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Cherry and Fresh Market Tomatoes: Differences in Chemical, Morphological, and Sensory Traits and Their Implications for Consumer Acceptance

Joan Casals [1,2,*], Ana Rivera [1,2], Josep Sabaté [1,2], Roser Romero del Castillo [1,2] and Joan Simó [1,2]

1 Miquel Agustí Foundation, Campus del Baix Llobregat, Carrer Esteve Terrades 8, Edifici D4, 08860 Castelldefels, Spain; ana.rivera@upc.edu (A.R.); jose.sabate@upc.edu (J.S.); roser.romero.del.castillo@upc.edu (R.R.d.C.); joan.simo@upc.edu (J.S.)

2 Department of Agri-Food Engineering and Biotechnology, BarcelonaTech, Campus del Baix Llobregat, Polytechnic University of Catalonia (UPC), Carrer Esteve Terrades 8, Edifici D4, 08860 Castelldefels, Spain

* Correspondence: joan.casals-missio@upc.edu; Tel.: +34-93-552-12-28

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Abstract: The tomato commercial groups cherry and fresh market, mainly classified by fruit size, have clearly segregated markets. We aimed to estimate the variation within and between these groups and to analyze factors that impact consumer acceptance. To this end, we studied the chemical profile (dry matter, sugars, acids) and fruit morphology (Tomato Analyzer) of 63 accessions grown in 2 environments (open air/soil culture; greenhouse/soilless culture). To identify traits underlying consumer preferences, we used a trained panel for quantitative descriptive sensory analyses and consumer surveys on a subset of genotypes. Our results confirm the higher content of reducing sugars (fructose, glucose), soluble solids, dry matter, and glutamic acid in the cherry group and the important effects of environment and genotype-by-environment interactions on fruit quality traits. The diversity within cherry for chemical composition is 1.4-fold to 2.1-fold that of fresh market. Differences in fruit morphological traits (weight, shoulder height, height/width relation) were highly related to fruit size, but no differences between groups were found for the internal structure of the fruit (locular relative content). Consumers value sweetness, glutamic acid, titratable acidity, and juiciness in cherry, and sweetness and taste intensity in the fresh market group. The implications for plant breeding are discussed.

Keywords: *Solanum lycopersicum* L.; sensory analysis; plant breeding; genetic diversity; ripening mutant; genotype-by-environment interaction

1. Introduction

Tomato (*Solanum lycopersicum* L.) is an economically important species, being the second horticultural crop in terms of area cultivated [1] and grown in nearly every country in the world [2]. It is also an important source of nutrients and nutraceutical compounds in the human diet [3]. Three gene pools have been described, the wild ancestor *S. pimpinellifolium*, the transitional form *S. lycopersicum* var. *cerasiforme*, and the cultivated species *S. lycopersicum* var. *lycopersicum* [4]. Although the cultivated species has very low diversity at the molecular level, its agronomic, morphologic, and quality traits are very diverse. Moreover, plant breeders can also benefit from the genetic diversity in economically important traits in the other 4 tomato wild relatives (*S. neorickii*, *S. chmielewskii*, *S. habrochaites*, *S. pennellii*) that can be crossed with *S. lyc.* var. *lycopersicum* [5]. Cultivated tomato can be divided into 3 main commercial groups, 2 grown for fresh consumption (cherry and fresh market) and 1 grown for processing into transformed products. The divergent breeding ideotypes applied for market specialization and histories of the groups has led to their genetic differentiation [6,7].

The cherry group is characterized by small fruits (<20 g for standard cherry, 20–50 g for cocktail cherry) [8]; Blanca et al. [4] suggested that from a genetic perspective this group includes a mixture of the different botanical cultivated species (*S. lyc.* var *cerasiforme, S lyc.* var *lycopersicum*) and also admixtures between *S. pimpinellifolium* and cultivated tomato. The fresh market group includes a wide diversity of fruit sizes (100–700 g), shapes, colors, and tastes [9], especially in the form of landraces found in the Mediterranean area, a secondary center of diversification of the species [10]. This group is composed solely of *S. lyc.* var. *lycopersicum* materials, and modern varieties have been bred for resistance to diseases, postharvest shelf life and some sensory traits (mainly fruit shape and color, and sugar and dry matter content) [11]. Finally, processing tomato varieties have been derived from the fresh market group and bred for adaptation to mechanical harvesting (determinate growth habit, jointless pedicel) and processing performance (Brix x yield, lycopene content, viscosity) [12]. Although processing varieties come from *S. lyc.* var. *lycopersicum*, intensive plant breeding in this group, including an important introgression of genetic variation from wild species, has resulted in a clear differentiation with the fresh market group [6].

