

Research Article

Relationships between Biochemical Criteria, Volatile Compounds, and Sensory Profiles of Ten Apricot Clones at Commercial and Consumption Ripening Stages

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In association with a desirable balance of sugars and organic acids, volatile compounds contribute to the important sensory attributes of apricots. This study assessed the biochemical, aromatic, and sensory qualities of ten Moroccan apricot clones at two maturity stages (M1: commercial stage and M2: consumption stage). Sucrose (1.84–7.09 g/100 g of fresh weight (FW)) and citric acid (0.56–2.25 g/100 g FW) were the main sugar and organic acid in fresh apricots, respectively. The principal identified volatile compounds classes were aldehydes, alcohols, and acetates. The major apricot volatile compounds, hexanal (15.43–696.35 $\mu\text{g}/\text{kg}$ FW), 2-hexenal (9.04–404.72 $\mu\text{g}/\text{kg}$ FW), β -linalool (8.49–880.50 $\mu\text{g}/\text{kg}$ FW), and 1-hexanol (3.35–86.00 $\mu\text{g}/\text{kg}$ FW), were previously reported to be major contributors to apricot flavor. Multivariate analysis revealed a significant impact of the ripening stage on the perception of sensory quality related to biochemical parameters. At the commercial stage, apricots were more firm and acidic, characterized by herbaceous odor and high citric acid level, while at the consumption stage, fruits were sweeter, having high reducing sugars (glucose and fructose) contents, and characterized by floral, fruity, and apricot flavors. Among suggested cultivars as suitable for consumption as fruits, red clones (“Cg 2” and “Mans 15”) and orange clones (“Marouch 16,” “Ab 5,” “Rtil 4” and “Marouch 4”) showed very interesting sensory attributes, aroma, and sugar-acid balance, expressing a good overall quality of apricot fruits.

1. Introduction

Apricot was considered in the Mediterranean’s countries as one of the most delicious temperate fruits, characterized by strong fruity aroma and a good taste based on high soluble sugars and reasonable organic acids that are considered as major determinants of the quality of the fruits [1]. Research programs were, thus, focused on improving the flavor of apricots regarding important roles played by the organic acids and soluble sugars in fruit [1, 2]. A better taste for apricot has been associated with an increase in the soluble sugar content [3], with sucrose as the main soluble sugar in the fruit [2].

In the case of fleshy fruit such as apricot fruit, alongside agronomic aspects (regularity of yields, vigor of trees,

resistance or tolerance to diseases, size, and color of fruit), internal fruit quality and appreciation of consumers are criteria taken into account earlier in the selection process. Therefore, the establishment of sensory profiles by panelists is a powerful tool for characterization of the different genotypes of apricot [4]. It allows good, relevant, and simple information by comparison to the instrumental methods of measuring firmness, sugar content, and acidity [5] and also allows evaluating other characteristics such as juiciness, flavor, and other taste attributes. Moreover, sensory ratings of fruit by panelists and biochemical measurements of fruit properties are useful methods in the evaluation of fruit quality [2, 6].

Previous studies have reported that sugars and organic acids contents play an important role in fruit taste through

the sugar/acid ratio [7–9]. Moreover, apricot quality consists of a balance of sugar and acidity, as well as a strong apricot aroma [10, 11]. So, the knowledge of the qualitative and quantitative compositions of acids and sugars in apricot fruits may prove to be a powerful tool in evaluating fruit maturity and quality [12].

Consumers' interest focuses on the flavor and aroma of apricot. The soluble sugars and organic acids were the most appreciable quality attributes of apricot [13], and they are directly related to the taste of fruit. Sweetness is mostly attributable to mono- and disaccharides, while sourness is linked with organic acids and pH. Sweetness and juiciness are also relevant quality characteristics of apricots [14]. Apricot is also very much appreciated for its pleasant and delicious aroma [15], which contributes to its organoleptic quality. These characteristics are strongly related to the cultivar and ripening stage [16]. Aroma is elicited by volatile compounds which originate from different metabolic pathways such as the fatty acid metabolism, amino acid metabolism, and carbohydrate metabolism [17]. Different proportions of the volatile components determine the overall aroma properties. Aroma also has a powerful impact on fruit quality and with the volatile components being a definitive factor species quality [14]. Moreover, the aroma of apricot is a major quality component that distinguishes the fruit of apricot from other fruits of the same family such as plums and their interspecific hybrids because it is associated with a large number of distinct volatile compounds, such as terpenes, alcohols, lactones, esters, and other C6 compounds (aldehydes and ketones) [14, 18, 19]. In addition, a recent study has also confirmed the importance of the aroma in the quality determination of apricot quality by the consumer, generally showing a direct impact on consumer acceptance [15].

Despite a large number of studies on the characterization of apricot quality, in particular on sugar and organic acid contents [3, 20–22] and volatiles compounds of fruits [18, 19, 23–25], no enough studies have been made to determine if an association exists between sensory criteria, volatile compounds, and sugar-acid balance, especially when they are related to ripening and genotype impacts. This association may represent an important quality parameter of apricot fruits.

To the best of our knowledge, this study is the first which provides data about the biochemical and aromatic compounds composition and sensory profile of Moroccan apricots during fruit ripening. The objectives of this work were as follows: (1) to describe the fruits sensory traits of ten Moroccan apricot clones and to determine their volatile compounds; (2) to analyse some quality criteria, namely, soluble sugars and organic acids contents, and their influence on apricot taste; and (3) to evaluate genotype and ripening stage impacts on apricot sensory and biochemical criteria.

2. Materials and Methods

2.1. Plant Material. The studied plant material included 10 apricot clones named “Boum A2,” “Agdez LG1,” “Marouch

4,” “Ab 5,” “Marouch 16,” “Rtil 4,” “Clone C,” “Mans 15,” “Agdez C2,” and “Cg 2” (Supplementary table 1). These clones were collected from apricot collection in the Saâda experimental field of the Regional Center for Agricultural Research in Marrakesh, National Institute for Agricultural Research, INRA, Morocco (30°21'8.4"N, 9°30'29"W).

The experimental orchard has 184 trees gathered in a collection for a surface of 2 ha. It was planted in 1995 and used for drip irrigation. The trees were planted at a density of 4.5 × 2 m, arranged in 7 columns × 30 rows and managed with standard cultivation practices:

- (i) Organic manure of 40 T/ha
- (ii) Major elements (NPK) equivalent to the annual needs (estimated at: N: 100–150 U/ha, P205: 80–100 U/ha; K20: 150 U/ha)
- (iii) An average size and thinning to adjust the load to the growth potential of the tree

The harvest was started in such a way as to optimize the compromise between optimal maturity favoring the expression of the taste quality of the fruits and the fruits aptitude for preservation in postharvest circuits. The flowering of the apricot tree is between February and March for a harvest between April and May for early cultivars and between May and June for other varieties.

All the clones were harvested at two different maturity stages (M1: commercially ripe and M2: consumption ripe) (Figure 1). For each clone, the ripening stage was based on assessing manually fruit firmness and surface color. The fruit was considered commercially ripe when it reached full size and an intense color (pale-yellow, orange, or red depending on genotype), but the apricot is still firm enough to withstand handling, transport, and storage. At the consumption stage, the fruit is soft and can easily be detached from the tree. It is the fruit dedicated to the local market and for almost immediate consumption (ready to be eaten). After harvest, apricot samples were placed into fruit crates and transferred to the laboratory for the analysis.

2.2. Sensory Analyses. Quantitative descriptive sensory analysis as described in the standard ISO 11035-2009 was performed. The analyses were carried out in the sensory analysis room of the Laboratory of Food Technology and Quality in the INRA, Marrakesh, established in accordance with the general guidelines for premises of sensory evaluation: ISO 8589-2007. The panel training procedure, including the sensory attributes and the scales of measures, was carried out according to a previous study [26]. The sensory profile consists of a list of 17 attributes (Table 1) referring to the appearance, smell, flavor, and texture of the fruits, which were assessed on a linear scale of intensity ranging from 0 to 10 (0 = extremely low intensity, 5 = medium intensity, and 10 = extremely high intensity).

The sensory evaluations were performed according to the published apricot attributes [12, 27, 28]. During each session, two clones were evaluated by sensory panelists according to the 17 attributes and the predefined methods. The evaluation was carried out on 5 fruits per stage of



FIGURE 1: Example of “Marouch 16” clone at two maturity stages (M1: commercially ripe and M2: consumption ripe). (a) M1-Marouch 16. (b) M2-Marouch 16.

TABLE 1: Sensory profile of apricot clones evaluated by panelists.

Sensory criteria	Attribute
Color	Unblush color
	Blush color
	Flesh color
Texture	Hardness
	Skin hardness
	Flesh cohesion
	Crunchy
Odor/flavor	Juiciness
	Herbaceous odor
	Apricot flavor
	Floral flavor
Taste	Sourness
	Sweetness
	Astringency
	Bitterness
	Persistence

maturity per clone, and the order of presentation of the samples was the same for the entire panel (8 panelists).

