



Postharvest monitoring and consumer choice on traditional and modern apricot cultivars

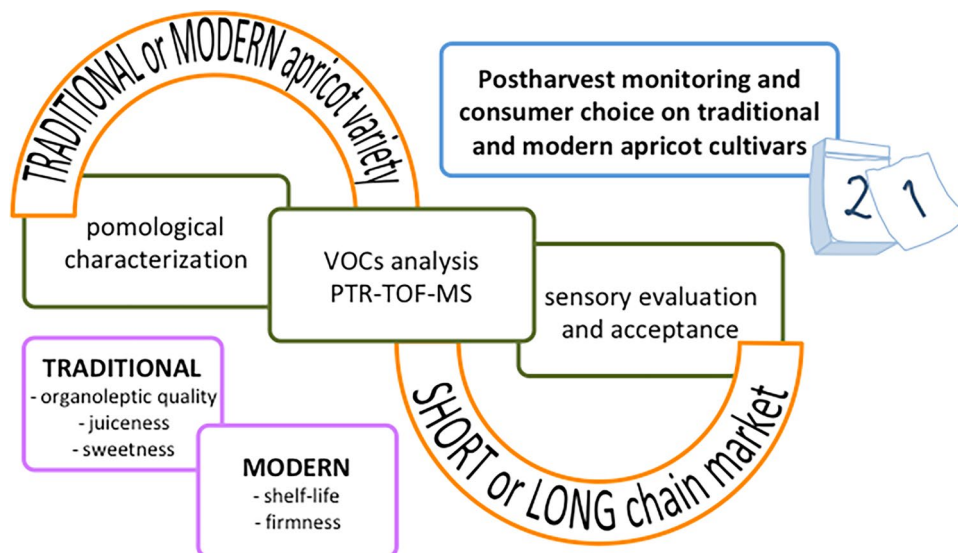
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Abstract

Apricot (*Prunus armeniaca* L.) fruit qualities are affected by harvest date and rapid off-tree ripening progression that limits their shelf life and marketability. Nowadays, consumers are generally dissatisfied with the sensory quality of apricot fruit sold on large-scale retail channels. Pomological analysis (color, firmness, total soluble solids, and total acidity), volatile organic compounds fingerprint and sensory evaluation were performed during the postharvest in two different apricot genotypes with the objective to: (1) characterize and compare two different apricot cultivars at harvest and at different postharvest times; (2) understand how the sensory quality changes during the postharvest process; (3) elucidate which sensory quality parameters drive the consumer's choice. For this purpose, 'Portici' (traditional cultivar) and 'Lady Cot' (modern one) grown in the same environment, were evaluated at commercial maturity harvest and for the following 15 days. Results indicate that the sensory quality of the selected cultivars was different, with 'Portici' showing better performances in terms of aroma, sweetness and juiciness, while 'Lady Cot' stood out in terms of firmness. Results also indicate a different trend of the traits analyzed and of the shelf-life, that was reduced for the traditional cultivar.

Graphical abstract



Keywords Consumer's choice · Fruit quality · Sensory quality · *Prunus armeniaca* · Postharvest

Introduction

Apricot (*Prunus armeniaca* L.) is an economically important temperate tree fruit, with a total world production around 4 million tonnes in 2020 (FAOSTAT, <https://www.fao.org/faostat/en/#data/QCL>). Italy is the leading country in Europe, with a production around 275.000 tonnes (FAOSTAT, <https://www.fao.org/faostat/en/#data/QCL>). Apricot germplasms show high variability in fruit size, shape, color, firmness, flavor, ripening date and quality [21]. Actually, apricot cultivars belonging both to the traditional and modern germplasm are cultivated in Italy. In particular, the introduction (since the early 2000s) of new cultivars made it possible to feed the markets until the end of August and to facilitate shipping and handling, with strong advantages for the supply chain traders. These new cultivars, characterized by one or more innovative genetic traits (such as red skin, slow softening flesh, resistance to Sharka, big size, hardness, late ripening, etc.), have numerous advantages but sometimes with the detriment of the fruit quality [44].

The market of fresh apricot is strictly dependent on the fruit quality, so much that the consumer is led to choose and buy apricots based on their unique and pleasant aroma and taste [37, 57]. These two important parameters are, respectively, due to volatile organic compounds (VOCs) types and amount, as well as to sugars and organic acids content and composition, and are highly linked to the fruit maturity reached at harvest. Indeed, throughout the ripening process, firmness and titratable acidity decrease, while soluble sugars and flavor increases [33], so that, at the consumer maturity stage, when fruits have the best potential in terms of taste qualities, the soft flesh expose them to mechanical damage, making apricot poorly suitable to distant transport [12] and susceptible to develop fungal diseases [24]. In this context, with the aim to maximize storage life and to reduce losses caused by physical damages, apricots are usually harvested at the commercial maturity stage (early maturity stage) when the fruit is firmer but also has high acidity and low sugar, and flavor is not completely developed (Rebeaud et al. 2019). Such poor sensory quality may be additionally mined by the frequent development of unpleasant taste and aroma [29]. Starting from these peculiarities of apricot fruit and its postharvest development, especially to facilitate shipping and to increase the shelf-life, in the past 20 years, new commercial apricot cultivars were selected for hardness and slow softening flesh. In addition, as required by the large-scale retail channel, the apricot breeding process started to focus on the color of the skin and flesh [47], while organoleptic (such as taste and aroma) and nutritional properties were often considered as secondary aims.

This may has brought a sensible reduction in the quality of modern apricot cultivars, and a consequent increase in

consumer disaffection [44]. Furthermore, such a situation may have been exacerbated by the practice of harvesting at the commercial maturity stage, following the quality specifications for large-scale retail channels, regardless of the best fruit organoleptic quality (Mastilovic et al. 2022), whose standards do not meet any more the expectations of the consumer (Rebeaud et al. 2019).

In this scenario, the aim of this study is to investigate the postharvest behavior of both a modern and traditional apricot cultivar, as a proxy to investigate apricot quality, by combining conventional measures (fruit flesh firmness, juice titratable acidity, soluble sugar levels and pH) with sensory analysis and non-conventional VOC analysis.

In addition, based on the aforementioned and given the consumer disaffection towards the low quality of apricots available for the mass retail markets, in this work, by comparing the physico-chemical properties, aroma volatile compounds and sensory evaluation at different shelf life times of two different apricot cultivars (a traditional and a newly released variety), we aim to get insights on which parameters are preferred by consumers. Thus, these results may help apricot breeders and producers to better understand consumer expectations and encourage a revival of the most appreciated and pleasant genetic traits linked to the sensory quality, to be implemented in new cultivars.

Material and methods

Fruit collection

In this study, carried out in 2020, apricot fruit belonging to two commercial and widespread apricot cultivars, namely ‘Portici’ (PC) and ‘Lady Cot’ (LC), were used (Fig. 1). ‘Lady Cot’ is a modern apricot cultivar appreciated for its large fruit size and high attractiveness due to the intense orange skin color and red blush (<https://www.cot-internatio>

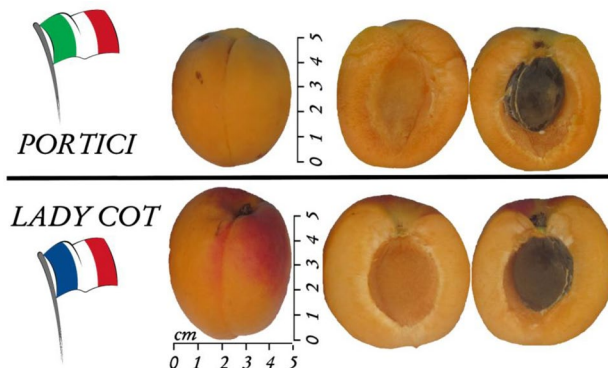


Fig. 1 Whole and cut in half ‘Portici’ (upper panel) and ‘Lady Cot’ (lower panel) apricot cultivars with scale (0–5 cm)

nal.eu/media/10479-cot-catalogue-fruitier-uk-2021-bd.pdf); ‘Portici’ is a mid-late cultivar belonging to the traditional Italian germplasm selected in the Vesuvian district (Naples) and distinguished by higher quality attributes, such as taste and aroma [8] but compared to ‘LC’ is sensitive to Sharka virus [39]. Commercial sales of ‘PC’ compared to ‘LC’ fruit are very limited, due to its limited shelf life. Both cultivars show high productivity, high fruit quality and attractiveness.

Apricot trees used for the study were grown in a commercial orchard located in Faenza at ~200 m a.s.l. in “Cimatti Enea Farm” (44.258, 11.919; Ravenna Province – Emilia Romagna Region, Italy). All the trees (6–8 year-old plants grafted on “Mirabolano 29-C”) were grown in a square system with row-to-row and plant-to-plant distances of 2 m and 4.5 m, respectively, following the “open vase” training system typical of the area. Weed control, irrigation and fertilization were carried out following the guidelines for apricot cultivation of Emilia-Romagna Region (https://agricoltura.regione.emilia-romagna.it/produzioni-agroalimentari/temi/bio-agro-climambiente/agricoltura-integrata/disciplinari-produzione-integrata-vegetale/Collezione-dpi/dpi_2020/norme/frutticole/nta-albicocco-2020.pdf). General information on the studied genotypes are reported in Table 1 and Fig. 1. Fruit of both cultivars were collected (in date 01.07.2020) following the commercial maturity rules. In particular, the commercial maturity of fruit was evaluated by the farmers, based on the color and firmness thresholds proposed by Agrintesa (Italian growers’ cooperative company).

About 40 kg of fruit of each cultivar were hand-picked, collected and selected for their uniform size and absence of disease or insect-pest attack. Subsequently, they were packed in different cardboard boxes and immediately transported to the Department of Agriculture, Food, Environment and Forestry of Florence University. The harvested fruits for each cultivar were divided into five lots (composed of ~8 kg of fruit). The first was evaluated after one day of harvest, while the other lots were kept in a climatic chamber, where fruit were placed in plastic bags and stored at 4 °C, and then analyzed for two weeks during postharvest conservation (4 ± 0.5 °C and 85% of relative humidity), at intervals of three

days, except between the fourth and five one, where four days elapsed. Physicochemical measurements, sensory and VOC analysis were performed for each sampling time (T1-T5).

Analysis of pomological character

Phenotypic variability

Fruit weights were recorded on 2 kg of fruit, with an electronic balance (Mettler Toledo AL104) to an accuracy of 0.001 g, while the dimensional properties (diameter and height) were measured with a digimatic caliper (Digimess IP54). Peel color properties (L*, a*, b*) in the CIELAB space were achieved on 15 fruits for each variety using a Minolta CR-200 chromatometer (Minolta, Ramsey, NJ, USA) following the protocol reported by Taiti et al. [51].

Firmness

Flesh firmness was determined using a digital penetrometer (Model 53,205, Turoni & Co., Italy) provided with a round tip (Ø mm). The measurements were done in the equatorial region of each apricot fruit (15 fruits for each variety and sampling time). Data were expressed as force (kg cm⁻²) required to rupture the pericarp.

Total soluble solids (TSS) and titratable acidity (TA)

Total soluble solids (TSS) were measured for each sampling time and apricot genotype (15 fruits for each variety and sampling time), at room temperature, using an N1 Atago refractometer (Atago Co., Japan) and the result was expressed as a percentage.

Titratable acidity (TA), expressed as grams of malic acid on 1 kg of fresh weight (FW), was determined by the AOAC method [2]. Ten apricots for each variety and sampling times were randomly sampled and squeezed by hand-pressing and the juice was evaluated. Each sample was run in triplicate. Moreover, TSS and TA data have been used to assess the TSS/TA ratio.

