

Article

Physicochemical, Volatile, and Sensory Characterization of Promising Cherry Tomato (*Solanum lycopersicum* L.) Cultivars: Fresh Market Aptitudes of Pear and Round Fruits

Julio Pérez-Marín ^{1,†}, Hanán Issa-Issa ^{2,†}, Jesús Clemente-Villalba ², José Miguel García-Garvía ², Francisca Hernández ³, Ángel A. Carbonell-Barrachina ², Ángel Calín-Sánchez ^{1,2} and Luis Noguera-Artiaga ^{2,*}

¹ Centro Integrado de Formación y Experiencias Agrarias de Jumilla (CIFE de Jumilla), Department of Agricultural Activities, Av. Ingeniero de la Cierva S/N, 30520 Jumilla, Murcia, Spain; julio.perez@murciaeduca.es (J.P.-M.); angel.calin@murciaeduca.es (Á.C.-S.)

² Research Group “Food Quality and Safety”, Department of Agro-Food Technology, Escuela Politécnica Superior de Orihuela (EPSO), Universidad Miguel Hernández de Elche (UMH), Ctra. Beniel, km 3.2, 03312 Orihuela, Alicante, Spain; hissa@umh.es (H.I.-I.); jesus.clemente@hotmail.com (J.C.-V.); jose.ggarvi@umh.es (J.M.G.-G.); angel.carbonell@umh.es (Á.A.C.-B.)

³ Research Group “Plant Production and Technology”, Department of Plant Science and Microbiology, Escuela Politécnica Superior de Orihuela (EPSO), Universidad Miguel Hernández de Elche (UMH), Ctra. Beniel, km 3.2, 03312 Orihuela, Alicante, Spain; francisca.hernandez@umh.es

* Correspondence: lnoguera@umh.es

† These authors contribute equal to work.



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Abstract: Tomato (*Solanum lycopersicum* L.) is a well-known plant that belongs to the Solanaceae family. It is a widely consumed vegetable, either fresh or industrially processed. The aim of this study was to characterize and compare the morphology, main physicochemical parameters, volatile composition, and sensory quality of 8 cherry tomato cultivars: 4 pear cherry tomatoes (Angelle, Seychelles, Santyplum, and Dolcetini) and 4 round cherry tomatoes (Katalina, Sweet star, C-95, and Karelya) to be able to replace the most popular ones in markets (Angelle and Katalina). Morphological parameters had significant differences among cultivars, while in terms of total soluble solids and titratable acidity, Dolcetini could be an interesting substitute of Angelle in pear cherry cultivars, while in round ones C-95 would be the closest one. Regarding sugars, Santyplum was probably the cultivar which could be placed into a similar place to Angelle, while in round ones, C-95 was probably the cultivar closest to Katalina. Santyplum, Seychelles (pear type), and C-95 (round type) are likely to be the most interesting cherry cultivars in providing a real alternative to the most cultivated ones, in terms of volatile profile and concentration of the main volatile compounds. Descriptive sensory analysis revealed that Seychelles cultivar in 9 of the 15 attributes under study could be considered as the most similar cultivar to replace Angelle, while in round types no clear and direct relationship was found with any cultivar. Finally, consumers reported similar values for Angelle and Seychelles pear type cultivars, while round ones did not show significant differences. In summary, it can be stated that Seychelles and C-95 are the best alternatives of pear and round cherry cultivars, respectively, as compared to the reference cultivars, Angelle and Katalina.

Keywords: *Lycopersicum esculentum*; titratable acidity; GC-MS; color; total soluble solids

1. Introduction

In 2018, tomato (*Solanum lycopersicum* L.) was the 10th crop in production in the world, Spain being the 8th world producer with a production of ~5,000,000 t [1].

The official standards for the commercialization of tomato in the world are established by Codex Alimentarius, Codex Stan 293-2008 [2]. In this standard, the types of tomatoes,

minimum quality requirements, categories according to quality, sizes, homogeneity, packaging, labeling, contaminants, and hygiene are detailed. It is important to determine physical quality parameters such as color, size, weight, and shape to understand the first approach of consumers towards tomatoes on the marketplace [3]; however, chemical parameters such as total soluble solid content (TSS), volatile, sugar, and organic acid profiles can influence consumer acceptability and fidelity to the type and brand of tomatoes they first approach by their appearance [4,5]. Today, consumers also want to consume tomatoes because of their beneficial effects on the human body, mainly linked to their high contents of mineral elements (K and P), vitamin C, and their antioxidant potential properties. The antioxidant capacity of tomatoes is mainly due to their lycopene content; this compound is a natural carotenoid responsible for their red color and represents ~80% of tomato pigments [6,7].

Currently, one of the most important tomato varieties is *Solanum lycopersicum* var. *cerasiforme*, which are known as cherry or cocktail tomatoes. The most peculiar characteristic of these fruits is their small size and that they are a one-bite-fruit. The best-selling cultivars of this type of tomatoes are Katalina (round-ones) and Angelle (pear-ones), characterized by their intense flavor and with high consumer acceptance. Studies comparing cherry with large-size tomatoes have shown that the former have higher contents of both sugars and organic acids, leading to a more intense tomato flavor. Moreover, cherry tomatoes also had higher contents of organic volatile compounds which clearly contributed to a more intense odor and aroma [8].

Previous studies revealed that some of the fundamental factors of the commercialization of tomatoes are related to volatile compounds, organic acids, and sugars [4,9]. Even the sugar content has been related to the better acceptability for the tomato consumer [10]. Taking advantage of the new drying technologies, a study was carried out relating these techniques to tomato flavor [11]. All these studies demonstrate that there is a lack of studies regarding the sensory analysis of cherry tomatoes in relation to the food field.

The aim of this study was to characterize and compare 8 cultivars of cherry tomatoes (4 pear or teardrop and 4 round cherry cultivars) to be able to decide which ones are similar and could replace the most popular ones in markets (Angelle (pear-ones) and Katalina (round-ones)). Morphology, color, titratable acidity, total soluble solids, sugars, organic acids, and volatile compounds were measured and analyzed, and sensory evaluation was carried out by both trained panelists and consumers to prove if the shape has an influence on the physico-chemical and sensory parameters of cherry tomatoes.