2.3. Dosage of Soluble Sugars and Organic Acids. Two replicates of 10 fruits for each maturity stage per clone were selected, ground, and kept at -80°C for biochemical analysis, especially soluble sugars, organic acids, and volatile compounds. The dosage was made on frozen crushed samples. For each replicate, 10 ml of distilled water is added to 2.5 g of frozen ground apricot. The preparation is homogenized and centrifuged for 10 min, at 4°C at 9000 g (Hettich 320R, Bäch, Switzerland). The supernatant is recovered after filtration on stamen. The supernatant must be diluted in order to correspond to the concentration range of the enzymatic kits.

Sugars (glucose, fructose, and sucrose) and organic acids (malic and citric acids) were quantified using an enzymatic method with kits for food analysis (R-Biopharm AG, Darmstadt, Germany), especially specific enzymatic test kits for L-malic acid, citric acid, glucose/fructose, and sucrose. Results are expressed in g/kg of fresh weight for sugars and acids. These measurements were performed with a SAFAS FLX-Xenius XM spectrofluorimeter (SAFAS, Monaco) equipped with a SAFAS automatic injection device.

2.4. Dosage of Volatile Compounds

2.4.1. Volatile Sample Preparation and HS-SPME Conditions. Volatile compounds were prepared by HS-SPME (Head space-Solid phase microextraction) using the previous method [19]. For each replicate, 5 g of frozen ground apricot was placed into a 20 mL headspace vial, sealed with a septum and an aluminum cap. $5\ \mu\text{l}$ of 4-nonanol solution at $0.22\ \mu\text{g}/\mu\text{l}$ was also added as an internal standard.

The SPME technique in the head space mode was used for the extraction of volatile compounds. The sampling was performed in an automated mode using the autosampler (TriPlus RSH autosampler, Thermo Scientific, USA) equipped with the $75\ \mu\text{m}$ Carboxen/Polydimethylsiloxane (CAR/PDMS) fiber from Supelco (Bellefonte, PA, USA). The fiber was preconditioned before the analysis, according to the instructions of the manufacturer. The sample was preheated to 40°C for 10 min for equilibration, and volatile compounds were extracted by exposing the SPME fiber to the headspace of the sample vial that was maintained at the same temperature for 30 min. The analytes were desorbed for 3 min from the fiber into the GC injector set at 250°C in the split mode (1 : 5).

2.4.2. GC-MS Conditions. Sample analyses were performed using a GC-MS System ISQ™ LT Single Quadrupole (Thermo Scientific, USA), equipped with a TriPlus RSH autosampler to automate SPME and a TGWAX-MS Column ($30\ \text{m} \times 0.25\ \text{mm} \times 0.5\ \mu\text{m}$). The mass spectrometer was operated in the electron ionization (EI) mode at the ionization voltage of 70 eV in the mass range of 31–210 m/z at a scan rate of 0.2 scan/s, with the transfer line and ionization source temperature of 250°C . The GC oven temperature program consisted of 40°C for 2 min (desorption period), $40\text{--}70^{\circ}\text{C}$ at $5^{\circ}\text{C}/\text{min}$, 70°C for 1 min, and $70\text{--}230^{\circ}\text{C}$ for 30 min at $10^{\circ}\text{C}/\text{min}$.

Helium was used as a carrier gas with a constant column flow rate of 1 ml/min. The identification of the volatile compounds was carried out comparing mass spectral data with those of the NIST 2014 library. The Refractive Index (RI) values were also compared with those described in the literature and determined under the same conditions for matching the volatile compounds. The individual volatile compounds (identified and unidentified peaks) were

tentatively quantified based on their peak areas relative to that of the internal standard (4-nonanol). Two analyses were performed for each sample. The results are expressed as 4-nonanol equivalent in $\mu\text{g}/\text{kg}$ of fresh weight.

2.5. Statistical Analysis. Statistical analyses were performed using the software package XLSTAT statistical software version 2011. The data were tested for differences between the clones using the one-way analysis of variance (ANOVA). The method used to discriminate among means (multiple range tests) was Fisher's least significant difference (LSD) procedure at 95.0% confidence level. Data parameters of each apricot clone were analyzed by means of multivariate analysis employing principal component analysis (PCA) and hierarchical cluster analysis. The analytical reproducibility of the obtained data was determined as pooled standard deviations (Pooled SD). This statistical parameter was calculated for each series of replicates per variable using the sum of individual variances weighted by the individual degrees of freedom.

3. Results and Discussion

3.1. Sensory Profiles. The apricot sensory data for each maturity stage are presented in Tables 2 and 3. An important variability was found between sensory attributes related to clones and maturity stages. Among apricot clones, significant differences were observed between the studied variables except for hardness, crunchiness, bitterness, astringency, and sourness for the M1 stage and flesh cohesion, herbaceous odor, bitterness, astringency, and acidity persistence for the M2 stage. Christen et al. [27] have also reported that bitterness and acidity persistence not allowed differentiating significantly between apricot varieties during the sensory measurements.

The evaluation by panel experts proved that apricot clones in the M2 stage had good characteristics for fresh consumption because of the high intensities of key attributes, especially fruity flavor (9.33) and sweetness (8.67) registered for "Cg 2." Regarding both the maturity stages (M1 and M2), different patterns were found, and different attributes levels were obtained for the studied apricot clones. Indeed, the ripening had a marked impact on the sensory characteristics of apricots. The sensory scores of lightness, skin hardness, hardness, bitterness, astringency, herbaceous odor, crunchiness, sourness, and persistence were higher in the M1 stage for all apricot clones (Table 2), while those of blush color, flesh color, juiciness, sweetness, apricot flavor, fruity flavor, and floral flavor were higher in the M2 stage (Table 3).

Blush color, skin hardness, fruity flavor, and sweetness were the attributes that best explain the difference between the studied clones (Figure 1). Comparing the results of both maturity stages, it was noticed that the M2 stage was the most appropriate stage for consumption of apricots compared to the commercial stage (M1). It has been characterized with high attributes of flavors and taste. It was, then, the best stage to show the qualitative potential of the studied

apricot clones. Indeed, at the M2 stage, regarding flavor notes, all studied clones showed a good apricot flavor (>5). The same profile was found for fruity flavor and a little different for floral flavor (<5) for "Boum A2," "Agdez LG1," and "Marouch 4." Regarding sweetness, an evolution of this criteria with skin color has been noticed (except for "Boum A2"), knowing that red clones, especially "Cg 2" was the sweetest, followed by orange clones and pale-yellow ones. However, the opposite was observed for sourness note, knowing that the pale-yellow apricots were sourer while the "Cg 2" had low note. In addition, for all clones, the M1 stage was characterized by high levels of sourness comparing to M2.

Among the studied apricots, "Cg 2" was the most appreciated clone, followed by "Marouch 16" and "Agdez C2" (Figure 2). They were highly aromatic, very tasteful, and had a balanced level of acidity and sweetness. But, in general, sensory data proved that all apricot clones are characterized by interesting quality attributes and they are appropriate for fresh consumption. This heterogeneity of the various sensory attributes may have its explanations on the biochemical properties of the apricot fruit related to genotype.

3.2. Soluble Sugars and Organic Acids Contents. The multivariate analysis revealed that, for both stages of maturity, soluble sugars and organic acids of the ten apricot clones are significantly different ($p \leq 0.05$).

The sugars and organic acids contents of the studied apricot clones are given in Figure 3. The three known soluble sugars of the apricot fruit have been quantified. The amounts of sucrose, glucose, and fructose depended on clone and the ripening stage. Sucrose was reported as a predominant soluble sugar in apricot followed by glucose and fructose [9, 12]. Le Bourvellec et al. [29] have reported recently that sucrose was the main sugar in fresh apricots ranging from 37 to 77% FW of total sugars, followed by glucose (13–33% FW) and fructose (9–39% FW). Fairly similar proportions were observed with the ten studied clones for sucrose (29–89%), glucose (4–49%), and fructose (6–22%) depending on clones and maturity stages, the highest in sucrose content being the lowest in glucose and fructose contents. The sugar concentrations are comparable and fairly in accordance with other studies [30–33] which reported concentration ranging from 1.2 to 11.7 g/100 g FW for sucrose, 0.6 to 5.46 g/100 g FW for glucose, and from 0.1 to 4.42 g/100 g FW for fructose.

Concerning organic acids, the major ones are malic and citric acids (Figure 3), in agreement with other studies [3, 22, 34–36]. The contents were in the concentration ranges reported previously [3] (citric acid: 1.2–21.6 and malic acid: 3.5–16.7 g/kg of FW) and on a large variability [31] (maturity stage and clones) (citric: 0.1–26.6 and malic: 0–20.2 g/kg of FW). The citric acid ranges were in agreement with the results found by Ayour et al. [22]. However, differences have been observed in the content of malic acid compared to this previous study [22]. This is probably due to the year impact on fruit acidity and the effect of the used method in each study (HPLC and enzymatic method). Several studies have indicated the importance of a relatively high organic acids content for a

TABLE 2: Sensorial descriptive analysis mean scores of ten apricot clones at the commercial ripe stage (M1).