Table 1 General description (fruit shape, origin and harvesting time), morphological parameters (fruit weight, diameter and height) and skin color (L*, a*, b*) evaluated at harvesting time on 50 fruits per variety

GENERAL DESCRIPTION				MORPHOLOGICAL PARAMETERS			SKIN COLOR (AVERAGE)		
Variety	Fruit shape (frontal view)	Origin	Harvesting maturity	Weight (g)	Diameter (mm)	Height (mm)	L*	a*	b*
‘Portici’ (PC)	2	Italy	Mid-late	65.15 ± 9.63	48.10 ± 1.84	50.47 ± 4.55	68.27 ± 2.05	11.84 ± 0.62	52.64 ± 0.95
‘Lady Cot’ (LC)	2	France	Mid-late	113.25 ± 12.88	58.73 ± 1.50	62.63 ± 5.29	68.61 ± 1.14	13.44 ± 1.12	55.83 ± 1.23

Descriptor list for apricot fruit was used to assess shape and harvesting time (Guerriero and Watkin, 1984)

PTR-ToF–MS measurements

VOCs analysis was performed following the method and instrumental setting previously described by Taiti and co-authors (2017). The experiment was conducted on both “whole” and “cut in half” (without core) fruit. In particular, the analysis was carried out by placing each fruit sample into a glass jar provided with opposite holes mounted on the lid. VOCs were measured using a high sensitivity PTR-ToF–MS (instrument model 8000, Ionicon Analytik GmbH, Innsbruck, Austria) operated with H_3O^+ as the primary ion and set with the following conditions: pressure 220 Pa, drift tube temperature 60 °C, voltage 594 V giving an E/N value of 130 Td (Td: Townsend; $10^{-17} \text{ V}\cdot\text{cm}^2\text{s}$). Thus, the acquired data expressed in ppbv (part per billion by volume) according to the formula described by Lindinger et al. (1998) were processed by TofDaq software (Tofwerk AG, Switzerland). Finally, the Tentative Identifications (TI) of compounds were based on models of fragmentation available in the literature and compared with published VOCs emitted from apricot fruit as reported in Tables A.2 and A.3

VOC emissions were monitored for all sampling times (T1–T5) until the fruit decay became visibly apparent. In particular, for the VOCs analysis each sample (“whole” or “cut in half”) was placed into a Bormioli glass jar (2 L for “whole” sample and 0.75 L for “cut in half” sample, respectively). For each variety and sampling times, samples were composed of (1) 1 kg (± 10 g) of “whole fruit” ($n=5$ replicates $\times 2$ cultivars); (2) one “cut in half fruit” without core ($n=8$ replicates $\times 2$ cultivars). In particular, the “cut in half” sample was prepared as follows: fruit was weighted, cut into two pieces, and private of the core; and after both the half were inserted in a glass jar for the VOCs analysis. Subsequently, the jar was flushed with clean air for 2 min and then incubated for 2 min at 20 °C to allow the accumulation of volatile compounds. The same incubation time was kept for the “whole” samples analysis. To avoid instrumental errors, the blank measurements were carried out after three fruit samples were analyzed, and a 5-min interval was kept between samples. Given the different sizes of the fruit, the results of “cut in half” samples were referred to as the weight unity equal to 50 g.

Sensory evaluation and acceptance

Sample preparation

Apricot sample preparation was made following the same procedure used previously by Taiti et al., [52]. For each sampling time, two hours before the sensory analysis, fruit were removed from the climatic chamber (where they were stored at 4 °C). For each sampling times, panel was composed of trained panelists, while the consumer test was

carried out by consumers in two different and separate sensory evaluation session.

Panel test

The same professional panelists ($n=8$), trained in sensory lexicon and methodology (according to ISO 1993) with experience in assessing vegetable and fruit products, evaluated the two apricot cultivars for each sampling time. The list of sensory attributes included 6 descriptors chosen directly by the assessors. In particular, the evaluation was done by filling a questionnaire sheet with the following descriptors: firmness, sweetness, flavor, acidity, juiciness as suggested by Piagnani et al. [44]. Finally, panelists expressed their overall appreciation as previously reported by many authors on apricot fruits [7, 28, 53]. The apricots evaluation was done using a score range of 1–9 for all descriptors (1 = none, 9 = high intensity). Eight healthy apricot fruit split into two pieces were selected for each cultivar and sampling time. Samples were presented in white plates to the judges and the evaluation was carried out in a standard sensory laboratory under well-controlled conditions. Mineral water was provided for palate cleansing between samples.

Consumer acceptability

About 80 (about 40% women and 60% men aged between 23 and 65 years) regular fruit consumers participated in a hedonic test performed at each sampling times. Consumers were volunteers from the staff and students affiliated to the University of Florence and were recruited at each “consumer session” by personal communication and e-mail. Before the consumer assessment, the fruit was kept for 2 h at room temperature to allow it to reach 20 °C. About 50 apricot fruits for variety were used for each sampling time. The samples could be re-tasted as often as desired. Consumer evaluations were carried out as described by Echeverría et al. [13]. Consumers had to rate apricot fruit cut into two half-pieces (one per variety) which were placed on white plates. Each consumer was asked to indicate his/her degree of liking/disliking using a nine-point hedonic scale (1—extremely dislike to 9—extremely like), where a score of 5.0 is considered a commercial quality limit. Therefore, consumer acceptance was calculated as the percentage of consumers who evaluated the samples with a scores > 5.0 . The degree of liking data was subjected to analysis of variance (ANOVA).

Statistical data analysis

Linear trend analysis

To compare ‘PC’ and ‘LC’ temporal evolution, linear trend analysis was performed on the variables of interest (e.g., pomological characters, VOCs emissions, sensory evaluation data). The goodness of fit was evaluated by the least square fitting process and the related determination coefficient (R^2). Fit statistical significance was estimated by inferential statistics throughout the two-sided hypothesis t-test. Trend was considered significant for $P < 0.05$. To assure the results robustness, the non-parametric Mann–Kendall trend test was also applied (MK, hereafter, Kendall [31, 32, Mann [38], since it allowed to relax of the linear regression underlying assumption of normally distributed residuals. Both the native R *stats* library R Core Team [46] and *kendall* R package (<https://cran.r-project.org/web/packages/Kendall/index.html>) were used.

Randomized inference

The statistical significance of the differences was assessed by randomized inference, using random shuffling non-parametric methods. No assumption was required about data distribution. First the real difference between two samples was computed. Then a unique series—obtained by merging the two samples—was built, and a large number of surrogate time series were generated by randomly shuffling the input time series with respect to time. For each run, two samples (of the same length as the original samples) were extracted, and their difference was computed and compared to the real difference between the original samples, thus obtaining a probability value, P_{diff} . The number of runs was set to $R = 10,000$. A 95% confidence level was chosen, and the difference between the input samples was assumed to be significant (i.e., not induced by random coincidence) when $P_{\text{diff}} < 0.05$. A script was written in R for this purpose.

Heatmaps

Heatmaps charts were used to graphically display correlation matrices and their confidence intervals. Each cell in the correlation matrix represents the correlation coefficient C_{ij} computed between the i -th and j -th quantities. The heatmap cells' color ranges from red (high correlation, $C_{ij} = 1$; coherent temporal trends) to blue (high anti-correlation, $C_{ij} = -1$; opposite evolution trends), passing from white (no correlation, $C_{ij} = 0$). Significance level was set to $\alpha = 0.05$. Black crosses indicate not-significant correlation values and the corresponding cells have been excluded from the analysis.

Ward clustering was chosen and it was performed by implementing Ward's [55] clustering criterion [16]. The *corrplot* library by R [19, 42] was used for this purpose.

Multivariate linear models

Regression linear models were applied to describe the dependence of a variable on other independent variables (regressors). The variable selection was performed by requiring the absence of collinearity among regressors, according to partial correlation analysis [17, 18, 50]. The model was built by including only those regressors showing a statistically significant correlation with the dependent variable and at the same time a low correlation with all the other explanatory variables. Finally, the best model was chosen using the Akaike Information Criterion (AIC, [3, 9], asking for the minimum AIC value, which measures the efficiency of the model with a penalty for the number of model parameters. The native R *stats* library R Core Team [46] was used to perform the analysis.

Results

Analysis of pomological characteristics

In this study, variations in pomological characters (i.e., firmness, TSS, TA and their ratio), were compared between two apricot cultivars, a modern one (‘LC’) and a traditional one (‘PC’). Their different characteristics at harvest and evolution during conservation are described below and shown in Table 1 and Fig. 2, where characteristics of fruit at harvest and linear trend analysis results for firmness (A), TSS (B), TA (C) and TSS:TA (D) are reported.

Weight, color and firmness

Table 1 shows that at harvest ‘LC’ fruit had greater weight and dimensions (diameter and height) with respect to ‘PC’. Likewise, the color differed between the two cultivars, with ‘LC’ having the highest values for a^* and b^* and therefore a more yellow and red colored skin. The plentiful coloring shown by ‘LC’ could be linked to the highest accumulation of various anthocyanins synthesized through the phenylpropanoid pathway [43].

At harvest ‘PC’ was the softest cultivar, while ‘LC’ the hardest (Fig. 2A). Once harvested, firmness declined, as expected during the ripening process, which leads to lower fruit quality due to the degradation of cell structures by respiration and metabolic activities [1]. The decline was faster in ‘LC’ with respect to ‘PC’, particularly in the early stage of

postharvest. Moreover, the difference of the mean between ‘PC’ and ‘LC’ firmness, evaluated for each sampling time by randomized inference (ref. to Sec. "Statistical data analysis"), was significant ($P_{\text{diff}} < 0.01$). This indicates that ‘LC’ always maintained a higher pulp firmness throughout the ripening process.

Total Soluble Solids (TSS), Titratable Acidity (TA) and their ratio (TSS:TA)

Other factors affecting the apricot quality are total soluble solids (TSS), titratable acidity (TA), and their ratio (TSS:TA). The ongoing apricot ripening leads to the breakdown of complex carbohydrates with an increase of TSS and a decrease in TA [21]. Sugars and organic acids play an important role in fruit taste through the sugar/acid ratio [5]. Indeed, as reported previously by Caliskan et al. [10], the

TSS:TA ratio is linked to consumer’s preference and is used as an index to determine the eating quality of apricots [35].

Accordingly, Fig. 2B shows that apricot fruit exhibited significant increasing trends in TSS during the postharvest ($P < 0.01$), more pronounced in the early stage of ripening and followed by a flat threshold in T5 (TSS < 17%). In particular, ‘LC’ showed a slightly higher trend, while its starting TSS value was lower than ‘PC’, although consistent. In general, no significant difference was observed between the two cultivars, indicating that TSS content is not a peculiar variable for distinguishing among their different ripening processes. Furthermore, both cultivars showed a TSS content higher than 10%, which represents the minimum value established by the EU to market apricots [10].