2. Materials and Methods

2.1. Plant Material

A total of 8 cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) cultivars were analyzed. Based on the shape, 4 cultivars belong to pear or teardrop shape (Seychelles, Angelle, Santyplum, and Dolcetini), with the other four belonging to round shapes (Katalina, Karelya, C-95, and Sweet star). Fruits of the 8 cherry tomato cultivars were collected (commercial ripening stage) from a commercial plantation, located at Los Arejos, Águilas, Murcia, Spain (37°27'17.2'' N 1°40'31.8'' W and 285 m above sea level). These cultivars were kindly provided by Looije S.L. The commercial plantation is cultivated under homogeneous conditions. Fruit harvest was conducted on the 19th of June 2019 and 2020 (the factor "year" did not significantly affect any of the main quality traits reported in Table 1, thus, results are reported as the average of the two years). Ten kilograms of each variety were selected and picked according to the optimal ripening stage and avoiding injured fruits to prevent skewing of results. After picking, fruits were immediately transported to the laboratory. All analyses were conducted within the 4 days after harvesting, except volatile compositions that were analyzed as soon as possible but in frozen material stored at −18 °C.

Table 1. Morphology, color, total soluble solids (TSS), titratable acidity (TA), sugars, and organic acids in cherry tomatoes as affected by cultivar for pear and round fruits.

Attributes	ANOVA †	Pear Cherry Tomatoes				ANOVA †	Round Cherry Tomatoes			
		Angelle	Seychelles	Santyplum	Dolcetini		Katalina	Sweet Star	C-95	Karelya
Eq. diameter (mm)	***	27.2 b ‡	22.2 c	22.5 c	29.1 a	NS	28.7	28.5	29.2	30.0
Long. diameter (mm)	*	37.9 a	35.8 b	37.3 ab	37.6 ab	*	27.4 b	28.5 ab	28.4 ab	29.2 a
Shape index (mm)	***	1.39 c	1.58 b	1.66 a	1.29 d	NS	0.95	1.00	0.97	0.97
Weight (g)	***	10.8 b	11.4 b	16.6 a	17.2 a	***	15.5 a	13.7 b	14.6 b	14.5 b
Color										
<i>L</i> *	*	38.4 b	38.7 b	39.4 ab	40.8 a	*	41.5 a	38.8 b	39.2 b	38.2 b
<i>a</i> *	***	18.9 b	22.5 a	22.2 a	17.3 c	***	18.4 a	15.6 c	14.2 d	17.4 b
<i>b</i> *	***	18.8 c	18.8 c	19.9 b	21.7 a	***	22.6 a	18.9 b	19.8 b	18.9 b
<i>C</i> *	***	26.7 b	29.3 a	29.8 a	27.8 b	***	29.2 a	24.5 b	24.4 b	25.7 b
<i>H</i>	***	44.8 b	39.9 c	41.9 c	51.5 a	***	51.0 b	50.6 b	54.3 a	47.3 c
TSS (°Brix)	***	9.42 a	8.56 b	7.68 c	8.48 b	*	8.88 ab	8.94 a	8.52 ab	8.46 b
TA (g citric acid kg ⁻¹ dw)	***	1.09 a	1.10 a	0.94 c	1.02 b	***	1.08 c	1.15 b	1.08 c	1.30 a
Sugars (g kg ⁻¹ dw)										
Glucose	**	37.0 b	34.9 c	36.7 bc	39.0 a	***	38.0 a	37.5 a	34.8 b	38.7 a
Fructose	***	13.5 c	16.1 b	15.3 b	17.2 a	***	14.3 b	17.1 a	14.4 b	12.7 c
Sorbitol	***	7.5 c	8.7 b	8.7 b	10.7 a	***	8.1 b	9.6 a	8.4 b	7.0 c
Organic acids (g kg ⁻¹ dw)										
Citric acid	***	1.2 b	1.1 c	1.2 b	1.4 a	***	1.7 c	1.8 b	1.9 a	1.5 d

†, *, **, ***, significant at $p < 0.05$, 0.01, and 0.001, respectively. ‡ Values (mean of 50, 25 and 5 replications for the morphological parameters, color, and sugars and organic acids, respectively) followed by the same letter, within the same row and tomato shape (pear or round), were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

2.2. Morphology and Color

Size and equatorial and longitudinal diameters of each tomato were measured using a digital caliper (model 500-197-20 150 mm; Mitutoyo Corp., Aurora, IL, USA). The weight was measured using a Mettler Toledo scale, model AG204 (Barcelona, Spain) with a precision of 0.1 mg. The color was measured using a Minolta colorimeter, model CR-300 (Osaka, Japan) with an illuminant D65 and an observer of 10°. Color data were provided as CIEL*a*b* coordinates. Analyses were run with 50 replications ($n = 50$).

2.3. Titratable Acidity and Total Soluble Solids

Total soluble solids (TSS) were measured with a digital Atago refractometer (model N-20; Atago, Bellevue, WA, USA) at 20 °C with values being expressed as °Brix. The titratable acidity (TA) and pH were determined by acid–base potentiometer (877 Titrino plus; Metrohm ion analyses CH9101, Herisau, Switzerland), using 0.1 N NaOH up to pH 8.1; values were expressed as g citric acid L⁻¹. Analyses were run with 25 replications ($n = 25$).

2.4. Determination of Sugars and Organic Acids

Sugars and organic acids were measured using the method previously described by Hernández et al. [12], with slight modifications. One gram of sample (obtained from ten grounded tomatoes) was mixed with phosphate buffer at pH 7.8, homogenized using Ultra-Turrax™ (IKA L004640, Staufen, Germany) for 1 min, and centrifuged for 10 min at 15,000 rpm. After that, samples were filtered using a 0.45 µm Millipore filter. The extracts were analyzed in a HPLC chromatograph Hewlett-Packard series 1100 (Wilmington, DE, USA). The elution buffer consisted of 0.1% phosphoric acid with a flow rate of 0.5 mL min⁻¹.

Sugars and organic acids were isolated using a Supelco column (Supelcogel™ C-610H column 30 cm × 7.8 mm, Supelco, Inc., Bellefonte, PA, USA) and a precolumn Supelguard (5 cm × 4.6 mm; Supelco) and the absorbance was measured at 210 nm using a diode-array detector (DAD). These same HPLC conditions (elution buffer, flow rate, and column) were used for the analysis of sugars. The detection was conducted using a refractive index detector (RID). Calibration curves were made with standards of sugars (sorbitol, maltitol, raffinose, glucose, fructose, and sucrose) and organic acids (tartaric, citric, oxalic, malic, quinic, shikimic, succinic, and fumaric) obtained from Sigma (Poole, UK) and used to quantify both type of compounds. Analyses were run with five replications ($n = 5$) and results were expressed as g L⁻¹ dw.

2.5. Volatile Compounds

The extraction of the volatile compounds from the tomato samples was carried out using the headspace solid-phase micro-extraction (HS-SPME) method. A sample of 5 g of ground tomatoes was placed on a 50 mL vial with a magnetic bar, with polypropylene caps and a polytetrafluoroethylene/silicone septum. After equilibration time of 5 min at 40 °C, a 30/50 µm fiber of a length of 2 cm (Supelco) consisting of DVB/CAR/PDMS (Divinylbenzene/Carboxen/Polydimethylsiloxane) was exposed to the vial headspace at 40 °C, with continuous agitation (600 rpm) in a magnetic stirrer (IKA C-MAG HS 4, IKA—Werke GmbH & Co. KG, Staufen, Germany). After 50 min of exposure, fiber was introduced into the injector of a gas chromatograph for analysis [13].