M1	Unblush color	Blush color	Hardness	Skin hardness	Flesh cohesion	Flesh color	Herbaceous odor	Apricot flavor	Fruity flavor	Floral flavor	Juiciness	Crunchiness	Sweetness	Bitterness	Astringency	Sourness	Persistence
Marouch 16	4.17 ^{bc}	6.00 ^c	5.33 ^{ab}	6.00 ^{ab}	7.65 ^{ab}	7.17 ^a	4.17 ^{ab}	7.00 ^{ab}	7.50 ^{ab}	6.01 ^{abc}	4.61 ^{ab}	3.70 ^b	5.91 ^{abc}	1.21 ^{ab}	1.00 ^{abc}	3.50 ^{ab}	2.31 ^{abc}
Marouch 4	3.57 ^{cd}	6.83 ^{bc}	6.00 ^a	3.58 ^d	8.37 ^a	6.67 ^{ab}	3.33 ^{bc}	6.33 ^{abc}	6.33 ^{bcd}	3.83 ^{de}	5.08 ^{ab}	4.21 ^{ab}	5.65 ^{bc}	0.81 ^b	1.51 ^a	3.52 ^{ab}	2.58 ^{abcd}
Mans15	3.67 ^{cd}	7.17 ^b	7.00 ^a	6.69 ^a	5.61 ^d	5.70 ^c	4.33 ^{ab}	5.50 ^{bc}	5.33 ^{cde}	5.21 ^{bcd}	1.84 ^d	6.33 ^a	6.32 ^{ab}	1.25 ^{ab}	0.35 ^{bc}	3.81 ^a	1.30 ^{bcd}
Agdez C2	4.80 ^{abc}	5.60 ^d	5.60 ^{ab}	3.80 ^d	7.80 ^{ab}	6.40 ^{ab}	4.60 ^{ab}	6.20 ^{abc}	6.80 ^{bc}	6.25 ^{ab}	5.05 ^{ab}	3.82 ^b	4.77 ^{bc}	0.81 ^b	0.61 ^{abc}	3.53 ^{ab}	2.81 ^{ab}
RTI1 4	4.67 ^{bc}	6.00 ^c	6.67 ^a	5.83 ^{ab}	8.27 ^a	6.83 ^{ab}	4.17 ^{ab}	5.19 ^{bc}	4.83 ^{de}	3.19 ^c	2.21 ^{cd}	4.51 ^{ab}	4.17 ^c	0.47 ^b	1.31 ^{ab}	3.47 ^{ab}	2.85 ^{ab}
Cg 2	2.33 ^d	8.00 ^a	5.00 ^{ab}	4.67 ^{cd}	6.44 ^{cd}	7.00 ^c	2.71 ^c	8.00 ^a	8.53 ^a	7.48 ^a	4.68 ^{ab}	4.66 ^b	7.73 ^a	0.50 ^b	0.00 ^c	2.51 ^c	0.60 ^d
Clone C	5.50 ^{ab}	5.83 ^d	5.83 ^a	3.68 ^d	6.61 ^{bcd}	5.50 ^c	4.67 ^{ab}	4.31 ^c	5.18 ^{de}	4.61 ^{bcd}	5.43 ^a	3.31 ^b	3.85 ^c	0.81 ^b	1.03 ^{abc}	3.83 ^a	3.16 ^a
Boum A2	6.33 ^a	5.17 ^d	6.00 ^a	5.00 ^c	7.17 ^{abc}	3.71 ^d	5.50 ^a	4.57 ^c	4.66 ^{de}	3.30 ^f	4.19 ^{abc}	3.35 ^b	4.72 ^{bc}	2.04 ^a	1.34 ^{ab}	4.03 ^a	1.00 ^{cd}
Ab 5	4.50 ^{bc}	5.50 ^d	5.33 ^{ab}	5.60 ^{ab}	6.51 ^{cd}	5.83 ^c	3.00 ^{bc}	5.73 ^{bc}	5.67 ^{cde}	5.31 ^{bcd}	3.02 ^{bcd}	4.20 ^{ab}	5.18 ^{bc}	0.84 ^b	0.32 ^{bc}	2.65 ^c	1.00 ^{cd}
Agdez LG1	3.50 ^{cd}	6.50 ^{bc}	3.50 ^b	5.50 ^{ab}	7.83 ^a	6.67 ^{ab}	4.33 ^{ab}	4.31 ^c	4.30 ^e	4.29 ^{cde}	2.77 ^{bcd}	4.00 ^{ab}	4.18 ^c	0.61 ^b	1.53 ^a	3.05 ^b	2.00 ^{abcd}
Pooled SD	2.4	3.6	3.2	3.7	2.3	3.1	2.2	2.8	2.5	3.0	2.0	1.9	2.3	0.8	0.8	1.6	1.4

Each value is the mean of 40 replicates for fresh apricot. Means with same letters within the same column do not differ significantly according to Fisher's LSD test at $p < 0.05$. Pooled SD: pooled standard deviation.

TABLE 3: Sensorial descriptive analysis mean scores of ten apricot clones at the consumption ripe stage (M2).

M2	Unblush color	Blush color	Hardness	Skin hardness	Flesh cohesion	Flesh color	Flesh color	Herbaceous odor	Apricot flavor	Fruity flavor	Floral flavor	Juiciness	Crunchiness	Sweetness	Bitterness	Astringency	Sourness	Persistence
Agdez C2	3.56 ^{bcd}	6.72 ^{bc}	4.43 ^b	2.71 ^d	8.00 ^b	6.45 ^{bc}	3.34 ^{ab}	3.34 ^{ab}	8.11 ^{abc}	8.40 ^{ab}	7.30 ^b	6.67 ^a	2.31 ^{bc}	5.31 ^{cd}	0.39 ^{ab}	0.35 ^{ab}	2.74 ^a	2.23 ^a
Marouch 16	3.66 ^{bcd}	6.61 ^{bc}	3.33 ^{bc}	5.00 ^b	7.33 ^{ab}	7.58 ^{ab}	3.00 ^{ab}	3.00 ^{ab}	8.23 ^{ab}	8.25 ^{ab}	6.74 ^{bc}	6.26 ^a	2.33 ^{bc}	7.08 ^{abc}	0.40 ^{ab}	0.43 ^b	2.30 ^{ab}	1.46 ^{ab}
Marouch 4	2.67 ^{cde}	7.33 ^b	4.00 ^{bc}	2.47 ^d	7.60 ^a	7.01 ^{abc}	2.41 ^{bc}	8.05 ^{abc}	8.05 ^{abc}	7.77 ^{bc}	4.57 ^d	7.10 ^a	2.70 ^b	7.43 ^{ab}	0.68 ^{ab}	1.00 ^a	2.35 ^{ab}	1.06 ^{ab}
RTil 4	4.00 ^{bc}	6.62 ^{bc}	4.67 ^b	4.39 ^{bc}	7.67 ^a	7.69 ^{ab}	3.07 ^{ab}	3.07 ^{ab}	7.00 ^{bcd}	6.25 ^{cd}	5.04 ^d	3.39 ^b	2.60 ^b	6.06 ^{cd}	0.29 ^{ab}	1.00 ^a	2.39 ^{ab}	1.69 ^{ab}
Mans15	3.00 ^{bcd}	7.23 ^b	6.61 ^a	6.00 ^a	5.63 ^b	6.39 ^{bc}	3.35 ^{ab}	3.35 ^{ab}	6.23 ^{bc}	6.31 ^{cd}	6.31 ^{bc}	3.00 ^b	5.00 ^a	7.24 ^{ab}	1.30 ^a	0.00 ^b	2.22 ^{ab}	0.42 ^b
Boum A2	5.61 ^a	5.43 ^c	4.63 ^b	3.29 ^{cd}	7.30 ^{ab}	3.60 ^d	4.00 ^a	4.00 ^a	6.65 ^{cde}	6.66 ^c	4.63 ^d	6.54 ^a	1.05 ^c	7.30 ^{ab}	0.35 ^{ab}	0.33 ^{ab}	2.30 ^{ab}	0.65 ^b
Cg 2	1.33 ^c	9.33 ^a	3.77 ^{bc}	3.31 ^{cd}	6.23 ^{ab}	7.61 ^{ab}	1.23 ^c	1.23 ^c	8.47 ^a	9.33 ^a	8.61 ^a	6.43 ^a	2.61 ^b	8.67 ^a	0.00 ^b	0.00 ^b	1.79 ^b	0.31 ^b
Clone C	4.33 ^{ab}	6.31 ^{bc}	4.24 ^b	2.57 ^d	6.27 ^{bc}	6.47 ^{bc}	3.32 ^{ab}	3.32 ^{ab}	5.30 ^c	6.43 ^{cd}	6.32 ^{bc}	6.48 ^a	1.35 ^{bc}	5.00 ^d	0.29 ^{ab}	0.00 ^b	2.35 ^{ab}	1.67 ^{ab}
Ab 5	3.70 ^{bcd}	6.67 ^{bc}	3.30 ^{bc}	4.61 ^{abc}	6.19 ^{ab}	6.33 ^c	2.40 ^{bc}	2.40 ^{bc}	6.61 ^{cde}	6.23 ^{cd}	5.67 ^{cd}	3.65 ^b	2.67 ^b	6.51 ^{bcd}	0.35 ^{ab}	0.00 ^b	1.60 ^b	0.40 ^b
Agdez LG1	2.34 ^{de}	7.30 ^b	2.55 ^c	3.44 ^{bcd}	7.67 ^a	8.00 ^a	2.59 ^{abc}	2.59 ^{abc}	5.33 ^c	5.00 ^d	4.60 ^d	3.61 ^b	2.45 ^{bc}	5.55 ^{cd}	0.00 ^b	0.61 ^{ab}	1.00 ^c	0.41 ^b
Pooled SD	2.7	2.6	1.8	2.2	1.7	3.2	2.9	2.9	3.1	2.2	1.7	3.0	2.7	2.4	0.8	0.5	1.2	1.1

Each value is the mean of 40 replicates for fresh apricot. Means with same letters within the same column do not differ significantly according to Fisher's LSD test at $p < 0.05$. Pooled SD: pooled standard deviation.