On the contrary, the TA content (Fig. 2C)—which was always significantly higher in ‘LC’ ($P_{\text{diff},T1-T3} < 0.05$; $P_{\text{diff},T4-T5} < 0.001$) with respect to ‘PC’—showed a rapid

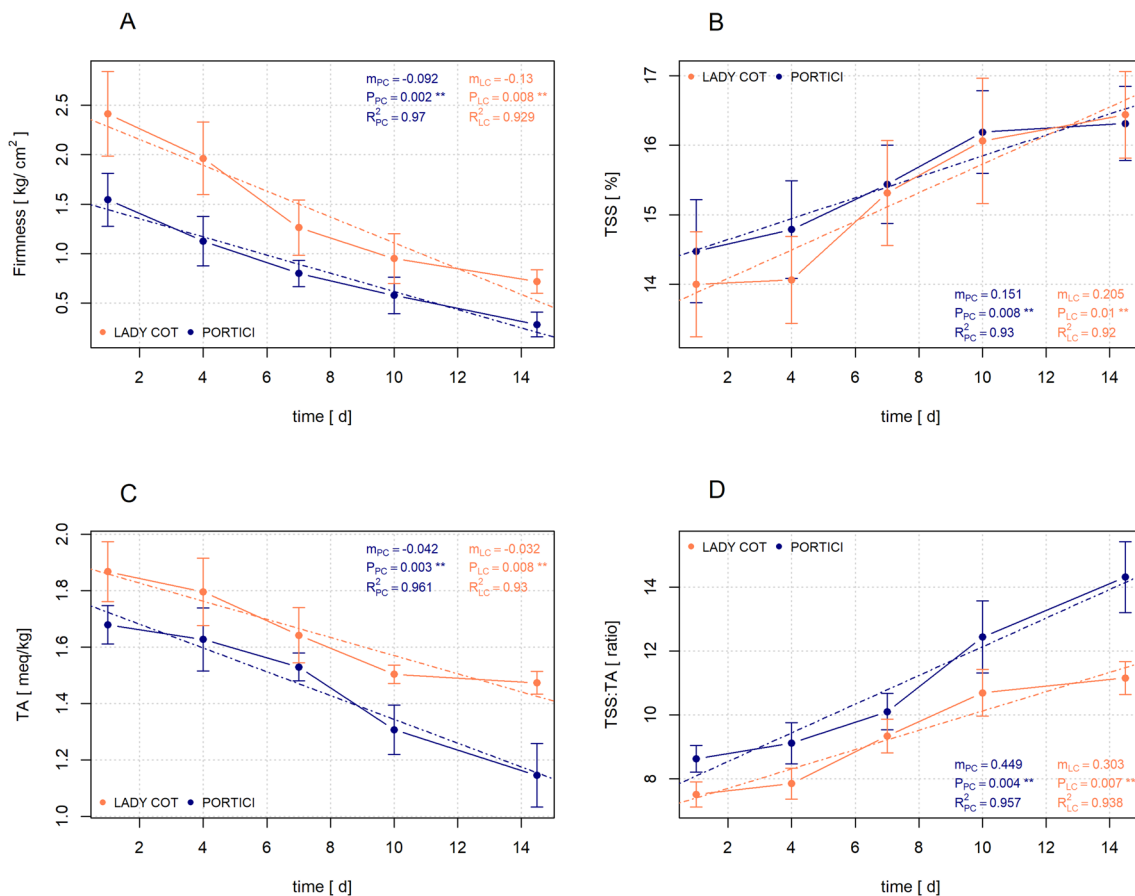


Fig. 2 Linear trend analysis performed over pomological parameters. Each panel corresponds to one parameter (A-firmness, B-TSS, C-TA and D-TSS:TA ratio). Each dot represents the mean value of replicates, and the error bars the corresponding standard deviation. For each parameter both PC (blue line) and LC (red coral line) time series are shown, superposed to the linear trend fit (dash-dotted lines). Time

(days from harvesting) is reported in the x-axis, where the sampling interval is equivalent to three days, except for T4–T5 step which corresponds to almost four days. Fit parameters are shown in plots legend. Significance codes: (.) = $P < 0.1$; (*) = $P < 0.05$; (**) = $P < 0.01$; (***) = $P < 0.001$. MK test P-value was equal to 0.026 in all cases, confirming the presence of monotonic increasing/decreasing trends

significant decreasing trend during the ripening process, more noticeable in ‘PC’.

Ripening index was shown to increase progressively in both studied cultivars, during the postharvest (Fig. 2D). In particular, ‘PC’ fruit exhibited a higher TSS:TA ratio compared to ‘LC’ fruit, and a steeper trend. Analogously to the TA content, the difference between the mean ripening index (TSS:TA) measured in ‘PC’ and ‘LC’ was significant for each sampling time ($P_{\text{diff}} < 0.05$), and increased after T4 due to ‘PC’ stronger positive trend and ‘LC’ upper threshold-like behavior.

VOCs profiling by PTR-ToF–MS

In this section, we show the results of PTR-ToF–MS analysis used to monitor the volatile emission of both ‘PC’ and ‘LC’ cultivars at harvest and during the postharvest (15 d). The analysis was effectuated on both “whole” and “cut in half” fruit to respect the different human perceptions at the time of purchase (“whole” fruit) and at the time of tasting and consumption (“cut in half” fruit). Tables A.2 and A.3 show the putative volatile compounds identified by their m/z ratio (measured), chemical name, molecular formula, concentration averages and the related references for ‘LC’ and ‘PC’, respectively. A total of 6 compounds were identified from “whole” samples, while 34 were detected from “cut in half” samples. Differences in VOC emissions intensity and temporal evolution were observed between the two apricot cultivars.

“Whole” samples

Six signals were detected by the “whole” samples (Fig. 3, Table A.2). Their total emission intensity turned out to be usually higher in ‘PC’ with respect to ‘LC’. In particular, two compounds – m/z 33.033 (TI: methanol) and m/z 59.049 (TI: acetone/propanal) – showed the highest emission intensity in both cultivars and were the major responsible for total emission intensity, followed by m/z 45.033 (TI: acetaldehyde) and m/z 61.028 (TI: acetic acid). On the contrary, m/z 89.059 (TI: butanoic acid/ethyl acetate) and m/z 103.075 (TI: 1-hexanol) showed the lowest signals.

Figure 4 shows the linear fit analysis performed for each identified compound and apricot cultivars. The fit parameters are reported in the plot legend. In general, VOCs emission was higher in ‘PC’ for all the sampling times, with some exceptions which are discussed in this section.

Pronounced increasing trends were recorded for m/z 33.033 (TI: methanol; Fig. 4A) and m/z 59.049 (TI: acetone/propanal; Fig. 4B). Methanol growth was steeper (more than double) in ‘PC’ with respect to ‘LC’, bringing to increasing significant differences between the mean emissions of the two cultivars with time ($P_{\text{diff}, T1, T3-T5} < 0.01$, $P_{\text{diff}, T2} < 0.05$).

On the contrary, the acetone/propanal growth turned out to be comparable between the two cultivars, indicating no big differences ongoing the experiment. Nevertheless, the emission by ‘PC’ was significantly higher with respect to ‘LC’, in the early stages of ripening, while they become comparable in time ($P_{\text{diff}, T1, T2} < 0.01$; $P_{\text{diff}, T3-T5} > 0.05$). A similar growth behavior was also observed for m/z 61.028 (TI: acetic acid, Fig. 4C), whose emissions were significantly higher for the ‘PC’ variety at all sampling times ($P_{\text{diff}} < 0.01$).

Instead, m/z 45.033 (TI: acetaldehyde, Fig. 4D) showed different behavior among the two cultivars. While ‘PC’ emission was clearly linear in growth ongoing the postharvest process, the release of acetaldehyde by ‘LC’ was low and pretty constant for the first ten days (< 10 ppbv), and a huge release was detected only in T5. In addition, acetaldehyde was the only VOC that showed comparable emissions between ‘PC’ and ‘LC’ at both harvesting time ($P_{\text{diff}, T1, T2} > 0.1$) and at the end of the experiment ($P_{\text{diff}, T5} > 0.05$).

No significant trend was detected for m/z 89.059 (TI: butanoic acid/ethyl acetate, Fig. 4E) and m/z 103.075 (TI: 1-hexanol, Fig. 4F), whose emission intensity was significantly higher in ‘PC’ compared to ‘LC’ ($P_{\text{diff}} < = 0.01$).

“Cut in half” samples

PTR-ToF–MS analysis of “cut in half” samples revealed 34 total peaks in both the studied cultivars (Table A.3). As expected, the number of compounds detected was higher in “cut in half” ($n = 34$) with respect to “whole” ($n = 6$) samples. Probably many of the compounds were emitted following the fruit cutting. Indeed, many plant-compounds are produced by plants and fruit: (1) as a wound response via the enzymatic metabolism of polyunsaturated fatty acids [54], and (2) as a response of trophic interactions due to microbes and insects attack [27]. Of these 34 detected signals, some are compounds belonging to alcohols, aldehydes, esters, ketones, hydrocarbons and terpenes, while others are their fragments. Most of the compounds here reported were previously identified as common components in apricot and some of them were selected as key aroma compounds in apricots [23, 26]. Since some compounds were detected only in traces in both samples (m/z 101.096, m/z 135.115 and m/z 137.132), it was not possible to better quantify their emission rate and, therefore, they were excluded from further analyses.

To reduce the dataset dimension and to cluster the emissions according to similar behavior, a correlation map was built for both ‘PC’ and ‘LC’ (Fig. 5; see Sec. “Heatmaps” for heatmaps interpretation). The corresponding linear trend analysis parameters of each emitted VOCs are reported in

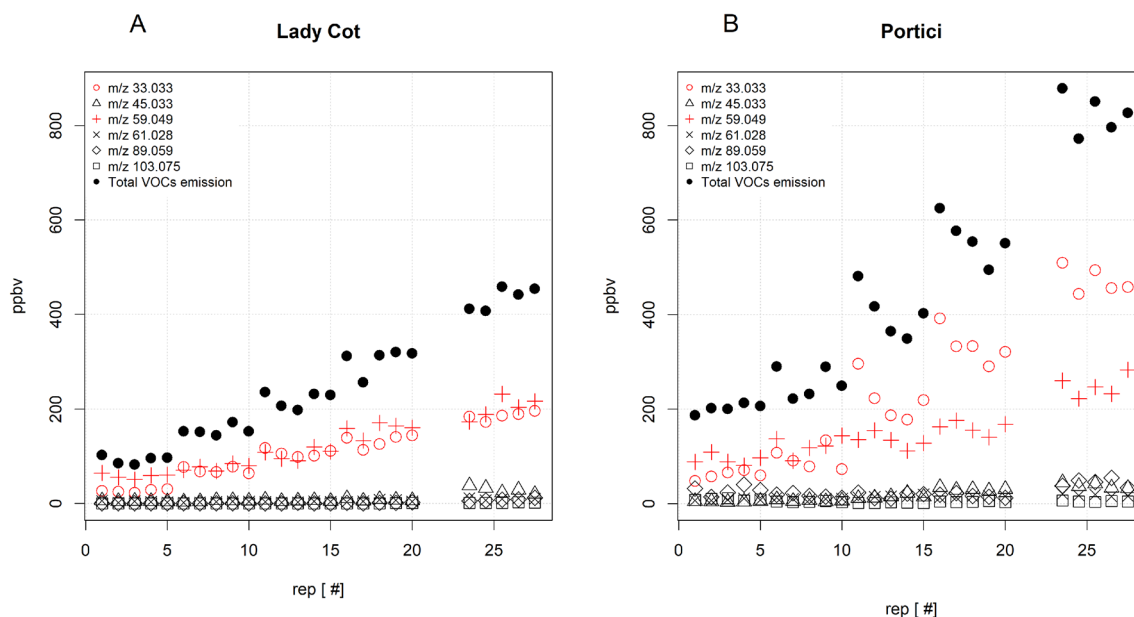


Fig. 3 VOC emissions (ppbv) released from “whole fruit” by different ‘LC’ (A) and ‘PC’ (B) apricot cultivars. Emissions (y-axis) are expressed in ppbv. All five replicates are represented for each sampling time. The harvest time (T1) corresponds to rep in [1, 5], while

the last sampling time (T5) corresponds to rep interval [23.5, 27.5], for visual reasons. The total VOCs emission is also reported for each cultivar (filled black bullets)

Table B.4, while the trend analysis of the main emitted VOCs is shown in Fig. 6.

Figure 5 suggests that the two apricot cultivars showed a different behavior during ripening. In particular, ‘PC’ showed a more complex evolution pattern involving several VOCs. The first top left red square in Fig. 5A (from m/z 73.065 to m/z 103.075) refers to all those VOCs which did not show any significant trend. A second cluster (from m/z 57.033 to m/z 55.054) is composed of all those VOCs showing a decreasing or neutral trend. Among them, only m/z 57.033 (TI: C3 fragments) and 81.069 (TI: (Z)-3-hexenal and other C6 fragments, Fig. 6F) showed significantly decreasing trends. A third and final cluster is characterized by increasing emissions over time (from m/z 57.069 to m/z 43.018). Significant trends were found for: m/z 33.033 (TI: methanol), m/z 43.018 (TI: ester fragments), m/z 45.033 (TI: acetaldehyde), m/z 47.049 (TI: ethanol), m/z 59.049 (TI: acetone/propanal), m/z 61.028 (TI: acetic acid), and m/z 69.069 (TI: isoprene). Most of these detected signals (Fig. 6’s panels A–D) are the same found in “whole” sample analysis.