The isolation and identification of the volatile compounds were performed using a gas chromatograph, Shimadzu GC-17A (Shimadzu Corporation, Kyoto, Japan), coupled with a Shimadzu mass spectrometer detector (GCMS QP-5050A). The chromatograph was equipped with a column Restek Rxi-1301Sil MS (Restek Corporation, Bellefonte, PA, USA), fused silica, 30 m × 0.25 mm × 0.25 µm film thickness. Analyses were carried out using He as carrier gas at a flow rate of 0.6 mL min⁻¹, a split ratio of 1:5, with scan mode (from 45 m/z to 400 m/z , and scan speed = 1000), and the following program: (a) initial temperature

80 °C; (b) rate of 3.0 °C min⁻¹ up to 210 °C and hold for 1 min; (c) rate of 25 °C min⁻¹ up to 300 °C and hold for 5 min.

The volatile compounds were identified using 3 methods: (i) retention indexes (RI), (ii) GC-MS retention time of the chemical compound, and (iii) comparison of the compound mass spectrum with those of databases (NIST05 and Adams 2012 spectrum library). The retention indexes were calculated using a mix of aliphatic hydrocarbons (Supelco), soluble in methanol and ranging between C-6 and C-22. Analyses were run in triplicate ($n = 3$).

2.6. Descriptive Sensory Analysis

A trained panel consisting of 10 highly trained panelists (aged 26 to 55 years; 5 female) from the research group Food Quality and Safety Group (Universidad Miguel Hernández de Elche, UMH, Orihuela, Alicante, Spain) conducted the descriptive sensory analysis. Each panelist had more than 600 h of experience with different types of food products.

The methodology used for the descriptive sensory analysis was that previously described by Noguera-Artiaga et al. [14], with some modifications. The scale used ranged from 0 (no intensity) to 10 (extremely high intensity) with 0.1 increments. Samples were served in odor-free, disposable 60 mL biodegradable cups at room temperature and were coded using 3-digit numbers. Unsalted crackers and mineral water were provided to panelists to clean their palates between samples. Analyses were run in triplicate ($n = 3$).

2.7. Affective Sensory Analysis (Consumer Panel)

One hundred consumers were recruited at UMH and Centro Integrado de Formación y Experiencias Agrarias de Jumilla (CIFEA, Jumilla, Murcia, Spain), and consisted of 57 men and 43 women aged between 18 and 60 years. The consumer study was carried out in the tasting rooms of UMH. Samples were served in odor-free, disposable 60 cc biodegradable cup at room temperature and were coded using 3-digit numbers; between samples and for palate cleansing, water and unsalted crackers were provided to consumers, together with the proper questionnaire. Consumers were asked about their global satisfaction degree using a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely), together with questions regarding attribute intensity using a Just About Right (JAR) scale. Analyses were run in triplicate ($n = 3$).

2.8. Statistical Analysis of Results

Experimental data were subjected first to the analysis of variance (ANOVA) and later to Tukey's multiple range test to compare the means. Significant differences were defined at $p < 0.05$. Additionally, data of the sensory descriptive analysis were subjected to principal component analysis, penalty analysis, and dendrogram. The software used was XLSTAT (Addinsoft, 2016.02.27444 version, Paris, France).

3. Results and Discussion

3.1. Morphology and Color

The results of equatorial and longitudinal diameter, weight, and parameters of color are shown in Table 1. In the pear type, all the parameters measured had significant differences between cultivars. In equatorial diameter, Dolcetini obtained the highest measure (29.1 mm), and Seychelles and Santyplum were the smallest ones (22.2 and 22.5 mm, respectively). Angelle had an intermediate measure of 27.2 mm. In longitudinal diameter, Angelle, Dolcetini, and Santyplum did not show significant differences with a measure around 37.5 mm. The shape index is the ratio between the longitudinal and equatorial length; in pear fruits, Santyplum had the highest value with 1.66; whilst Angelle obtained a quotient of 1.39, not far off from Dolcetini with 1.29. These shape index results were similar to those reported by Wu et al. [15] in their comparison between the morphology of different fruits, among which were found the round and pear cherry tomatoes. Regarding the weight, there were two different groups; Dolcetini and Santyplum weighed 16 and 17.2 g, respectively, while Angelle and Seychelles 10.8 and 11.4 g, respectively.

Regarding color, in pear cherry cultivars, the L^* parameter (lightness) did not show significant differences, except Dolcetini, the values ranging from 38.4 to 39.4. Angelle had an intermediate value (18.9) of a^* parameter (red/green), lower than Santyplum and Seychelles with values of 22.2 and 22.5, respectively. In the b^* parameter (coordinate yellow/blue), Angelle and Seychelles obtained the lowest value (18.8, both), Dolcetini being with 21.7 the highest value. In C^* (chroma), there were two different groups; on the one hand, Santyplum and Seychelles obtained the highest values (29.8 and 29.3); the other group (Angelle and Dolcetini) had 26.7 and 27.8, respectively. In the H parameter (Hue), Angelle obtained an intermediate value (44.8) showing significant differences to the rest of cultivars.

Regarding round cultivars, equatorial diameter did not show significance differences between cultivars, while in longitudinal diameter Katalina, Sweet star, and C-95 did not have significant differences; however, Katalina showed the lowest value (27.4 mm). With respect to shape index, round cultivars did not show significance differences among cultivars, although these indexes were very similar to the results of Wu, Tao, Ai, Luo, Mao, Ying, and Li [9]. With respect to the weight, Katalina was the heaviest cultivar (15.5 g) compared to the other three round cultivars where no significant differences were found among them. In 4 out of 5 parameters of color (L^* , a^* , b^* and C^*), Katalina obtained the highest values respective to the other cultivars, even showing differences of more than 2 units in some parameters. The only parameter in which Katalina did not obtain the highest value was in H (Hue), with C-95 being the cultivar that obtained the highest value (54.8). Katalina and Sweet star reached intermediate values (51.0 and 50.6, respectively).

3.2. Total Soluble Solids and Titratable Acidity (TSS and TA)

Both pear and round cherry tomatoes had significant differences among cultivars in terms of TSS and TA (Table 1). In pear fruits, Angelle had the highest value (9.42 °Brix), while Santyplum had the lowest one (7.68 °Brix), reporting significant differences with the rest of cultivars. With respect to TA, Angelle and Seychelles showed the highest value in this parameter (1.09 and 1.10 g citric acid kg^{-1} dw, respectively).