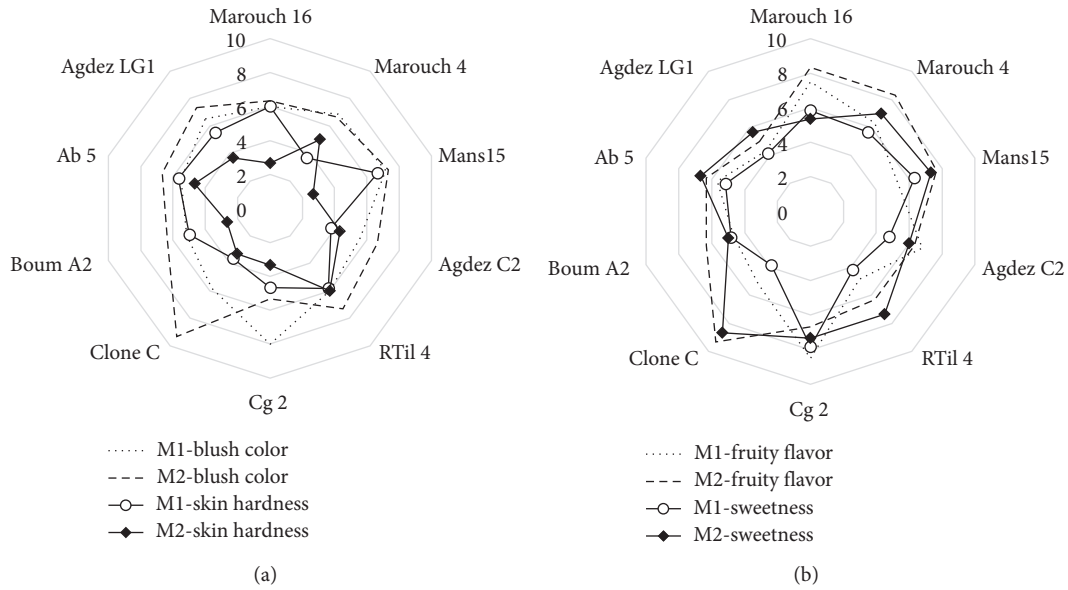


FIGURE 2: Main sensory attributes differentiating between clones at the commercial maturity (M1) and consumption (M2) stages.

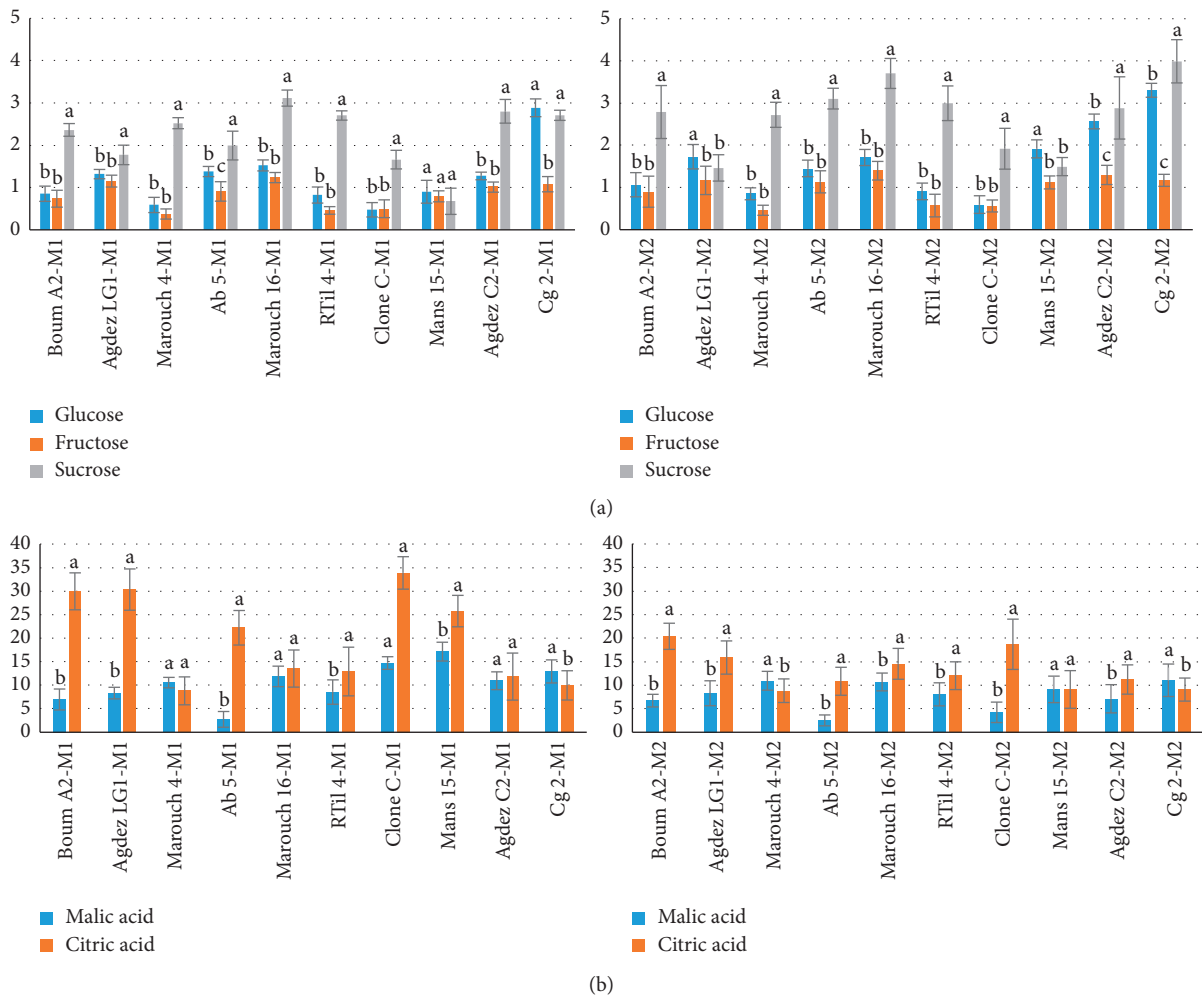


FIGURE 3: Soluble sugars and organic acid contents of ten apricot clones at commercial ripe (M1) and consumption ripe (M2) stages. The error bars represent the standard deviation of each replicate per maturity stage per clone. The means with same letters do not differ significantly according to Fisher's LSD test at $p < 0.05$. (a) Sugars (g/100 g of fresh weight). (b) Organic acids (meq/100 g fresh weight).

balanced fruit taste and attractive freshness; particularly, cultivars with high contents of citric acid are highly appreciated [37]. The taste can be described as comprised of five primary components: sweet, salty, sour, bitter, and umami [38]. Indeed, a balanced taste needed a balance between these five components whose organic acids content play a main role. Organic acids content helps to this balance as a function of pH, as well as several factors associated with other acids such as concentration, total acidity, and quantity of undisociated acids. This shows that the organic acid content is important to keep the taste balance and any lack of acid influences the organoleptic quality of fruit [39]. Dolenc-Sturm et al. [12] have shown that, in sensory evaluations of fruits, sugars and organic acids, as well as their ratios, could be decisive in the quality of apricot taste.

In this study, citric acid was predominant for 8 apricot clones over 10 at the commercial stage (M2). For the ripest fruits, citric acid remains highly predominant for 4 clones ("Boum A2," "Clone C," "Agdez LG1," and "Ab 5"), malic acid being the major acid for red clones ("Mans 15" and "Cg 2") and "Marouch 4." The perception of citric acid was higher than that of malic acid. Containing three ionizable hydrogens per molecule, the citric acid is known for a bright, tart flavor that dissipates quickly with ripening. This acid pairs well with fruit flavors, especially citrus [40]. However, the malic acid is known for its smooth tartness and lingering sourness, works well with high intensity sweeteners, as its lingering sourness balances prolonged sweet tastes. Also, it is known for the ability to enhance fruit flavors [40].

For most studied clones, it is observed that the concentration of organic acids tends to decrease and the sugar content increases with maturity. However, these trends were weak compared with the study of Ayouf et al. [22] and with other previous studies [28, 41]. Indeed, we observed a weak ripening effect on biochemical composition of apricots by comparing with the clone effect which was predominant especially on the organic acids ($p \leq 0.001$).

3.3. Volatile Compounds. The volatile compounds identified in the studied apricot clones and their concentrations for commercial and consumption stages are listed in Tables 4 and 5, respectively. Twenty-five volatile compounds, including 10 aldehydes, 4 ketones, 7 alcohols, 4 acetates, and one acid, were identified. These classes were the most detected in previous studies on apricot fruits [14, 19, 42]. The major apricot volatile compounds identified in this study (hexanal, 2-hexenal, β -linalool, and 1-hexanol) were previously reported to be the major contributors to apricot aroma [30, 43], which include ethanol, hexanal, hexyl acetate, (Z)-3-hexenyl acetate, (E)-2-hexenyl acetate, 1-hexanol, (Z)-3-hexenol, and (E)-2-hexen-1-ol [44–47].