Looking at ‘LC’ (Fig. 5B), the pattern of evolution is defined by a few VOCs. Similarly to ‘PC’, the dataset variability is dominated by a first cluster embedding all those VOCs showing a flat trend (from m/z 93.069 to m/z 91.050). A second small cluster is made up of VOCs showing a significant growing trend: m/z 33.033 (TI: methanol),

m/z 47.049 (TI: ethanol), m/z 45.033 (TI: acetaldehyde), m/z 59.049 (TI: acetone/propanal), m/z 43.018 (TI: ester fragments) and m/z 61.028 (TI: acetic acid). Most of these compounds were the same found in ‘PC’. The other clusters are less defined, being characterized by flat or not significant trends. Among them only m/z 57.033 (TI: C3 fragments) and 81.069 (TI: (Z)-3-hexenal and other C6 fragments, Fig. 6F) clustered together due to common significantly decreasing trends. In particular, the decreasing emissions of C6 compounds or their fragments (i.e. m/z 57.033 ((E)-2-hexenal fragment), m/z 79.054 (aromatic compound fragments), m/z 81.069 ((Z)-3-hexenal and other C6 fragments), m/z 93.069 (C6 and terpene fragments) and m/z 99.080 (cis-3-hexenal/2-hexenal)), which have been observed over time in both apricot cultivars (see Table B.4), were probably linked to the ripening process where the green-notes give way to sweeter odors.

Taking into account previous results, Fig. 7 shows ‘LC’ and ‘PC’ mostly emitted VOCs. The emissions of both apricot cultivars were dominated by m/z 45.033 (TI: acetaldehyde) and m/z 59.049 (TI: acetone/propanal), followed by m/z 33.033 (TI: methanol). Analogously to “whole” sample analysis (ref. to Fig. 3), the total VOCs emission (Fig. 7, black dots) suggested that ‘PC’ emissions were higher and/or faster with respect to ‘LC’ during the postharvest. Analogously to the “whole” sample case, in fact, m/z 59.049 (TI: acetone/propanal) emission temporal trend was

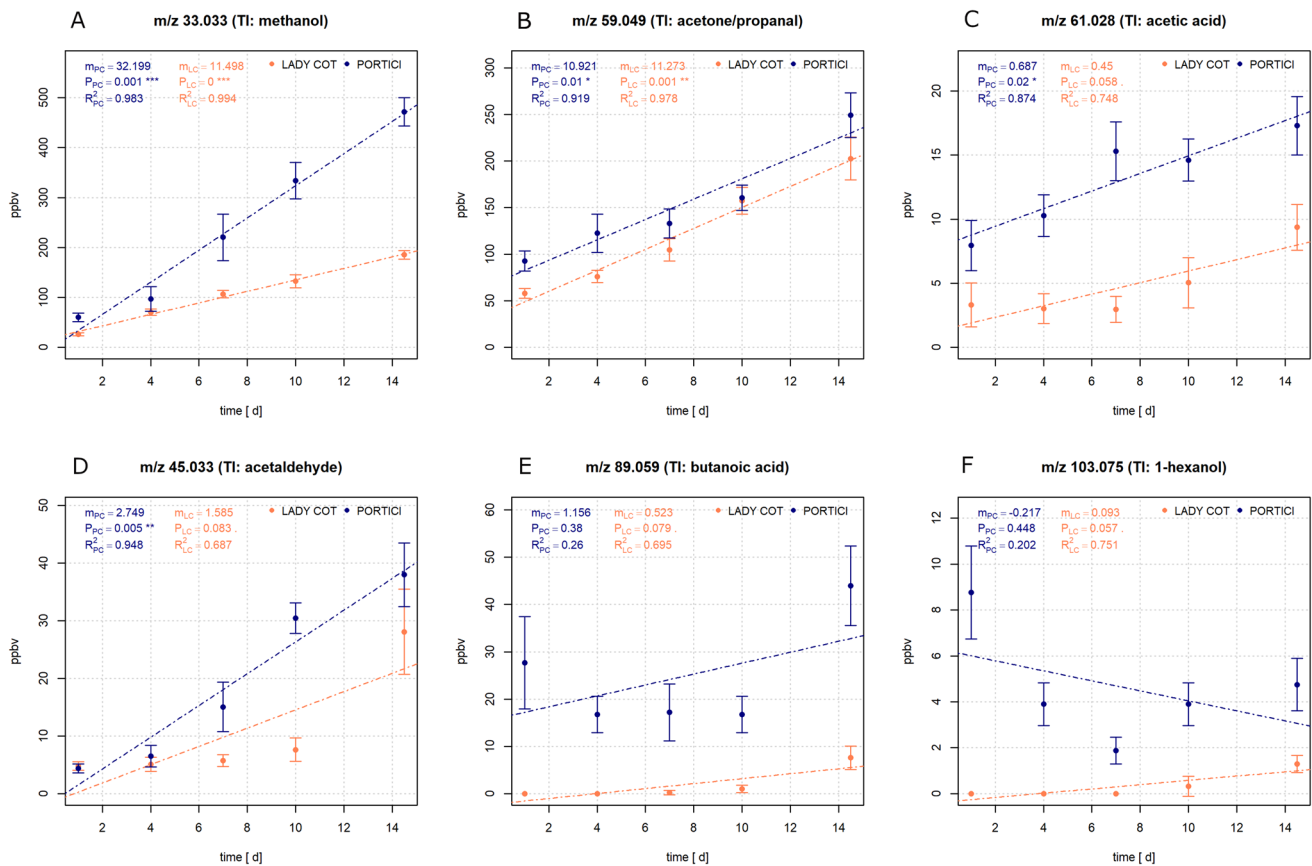


Fig. 4 Linear fit analysis performed over the VOCs emitted (ppbv) by “whole fruit” samples. Each panel corresponds to one VOC: **A**= m/z 33.033 (TI: methanol), **B**= m/z 59.049 (TI: acetone/propanal), **C**= m/z 61.028 (TI: acetic acid), **D**= m/z 45.033 (TI: acetaldehyde), **E**= m/z 89.059 (TI: butanoic acid), **F**= m/z 103.075 (TI: 1-hexanol). Each dot represents the average of 5-replicates and the associated

error bars their standard deviation. For each protonated mass both ‘PC’ and ‘LC’ time series are shown (in blue and red coral, respectively), superposed to the linear trend fit. Fit parameters are shown in the legend. Significance codes: (.)= $P < 0.1$; (*)= $P < 0.05$; (**)= $P < 0.01$; (***)= $P < 0.001$

similar between the two cultivars, while different behavior was evident in m/z 45.033 (TI: acetaldehyde), m/z 47.049 (TI: ethanol), and m/z 61.028 (TI: acetic acid). Since the development of off-flavors is linked to fermentative metabolism [30], which causes the accumulation of acetaldehyde, ethanol, and other acetate compounds to levels above their threshold concentrations, “cut in half” VOCs analysis suggested that ripening process was faster in ‘PC’ with respect to ‘LC’, probably due to genetic factors of the two cultivars.

Finally, significant trends were found in those VOCs already significant in the “whole” sample case.

Sensory evaluation and consumer acceptance

Being apricot a climacteric fruit, many sensory quality attributes, such as color, firmness, acidity, sweetness, and flavor, vary during the postharvest process. Here we have compared the commercial and the postharvest sensory quality of two different apricot cultivars with the aim of

understanding why consumers are becoming disaffected with this fruit.

Sensory evaluation

The average scores of six sensory attributes evaluated by panelists (i. e., flavor, firmness, juiciness, sweetness, acidity and overall judgment) for each sampling times are represented by a spider plot (Fig. 8), and the corresponding linear fit analysis is reported in Fig. 9, to assess the significance of sensory attributes temporal evolution. By sensory analysis it emerged how at harvest and early post-harvest (T1-T2) ‘PC’ cultivar scored the highest appreciation (overall judgement) from the panelists, presumably related to the stronger flavor, sweetness and juiciness of its fruit, as confirmed by the significant differences observed for these properties between the two cultivars ($P_{diff,T1-T2} < 0.01$; $P_{diff,T1-juic} < 0.05$). On the contrary, ‘LC’

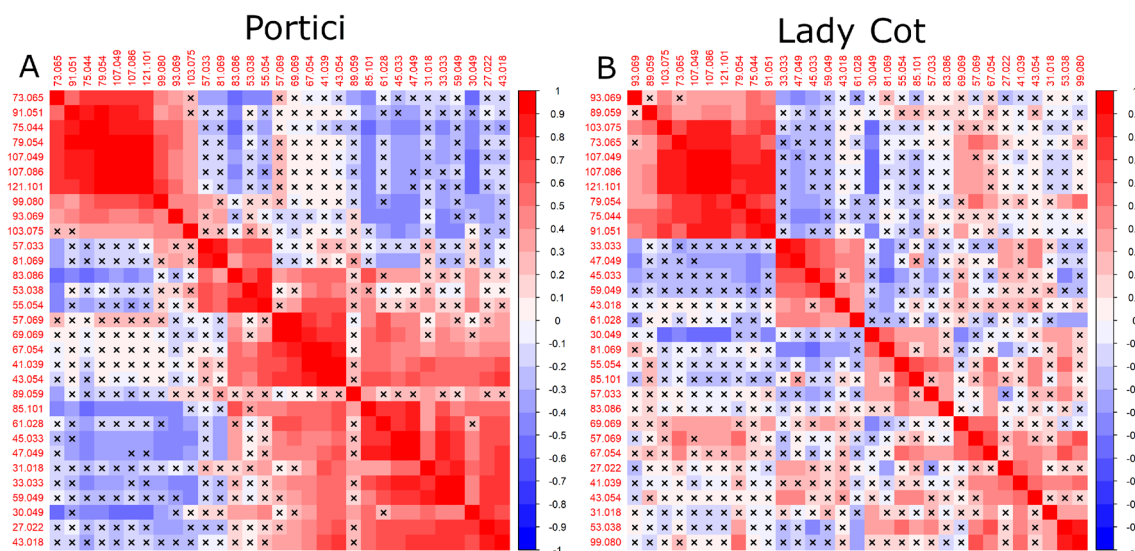


Fig. 5 Correlation maps of the protonated masses (red values expressed as m/z) emitted by “cut in half fruit” samples from ‘Portici’ (panel A) and ‘Lady Cot’ (panel B). The color map ranges from high

correlation ($C_{ij}=1$, red cells) to high anti-correlation ($C_{ij}=-1$, blue cells). Significance level is set to $\alpha=0.05$. Black crosses indicate not-significant correlation values

emerged for firmness and acidity ($P_{\text{diff},T1-T2} < 0.01$). This result changed at T3 (day 7), where the overall quality between the two cultivars was reversed and ‘LC’ kept a higher rating compared to ‘PC’. The situation further worsened after ten days of storage (T4), when the fruit sensory quality of both cultivars decreased further. However, ‘LC’ still received the highest score ($P_{\text{diff},T4-T5} < 0.05$) due to its higher firmness. Therefore, as no significant trends were observed in the sweetness and acidity of ‘PC’ (Fig. 9D-E), and taking into account the lack of significant differences in both cultivars’ juiciness score after T2 ($P_{\text{diff},T2-T5} > 0.8$, Fig. 9C), the reversal in the tasters evaluation seemed related: (i) to the significant decrease in ‘PC’ flavour (Fig. 9A), which reached the same score of ‘LC’ ($P_{\text{diff},T3} > 0.4$); (ii) to the higher score of ‘LC’ firmness parameter (Fig. 9B; $P_{\text{diff},T3} < 0.01$).