In round cherry tomatoes, Sweet star with 8.94 °Brix was above of the rest of round cultivars, although there were no significant differences between Katalina and C-95. In TA, Katalina and C-95 obtained the same value (1.08 g citric acid kg^{-1} dw), lower than Sweet star and Dolcetini. In both pear and round cherry cultivars, the TSS values were slightly lower than those reported by Carillo et al. [16].

In terms of total soluble solids and titratable acidity, Dolcetini could be an interesting substitute for Angelle in pear cherry cultivars, while in round ones, all cultivars were similar to Katalina; however, the cultivar which could be most similar, and the best positioned to replace the most popular one, would be C-95.

3.3. Sugars and Organic Acids

Three sugars were detected in all samples: glucose, fructose, and sorbitol, showing significant differences among cultivars (Table 1). In all cases, the most abundant sugar was glucose, whose concentration was similar between round and pear cultivars [3,17].

In pear cultivars, Dolcetini showed the highest concentration of sugars with significant differences with respect to the other cultivars; therefore, it would not be the optimal cultivar to replace Angelle. Glucose content showed significant differences among pear cherry tomatoes with values ranging from 34.9 g kg^{-1} dw to 39.0 g kg^{-1} dw for Seychelles and Dolcetini, respectively. Regarding fructose, Angelle obtained the lowest value (13.5 g kg^{-1} dw), Santyplum and Seychelles being the closest to this concentration with 15.3 g kg^{-1} dw and 16.1 13.5 g kg^{-1} dw, respectively. Again, Dolcetini cultivar showed the highest content of fructose (17.2 g kg^{-1} dw) as in the case of glucose. The sorbitol concentration in pear cultivars showed very similar trend to fructose, the lowest value being for Angelle (7.5 g kg^{-1} dw), Santyplum and Seychelles showed intermediate content (8.7 g kg^{-1} dw, both), Dolcetini being the cultivar with the highest content of sorbitol.

Santyplum was probably the cultivar in terms of sugar which could be placed into a similar place than Angelle.

Regarding round cultivars, Katalina, Sweet star, and Karelya had very similar concentrations of glucose ($38.0 \text{ g kg}^{-1} \text{ dw}$, $37.5 \text{ g kg}^{-1} \text{ dw}$, and $38.7 \text{ g kg}^{-1} \text{ dw}$, respectively), while the content of fructose of Sweet star had the highest concentration ($17.1 \text{ g kg}^{-1} \text{ dw}$); in this sugar, the most similar variety for Katalina was C-95 ($14.3 \text{ g kg}^{-1} \text{ dw}$ and $14.4 \text{ g kg}^{-1} \text{ dw}$, respectively). Sorbitol was very similar to fructose, Sweet star being the cultivar with the highest concentration ($9.6 \text{ g kg}^{-1} \text{ dw}$). Katalina and C-95 obtained very close results with $8.1 \text{ g kg}^{-1} \text{ dw}$ and $8.4 \text{ g kg}^{-1} \text{ dw}$, respectively. C-95 was probably the cultivar closest to Katalina in sugar terms. On the other hand, only citric acid was found in all cultivars and in both pear and round types, there were significant differences between cultivars.

In pear cherry cultivars, Angelle and Santyplum obtained the same concentration in citric acid ($1.2 \text{ g kg}^{-1} \text{ dw}$), being lower than Dolcetini cultivar which was the one that obtained the highest concentration ($1.4 \text{ g kg}^{-1} \text{ dw}$). In round cherry types, Katalina had an intermediate concentration ($1.7 \text{ g kg}^{-1} \text{ dw}$) between Sweet star and Karelya (1.8 and $1.5 \text{ g kg}^{-1} \text{ dw}$, respectively). These compounds were detected as most concentrated compounds in other cultivars of tomato [18,19].

3.4. Volatile Composition

Table 2 shows the volatile compounds present in 8 cherry tomato cultivars with their respective descriptors. Twenty-five volatile compounds were identified from 5 different families as follows: aldehydes (14), ketones (6), alcohols (3), ethers (1), and thiazoles (1).

Table 3 shows that aldehydes presented a higher percentage in their volatile concentration (e.g., the contents of hexanal and (*E*)-2-heptenal represent between 47–69% of the total volatile compounds) followed by ketones and alcohols. Hexanal was the predominant compound in the aroma profile of cherry tomato cultivars, representing 40.1%, their content being significantly higher in round cultivars (45.2%) as compared to the pear ones (35.0%). These results are consistent with those reported by Alonso et al. [20]; (*E*)-2-hexenal also presented a high concentration in 7 of the 8 cherry tomato cultivars, not including the Dolcetini cultivar (pear type).

In pear cherry cultivars, Angelle and Santyplum reported no significant differences in the concentration of hexanal, with values of 48% and 39.5%, respectively. Hexanal concentration of round cultivars did not show significant differences between Katalina and C-95. Regarding (*E*)-2-hexenal of pear types, Seychelles and Santyplum showed even higher values (24.9% and 27.4%, respectively) as compared to Angelle (16.8%), while in round ones, Karelya and Katalina had the highest values of this compound (19.7% and 15.7%, respectively) (Table 3).

Other volatile compounds with high concentration were:

- 1-Hexanol: pear cherry tomato cultivars: Santyplum (4.13%) and Angelle (4.07%); round cherry tomato cultivars: Katalina (4.55%) and Sweet star (4.39%).
- (*E*)-2-Heptenal: pear cherry tomato cultivars: Dolcetini (6.31%); round cherry tomato cultivars: Sweet star (4.53%) and C95 (4.04%).
- 6-Methyl-5-hepten-2-one: pear cherry tomato cultivars: Dolcetini (4.78%) and Seychelles (4.36%).
- 2-Isobutylthiazole: pear cherry tomato cultivars: Dolcetini (9.72%); round cherry tomato cultivars: Sweet star (7.98%).
- Nonanal: pear cherry tomato cultivars: Dolcetini (5.79%) and Angelle (4.40%); round cherry tomato cultivars: Sweet star (8.36%) and C-95 (5.42%).
- 1-Penten-3-one: pear cherry tomato cultivars: Dolcetini (7.82%).

Table 2. Volatile compounds, retention index, and descriptors in cherry tomatoes as affected by cultivar for pear and round fruits.