Continuous breeding efforts to increase yield, shelf life, and resistance to pests and disease, together with current cultivation and storage practices, have had detrimental effects on tomato sensory quality [13,14], and 30 years ago began to complain about the lack of flavor of tomatoes [15]. This loss of sensory quality seems to affect more fresh market than cherry varieties, which are perceived as tastier [16], probably due to their higher concentration of sugars [17,18] and sensory-important volatiles [19,20]. Thus, plant breeders have attempted to transfer quantitative trait loci (QTLs) controlling fruit quality traits from small-fruited cherry to fresh market varieties. Although breeding programs were successful in increasing concentrations of sugar, acid, and pigment, these positive effects were accompanied by a significant decrease in fruit size [21–23], suggesting that the effects on sugar and acid were secondary to the effect on fruit size [24]. Thus, the negative correlation between fruit size and sugar content [25] has limited advances in breeding for quality in the fresh market group.

As transferring cherry's quality traits to fresh market or processing tomatoes seems impracticable [8], breeders have focused on exploiting the genetic diversity found in compatible species and within each group. Therefore, it is important to know the variability available within each group and compatible species. Moreover, considering the importance of environmental and genotype*environment effects on fruit quality [18,26,27], phenotypic variability should be studied in the diverse growing environments for tomato production (mainly open air/greenhouse; soil/soilless culture). Additionally, plant breeders need information on how the chemical profile is related with the sensory profile [28–30] and consumers' preferences [31,32], as in some cases this will allow for the use of DNA or metabolite markers to breed tastier tomatoes [14]. Although the relationships between metabolite concentrations and sensory profile have been widely explored [29,33], most studies have focused exclusively on the fresh market or on the cherry group; few have explored the sensory and chemical differences between the two groups and how these differences impact consumer acceptance. It is worth mentioning that Hobson and Bedford's [16] paper, published 30 years ago, is still used to describe the differences in sensory traits and consumer acceptance between cherry and fresh market tomatoes.

To better understand the chemical and sensory traits underlying consumers' preferences in the cherry and fresh market groups and differences between them, this study explored: (i) the differences in quality traits (chemical, morphological, and sensory traits) between cherry and fresh market tomatoes, (ii) the effect of commercial growing conditions (open air/soil, greenhouse/soilless culture) on these traits, and (iii) the relationship between consumers' preferences and sensory and chemical profiles in these two groups.

2. Materials and Methods

2.1. Plant Materials and Experimental Design

To represent the genetic diversity for chemical composition and fruit morphology, we selected 54 accessions (16 of cherry and 38 of fresh market tomatoes, Table 1) based on our own previous results (unpublished data). We also included inbreds carrying the ripening mutations alcobaça (*alc*) (4 accessions) [34] and ripening inhibitor (*rin*) (4 accessions) [35], because they are widely used in plant breeding and have a huge impact on fruit quality. Moreover, we included one accession of the wild relative *S. pimpinellifolium* (LA2904, TGRC). Thus, the materials are representative of the different genetic resources used in plant breeding, including different genetic configurations (inbreds, hybrids), origins (modern varieties, landraces, mutant stocks), and fruit shapes (ellipsoid (6%), flat (23%), heart 6%), long (2%), Long rect. (14%), ox heart (5%), rectangular (3%), and round (27%), according to the classification proposed by Visa et al. [36]).

The trials were carried out in two growing environments: open field (soil culture) and glass greenhouse (soilless culture) at the same experimental station (Cabrera de Mar, NE Spain, 41°31′19.2″ N 2°24′42.8″ E). Four week-old seedlings were transplanted in the two environments at the end of April. In each environment, we used a fully randomized design, with 45 plants per accession. Plants were grown using standard irrigation and fertilization procedures specific for each growing environment, and were conducted to one-stem by pruning lateral stems each 2 weeks. In a single harvest in mid-August, we collected fruits at commercial size and in red ripe (RR) stage from 3rd–5th trusses from each plot (18 fruits for morphological and chemical analyses and >100 fruits from the accessions selected for sensory analysis). Fruits were rinsed and evaluated by panels of trained sensory analysts and of untrained consumers within 2 days of harvesting.

2.2. Measurements

2.2.1. Morphometrics

From each plot, 18 fruits were individually weighed and used for morphological analysis; 9 fruits were cut longitudinally and 9 fruits transversally to measure different morphological traits. Fruits were scanned using a Brother DCP-J562DW scanner at a resolution of 300 dpi, and the traits "relative locular area" (locular area/total area, measured in the transversal section, in %), "shoulder height" (the relative depth of the peduncle depression, measured in the longitudinal section), and "fruit shape index external I" (height/width relationship, measured in the longitudinal section) were estimated using Tomato Analyzer version 3 software [37]. Then, the locular content of the transversally cut fruits was removed and weighed to calculate the relative locular fresh content (weight of locular content/fruit weight, in %).