This hypothesis was confirmed by a multi-regression linear model (Appendix C), which showed that flavor was by far the most relevant explanatory variable for both cultivars overall judgment. This result agrees with Álvarez-Hernández et al. [4], which observed how the flavor is the main sensory parameter that highly affects the sensory overall quality. The model highlighted two further explanatory variables, i.e. juiciness for ‘PC’ and acidity for ‘LC’ (Table C.5). In other words, in addition to flavor, juiciness turned out to be a distinguishing character for ‘PC’, as acidity for ‘LC’.

Consumer acceptance

By studying “consumer preferences” it was possible to observe the quality from the point of view of the consumer and try to understand which are the apricot sensory quality parameters that most affect the purchase choice. Indeed, being the “consumer evaluation” highly correlated with acceptability and perceived quality by consumers, it may help to understand which sensory quality attributes drive their choices and tastes [12]. In this study, the result of the consumer test, reported in Fig. 10, showed clear differences between the two cultivars studied, confirming what the trained panelists expressed. Indeed at harvest, the liking obtained by ‘PC’ resulted higher than those shown by ‘LC’ and a similar trend was observed at T2. Therefore, since the sugar content and firmness of both cultivars at T1 and T2 showed similar values, the result obtained for ‘PC’ about the consumers liking and preference, was probably due to the higher TSS:TA ratio (ref. to Fig. 2), flavor and juiciness attributes (Fig. 8) and in accordance with the results obtained previously by Stanley et al. [49]. On the contrary, at T3 ‘LC’ fruit were preferred compared to ‘PC’ fruit while at T4 and T5, both cultivars showed a negative liking rating.

Furthermore, to better understand the consumer’s choice, the “consumer acceptance” was calculated. Figure 10 shows how ‘PC’ obtained the higher consumer acceptance at T1 and T2 (100% and 93%, respectively), while ‘LC’ obtained lower scores (82% and 80% for T1 and T2, respectively). This result overturns at T3, where ‘LC’ obtained the 75% of acceptability versus the 47% shown by ‘PC’, whilst at T4

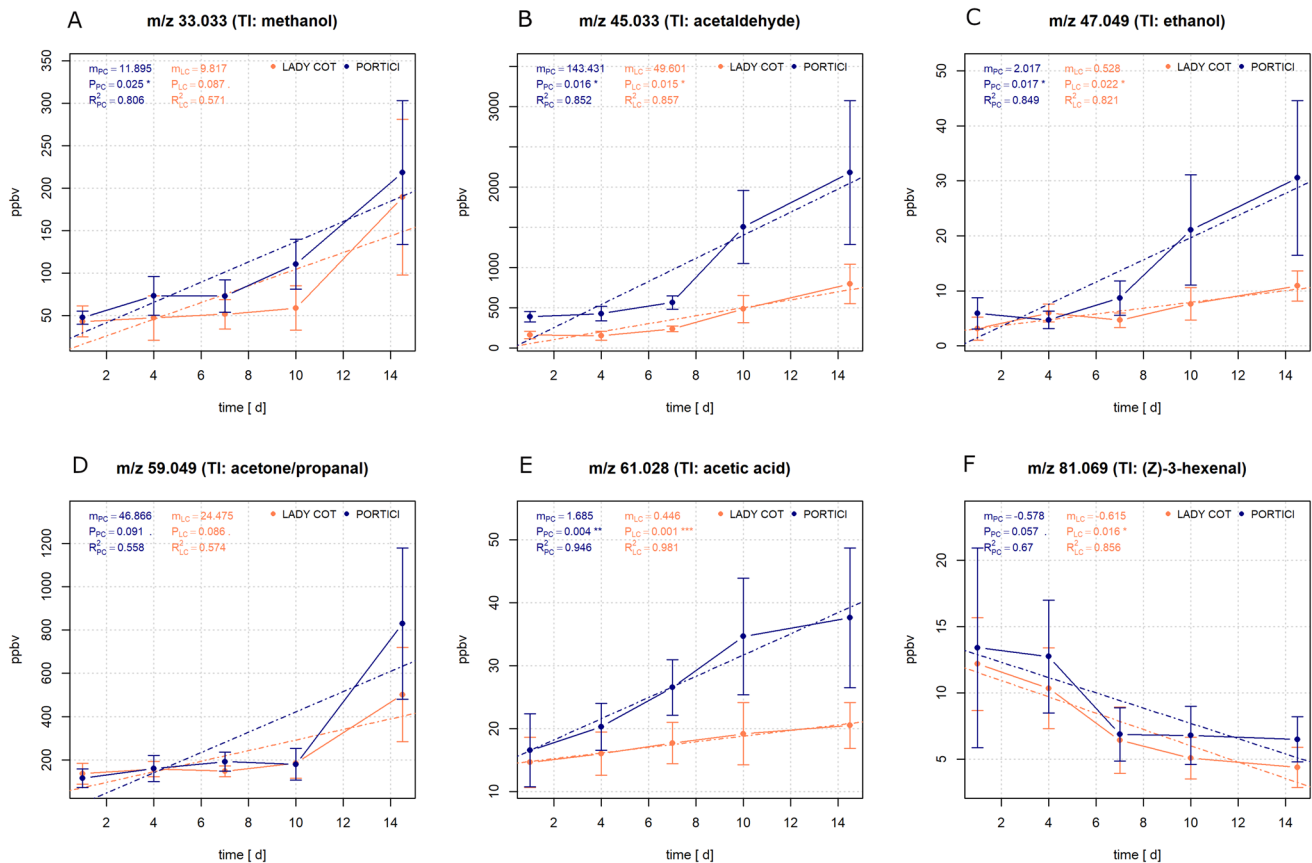


Fig. 6 Linear fit analysis performed over the VOCs emitted (ppbv) by “cut in half fruit” samples. Each panel corresponds to one VOC: **A**= m/z 33.033 (TI: methanol), **B**= m/z 45.033 (TI: acetaldehyde), **C**= m/z 47.049 (TI: ethanol), **D**= m/z 59.049 (TI: acetone/propanal), **E**= m/z 61.028 (TI: acetic acid), **F**= m/z 81.069 (TI: (Z)-3-hexenal and C6 fragments). Each dot represents the replicates average and

the associated error bars and their standard deviation. For each protonated mass both ‘PC’ and ‘LC’ time series are shown (in blue and coral, respectively), superposed to the linear trend fit. Fit parameters are shown in the legend and in Table B.4. Significance codes: (.)= $P < 0.1$; (*)= $P < 0.05$; (**)= $P < 0.01$; (***)= $P < 0.001$

and T5 only a few consumers expressed a positive opinion for both cultivars (values generally below 43%). In conclusion, the consumer preferences highlight how PC is the preferred apricot, while ‘LC’, although having obtained a lower acceptability value, is accepted for a longer time.

Discussion

In the present study two commercial and widespread apricot cultivars, a traditional and a modern one, belonging to the old and new market, respectively, ‘Portici’ (PC) and ‘Lady Cot’ (LC), were characterized and compared at harvest and at different postharvest times to investigate (1) how the reciprocal sensory quality changes during the postharvest process; (2) which sensory quality parameters drive the consumer's choice and the consumers' disaffection.

Physicochemical, aromatic and sensory parameters changed following postharvest fruit storage differently in the two apricot cultivars. In particular, ripening index (expressed as TSS:TA ratio), firmness, aroma and flavor turned out to be the parameters most variables overtime (from T1 to T5).

This behavior was more pronounced and faster in ‘PC’ compared to ‘LC’ fruit. In particular, ‘LC’ retained its hardness and firmness for a longer time, thus showing a higher shelf life with respect to ‘PC’, which degraded more quickly. On the other hand, as expressed by the sensory evaluation (either from trained than untrained judges) the overall quality of ‘PC’ was much higher than that of ‘LC’ up to T3. Nevertheless, as shown in §3.4 Section, ‘LC’ better kept its sensory quality over time, without ever reaching the high quality provided by ‘PC’ at T1 and T2. As a consequence, the consumers' liking and acceptance scores reversed in T3, turning out to be in favor of ‘LC’ compared to ‘PC’, which probably underwent a decay phenomenon during the postharvest (firmness and juiciness decrease and flavor decay).

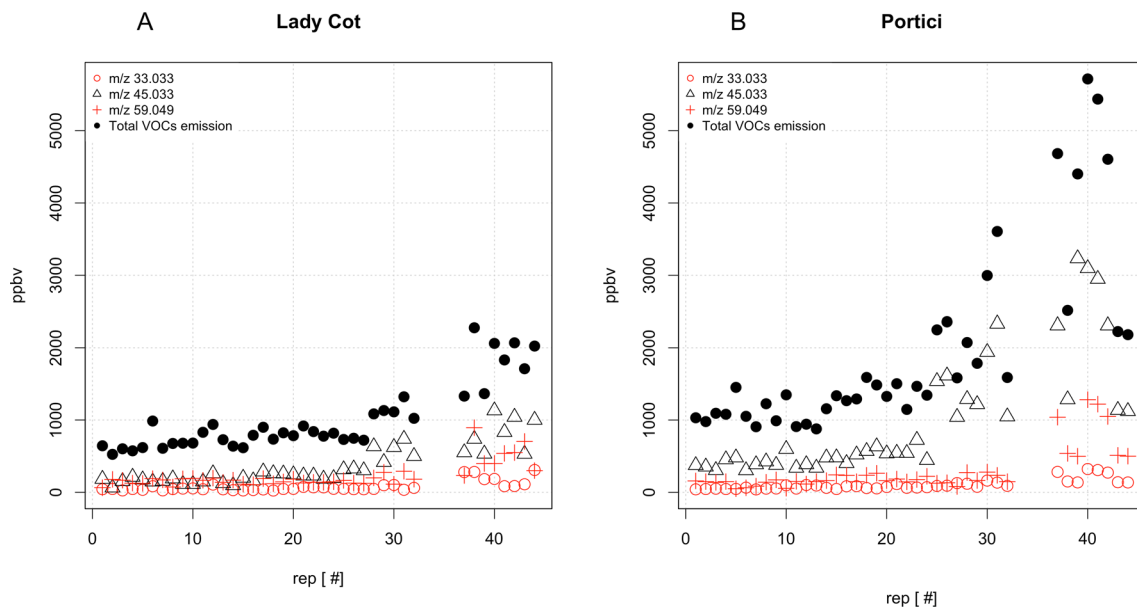


Fig. 7 Signal intensities of some VOCs such as: m/z 33.033 (TI: methanol), m/z 45.033 (TI: acetaldehyde) and m/z 59.059 (TI: acetone/propanal) emitted by ‘LC’ (panel A) and ‘PC’ (panel B) apricot cultivars using “cut in half” samples. Emissions (y-axis) are expressed in ppbv. All 8 replicates are represented for each sampling

time. The harvest time (T1) corresponds to rep in [1, 8], while the last sampling time (T5) corresponds to rep interval [37, 44], for visual reasons. The total VOCs emission is also reported for each cultivar (filled black bullets)

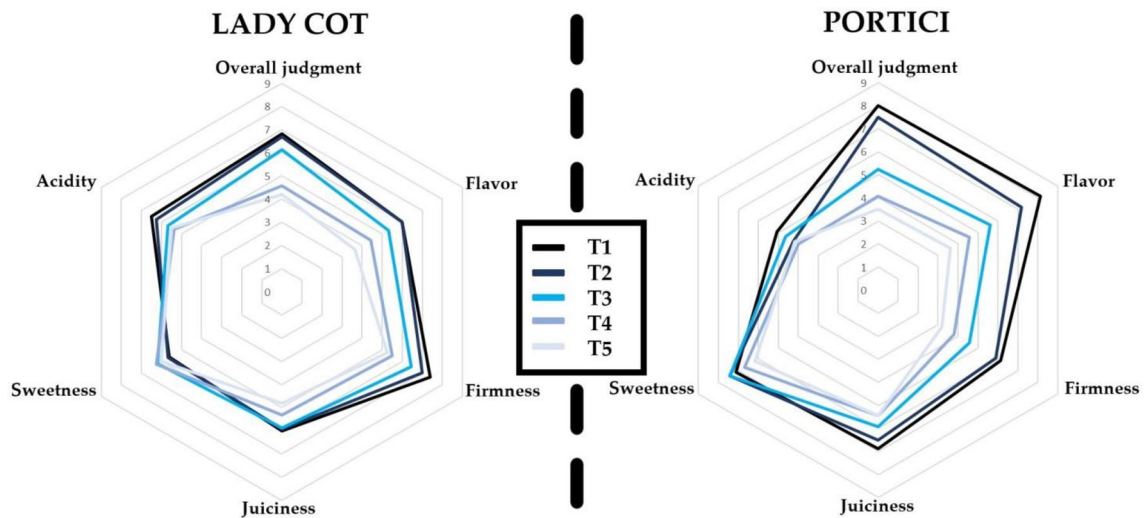


Fig. 8 Spider plot built on the average values of the scores of six attributes (flavor, firmness, juiciness, sweetness, acidity and overall appreciation) provided by trained panelists. Different colors highlight different sampling times