Compounds	RT [†] (min)	Chemical Family	KI	Descriptors [‡]
1-Penten-3-one	4.390	Ketone	748	Vegetable, green sweet
Allyl ethyl ether	4.552	Ether	754	Green
2-Methyl-2-butenal	5.649	Aldehyde	792	Green, fruity
2-Pentanal	6.038	Aldehyde	805	Fruity, vanilla, woody
Hexanal	6.907	Aldehyde	836	Fresh, cut grass
(E)-2-Hexenal	9.042	Aldehyde	907	Almond, apple, green, sweet, vegetable, leafy
1-Hexanol	9.328	Alcohol	914	Green, herbaceous, woody, sweet
Heptanal	10.373	Aldehyde	941	Oily, fruity, woody, fatty, nutty
(E)-2-Heptenal	13.290	Aldehyde	1014	Apple, lemon, green, spicy, vegetable
1-Octen-3-one	13.659	Ketone	1022	Cucumber, mushroom, earthy, vegetable
Benzaldehyde	13.807	Aldehyde	1025	Almond, anise, balsam, cherry, floral, herbaceous
6-Methyl-5-hepten-2-one	14.119	Ketone	1032	Oily, herbaceous, green, floral
5-Methyl-2(5H)-furanone	14.494	Ketone	1040	Earthy, green, tobacco, fruity
Octanal	14.809	Aldehyde	1047	Honey, fruity, citrus, fatty
2-Isobutyl thiazole	16.034	Thiazole	1074	Fermented, green
Phenyl acetaldehyde	17.874	Aldehyde	1113	Green, floral
(E)-2-Octenal	18.170	Aldehyde	1119	Spicy, herbaceous, green
Nonanal	19.789	Aldehyde	1153	Apple, coconut, grape, lemon, oily, vegetable, rose
1-Octen-3-ol	21.215	Alcohol	1182	Creamy, earthy, herbaceous, vegetable
Phenylethyl alcohol	21.832	Alcohol	1195	Honey, rose
(Z)-4-Decenal	24.483	Aldehyde	1249	Orange
Decanal	24.928	Aldehyde	1258	Waxy, floral, citrus, sweet
(Z,Z)-2,4-Decadienal	30.463	Aldehyde	1374	Fatty, citrus
Neryl acetone	37.078	Ketone	1519	Fatty
β -Ionone	39.348	Ketone	1571	Floral

[†] RT = retention time; KI = experimental retention index. [‡] Sigma-Aldrich flavor and fragrances.

Table 3. Relative abundance (%) of volatile compounds in cherry tomatoes as affected by cultivar for pear and round fruits.

Compounds	ANOVA †	Pear Cherry Tomatoes				ANOVA	Round Cherry Tomatoes			
		Angelle	Seychelles	Santyplum	Dolcetini		Katalina	Sweet star	C-95	Karelya
1-Penten-3-one	***	1.03 c ‡	2.19 b	2.35 b	7.82 a	***	1.56 a	1.38 a	0.87 b	1.03 b
Allyl ethyl ether	***	0.29 b	0.53 b	0.49 b	11.0 a	**	0.37 b	0.52 a	0.28 b	0.30 b
2-Methyl-2-butenal	***	0.67 b	0.81 b	0.45 b	2.74 a	***	1.27 a	1.18 a	0.23 c	0.74 b
2-Pentanal	***	0.28 b	0.54 b	0.72 b	1.83 a	**	0.65 a	0.47 b	0.18 c	0.42 b
Hexanal	***	48.0 a	32.8 b	39.5 ab	19.61 c	**	52.8 a	32.6 b	53.7 a	41.6 ab
(E)-2-Hexenal	***	16.8 b	24.9 a	27.4 a	0.40 c	**	15.7 ab	14.6 b	13.7 b	19.7 a
1-Hexanol	***	4.07 a	1.68 b	4.13 a	0.65 c	**	4.55 a	4.39 a	2.24 b	2.88 b
Heptanal	***	0.56 b	0.70 b	0.57 b	2.44 a	**	0.29 b	0.73 a	0.53 ab	0.36 b
(E)-2-Heptenal	***	2.77 b	3.03 b	2.08 b	6.31 a	***	2.04 c	4.53 a	4.04 ab	3.19 b
1-Octen-3-one	**	0.62 b	1.03 b	0.43 b	2.34 a	***	0.29 c	2.36 a	1.17 b	0.70 bc
Benzaldehyde	**	1.05 b	2.15 a	1.42 b	1.74 b	**	1.26 b	1.05 b	1.28 b	2.65 a
6-Methyl-5-hepten-2-one	***	2.99 b	4.36 a	3.08 b	4.78 a	**	1.30 b	2.31 a	2.07 ab	1.85 b
5-Methyl-2(5H)-furanone	***	2.49 b	4.60 a	3.17 b	3.50 b	***	2.33 b	2.84 b	2.07 b	4.15 a
Octanal	**	1.97 b	1.89 b	1.51 b	2.23 a	**	1.57 b	2.89 a	1.91 b	1.71 b
2-Isobutyl thiazole	***	1.94 c	4.16 b	1.95 c	9.72 a	***	2.69 b	7.98 a	3.31 b	2.85 b
Phenyl acetaldehyde	***	1.13 b	0.33 c	0.23 c	9.55 a	**	0.51 ab	0.17 b	0.31 b	0.86 a
(E)-2-Octenal	***	2.59 b	4.70 a	2.07 b	2.85 b	***	1.61 c	4.55 a	2.30 b	2.45 b
Nonanal	**	4.40 b	4.13 b	4.09 b	5.79 a	***	4.21 b	8.36 a	5.42 b	4.18 b
1-Octen-3-ol	***	0.66 b	1.03 a	0.82 b	0.17 c	**	0.52 b	0.36 b	0.60 b	1.15 a
Phenylethyl alcohol	***	1.22 a	0.61 b	0.63 b	0.28 c	*	0.39 b	0.10 b	0.41 b	0.78 a
(Z)-4-Decenal	***	0.36 b	0.16 b	0.25 b	2.34 a	*	0.33 b	0.72 a	0.16 b	0.38 b
Decanal	*	0.96 a	0.85 a	0.38 b	0.64 b	**	1.17 b	1.45 ab	1.19 b	1.69 a
(Z,Z)-2,4-Decadienal	**	1.11 a	0.88 b	0.71 b	0.86 b	***	1.40 b	1.84 a	0.41 c	0.50 c
Neryl acetone	***	1.89 a	1.74 ab	1.41 b	0.28 c	**	1.13 b	2.17 ab	1.25 b	2.76 a
β-Ionone	*	0.19 a	0.19 a	0.14 b	0.13 b	***	0.08 c	0.42 b	0.31 b	1.07 a

†, *, **, ***, significant at $p < 0.05$, 0.01, and 0.001, respectively. ‡ Values (mean of 3 replications) followed by the same letter, within the same row and tomato shape (pear or round), were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

These same compounds have been previously reported as the predominant ones in this type of fruit. In addition, their concentrations are reported to increase after tissue breakdown [21].

Therefore, Santyplum, Seychelles (pear type), and C-95 (round type) are likely to be the most interesting cherry cultivars to provide a real alternative to the most cultivated ones in terms of volatile profile and concentration of the main volatile compounds. On the other hand, Dolcetini could be a good option if fruits with a different and more complex aromatic profile are of interest.