The volatile profiles indicated qualitative and quantitative differences ($p \leq 0.05$) among clones but no specific relation with the ripening stage. Among these compounds, 10 compounds could contribute to discriminate apricot clones, namely, methyl acetate, ethanol, 1-penten-3-ol, 2-hexen-1-ol acetate, 6-methyl-5-hepten-2-one, 1-hexanol, 2-hexen-1-ol, β -linalool, β -cyclocitral, and β -ionone.

Highest concentrations were found for hexanal in both M1 and M2 stages. A previous study reported that hexanal and 2-hexenal are abundant in Turkish apricots where they are the major aldehydes. The concentration of hexanal in some of these cultivars varied from 28.4 to 1475.3 $\mu\text{g}/\text{kg}$ FW [19]. In another study [23], a concentration of 22.00 $\mu\text{g}/\text{kg}$ FW was found for the same compound in apricot. The concentration of identified aldehydes in this study was considerably higher and depended strongly on the clone. For benzaldehyde, it has been reported as the main component of essential oil in Japanese apricots [46].

β -Linalool, 1-hexanol, and 2-hexen-1-ol were the most abundant alcohols (Table 4), which is in accordance with preceding studies [19, 23, 44]. It has been reported that alcohols vary from 123.10 to 938.20 $\mu\text{g}/\text{kg}$ in apricot [19]. Other studies reported that among alcoholic structures including mainly six carbons, butanol [14], (Z)-3-Hexenol [47], (E)-2-Hexen-1-ol [23, 47], linalool [14, 44, 47], and 1-hexanol [44], the compounds 1-hexanol, (Z)-3-hexenol, and (E)-2-hexen-1-ol were present at high concentrations in all cultivars.

The ketones represent the third volatile compounds group. Among these ketones, 3-hydroxy-2-butanone was the most abundant. These results are in agreement with those reported by Ndomo et al. [48]; they have also reported that 3-hydroxy-2-butanone is responsible for the creamy flavor and used as a flavoring agent in some industrial preparation. However, in other previous studies [14, 19, 44], β -ionone and 6-methyl-5-hepten-2-one, which are also detected in this study, have been reported as the most dominant volatile components of fresh apricot. 6-Methyl-5-hepten-2-one and beta-ionone are characterized by the floral aroma [44]. Four acetate esters were found in low concentrations compared to the literature such as 853.10 $\mu\text{g}/\text{kg}$ FW which was recorded in apricot by Gokbulut and Karabulut [19]. The most abundant ester was the methyl acetate, and it is one of the volatiles that discriminated the apricot clones. It has been described as contributors of the fruity characteristic according to the same authors [19].

Compared to the other classes of volatiles compounds, the acids group had the lowest abundance, which is in agreement with other studies [19, 48], and was only represented by acetic acid. Similar concentrations were reported [19]. Although, it was previously reported [45] that acetic acid was the most abundant among the 31 important volatile compounds of fresh apricots.

Based on volatiles quantification results, among all apricot clones, "Agdez C2," "Ab 5," "Cg 2," and "Mans 15" were determined with the highest concentration levels in both the maturity stages. However, compared to the literature, most studied apricot clones are rich in aromatic compounds according to their volatile compound contents at two different stages of maturity.

3.4. Correlations between Sensory Perception and Biochemical Traits. The comparison between sensory attributes, organic acids, and soluble sugars showed significant correlations. Two groups of sensory characteristics were identified: a first group of positively correlated attributes

TABLE 4: Concentration (in $\mu\text{g}/\text{kg}$ of fresh weight) of volatile compounds identified in ten apricot clones at the commercial ripe stage (M1).

Volatile compounds	RI	"Mans 15"	"Cg 2"	"Ab 5"	"Agdez C2"	"Marouch 4"	"Rtil 4"	"Clone C"	"Marouch 16"	"Agdez LG1"	"Boum A2"
<i>Aldehydes (9)</i>											
Acetaldehyde	831	143.2 ± 24.3 ^a	150.5 ± 46.8 ^a	119.5 ± 26.0 ^a	22.6 ± 5.3 ^b	145.2 ± 30.3 ^a	184.3 ± 43.1 ^a	187.4 ± 35.2 ^a	105.2 ± 19 ^a	91.4 ± 17.3 ^{ab}	57.7 ± 11.8 ^b
Hexanal	1102	398.2 ± 66.5 ^b	147.7 ± 27.3 ^d	417.7 ± 51.3 ^a	n.d.	182.3 ± 22.6 ^d	90.2 ± 11.9 ^c	282.7 ± 30.1 ^c	87.2 ± 10.5 ^c	125.3 ± 11.3 ^d	83.5 ± 11.6 ^c
Pentanal	1153	97.0 ± 20.4 ^{ab}	69.8 ± 14.5 ^b	32.5 ± 7.6 ^b	110.4 ± 23.6 ^a	111.8 ± 19.3 ^a	98.7 ± 24.6 ^{ab}	131.7 ± 34.6 ^a	46.9 ± 12.5 ^b	137.6 ± 34.6 ^a	25.5 ± 9.5 ^b
2-Hexenal	1249	321.3 ± 45.6 ^a	106.5 ± 20.5 ^b	345.6 ± 50.1 ^a	92.6 ± 34.7 ^{bc}	64.6 ± 17.8 ^c	56.0 ± 18.9 ^c	71.2 ± 27.6 ^c	31.7 ± 12.1 ^c	12.7 ± 6.5 ^c	49.8 ± 15.5 ^c
Butanal-2-methyl	1257	15.1 ± 7.8 ^b	n.d.	30.2 ± 10.1 ^b	n.d.	24.6 ± 7.6 ^b	89.8 ± 22.7 ^a	7.4 ± 2.8 ^b	28.8 ± 15.6 ^b	17.0 ± 4.6 ^b	16.2 ± 7.0 ^b
Butanal-3-methyl	1267	30.9 ± 12.2 ^b	82.0 ± 20.5 ^a	17.1 ± 7.6 ^b	n.d.	14.1 ± 5.5 ^b	n.d.	n.d.	13.4 ± 3.9 ^b	4.8 ± 1.1 ^b	18.7 ± 7.7 ^b
Benzaldehyde-4-methyl	1288	13.8 ± 4.5 ^b	36.2 ± 10.5 ^a	66.8 ± 18.8 ^a	17.3 ± 3.6 ^b	65.7 ± 17.7 ^a	8.4 ± 2.5 ^b	13.5 ± 3.7 ^b	6.8 ± 1.7 ^b	4.1 ± 0.8 ^b	n.d.
Benzaldehyde	1536	40.5 ± 10.6 ^b	136.9 ± 30.2 ^a	139.9 ± 23.6 ^a	43.0 ± 11.7 ^b	90.0 ± 23.0 ^{ab}	40.0 ± 11.7 ^b	33.6 ± 15.5 ^b	13.5 ± 3.8 ^b	n.d.	n.d.
β -Cyclocitral	1651	23.9 ± 7.7 ^{ab}	32.5 ± 8.0 ^a	76.7 ± 23.8 ^a	11.3 ± 1.7 ^b	38.6 ± 11.0 ^a	13.2 ± 3.9 ^b	22.5 ± 7.8 ^{ab}	21.2 ± 3.7 ^{ab}	16.5 ± 4.3 ^b	27.6 ± 7.7 ^{ab}
<i>Ketones (4)</i>											
2-Propanone	866	18.0 ± 7.8 ^d	217.9 ± 43.8 ^a	13.5 ± 3.2 ^d	13.3 ± 3.6 ^d	2.2 ± 0.7 ^d	14.4 ± 6.5 ^d	104.5 ± 25.5 ^b	5.03 ± 1.1 ^d	251.9 ± 77.9 ^a	60.2 ± 22.2 ^c
β -Ionone	1973	23.9 ± 7.2 ^b	32.5 ± 8.9 ^b	76.7 ± 22.6 ^a	14.3 ± 6.4 ^b	38.6 ± 12.3 ^b	13.2 ± 5.4 ^b	22.5 ± 6.7 ^b	21.2 ± 7.1 ^b	16.5 ± 4.7 ^b	27.6 ± 10.5 ^b
6-Methyl-5-hepten-2-one	1982	2.9 ± 0.6 ^a	n.d.	5.9 ± 2.7 ^a	n.d.	11.8 ± 5.5 ^a	2.4 ± 0.8 ^a	2.3 ± 0.7 ^a	4.4 ± 0.7 ^a	n.d.	1.1 ± 0.1 ^a
3-Hydroxybutanone	1998	75.8 ± 20.0 ^b	6.9 ± 1.7 ^c	7.2 ± 2.4 ^c	74.7 ± 11.7 ^b	7.8 ± 1.9 ^c	177.4 ± 65.8 ^a	7.9 ± 3.0 ^c	8.3 ± 2.7 ^c	3.3 ± 1.6 ^c	2.1 ± 0.5 ^c
γ -Decalactone	2134	12 ± 27.0 ^a	168.0 ± 31.1 ^a	111.0 ± 39.2 ^a	105.0 ± 26.7 ^a	102.0 ± 32.9 ^a	138.0 ± 40.0 ^a	87.0 ± 22.1 ^b	153.0 ± 61.0 ^a	123.0 ± 44.0 ^a	n.d.
<i>Alcohols (7)</i>											
Ethanol	955	323.8 ± 44.7 ^a	93.7 ± 12.0 ^{bc}	33.1 ± 8.7 ^c	80.2 ± 28.7 ^{bc}	n.d.	150.9 ± 38.2 ^b	161.2 ± 33.2 ^b	70.1 ± 18.9 ^c	43.3 ± 17.1 ^c	71.6 ± 27.9 ^c
1-Butanol	1115	30.4 ± 12.6 ^a	12.1 ± 1.4 ^a	25.2 ± 9.1 ^a	58.1 ± 17.2 ^a	28.7 ± 13.2 ^a	16.8 ± 4.6 ^a	22.2 ± 7.7 ^a	34.0 ± 11.0 ^a	21.1 ± 7.1 ^a	3.1 ± 1.8 ^a
1-Penten-3-ol	1156	13.6 ± 3.5 ^a	n.d.	n.d.	n.d.	6.7 ± 2.7 ^a	4.3 ± 1.2 ^a	n.d.	n.d.	n.d.	n.d.
1-Hexanol	1207	48.5 ± 14.5 ^a	41.0 ± 10.1 ^a	10.2 ± 1.2 ^a	33.2 ± 6.9 ^a	3.8 ± 0.8 ^a	47.2 ± 11.5 ^a	4.8 ± 0.7 ^a	6.2 ± 1.6 ^a	n.d.	3.3 ± 1.7 ^a
2-Hexen-1-ol	1367	56.2 ± 21.0 ^a	21.7 ± 8.9 ^a	16.4 ± 4.9 ^a	58.7 ± 16.8 ^a	7.5 ± 2.6 ^a	21.5 ± 5.4 ^a	17.2 ± 2.5 ^a	5.6 ± 2.1 ^a	n.d.	6.2 ± 3.1 ^a
β -Linalool	1432	63.5 ± 17.9 ^c	217.0 ± 90.1 ^c	880.5 ± 153.7 ^a	60.0 ± 17.9 ^c	351.3 ± 61.1 ^b	100.1 ± 20.0 ^d	31.2 ± 6.2 ^c	9.2 ± 2.1 ^c	40.1 ± 11.7 ^e	95.2 ± 24.9 ^d
1-Butanol-2-methyl	1444	31.4 ± 5.7 ^a	n.d.	n.d.	38.6 ± 8.8 ^a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
<i>Acetates (4)</i>											
Methyl acetate	912	68.9 ± 12.5 ^a	80.7 ± 21.2 ^a	46.0 ± 8.3 ^b	46.0 ± 11.8 ^b	46.3 ± 13.8 ^b	74.5 ± 15.8 ^a	28.5 ± 8.5 ^b	30.8 ± 6.0 ^b	n.d.	12.9 ± 4.2 ^b
Butylacetate	1165	16.1 ± 7.9 ^b	n.d.	n.d.	63.7 ± 17.7 ^a	n.d.	n.d.	n.d.	22.8 ± 7.9 ^b	30.5 ± 12.1 ^b	n.d.
3-Hexen-1-ol acetate	1287	56.9 ± 17.0 ^a	9.1 ± 1.9 ^b	7.1 ± 2.1 ^b	29.5 ± 5.7 ^b	4.0 ± 1.7 ^b	3.1 ± 1.2 ^b	4.5 ± 2.1 ^b	n.d.	n.d.	2.8 ± 0.2 ^b
2-Hexen-1-ol acetate	1331	66.3 ± 12.4 ^a	33.7 ± 6.9 ^b	n.d.	33.3 ± 12.1 ^b	n.d.	7.6 ± 3.3 ^b	n.d.	n.d.	n.d.	n.d.
<i>Acids (1)</i>											
Acetic acid	1478	54.4 ± 12.5 ^b	57.5 ± 15.9 ^b	63.9 ± 15.0 ^b	112.2 ± 37.8 ^a	68.9 ± 15.8 ^b	29.9 ± 12.1 ^b	65.7 ± 15.7 ^b	28.5 ± 7.9 ^b	53.3 ± 15.2 ^b	16.3 ± 3.5 ^b