2.2.2. Chemical Analysis

To analyze the chemical composition, we used the same fruits used for morphological analyses. The 9 transversally and 9 longitudinally cut fruits were blended separately to construct 2 biological replicates of each plot (about 500 g per sample). Each homogenate was distributed in 10 polyethylene pots, frozen, and stored at −20 °C until the analysis. Prior to analysis, each pot was thawed at 4 °C during 4 h and rehomogenized. For the accessions evaluated by the sensory panels, the chemical analyses were performed on aliquots of the homogenates presented to panelists; thus, panelists evaluated sensory traits in the same samples analyzed with instrumental methods.

Table 1. Main characteristics of the germplasm assayed. Accessions in which sensory traits were evaluated are marked with asterisks: * marks those evaluated only by the trained panel and ** marks those evaluated by both the trained panel and untrained consumers.

Genotype	Group	Origin	Year of Release	Genetic Constitution	Source [1]	Fruit Morphology [2]	Fruit Weight (g)
Akira	Cherry	Modern variety	2010	Hybrid	Syngenta	Ellipsoid	30.7 ± 3.3
Angelle **	Cherry	Modern variety	2010	Hybrid	Syngenta	Ellipsoid	15.2 ± 2.9
CPEA01	Cherry	Breeding inbred	-	Inbred	Fito	Long rect.	17.9 ± 3.1
CPEA02	Cherry	Breeding inbred	-	Inbred	Fito	Long rect.	11.5 ± 1.9
CPEA03	Cherry	Breeding inbred	-	Inbred	Fito	Long rect.	17.6 ± 4.1
CPEA04	Cherry	Breeding inbred	-	Inbred	Fito	Long rect.	16.6 ± 2.5
EA01965	Cherry	Landrace	-	Inbred	IPK	Round	9.2 ± 2.5
EA03306	Cherry	Landrace	-	Inbred	IPK	Round	4.8 ± 1.9
HA110331 **	Cherry	Modern variety	2010	Hybrid	Fito	Long rect.	22.2 ± 3.4
HA120406 **	Cherry	Modern variety	2010	Hybrid	Fito	Long rect.	19.7 ± 4.2
Luciplus	Cherry	Modern variety	2010	Hybrid	Hazera	Long rect.	23.5 ± 5.2
MiniStar *	Cherry	Modern variety	2000	Hybrid	Sakata	Ellipsoid	15.5 ± 4.3
Ornella **	Cherry	Modern variety	2010	Hybrid	Hazera	Long rect.	19.0 ± 5.1
Pixel	Cherry	Modern variety	2000	Hybrid	ISI Sem.	Long rect.	50.5 ± 9.6
Snack	Cherry	Modern variety	2000	Hybrid	Syngenta	Heart	39.3 ± 4.0
VESLB01	Cherry	Breeding inbred	-	Inbred	Fito	Long	17.9 ± 3.4
1201–861	Fresh market	Modern variety	2010	Inbred	Fito	Flat	254.2 ± 64.7
Alisa Craig	Fresh market	Modern variety	-	Inbred	TGRC	Round	54.4 ± 9.7
Anairis **	Fresh market	Modern variety	2000	Hybrid	Seminis	Flat	313.1 ± 92.7
BCVB01	Fresh market	Modern variety	2010	Inbred	Fito	Flat	172.1 ± 40.0
BCVB02	Fresh market	Modern variety	2010	Inbred	Fito	Round	231.7 ± 66.5
Byelsa	Fresh market	Modern variety	2010	Hybrid	Fito	Heart	113.5 ± 22.7
Caniles	Fresh market	Modern variety	2010	Hybrid	Zeraim Ib.	Ellipsoid	95.9 ± 12.2
Cartesio	Fresh market	Modern variety	2010	Hybrid	Clause	Round	126.4 ± 20.6
COLB02	Fresh market	Modern variety	2010	Inbred	Fito	Round	46.7 ± 10.8
COLLB01	Fresh market	Modern variety	2010	Inbred	Fito	Flat	119.8 ± 28.7
Daniela *	Fresh market	Modern variety	1990	Hybrid	Hazera	Round	147.8 ± 34.8
Danubio	Fresh market	Modern variety	2000	Hybrid	Clause	Round	232.9 ± 33.7
Delizia	Fresh market	Modern variety	2000	Hybrid	Clause	Round	300.5 ± 126.2
Egara **	Fresh market	Modern variety	2011	Hybrid	Fito	Flat	210.4 ± 58.1
Flor de Baladre	Fresh market	Landrace		Inbred	COMAV	Flat	219.5 ± 84.1
Garden Gem	Fresh market	Modern variety	2010	Hybrid	U. Florida	Heart	61.1 ± 8.7