3.5. Descriptive Analysis and Principal Components Analysis (PCA)

Fifteen attributes were evaluated: one was related to appearance, six related to the product flavor, and eight about its texture. All the attributes of the descriptive analysis showed significant differences in both pear cherry tomato and round cherry tomato.

In pear cherry cultivars (Table 4), Angelle, Seychelles, and Santyplum did not show significant differences in their appearance (9.2, 9.1, and 8.8, respectively). Regarding the attributes of flavor, a more specifically, sweet flavor, Santyplum showed the highest value (7.6), while between Angelle and Seychelles there were no significant differences (7.2 and 7.1, respectively). In fruity attribute, Angelle showed an intermediate value (6.9), not showing a significant difference between Seychelles and Santyplum (7.1 and 6.7, respectively).

Table 4. Descriptive sensory analysis in pear cherry tomatoes as affected by cultivar.

Attributes	ANOVA †	Angelle	Seychelles	Santyplum	Dolcetini
Appearance					
Homogeneity	***	9.2 a ‡	9.1 a	8.8 a	6.0 b
Flavor					
Sweet	***	7.2 b	7.1 b	7.6 a	5.9 c
Sour	***	3.3 b	3.3 b	2.7 b	4.2 a
Tomato ID	***	7.1 b	7.8 a	7.2 b	7.0 b
Fruity	***	6.9 ab	7.1 a	6.7 b	6.2 c
Herbaceous	***	2.7 c	2.9 b	2.9 b	3.8 a
Aftertaste	***	5.9 b	6.1 b	6.8 a	5.8 b
Texture					
Hardness	***	6.1 b	6.1 b	6.1 b	7.4 a
Crunchy	***	5.2 b	5.0 b	5.0 b	6.4 a
Juiciness	***	5.9 a	4.6 c	2.7 d	6.3 a
Pulp quantity	***	5.5 c	5.8 bc	6.0 ab	6.3 a
Peel quantity	**	2.9 a	2.8 ab	2.9 a	2.7 b
Seed and juice quantity	***	3.2 a	2.2 c	1.9 d	2.6 b
Saliva solubility	***	5.3 a	5.8 b	3.4 d	4.5 c
Residual skin quantity	***	2.1 c	1.9 d	2.9 b	4.0 a

† NS = not significant at $p > 0.05$; **, ***, significant at $p < 0.01$ and 0.001 , respectively. ‡ Values (mean of 3 replications) followed by the same letter, within the same row, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

In round cherry cultivars (Table 5), Karelya obtained the highest value in sour flavoring (6.3) showing a great difference with cultivars whose scores were closest (Katalina and C-95, 4.2 and 4.4, respectively). In the case of the herbaceous attribute, the trend was similar to the sour attribute with Karelya showing the highest value (5.8) followed by Katalina and C-95, for which scores were 4.5 and 4.4, respectively. Regarding hardness, Katalina was the cultivar with the highest value (8.3), while Sweet star showed the lowest (6.9). Crunchy showed a trend very similar to hardness, with Katalina and C-95 showing the highest values (7.9 and 7.7, respectively) while Sweet star showed again the lowest one (6.5). Juiciness was an attribute with great differences among samples, where Katalina obtained a score of 8.8 and C-95 reported a value of 4.9. With respect to the saliva solubility

attribute, Katalina showed again the highest value (8.0), with Sweet star showing the lowest one (4.9).

Table 5. Descriptive sensory analysis in round cherry tomatoes as affected by cultivar.

Attributes	ANOVA †	Katalina	Sweet star	C-95	Karelya
Appearance					
Homogeneity	***	9.2 a ‡	8.0 b	6.7 c	7.6 b
Flavor					
Sweet	***	5.7 c	7.5 a	6.1 b	4.6 d
Sour	***	4.2 b	3.1 c	4.4 b	6.3 a
Tomato ID	***	8.0 a	7.4 b	8.1 a	6.1 c
Fruity	***	6.4 a	6.6 a	6.5 a	5.6 b
Herbaceous	***	4.5 b	2.6 c	4.4 b	5.8 a
Aftertaste	***	7.0 a	6.2 b	7.1 a	6.2 b
Texture					
Hardness	***	8.3 a	6.9 c	7.7 b	7.4 b
Crunchy	***	7.9 a	6.5 c	7.7 ab	7.4 b
Juiciness	***	8.8 a	6.8 b	4.9 d	6.3 c
Pulp quantity	***	4.0 c	4.1 c	5.2 a	4.9 b
Peel quantity	**	2.1 d	3.8 a	2.9 c	3.2 b
Seed and juice quantity	***	4.2 a	4.1 a	2.7 c	3.4 b
Saliva solubility	***	8.0 a	4.9 d	6.2 c	6.6 b
Residual skin quantity	***	2.7 c	4.7 a	4.4 b	4.3 b

† NS = not significant at $p > 0.05$; ***, significant at $p < 0.001$. ‡ Values (mean of 3 replications) followed by the same letter, within the same row, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

For better of understanding of the relationships between the cultivars of cherry tomatoes (pear and round), principal component analysis (PCAs) was done, using descriptive sensory attributes (Figure 1). PCA explained above 68.08% of the data variability. Three groups were the most relevant associations:

- Angelle and Seychelles were linked with descriptors such as sweet, fruity, and homogeneity.
- Katalina was linked with descriptors such as hardness, crunchy, saliva solubility, and juiciness.
- Karelya was linked with descriptors such as herbaceous and sour.

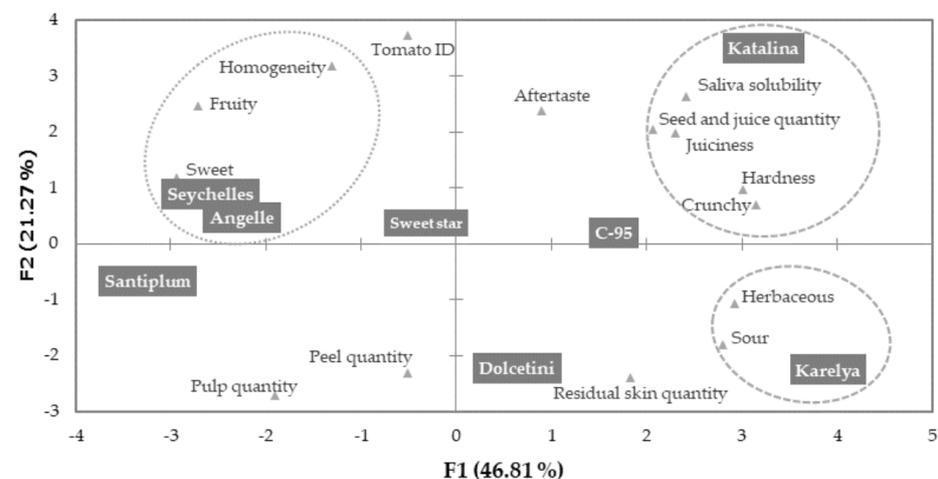


Figure 1. Principal components analysis of descriptive sensory analysis.