Values are means ± standard deviation (SD) of two replicates of 10 fruits for each maturity stage (M1 and M2) per clone. n.d.: not detected. Means with same letters within the same line do not differ significantly according to Fisher's LSD test at $p < 0.05$.

TABLE 5: Concentration (in $\mu\text{g}/\text{kg}$ of fresh weight) of volatile compounds identified in ten apricot clones at the consumption ripe stage (M2).

Volatile compounds	RI	"Mans 15"	"Cg 2"	"Ab 5"	"Agdez C2"	"Marouch 4"	"Rtil 4"	"Clone C"	"Marouch 16"	"Agdez LG1"	"Boum A2"
<i>Aldehydes (9)</i>											
Acetaldehyde	831	99.8 ± 16.5 ^b	208.4 ± 28.2 ^a	98.2 ± 12.1 ^b	141.3 ± 38.2 ^b	133.4 ± 20.1 ^b	229.0 ± 32.4 ^a	180.0 ± 30.2 ^{ab}	154.4 ± 31.2 ^b	122.0 ± 17.5 ^b	31.6 ± 7.4 ^c
Hexanal	1102	124.3 ± 23.5 ^d	201.5 ± 33.3 ^c	696.3 ± 77.8 ^a	203.0 ± 37.5 ^c	490.8 ± 44.3 ^b	190.1 ± 39.2 ^d	158.8 ± 29.9 ^d	15.4 ± 3.5 ^c	93.7 ± 11.1 ^{de}	110.2 ± 20.4 ^d
Pentanal	1153	522.5 ± 70.1 ^a	78.5 ± 26.4 ^c	164.0 ± 40.3 ^b	117.4 ± 25.5 ^b	12.0 ± 3.5 ^d	107.6 ± 24.6 ^b	76.8 ± 11.5 ^c	61.4 ± 21.5 ^c	33.8 ± 10.6 ^d	69.1 ± 18.5 ^c
2-Hexenal	1249	102.2 ± 34.5 ^b	135.9 ± 31.7 ^b	404.7 ± 61.5 ^a	46.3 ± 18.0 ^c	422.0 ± 82.3 ^a	78.7 ± 22.6 ^c	43.8 ± 14.9 ^c	9.0 ± 4.5 ^c	51.1 ± 18.7 ^c	23.0 ± 8.5 ^c
Butanal-2-methyl	1257	19.6 ± 8.6 ^a	n.d.	2.5 ± 0.7 ^a	n.d.	24.3 ± 8.3a	16.3 ± 6.8 ^a	14.8 ± 5.1 ^a	n.d.	20.4 ± 4.6 ^a	22.7 ± 7.9 ^a
Butanal-3-methyl	1267	6.7 ± 1.4 ^b	107.9 ± 26.7 ^a	n.d.	n.d.	6.8 ± 2.2 ^b	8.9 ± 1.6 ^b	n.d.	18.9 ± 5.5 ^b	3.1 ± 0.6 ^b	7.5 ± 0.8 ^b
Benzaldehyde-4-methyl	1288	14.7 ± 3.5 ^a	47.8 ± 15.6 ^a	34.4 ± 11.8 ^a	33.3 ± 11.4 ^a	30.5 ± 9.9 ^a	20.4 ± 4.4 ^a	10.9 ± 2.6 ^a	18.2 ± 6.1 ^a	2.0 ± 0.2 ^a	9.0 ± 1.7 ^a
Benzaldehyde	1536	55.9 ± 21.5 ^b	189.0 ± 38.1 ^a	27.8 ± 3.7 ^b	82.6 ± 18.9 ^b	70.7 ± 11.5 ^b	49.8 ± 12.5 ^b	27.5 ± 10.6 ^b	54.3 ± 16.9 ^b	n.d.	n.d.
β -Cyclocitral	1651	n.d.	20.6 ± 3.7 ^a	27.7 ± 11.5 ^a	16.4 ± 3.9 ^a	58.8 ± 23.7 ^a	21.7 ± 5.7 ^a	17.5 ± 4.7 ^a	n.d.	32.2 ± 7.9 ^a	21.4 ± 8.2 ^a
<i>Ketones (4)</i>											
2-Propanone	866	18.7 ± 8.5 ^c	367.7 ± 87.9 ^a	5.5 ± 1.4 ^c	124.2 ± 40.1 ^b	32.2 ± 7.5 ^c	5.6 ± 2.3 ^c	29.2 ± 11.1 ^c	5.6 ± 2.0 ^c	119.4 ± 44.4 ^b	74.8 ± 13.8 ^c
β -Ionone	1973	n.d.	70.6 ± 27.7 ^a	27.7 ± 11.1 ^a	16.4 ± 3.5 ^a	58.8 ± 14.8 ^a	21.7 ± 7.9 ^a	17.5 ± 5.9 ^a	n.d.	32.2 ± 10.0 ^a	21.4 ± 5.7 ^a
6-Methyl-5-hepten-2-one	1982	14.8 ± 3.8 ^a	n.d.	4.1 ± 1.3 ^a	1.5 ± 0.4 ^a	11.9 ± 5.0 ^a	77.7 ± 20.1 ^a	9.2 ± 2.9 ^a	n.d.	n.d.	n.d.
3-Hydroxybutanone	1998	174.6 ± 38.7 ^b	12.0 ± 2.7 ^c	411.3 ± 99.1 ^a	12.5 ± 5.8 ^c	4.0 ± 1.3 ^c	10.8 ± 3.7 ^c	16.8 ± 4.7 ^c	195.4 ± 22.6 ^b	3.7 ± 1.6 ^c	1.6 ± 0.9 ^c
γ -Decalactone	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
<i>Alcohols (7)</i>											
Ethanol	955	429.7 ± 79.9 ^a	165.2 ± 66.5 ^c	242.0 ± 50.8 ^b	196.1 ± 39.6 ^{bc}	n.d.	253.9 ± 57.9 ^b	283.1 ± 54.1 ^b	402.6 ± 92.7 ^a	41.6 ± 15.0 ^d	183.7 ± 58.9 ^c
1-Butanol	1115	58.4 ± 19.4 ^b	26.1 ± 5.6 ^b	12.8 ± 1.6 ^b	31.9 ± 11.0 ^b	24.3 ± 8.4 ^b	69.8 ± 14.6 ^b	114.0 ± 26.8 ^a	27.5 ± 8.5 ^b	6.5 ± 2.8 ^b	13.2 ± 3.9 ^b
1-Penten-3-ol	1156	n.d.	n.d.	9.9 ± 3.7 ^a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1-Hexanol	1207	81.1 ± 22.2 ^a	61.5 ± 11.5 ^a	86.0 ± 20.0 ^a	n.d.	9.2 ± 2.6 ^b	n.d.	19.5 ± 3.1 ^b	68.7 ± 12.5 ^a	n.d.	n.d.
2-Hexen-1-ol	1367	40.0 ± 12.1 ^b	17.7 ± 2.8 ^b	63.9 ± 15.8 ^a	17.4 ± 12.5 ^b	23.2 ± 3.9 ^b	4.1 ± 0.7 ^b	8.7 ± 2.8 ^b	22.6 ± 4.6 ^b	4.8 ± 1.9 ^b	n.d.
β -Linalool	1432	8.5 ± 1.7 ^d	283.5 ± 80.2 ^b	78.2 ± 21.9 ^d	25.7 ± 7.1 ^d	728.4 ± 169.2 ^a	221.1 ± 41.9 ^b	15.8 ± 3.7 ^d	49.9 ± 13.9 ^d	236.6 ± 42.0 ^b	112.0 ± 30.0 ^c
1-Butanol-2-methyl	1444	146.4 ± 49.2 ^a	n.d.	n.d.	n.d.	n.d.	n.d.	52.0 ± 13.7 ^b	n.d.	n.d.	n.d.
<i>Acetates (4)</i>											
Methyl acetate	912	115.9 ± 27.2 ^a	35.5 ± 7.4 ^b	38.9 ± 6.9 ^b	53.7 ± 12.0 ^b	35.2 ± 8.2 ^b	49.7 ± 14.9 ^b	46.1 ± 9.7 ^b	101.2 ± 29.2 ^a	21.7 ± 4.9 ^b	10.8 ± 2.6 ^b
Butylacetate	1165	145.7 ± 41.2 ^a	n.d.	n.d.	64.9 ± 8.2 ^b	n.d.	49.0 ± 8.2 ^b	69.3 ± 17.8 ^b	n.d.	n.d.	19.1 ± 2.7 ^b
3-Hexen-1-ol acetate	1287	156.8 ± 30.2 ^a	6.3 ± 2.4 ^b	46.7 ± 12.7 ^b	9.5 ± 2.3 ^b	3.3 ± 0.7 ^b	5.3 ± 2.2 ^b	n.d.	4.2 ± 1.1 ^b	3.8 ± 0.7 ^b	n.d.
2-Hexen-1-ol acetate	1331	71.3 ± 21.9 ^a	48.3 ± 11.0 ^b	38.6 ± 11.1 ^b	11.5 ± 3.3 ^c	4.1 ± 0.7 ^c	n.d.	n.d.	6.4 ± 2.6 ^c	n.d.	n.d.
<i>Acids (1)</i>											
Acetic acid	1478	56.5 ± 11.6 ^b	63.8 ± 12.8 ^b	121.8 ± 18.5 ^a	64.6 ± 10.5 ^b	54.2 ± 8.2 ^b	49.4 ± 15.0 ^b	47.4 ± 10.2 ^b	53.4 ± 18.1 ^b	20.6 ± 5.2 ^b	37.0 ± 8.9 ^b

Values are means ± standard deviation (SD) of two replicates of 10 fruits for each maturity stage (M1 and M2) per clone. n.d.: not detected. Means with same letters within the same line do not differ significantly according to Fisher's LSD test at $p < 0.05$.

consisting of lightness, firmness, sourness, bitterness, astringency, herbaceous odor, crunchiness, and acidity persistence and a second group of correlated attributes constituted by blush color, sweetness, apricot flavor, fruity flavor, floral flavor, and juiciness. However, both the groups are negatively correlated.

