-one, 4-acethyl-2,3,4,5,5-pentamethyl 50506-59-7	NA	Ester	Fatty acids		■	■		■	■
45	Octylbutyrate 110-39-4	Fruity	Ester	Fatty acids		■	■			■
46	Octyl hexanoate 4887-30-3	Fruity	Ester	Fatty acids		■	■		■	■
47	2- Trans-hexenyl acetate 2497-18-9	Green	Ester	Fatty acids					■	
48	Biciclo[3.1.1]hept-2-ene, 3,6,6 trimethyl 4889-83-2	NA	Terpene	Carbohydrates		■	■		■	■
49	Isoamylacetate 123-92-2	Banana	Terpene	Carbohydrates					■	■
50	Methyl butyrate 623-42-7	Apple	Ester	Fatty acids					■	■
51	Isoamyl alcohol 123-51-3	Fermented	Alcohol	Fatty acids					■	■
52	Acetoin 513-86-0	Sweetish	Ester	Fatty acids					■	■
53	Pentanal 110-62-3	Fermented	Aldehyde	Fatty acids					■	■
54	β-terpinene 99-84-3	NA	Terpene	Carbohydrates					■	■
55	Ethyl octanoate 106-32-1	Fruity	Ester	Fatty acids					■	■
56	Octyl isobutyrate 109-15-9	Wax	Ester	Fatty acids					■	■
57	Aromadendrene 72747-25-2	Woody	Terpene	Carbohydrates					■	■
58	Amyl isobutyrate 2445-72-9	Fruity	Ester	Fatty acids				■	■	
59	Methyl hexanoate 106-70-7	Pineapple	Ester	Fatty acids					■	

*Compound number (CN), unique record number at the Chemical Abstracts Service (CAS) database, an American Chemical Society division, characteristic flavor, chemical classification, precursor, and stage in which the compound was identified. Information not found in the literature was identified as NA.

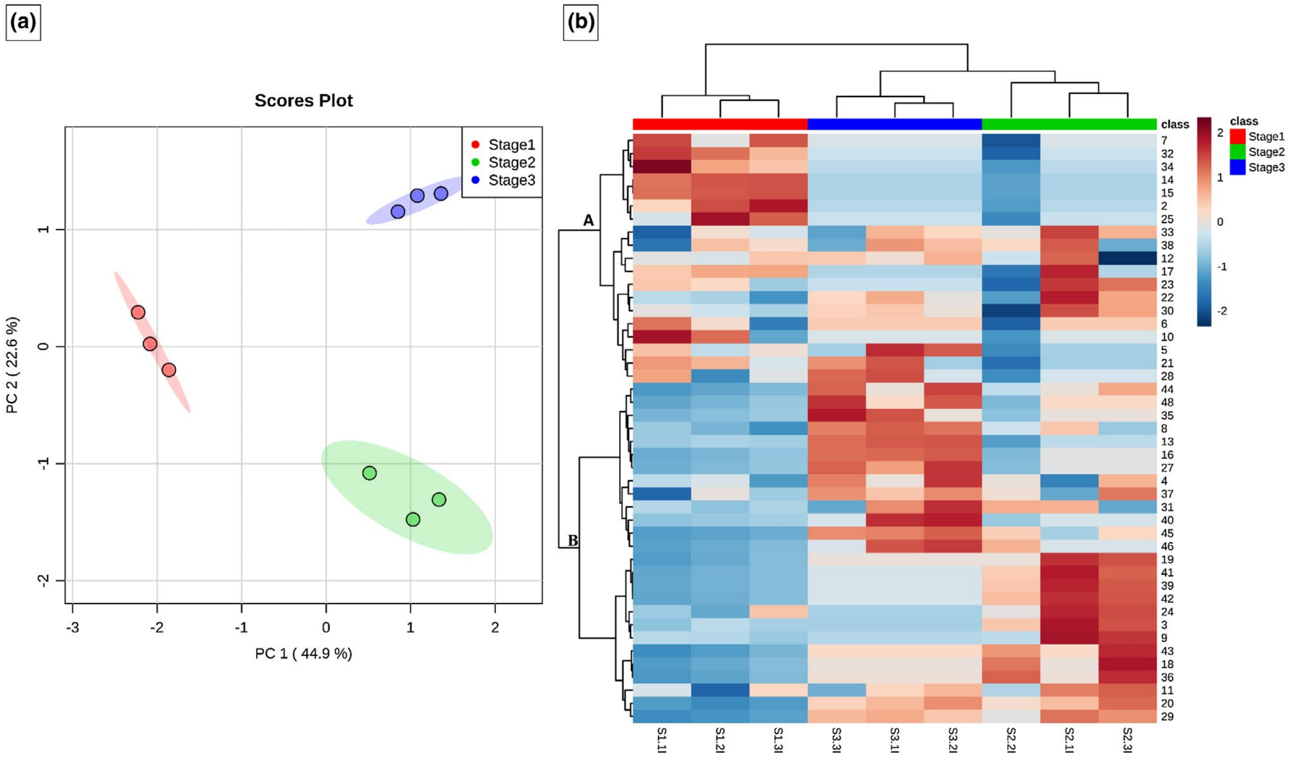

FIGURE 6 Multivariate analysis of volatile uvaia compounds in the three investigated maturation stages of uvaia fruit, on the first day postharvest. (a) Principal component analysis and (b) Hierarchical grouping analysis and Heatmap, where numbers indicate the compounds described in Table 1, where: I = inicial, harvest day, with three replicates for each stage. For a given row of the Heatmap, blue and red colors correspond, respectively, to low and high values of organic volatiles compounds