In the reported associations, it is possible to observe how Angelle and Seychelles comprise a united group; however, this fact does not take place with Katalina, which is

not associated with another cultivar. The dendrogram (Figure 2) reflects the same union between Angelle and Seychelles, making evident the affinity between these two cultivars, while, Katalina has a greater similarity despite of the differences with Sweet star cultivar.

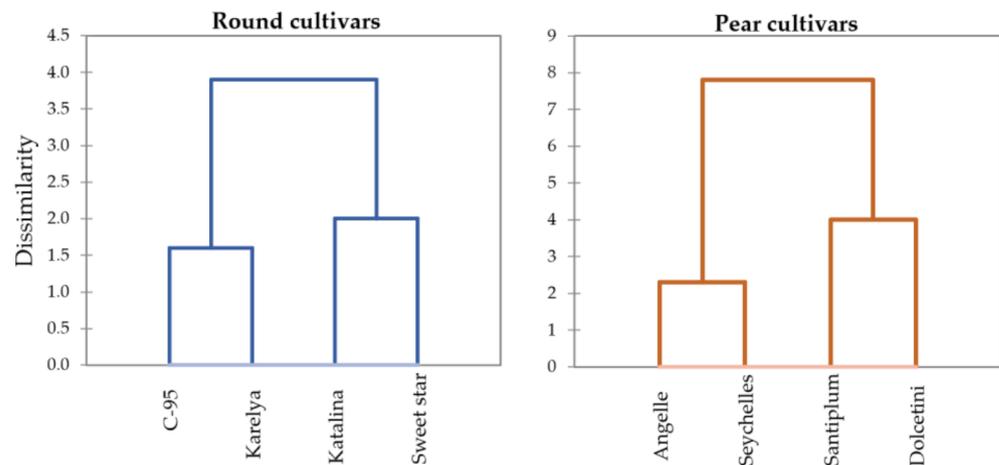


Figure 2. Dendrogram of round and pear cherry tomato cultivars.

In summary, the Angelle cultivar, as a reference of pear cherry tomatoes, did not show significant differences in the descriptive sensory analysis when compared to the Seychelles cultivar in 9 of the 15 attributes under study (homogeneity, sweet, sour, fruity, aftertaste, hardness, crunchy, pulp quantity, and peel quantity), thus being considered the most similar cultivar to replace Angelle. In round cherry types, where Katalina can be considered the reference cultivar, no clear and direct relationship was found with any cultivar, although the closest was C-95, showing no significant differences in 6 attributes of descriptive sensory analysis.

3.6. Consumer Study and Penalty Analysis (PA)

Ten attributes were analyzed in the consumer study and the resulting preferences for each cultivar are shown in Table 6. To complement the consumer study, a penalty analysis (PA) was carried out to help the data interpretation from the JAR analysis (Figure 3). This PA shows how optimal the intensity of each attribute under study [22]. The attributes which should need to be improved, by excess or defect, will be those producing a drop of at least 1 unit of satisfaction grade for at least 20% of consumers.

Table 6. Consumer study in cherry tomatoes as affected by cultivar.

	Color	Size	Flavor	Sour	Sweet	Hardness	Juiciness	Aftertaste	Peel/Pulp	Global
ANOVA [†]										
Pear	***	***	***	***	***	***	**	***	***	***
Round	**	NS	**	**	***	**	**	**	***	*
	Pear Tomatoes [‡]									
Angelle	7.2 a	6.1 a	6.0 a	5.6 a	5.9 a	5.6 ab	5.8 a	5.3 ab	3.6 a	5.8 a
Seychelles	6.6 b	6.1 a	6.2 a	5.5 a	5.9 a	5.8 a	5.7 ab	5.5 a	2.9 b	6.0 a
Santyplum	6.8 b	5.8 a	5.6 b	5.2 b	5.4 b	5.2 c	5.5 bc	5.2 b	2.7 c	5.3 b
Dolcetini	5.4 c	5.0 b	5.2 c	4.9 c	5.3 b	5.4 bc	5.3 c	4.9 c	2.6 c	5.1 b
	Round Tomatoes [‡]									
Katalina	6.9 a	6.3	6.4 a	6.1 a	6.2 a	6.0 ab	6.2 a	6.1 a	2.9 b	6.2 a
Sweet star	6.5 bc	6.4	6.1 ab	5.8 ab	6.1 ab	6.2 a	6.2 a	6.0 a	3.1 a	5.9 ab
C-95	6.2 c	6.5	5.9 b	5.5 b	5.8 bc	5.8 b	5.8 b	5.8 ab	2.6 c	5.9 ab
Karelya	6.6 ab	6.5	6.2 ab	5.7 b	5.6 c	5.8 b	5.9 ab	5.5 b	2.6 c	5.8 b

[†] NS = not significant at $p > 0.05$; *, **, ***, significant at $p < 0.05$, 0.01, and 0.001, respectively. [‡] Values (mean of 3 replications) followed by the same letter, within the same column and tomato shape (pear or round), were not significantly different ($p > 0.05$), according to Tukey's least significant difference test.