In addition, good correlations appeared between some sensory attributes and the biochemical measurements, especially between color attributes and reducing sugars (glucose and fructose). The first group of attributes (named the sour group) was negatively correlated with glucose and fructose, positively correlated with citric acid, and vice versa for some attributes of group 2 (named sweet group) which were positively correlated with soluble sugars (glucose and fructose) and negatively with organic acids, especially citric acid. These results are consistent with a previous study which showed that perceptions of sugar and acidity interfered heavily in apricots. In fact, the more firm an apricot is, the more acidic it will be considered and slightly sweet, which depends on ripening and genotype impacts. It has also been shown that the perception of sweet taste depends not only on the soluble sugars content but also on acidity and firmness of apricot fruit [49]. Too much firmness is, therefore, inappropriate because consumers are primarily looking for sweetness, flavor, and fondant criteria [50]. This balanced relationship between the sugar and acid contents is very important on the quality of apricot fruits, as it was already reported in previous studies [22, 51, 52]. It made it possible to highlight all the sensory attributes and to discriminate apricots organoleptic quality.

In relation with the evolution of radars maps between the two maturity stages, a very strong effect of the ripening stage was observed noticed with the strongest correlations: positive between the three color attributes, the sweetness, and the juiciness and negative with the texture criteria (strongly correlated with each other). These correlations explain the processes of the loss of firmness and, therefore, the softening of the fruit, the degradation of chlorophylls, the accumulation of carotenes, and the increase of sugars during maturation. Moreover, the three tested flavors (apricot, fruity, and floral) were positively correlated with each other and negatively correlated with the herbaceous flavor, which is explained by the evolution of the aroma during the maturity.

Principal component analysis was performed between studied variables. The observed variability of 53.82% was explained by the first two principal components (F1 and F2) (Figure 4). F1 explains 31.74% of total variance, it opposed the sensory attributes that described the fruit in stage M1, namely, firmness, sourness, crispness, bitterness, astringency, unblush color, herbaceous odor, and malic and citric acids, from those that associated to stage M2, namely, sweetness, apricot, fruit and floral flavors, blush color, juiciness, and soluble sugars. The component F1, thus, highlights sensory attributes and volatiles associated to fruit maturity. Positive correlations (Figure 4(a)) were found between the sensory attributes of stage M2 and β -cyclocitral ($R=0.658$), β -ionone ($R=0.765$), butanal-3-methyl ($R=0.544$), and acetaldehyde ($R=0.500$). The attributes of

the M1 stage were correlated with 2-hexenol ($R=0.507$) and 1-hexanol ($R=0.495$). A previous study reported that β -ionone significantly increases during fruit ripening correlated with sucrose and sweetness flavor, and it appears to be the key characteristic flavor factor contributing to consumer acceptance [53]. Moreover, β -ionone contributes to the flower and fruity notes of apricot, and it was reported negatively correlated with hexanal, which imparts green and grassy aromas and sourness [54]. The maturity stage affected the concentrations of aldehyde compounds (which decrease with ripening), especially the hexanal. The sample map (Figure 4(b)) discriminated the maturity stages along the F1 axis. At the M1 stage, apricots were firmer and acidic, characterized by herbaceous odor, and were rich in aldehydes and alcohols, especially 2-hexenol and 1-hexanol. At stage M2, fruits were sweeter, rich in sugars, characterized by floral fruit and apricot flavors, and were correlated especially with β -ionone, β -cyclocitral, butanal-3-methyl, and acetaldehyde.

However, most volatile compounds were better discriminated by the F2, which opposed 2-hexenol ($R=0.777$) and 1-hexanol ($R=0.830$) to butanal-2-methyl ($R=-0.566$) and benzaldehyde-4-methyl ($R=-0.515$). In terms of samples, F2 was mostly defined by the clone Agdez C2 at the M1 stage, which had a volatile fingerprint different from all other apricots, with high acetic acid and acetate esters, pentanal, or 1-hexanol. Hexanal ($R=0.647$), 2-hexenal ($R=0.763$), 2-hexenol acetate ($R=0.528$), and benzaldehyde ($R=0.512$) were better represented on the F3 (data not shown).