Although the acceptance of apricots has been demonstrated to be related to the sugar content [15, 41], in this study we have observed that consumer preferences were not driven by this quality attribute alone. Indeed, while TSS increased over time in both cultivars and ‘PC’ sugar content

was slightly higher with respect to ‘LC’ especially near harvesting, only neglecting differences were observed between the sugar content of the two cultivars during subsequent samplings. On the contrary, the acidity content (TA)—which decreased in time in both cultivars—was characterized by significant differences between the two cultivars at each

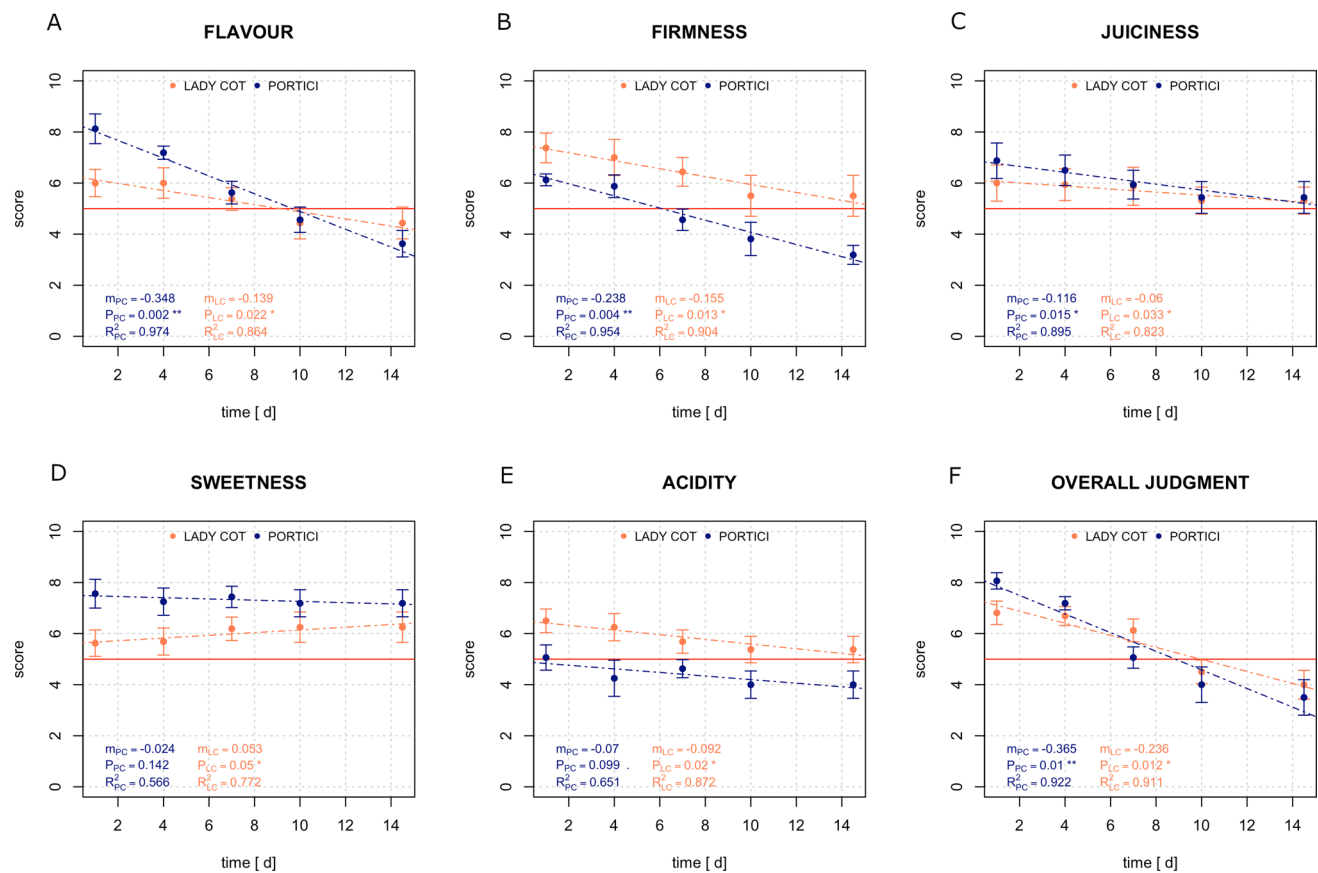


Fig. 9 Results of sensory evaluation by trained panelists. For each sampling time, the following sensory attributes are recorded: flavor (A), firmness (B), juiciness (C), sweetness (D), acidity (E), and overall appreciation (F). Each dot corresponds to the average score computed over 8 panelists evaluations, and the error bars correspond to

the standard deviation of the mean. Horizontal red line in all panels indicates the threshold for panelists' taste satisfaction (score=5). Linear fit parameters are shown in the legend. Significance codes: (.)= $P < 0.1$; (*)= $P < 0.05$; (**)= $P < 0.01$; (***)= $P < 0.001$

sampling time. The increase in sugar content in conjunction with the decrease in acidity during the postharvest time resulted in an increasing TSS:TA ratio in both apricot cultivars. Significant differences emerged between the TSS:TA ratio of the two cultivars, at each sampling time, similarly to TA. Therefore, it was hypothesized that the higher acidity of 'LC' cultivar had a negative effect on the organoleptic quality both at the harvest and especially during harvesting time leading to lower consumer satisfaction, while the higher sweetness of 'PC' was not sufficient to guarantee a higher level of consumer satisfaction during the time of the experiment.

This study also showed that consumer satisfaction is affected by a decrease in fruit firmness during fruit ripeness, which resulted in lower mouthfeel and reduced sensory quality [4, 49]. In fact, the typical firmness loss in ripening and then in the postharvest process leads to lower fruit quality, due to the degradation of cell structures by respiration and metabolic activities [1]. This behavior was observed in both cultivars as the postharvest progressed,

with 'PC' showing the lowest values at the harvest time and the most significant drop in time. In this case, the firmness values shown by 'LC' fruit were much higher (i.e., harder fruit) compared to the 'PC' ones. The low firmness values shown by 'PC' are a limiting factor for its handling and marketing within the large-scale retail organization market.

Moreover, the apricot fruit on the market is perceived by consumers as a little sweet, hard and not ripe [22], in agreement with our results. Nevertheless, the sensory evaluation analysis highlighted how flavor (aroma and taste) attributes affect consumer preferences and represent the most significant driver of the overall eating and sensory quality in both cultivars. Indeed, the apricot aroma is linked to genetic, environmental and postharvest factors and is due to a mix of volatile compounds originating during the different phases of fruit ripening [28]. Therefore, our VOCs analysis emerged how the emission of some aroma compound detected increased over time more quickly in 'PC' compared to 'LC' highlighting a great influence of this behaviour on

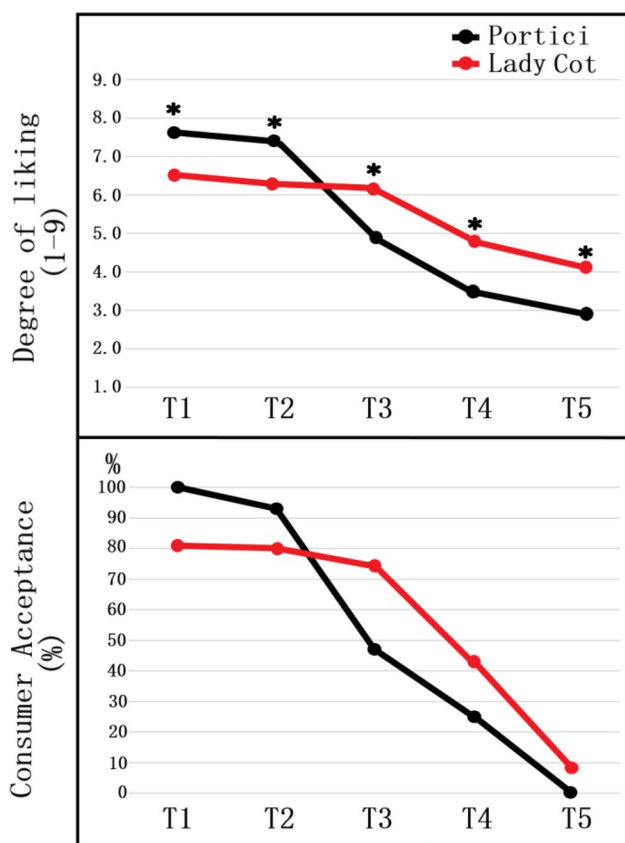


Fig. 10 Results of consumer evaluation. Degree of liking and consumer acceptance of two different apricot cultivars harvested at the physiological maturity stage. Degree of liking measured on 9-point hedonic scale (1, dislike extremely; 5, neither like nor dislike and 9, like extremely). Consumer acceptance was expressed as a percentage of consumers who evaluated the samples with scores > 5.0. The asterisks over data indicate a significant difference, for the specific sampling date, between means (non-parametric T-test, $p < 0.01$)

the sensory overall quality. In particular, as reported in §3.2 Section, we have detected in both apricot cultivars (i) a strong increase of VOCs linked to fermentative metabolism (i.e. methanol, acetaldehyde, acetic acid); (ii) a strong reduction in the emission intensity of C6 compounds and their fragments during the postharvest time (i.e. (E)-2-hexenal, aromatic compound, (Z)-3-hexenal and other C6) in the “cut in half” samples.

Concerning (i), since VOCs play a key role in flavor perception and thus in the acceptability of products by consumers, it is likely that an excessive increase in VOC emissions will result in the development of unpleasant aromas and flavors, as reported by expert panels (§3.4.1 Section). For example, acetaldehyde emissions—that increased in both

“whole” and “cut in half” samples during the postharvest time—is probably one of the main aromatic compounds linked to consumer disaffection. This volatile compound plays a crucial role in flavor and odor of ripening fruit [48]. In different climacteric fruit (i.e. mango, avocado, banana) the levels of acetaldehyde increased steadily throughout the ripening process [51, 56]. When acetaldehyde accumulates slowly during fruit maturation, together with methanol, ethanol and other acetate compounds, it plays an important role in the biosynthesis of fruit aroma. On the contrary, when the accumulation of acetaldehyde and other acetate compounds increases rapidly to high levels it causes the development of undesirable flavors linked to fermentative metabolism [30], leading to problems in postharvest storage [45]. In this study, the increased emissions of acetaldehyde, methanol, ethanol (only in the “cut in half” samples), and acetate compounds observed during the postharvest period (especially after T3) differed between the two apricot cultivars. This difference highlighted a different ripening behavior due possibly to genetic diversity between the two cultivars.

Concerning (ii), the reduction in the emission of C6 compounds and their fragments in “cut in half” samples, observed over time in both apricot cultivars, was probably linked to the ripening process where the green-notes give way to sweeter odors.

It is noteworthy as the apricot fruit’s aroma changes from “whole” and “cut in half” sample. VOCs production type and emissions change among different fruit tissues, reaching the highest values when the fruit is cut. In our case, the VOC profile showed the increase of butanoic acid/ethyl acetate and other ethyl compounds only in the “whole” samples during the ripening process. These compounds are probably related to the increase in acetaldehyde emissions from both cultivars [34] and are important aroma compounds that contribute to the overall apricot aroma [5] probably emitted mostly from the fruit skin. Moreover, the higher emission of these compounds from the ‘PC’ variety could contribute to its more floral and pleasant notes with respect to ‘LC’.