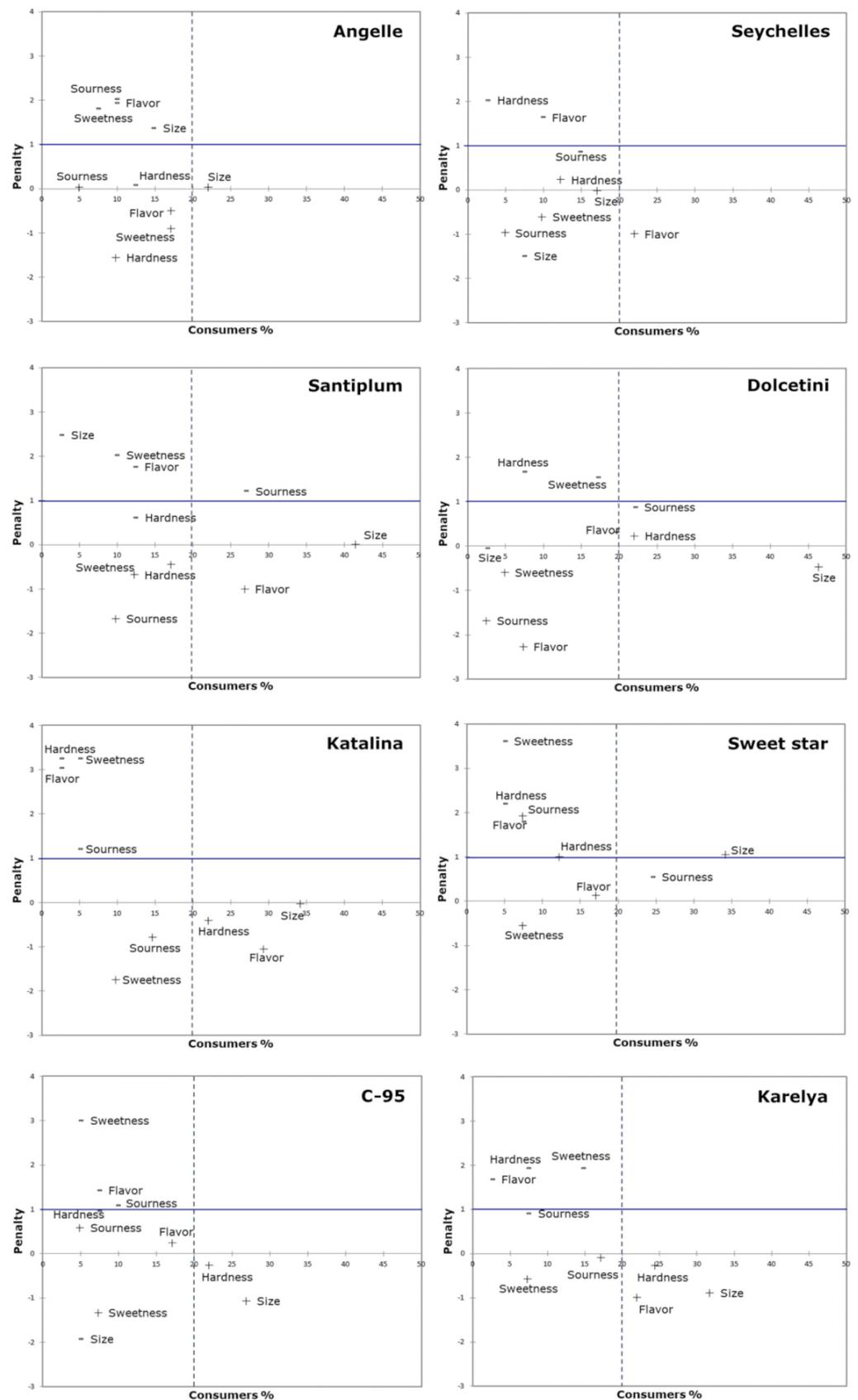


Figure 3. Penalty analysis (PA) of pear and round cherry tomato cultivars.

In pear cherry cultivars, consumers evaluated 8 of the 10 attributes reporting similar values for Angelle and Seychelles cultivars. The two attributes which had significant

differences among Angelle and Seychelles were color and peel/pulp; in both attributes, Angelle scored higher than Seychelles (color = 7.2 and 6.6, respectively; peel/pulp = 3.6 and 2.9, respectively). In general, Santyplum and Dolcetini obtained lower intensities than Angelle and Seychelles. In the aftertaste attribute, there were no significant differences between Angelle and Santyplum. One of the most important attributes is global, since it gives an idea of the set of all the attributes for the consumer. In the case of pear cherry type, Angelle and Seychelles obtained a similar scoring, Seychelles being even higher than the reference one, Angelle, with values of 5.8 and 6.0, respectively.

On the other hand, in round cherry cultivars, Katalina and Sweet star did not show significant differences in 8 of the 10 attributes analyzed by consumers, while only two attributes showed significant ones, color and peel/pulp. Katalina obtained the best color evaluation (6.9), reporting no significant differences in this attribute compared to the Karelya cultivar (6.6). Regarding peel/pulp, Sweet star obtained the best core (3.1), followed by the Katalina cultivar (2.9). Regarding the size attribute, there were no significant differences between the cultivars. In global, Katalina, Sweet star, and C-95 did not show significant differences, although the cultivar which obtained the highest score was Katalina (6.2).

Penalty analysis for pear cherry cultivars showed how consumers consider that any attribute should be improved due to its intensity when talking about Angelle, Seychelles, and Dolcetini; however, according to consumers, Santyplum cultivar has a very low level of sourness intensity.

In round cherry cultivars, the trend of PA is very similar to pear cherry types, where according to consumers Katalina, Sweet star and Karelia should not improve any attribute due to its intensity except in the case of the size of Sweet star, which must be improved due to the reported big size.

4. Conclusions

The characterization and comparison of 8 cultivars of cherry tomatoes (4 pear or teardrop and 4 round cherry cultivars) were carried out to determine which cultivars would be similar and could replace from markets the most popular ones (Katalina (round ones) and Angelle (pear ones)). This approach was reached by several determinations such as morphology, color, titratable acidity, total soluble solids, sugars, organic acids, and volatile compounds, as well as a sensory evaluation by both trained panelists and consumers. Morphology parameters (weight, shape ratio, etc.) had significant differences among cultivars but did not show a clear trend to determine the closest cultivars to Katalina and Angelle cultivars. In terms of total soluble solids and titratable acidity, Dolcetini could be an interesting substitute for Angelle in pear cherry cultivars, while in round ones, all cultivars were similar to Katalina; however, the cultivar which could be most similar and the best positioned to replace the most popular would be C-95. Regarding sugars, Santyplum was probably the cultivar which could be placed into a similar place to Angelle, while in round ones, C-95 was probably the cultivar closest to Katalina. On the other hand, only citric acid was found in all cultivars showing significant differences among pear and round cultivars. Santyplum, Seychelles (pear type), and C-95 (round type) are likely to be the most interesting cherry cultivars to be a real alternative to the most cultivated ones, in terms of volatile profile and concentration of the main volatile compounds. Descriptive sensory analysis revealed that the Seychelles cultivar, in 9 of the 15 attributes under study (homogeneity, sweet, sour, fruity, aftertaste, hardness, crunchy, pulp quantity and, peel quantity), could be considered the most similar cultivar to replace Angelle, while in round types, no clear and direct relationship was found with any cultivar, although the closest was C-95, showing no significant differences in 6 attributes of descriptive sensory analysis. Finally, consumers evaluated 8 of the 10 attributes reporting similar values for Angelle and Seychelles pear type cultivars, while round ones did not show significant differences. In summary, in terms of sensory analysis, it can be stated that Seychelles and C-95 are the best alternatives of pear and round cherry cultivars, respectively, as compared to the reference cultivars, Angelle and Katalina. Further studies must be conducted, and their

bullets points must focus on (i) comparing the production of the reference cultivars and the alternative ones that have been proposed in current study and (ii) improving those attributes, detected by penalty analysis, that consumers have evaluated with the lowest scores to provide more than one alternative per type of cherry cultivar.

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