The apricot samples were harvested at different time intervals depending on the degree of ripening (M1: commercial and M2: consumption). In fact, the factorial representation of the sensory profile depends to the concentrations of volatile compounds which also depend on a series of physical and biochemical changes during maturation [19]. Nevertheless, an impact of the genotype seems so important, such as the volatile compositions of apricot cultivars growing under the same conditions turned out to be considerably different. The differentiations in volatile compositions and sensory profiles of apricot fruits were also reported in data from previous studies [14, 19, 44, 47].

Regarding apricot clones, the orange (especially "Ab 5," "Marouch 4," and "Marouch 16") and the red ones ("Mans 15," "Cg 2") are most rich in volatile compounds in both maturity stages. "Ab 5" was rich in apricot flavors and characterized with a balance of volatile compounds (qualitatively and quantitatively). "Cg 2" is characterized by a good acid-sugar balance regarding its composition in soluble sugars and organic acids. Also, "Cg 2" represents the genotype least affected by maturation, and this shows a sensory quality of this clone that could be the issue of fruit valuation for a longer maturation period of apricots.

Gokbulut and Karabulut [19] also reported that the apricot sensory profile depends on a series of physical and biochemical changes during maturation. The differentiations in aroma composition and sensory profiles of apricot genotypes fruits were also reported previously [19, 44, 47]. Regarding apricot clones, the red apricots, especially "Cg 2" and orange ones (especially "Ab 5" and "Marouch 16"), were characterized by

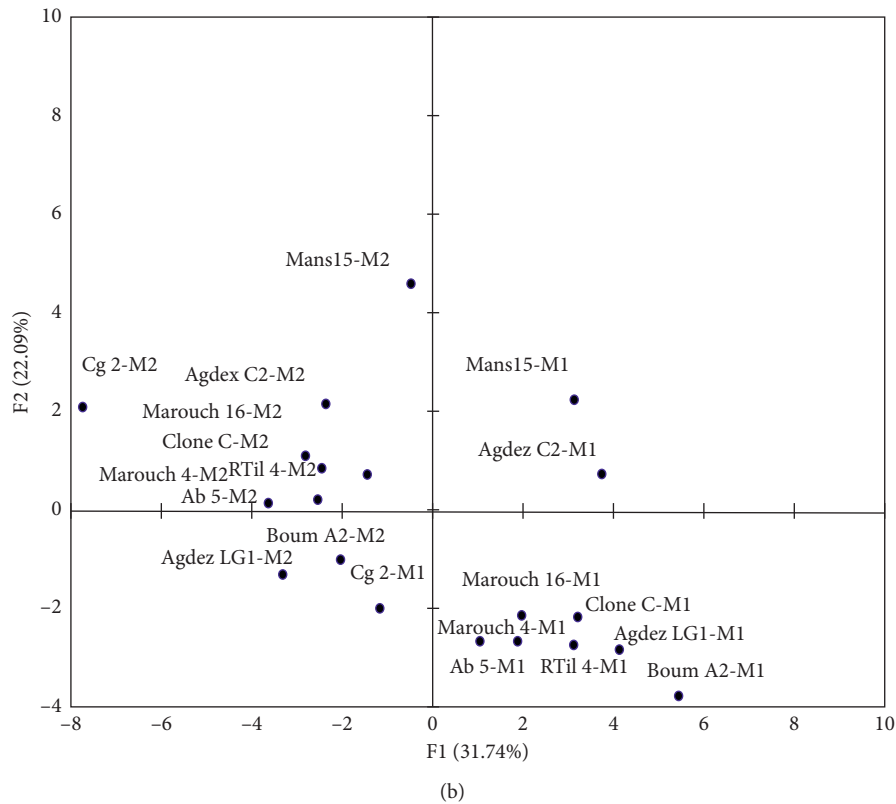
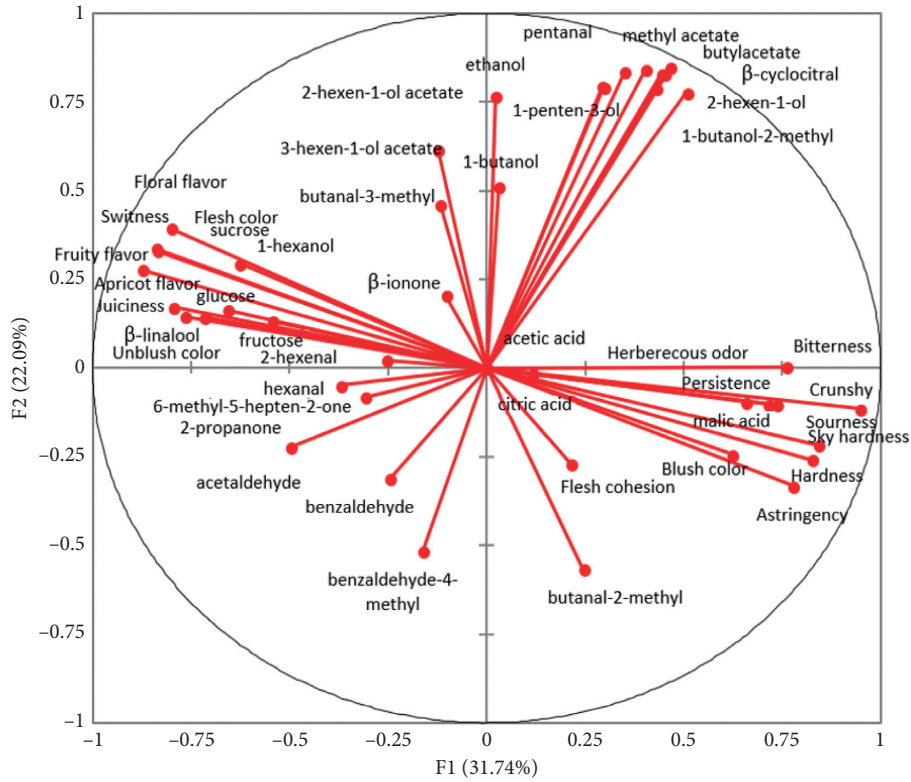


FIGURE 4: Principal component analysis (PCA) of volatile compounds and the sensory profile of apricot clones. (a) Correlation circle of sensory attributes, soluble sugars, organic acids, and volatile compounds. (b) Segregation of the apricot clones based on the studied parameters depending on maturity stages (M1: commercial ripe; M2: consumption ripe).

good organoleptic quality, with “Cg 2” as the most floral one. “Ab 5,” “Marouch 4,” “Agdez C2,” and “Rtil 4” were characterized with good sensory attributes for the M2 stage and were rich in apricot flavors. Moreover, “Cg 2” was characterized by a good acid-sugar balance regarding its composition in soluble sugars and organic acids in both maturity stages. It represents the genotype least affected by maturation. This shows a sensory quality of this clone that could be a subject of fruit valuation for a longer maturation period. Gokbulut and Karabulut [19] also reported that the apricot sensory profile depends on a series of physical and biochemical changes during maturation. The differentiations in aroma composition and sensory profiles of apricot genotypes fruits were also reported previously [19, 44, 47]. Regarding apricot clones, the red apricots, especially “Cg 2” and orange ones (especially “Ab 5” and “Marouch 16”), were characterized by good organoleptic quality, with “Cg 2” as the most floral one. “Ab 5,” “Marouch 4,” “Agdez C2,” and “Rtil 4” were characterized with good sensory attributes for the M2 stage and were rich in apricot flavors. Moreover, “Cg 2” was characterized by a good acid-sugar balance regarding its composition in soluble sugars and organic acids in both maturity stages. It represents the genotype least affected by maturation. This shows a sensory quality of this clone that could be a subject of fruit valuation for a longer maturation period.

4. Conclusions

For a tasty fruit like apricot, quality is defined by the perception of several criteria broken down and dissected using sensory and biochemical indicators. The ten studied Moroccan clones have very promising and interesting sugars and organic acids contents and sensory profiles, leading to reasonably good overall fruit quality. This study also highlighted that soluble sugars and organic acids are important biochemical parameters for the sensory perception of apricot fruit. The principal component analysis revealed that the maturity stage has a significant impact in determining the perception of sensory quality related to biochemical parameters. Red apricots were among the recommended cultivars for the cultivation and for apricots consumption as fruits, especially “Cg 2” which was considered the most flavorful and aromatic clone, followed by “Marouch 4,” “Agdez C2,” “Mans 15,” “Ab 5,” and “Rtil 4” which were characterized with good sensory attributes at the consumption stage (M2). In addition, all clones were characterized in this study by very interesting sensory attributes and sugar-acid balances expressing a good overall quality of the fruits. The excellent quality properties of these clones, as well as the criteria associated with the ripening stages, certainly represent valuable genetic characteristics for extending the harvesting season of good quality apricots in Morocco and in all Mediterranean regions.

Data Availability

The data (experiences, analyses, and results) used to support the findings of this study are included within the article and in other published articles. A prior study was cited at

relevant places within the text as reference [22], and other articles are available at https://www.researchgate.net/scientific-contributions/2110738085_Jamal_Ayour.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Supplementary Materials

Supplementary TABLE 1: morphological characteristics of the studied ten apricot clones. (*Supplementary Materials*)

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