Summarizing, the best flavor (aroma and taste) of ‘PC’, coupled with the lower acidity and the higher TSS:TA ratio, allows it to fully satisfy consumer and expert liking near the harvesting, and then rapidly degrade with a further increase of organic compounds emission. On the contrary, the limited flavor of ‘LC’ combined with good firmness, did not fully meet with consumer approval, although it ensured a slower deterioration of the fruit and satisfaction index as required by the long chain market. These results clearly suggest that the flavor (aroma and taste) play a key role in consumer liking and thus in the acceptability of apricot fruit by consumers,

so much so that it seems to be necessary to improve this attribute to ensure the increase of apricot consumptions. Accordingly, it is suggested that future breeding programs should favour cultivars able to develop quality characters such as a pleasant aroma during ripening, adequate sugar content, as well as those needed for optimal marketability.

Conclusion

According to the results obtained, by coupling chemical analysis and consumer test during postharvest, important information on both the fruit and consumer behavior is achieved, useful to assess handling and storage strategies suitable for the postharvest process. Indeed, the results of this study suggest that physicochemical parameters and VOCs emission, monitored during the postharvest process, change significantly and influence consumer satisfaction and choice. Particularly fruit aromatic fingerprint and VOCs concentration represent potentially good indicators for the fruit quality and its acceptance by the consumer. The comparison of cultivars belonging to the modern ('Lady Cot') and

traditional ('Portici') market allows us to highlight how the first type shows more attractive aspects and firmness than the second one, but also a leaner flavor profile and lacks many of the key compounds that positively influence the consumer's liking of apricots. The results of this comparison obviously cannot lead to general conclusions, however, the increase of consumers' request for high-quality apricots highlights the need to recover some of the traditional aromatic cultivars (such as the "Vesuvian Apricots group"—[11] with the aim to help the breeders to develop other modern ones, suitable for the long supply chains and with hard fruit (to facilitate handling and marketing) without neglecting high sensory quality (to satisfy the consumer's requirements).

Appendix A

VOCs profiling by PTR-ToF-MS: "Whole" samples

See Appendix Table 2

Table 2 VOCs profiling by PTR-ToF-MS analysis of "whole" samples

(A) LADY COT									
Code	m/z	Formula	Tentative Identification	$\mu \pm \sigma$ T1	$\mu \pm \sigma$ T2	$\mu \pm \sigma$ T3	$\mu \pm \sigma$ T4	$\mu \pm \sigma$ T5	
1	33.033	CH ₅ O+	Methanol	26.2 ± 6.2	70.3 ± 6.5	106.6 ± 33.1	132.5 ± 12.8	185.3 ± 18.6	
2	43.055	C ₃ H ₇ +	Fragment (alcohol, ester, acetate)	4.8 ± 2	5.1 ± 1.2	5.7 ± 1.8	7.6 ± 2	28.1 ± 7.4	
3	59.049	C ₃ H ₇ O+	Acetone	57.8 ± 8.2	75.9 ± 6.6	101.6 ± 20.2	157.4 ± 14.4	202.7 ± 22.9	
4	61.028	C ₂ H ₅ O ₂ +	Acetic acid*	3.3 ± 1	3 ± 1.2	3 ± 1.5	5 ± 2	9.4 ± 1.8	
5	89.058	C ₄ H ₉ O ₂ +	butanoic acid/ethyl acetate*	0 ± 0	0 ± 0	1 ± 0	1 ± 0	7.6 ± 2.5	
6	103.075	C ₆ H ₁₅ O+	1-hexenol#	0 ± 0	0 ± 0	0 ± 0	1 ± 0	1.6 ± 0.4	
Total VOCs emission (ppbv)				92.2	154.3	217.8	304.5	434.6	
(B) PORTICI									
Code	m/z	Formula	Tentative Identification	$\mu \pm \sigma$ T1	$\mu \pm \sigma$ T2	$\mu \pm \sigma$ T3	$\mu \pm \sigma$ T4	$\mu \pm \sigma$ T5	
1	33.033	CH ₅ O+	Methanol	60.1 ± 19.2	96.6 ± 24.6	180.5 ± 49	333.8 ± 36.7	471.9 ± 28	
2	43.055	C ₃ H ₇ +	Fragment (alcohol, ester, acetate)	4.4 ± 1.4	6.5 ± 1.8	8 ± 4.2	30.4 ± 3.6	38 ± 5.5	
3	59.049	C ₃ H ₇ O+	Acetone	92.6 ± 11	122.4 ± 20.6	132.8 ± 28	160.5 ± 20.5	249.1 ± 24	
4	61.028	C ₂ H ₅ O ₂ +	Acetic acid*	7.9 ± 1.5	10.3 ± 1.6	15.3 ± 5.2	14.6 ± 2.6	17.3 ± 2.3	
5	89.058	C ₄ H ₉ O ₂ +	butanoic acid/ethyl acetate*	27.7 ± 8.6	16.7 ± 3.9	17.2 ± 8	16.7 ± 3.9	44 ± 8.4	
6	103.075	C ₆ H ₁₅ O+	1-hexenol#	4.8 ± 1.6	3.9 ± 0.9	2.9 ± 1.4	3.9 ± 0.9	4.8 ± 1.1	
Total VOCs emission (ppbv)				197.5	256.4	356.8	560.0	824.9	

The table shows the mass/charge (m/z) ratio, chemical formula, tentative identification for each emitted VOC and its average emission (μ) ± standard deviation (σ) for each sampling time (T1-T5). VOCs emission is expressed in ppbv. (A) 'Lady Cot' (B) 'Portici'. **Tentative identification:** compounds tentatively identified refer to previous studies (*[23],#[26] and proton affinity list from Ionicon Analytik GmbH. Values equal to "1.00" refer to signals (m/z) present in traces

VOCs profiling by PTR-ToF-MS: “Cut in half” samples

See Appendix Table 3

Table 3 VOCs profiling by PTR-ToF-MS analysis of “cut in half” samples

(A) LADY COT

Code	m/z	Formula	Tentative Identification	$\mu \pm \sigma$ T1	$\mu \pm \sigma$ T2	$\mu \pm \sigma$ T3	$\mu \pm \sigma$ T4	$\mu \pm \sigma$ T5
1	27.022	C2H3+	Acetylene	42.6±20.5	47.8±18.7	50.4±20.4	49.6±17.4	63.4±24.8
2	30.049	C2H5+	Ethylene isotope	3.7±0.5	3.8±1.3	3.2±0.4	4.3±0.4	4.7±0.3
3	31.018	CH3O+	Formaldehyde	40.5±14.3	34.7±18.1	33.8±11.4	37±2.4	47.9±15.3
4	33.033	CH5O+	Methanol	43.3±18.1	47.4±16	51.7±17.2	58.9±16.1	189.4±41.5
5	41.038	C3H5+	Fragment (alcohol, ester)	33.6±14.9	47.6±12.1	39.2±10.8	34.3±14	48.2±22.6
6	43.018	C2H3O+	Fragment (ester)	20±17.8	33.8±18.2	39.3±15.1	36.7±15.1	50.4±12.5
7	43.055	C3H7+	Fragment (alcohol, ester, acetate)	15.7±7.7	18.3±6.1	19.1±3.4	13.4±5.9	21.1±8.8
8	45.033	C2H5O+	acetaldehyde*	159.9±44.6	152.1±54.6	236.2±34	482.4±118	795±224.8
9	47.049	C2H7O+	Ethanol	3.2±1.1	6±1.6	4.7±1.3	7.6±2.9	10.9±2.7
10	53.038	C4H5+	Fragment (ester)	2.1±0.8	3.6±2	1.6±0.6	1.3±0.5	1.1±0.2
11	55.055	C4H7+	Fragment (aldehyde)	49±11.4	66.6±21.1	32.8±12.7	29.5±14.6	23.8±9
12	57.033	C3H5O+	C3 aldehyde and ketone fragments	25.3±5.4	24.5±8	18.9±9.6	14.8±9.3	12.9±3.5
13	57.069	C4H9+	Fragment (alcohol)	3.5±1.2	13.9±4.5	13.6±6.1	8.7±3.1	7.6±2.5
14	59.049	C3H7O+	Acetone	136.1±38.1	157.7±35.5	147.6±24.8	184.2±48.3	501.7±208
15	61.028	C2H5O2+	Acetic acid*	14.7±4	16±3.4	17.7±3.3	19.2±4.9	20.5±3.6
16	67.054	C5H7+	C5 fragments	1.5±0.9	2.4±0.5	2.1±0.3	1.5±0.5	1.6±0.8
17	69.069	C5H9+	Isoprene*	1±0.3	2.8±1.1	7.6±2	4.7±2.1	6±2.9
18	73.054	C4H9O+	2-Butanone*	1.6±0.5	1.5±0.3	3.1±0.8	1.2±0.3	1.3±0.6
19	75.044	C3H7O2+	Methyl acetate*	10.6±3.5	7.6±3.1	14.6±6.5	7.5±1.5	2.5±1.4
20	79.054	C6H7+	Benzene/alkyl and terpene fragment	2.2±1.1	3.5±1.6	4.5±1.2	1.1±0.3	1.2±0.4
21	81.069	C6H9+	(Z)-3-hexenal and C6 fragment *	12.2±3.5	10.4±3	6.4±2.5	5.1±1.6	4.4±1.5
22	83.086	C6H11+	C6 compounds/Hexenol fragment	7.9±2.6	5.7±2.8	6.5±3	8±3.6	5±1.5
23	85.101	C6H13+	Alcohol fragment (e.g. 1-hexanol)	1.1±0.3	1.3±0.5	1±0.1	1.2±0.3	1±0.2
24	89.058	C4H9O2+	butanoic acid/ethyl acetate*	2.4±0.7	2.5±1	3.3±1.9	1.9±0.2	2±0.2
25	91.050	C4H11O2+	2,3-Butanediol	2±0.8	1.7±0.6	2.3±0.6	1±0.2	1±0.2
26	93.069	C7H9+	Terpene and C6 fragments	3.3±1.1	2.5±1.3	7±1.9	1.1±0.3	1.3±0.3
27	99.080	C6H11O+	(E)-2-hexenal*	4.7±0.5	4.8±1.4	3.3±0.9	1.2±0.5	1.5±0.6
28	101.096	C6H13O+	hexenal*	1±0	1±0	1±0	1±0	1±0
29	103.075	C6H15O+	1-hexenol#	1±0.2	1.1±0.2	3.3±0.9	1±0.1	1±0.3
30	107.049	C7H7O+	Benzaldehyde*	1.5±0.2	1.2±0.4	4±2.5	1.1±0.3	1.2±0.4
31	107.080	C8H11+	p-Xylene	3±0.8	2.8±0.9	5.4±2.7	1.2±0.5	1.4±0.6
32	121.101	C9H13+	Terpene fragment	2±0.9	2.1±1.2	5.4±3	1.1±0.3	1.4±0.7
33	135.115	C10H15+	p-Cymene#	1±0	1±0	1±0	1±0	1±0
34	137.137	C10H17+	monoterpenes (e.g. limonene)#	1±0	1±0	1±0	1±0	1±0
Total VOCs emission (ppbv)				654.1	730.5	792.7	1024.8	1835.4

Table 3 (continued)