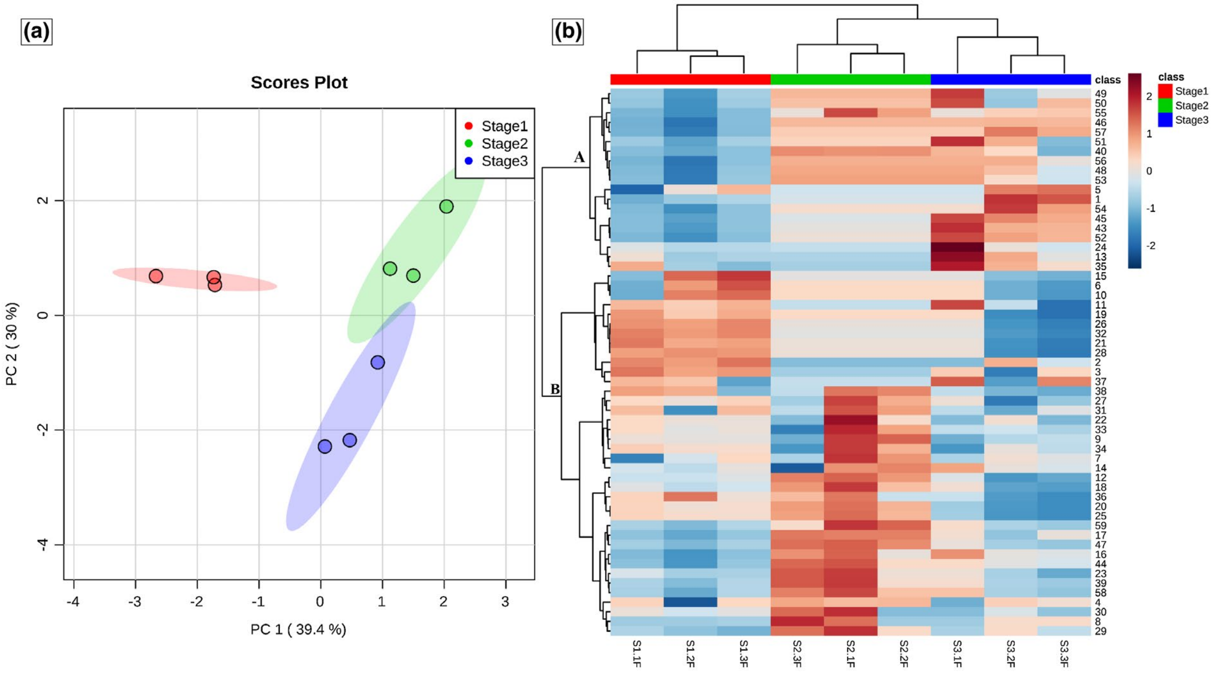

FIGURE 7 Multivariate analysis of volatile uvaia compounds in the three investigated maturation stages of uvaia fruit, at the end of the storage period (a) Principal component analysis and (b) Hierarchical grouping analysis and Heatmap, where numbers indicate the compounds described in Table 1, where *F* = final, last day of the storage period, with three replicates for each stage. For a given row of the Heatmap, blue and red colors correspond, respectively, to low and high values of organic volatiles compounds

involved in the formation of volatile compounds derived from fatty acid degradation (Saltveit, 1999), as well as carotenoid synthesis, important substrates for aroma formation (Paliyath et al., 2008).

However, even with increased volatile compounds in the green fruit profile, no development of an aroma similar to that of mature harvested uvaia was observed at end of the ripening process. The compounds in greatest abundance at the beginning of storage in stage 1, namely herbal, fresh, and green aromas, were persistent during the storage period, indicating the loss of sensorial quality (Figure 7). Similar behavior has been reported for apples and strawberries (Bangerth, Song, & Streif, 2012; El Hadi, Zhang, Wu, Zhou, & Tao, 2013).

4 | CONCLUSIONS

C_2H_4 production increased with maturation, while respiration did not. Green harvested uvaias presented the same acidity, flavonoids, carotenoids, phenolic compounds, and antioxidant capacity of mature harvested fruit. Uvaia fruit harvested at stage 1 increased fruit shelf life by 2 days. On the other hand, early harvest negatively influenced fruit quality, decreasing soluble solids content, and altering volatile compound profiles. In addition to maturation-related compound synthesis not being completed at stage 1, volatile compounds characteristic of the green scent persisted until the end of the storage period.

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CONFLICT OF INTEREST

The authors declared that they have no conflict of interest.

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