(B) PORTICI								
Code	m/z	Formula	Tentative Identification	$\mu \pm \sigma$ T1	$\mu \pm \sigma$ T2	$\mu \pm \sigma$ T3	$\mu \pm \sigma$ T4	$\mu \pm \sigma$ T5
1	27.022	C2H3+	Acetylene	84.7±25.4	71.7±21.2	77.4±24.4	83±27.5	155.8±44.3
2	30.049	C2H5+	Ethylene isotope	3.4±1.4	4.4±2.9	4.2±1.3	5.3±1.7	6.8±3.1
3	31.018	CH3O+	Formaldehyde	49±18.8	29.3±13.4	24.4±13.7	33±6.8	97.8±22.8
4	33.033	CH5O+	Methanol	47.8±7.7	73.4±12.9	83.1±19.2	130.8±29.4	218.4±44.6
5	41.038	C3H5+	Fragment (alcohol, ester)	55.2±8.4	43.6±8.3	57±9	47.9±15.6	74.1±20.7
6	43.018	C2H3O+	Fragment (ester)	64.5±30	53.5±25.2	61.8±11.6	70.6±19.8	123.1±33.9
7	43.055	C3H7+	Fragment (alcohol, ester, acetate)	24.9±10	23.7±6.3	32.5±6.5	36.5±12.5	40.4±11.1
8	45.033	C2H5O+	acetaldehyde*	385.4±65.2	425.4±89.1	564.8±72.9	1502.8±323	2179.5±612.3
9	47.049	C2H7O+	Ethanol	5.9±2.8	4.7±1.6	8.7±3.1	21.1±9	30.5±11
10	53.038	C4H5+	Fragment (ester)	3.4±1	2.5±0.8	2.2±0.8	2.4±0.8	2.1±1
11	55.055	C4H7+	Fragment (aldehyde)	92.5±27.9	66.8±20.3	51.1±11.9	73.1±27.9	66.7±22.7
12	57.033	C3H5O+	C3 aldehyde and ketone fragments	47.5±16.6	39.9±12	20.7±11.3	19.8±11.4	19.9±11.2
13	57.069	C4H9+	Fragment (alcohol)	6.7±2.1	7.1±2.3	20.5±6.9	18±8.9	17.2±6.1
14	59.049	C3H7O+	Acetone	115.8±33	159.8±30	191.6±43.8	179.6±53.7	830±149.2
15	61.028	C2H5O2+	Acetic acid*	16.6±5.8	20.3±3.7	26.6±4.4	34.7±7.3	39.6±11.1
16	67.054	C5H7+	C5 fragments	2.7±0.5	2.1±0.7	3±0.5	3±0.7	3.3±0.9
17	69.069	C5H9+	Isoprene*	2.6±0.7	3.5±0.7	9.3±2.6	12.6±4.8	12.8±4
18	73.054	C4H9O+	2-Butanone*	1.8±0.5	1.6±0.7	4.3±0.8	1.2±0.6	2.5±1.3
19	75.044	C3H7O2+	Methyl acetate*	15.3±3.9	12.6±3	18.4±6.3	10.6±3	6.9±2.8
20	79.054	C6H7+	Benzene/alkyl and terpene fragment	3.4±0.9	2.1±0.9	2.9±0.8	1±0.2	1.3±0.6
21	81.069	C6H9+	(Z)-3-hexenal and C6 fragment *	13.4±4.5	12.7±4.3	6.9±2	6.8±2.2	6.5±1.7
22	83.086	C6H11+	C6 compounds/Hexenol fragment	14.1±5	14.7±4.9	13.8±2.8	11.5±4.6	13.5±4.9
23	85.101	C6H13+	Alcohol fragment (e.g. 1-hexanol)	1.3±0.4	1±0	1±0	2.5±0.7	1.9±1
24	89.058	C4H9O2+	butanoic acid/ethyl acetate*	6.9±2.5	4.2±1.9	4.3±2.7	7±2.5	5.6±2.2
25	91.050	C4H11O2+	2,3-Butanediol	3.5±2	3±2.9	6.1±11.1	1±0	1±0
26	93.069	C7H9+	Terpene and C6 fragments	5.9±1.1	4±4.3	4.4±3.7	1±0	1.7±0.6
27	99.080	C6H11O+	(E)-2-hexenal*	4.2±0.9	4.3±1.3	3.4±1	1.5±0.8	1.9±0.8
28	101.096	C6H13O+	hexenal*	1±0	1±0	1±0	1±0	1±0
29	103.075	C6H15O+	1-hexenol#	3.8±0.7	1±0	2.9±1	1.8±0.7	1±0
30	107.049	C7H7O+	Benzaldehyde*	2.2±0.7	2.2±1.5	8.6±2.3	1±0	1±0
31	107.080	C8H11+	p-Xylene	4.3±2.3	4.6±4.7	6.1±6	1±0	2±0.8
32	121.101	C9H13+	Terpene fragment	3.6±1	3±2.5	6.8±3.4	1±0	1.9±0.5
33	135.115	C10H15+	p-Cymene#	1±0	1±0	1±0	1±0	1±0
34	137.137	C10H17+	monoterpenes (e.g. limonene)#	1±0	1±0	1±0	1±0	1±0
Total VOCs emission (ppbv)				1095.2	1105.6	1331.5	2326.0	3969.8

The table shows mass/charge (m/z) ratio, chemical formula, tentative identification for each emitted VOC and its average emission (μ)± standard deviation (σ) for each sampling time (T1-T5). VOCs emission is expressed in ppbv. (A) 'Lady Cot' (B) 'Portici'. **Tentative identification:** compounds tentatively identified refer to previous studies (*[23],#[26] and proton affinity list from Ionicon Analytik GmbH. Values equal to "1.00" refer to signals (m/z) present in traces

Appendix B

See Appendix Table 4

Table 4 Linear fit parameters for “cut in half” samples VOCs emitted by ‘Portici’ (PC) and ‘Lady Cot’ (LC) cultivars, respectively

m/z	PORTICI			LADY COT		
	m_{PC}	P_{PC}	R^2_{PC}	m_{LC}	P_{LC}	R^2_{LC}
27.022	5.032	0.135	0.439	1.288	0.067	0.635
30.049	0.018	0.943	– 0.331	– 0.157	0.281	0.152
31.018	2.978	0.428	– 0.043	– 0.233	0.904	– 0.326
33.033	11.895	0.025*	0.806	9.817	0.087	0.571
41.04	1.403	0.256	0.193	0.534	0.507	– 0.122
43.018	4.33	0.091	0.557	1.937	0.023*	0.813
43.05	0.908	0.109	0.507	0.091	0.837	– 0.311
45.033	143.431	0.016*	0.852	49.601	0.015*	0.857
47.049	2.017	0.017*	0.849	0.528	0.022*	0.821
53.038	– 0.077	0.103	0.522	– 0.132	0.203	0.291
55.054	– 1.285	0.447	– 0.064	– 2.613	0.114	0.494
57.033	– 1.992	0.088	0.567	– 1.024	0.007**	0.914
57.07	0.917	0.154	0.395	0.057	0.912	– 0.327
59.049	46.866	0.091	0.558	24.475	0.086	0.574
61.028	1.685	0.004**	0.946	0.446	0.001***	0.981
67.054	0.063	0.183	0.33	– 0.022	0.645	– 0.227
69.069	0.929	0.018*	0.841	0.349	0.186	0.324
73.06	0.026	0.855	– 0.316	– 0.029	0.755	– 0.284
75.044	– 0.821	0.607	– 0.202	– 0.696	0.512	– 0.127
79.054	– 0.177	0.74	– 0.277	– 0.144	0.642	– 0.225
81.069	– 0.578	0.057	0.67	– 0.615	0.016*	0.856
83.086	0.043	0.91	– 0.327	– 0.118	0.422	– 0.036
85.1	0.079	0.238	0.225	– 0.013	0.387	0.004
89.059	0.006	0.968	– 0.332	– 0.046	0.463	– 0.08
91.05	– 0.244	0.746	– 0.28	– 0.108	0.837	– 0.311
93.069	– 0.34	0.201	0.294	– 0.16	0.271	0.169
99.08	– 0.104	0.422	– 0.036	– 0.215	0.488	– 0.104
101.096	0	0.178	0.342	0.002	0.638	– 0.223
103.075	– 0.149	0.262	0.184	– 0.008	0.95	– 0.331
107.049	– 0.124	0.741	– 0.277	– 0.032	0.9	– 0.325
107.086	– 0.311	0.831	– 0.31	– 0.184	0.843	– 0.313
121.101	– 0.192	0.805	– 0.302	– 0.092	0.861	– 0.317
135.115	– 0.036	0.831	– 0.31	– 0.005	0.959	– 0.332
137.132	0	–	–	0	–	–

The following parameters are reported: angular coefficient (m_{pc} and m_{lc}), P -value (P_{pc} and P_{lc}), and determination coefficient (R^2_{pc} and R^2_{lc}). The suffixes ‘PC’ and ‘LC’ indicate ‘Portici’ and ‘Lady Cot’ cultivars, respectively. Negative R^2_{pc} and R^2_{lc} states for not significant fit. Significance codes: (.) = $P < 0.1$; (*) = $P < 0.05$; (**) = $P < 0.01$; (***) = $P < 0.001$

Appendix C

See Appendix Table 5

Table 5 Multi-regressive linear models applied to sensory analysis

A		PORTICI		B		LADY COT	
Residuals							
<i>Min</i>	<i>IQ</i>	<i>Median</i>	<i>3Q</i>	<i>Max</i>	<i>Min</i>	<i>IQ</i>	<i>Median</i>
-1.88	-0.53	0.18	0.42	1.52	-1.32	-0.24	-0.08
Model coefficients							
<i>Regres-</i>	<i>Estimate</i>	<i>std. err</i>	<i>t value</i>	<i>Pr(> t)</i>	<i>Regres-</i>	<i>Estimate</i>	<i>Std. err</i>
<i>sors</i>					<i>sors</i>		
Flavor	0.79	0.09	8.62	1.79E-10 ***	Flavor	0.68	0.11
Juiciness	0.18	0.09	2.01	0.05	Acidity	0.40	0.10
Statistical significance							
<i>Residual std. error:</i> 0.79 on 38 degrees of freedom				<i>Residual std. error:</i> 0.56 on 38 degrees of freedom			
<i>Multiple R²:</i> 0.98 <i>Adjusted R²:</i> 0.98				<i>Multiple R²:</i> 0.99 <i>Adjusted R²:</i> 0.99			
<i>F-statistics:</i> 1123 on 2 and 38 DF				<i>F-statistics:</i> 2226 on 2 and 38 DF			
<i>P-value < 2.2E-16</i>				<i>P-value < 2.2E-16</i>			

A PC: Overall judgment ~ flavor + juiciness; **B** LC: Overall judgment ~ flavor + acidity. Significance codes: (.) = $P < 0.1$; (*) = $P < 0.05$; (**) = $P < 0.01$; (***) = $P < 0.001$

Multi-regressive linear model applied to sensory analysis

A simple linear model was applied to describe the overall judgment score (dependent variable) in terms of sensory attributes (regressors). Since overall judgment is assumed to be 0 if all scores are 0, the linear regression was given through the origin. Concerning ‘PC’ (Table C.5A), the linear model results suggested that overall judgment was mainly related to flavor and juiciness, this last contributing to the perceived good taste at the beginning (T1), as the lower associated P-value suggests. In turn, aroma showed a significant negative partial correlation with time ($c_{part} = -0.45$), due to fruit perishing, and positive partial correlations with firmness ($c_{part} = 0.50$) and sweetness ($c_{part} = 0.52$), which both are connected to a positive judgment, especially in fresh fruit. This implies that only one among aroma, sweetness, firmness, and time had to be included in the fit regressors to explain the overall judgment of temporal evolution, avoiding collinearity. By combining these results with linear fit ones, aroma and juiciness were chosen as the main explicative variable for ‘PC’ taste. Concerning ‘LC’, the overall judgment was driven by aroma and acidity (Table C.5B). Effectively, acidity was always significantly higher in LC cultivars (ref. to Sect. "Total Soluble Solids (TSS), Titratable Acidity (TA) and their ratio (TSS:TA)"), and this has perhaps determined the lower overall judgment. Furthermore, in the linear model, acidity showed a significant negative partial correlation with sweetness ($c_{part} = -0.36$).

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Data availability Data can be available under requirements.

Declarations

Conflict of 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.

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