Table 1. *Cont.*

Genotype	Group	Origin	Year of Release	Genetic Constitution	Source [1]	Fruit Morphology [2]	Fruit Weight (g)
Garden Tresure	Fresh market	Modern variety	2010	Hybrid	U. Florida	Oxheart	347.4 ± 63.8
HA120081	Fresh market	Modern variety	2010	Hybrid	Fito	Flat	198.9 ± 53.6
HB10199 **	Fresh market	Modern variety	2010	Hybrid	Fito	Round	115.1 ± 25
Ikram	Fresh market	Modern variety	1990	Hybrid	Syngenta	Round	117.0 ± 34.6
Jack	Fresh market	Modern variety	1993	Hybrid	Seminis	Round	309.6 ± 103.7
LA3179	Fresh market	Genetic resource	-	Inbred	TGRC	Round	68.8 ± 13.3
LC430	Fresh market	Landrace	-	Inbred	FMA	Flat	305.2 ± 131.4
LVAA03	Fresh market	Breeding inbred	-	Inbred	Fito	Oxheart	142.2 ± 51.9
LVAA04	Fresh market	Breeding inbred	-	Inbred	Fito	Round	196.1 ± 72.3
Montgrí **	Fresh market	Landrace	2005	Inbred	FMA	Oxheart	183.5 ± 66.9
OBGB01	Fresh market	Breeding inbred	-	Inbred	Fito	Flat	119.3 ± 70.3
Paladium	Fresh market	Modern variety	2013	Hybrid	Fito	Round	124.4 ± 24.2
Raf	Fresh market	Modern variety	1980	Inbred	Clause	Round	181.0 ± 34.1
Ramazur	Fresh market	Modern variety	2010	Hybrid	E. Zaden	Round	61.4 ± 7.3
Ramyle	Fresh market	Modern variety	2000	Hybrid	R. Zwaan	Round	108.6 ± 11.8
RCLA01	Fresh market	Breeding inbred	-	Inbred	Fito	Round	114.6 ± 32.4
RCLA03	Fresh market	Breeding inbred	-	Inbred	Fito	Round	98.7 ± 25.5
Retinto	Fresh market	Modern variety	2000	Hybrid	Seminis	Round	123.7 ± 29.1
Sant Jeroni	Fresh market	Landrace	-	Inbred	FMA	Flat	219.9 ± 40.6
Valencià	Fresh market	Landrace	-	Inbred	Fito	Flat	196.5 ± 50.8
Vernal	Fresh market	Modern variety	2000	Hybrid	E. Zaden	Flat	209.9 ± 63.5
VESLB02	Fresh market	Breeding inbred	-	Inbred	Fito	Flat	246.6 ± 86.0
HB06545	Rip. mut. (*alc*)	Modern variety	2010	Hybrid	Fito	Round	71.5 ± 10.1
LC269	Rip. mut. (*alc*)	Landrace	-	Inbred	FMA	Round	105 ± 31.7
LC378	Rip. mut. (*alc*)	Landrace	-	Inbred	FMA	Flat	84.5 ± 33.7
Punxa	Rip. mut. (*alc*)	Landrace	-	Inbred	FMA	Heart	89.8 ± 18.1
LVAA01	Rip. mut. (*rin*)	Breeding inbred	-	Inbred	Fito	Flat	112.4 ± 36.8
LVAB02	Rip. mut. (*rin*)	Breeding inbred	-	Inbred	Fito	Round	193.4 ± 68.5
RCLA02	Rip. mut. (*rin*)	Breeding inbred	-	Inbred	Fito	Round	62.4 ± 14.7
RCLA04	Rip. mut. (*rin*)	Breeding inbred	-	Inbred	Fito	Round	128.1 ± 31.4
LA2904	Wild species	*S. pimpinellifolium*	-	Inbred	TGRC	Round	1.4 ± 0.4

[1] TGRC: Tomato Genetics Resource Center, University of California-Davis, USA; FMA: Miquel Agustí Foundation, Polytechnic University of Catalonia, Spain; IPK: IPK Gatersleben, Leibniz Institute of Plant Genetics and Crop Plant Research, Germany; COMAV: Centro de Conservación y Mejora de la Agrodiversidad Valenciana, Universidad Politécnica de Valencia, Spain. [2] Long. rect. = long rectangular.

Soluble solids content (SSC) and dry matter content were directly determined in the homogenates. SSC was determined with a hand refractometer (Erma, Tokyo, Japan) and expressed as °Brix. Dry matter content was measured by drying the samples in an air oven to constant weight (65 °C, 72 h) and expressed as a percentage. Total acidity was determined by titration with NaOH 0.1 M up to pH = 8.1, and expressed as g citric acid/100 g fresh weight (fw). Sugars were extracted from the samples using deionized water. About 30 g of homogenate was mixed with 20–30 mL of water, shaken for 15 min, and centrifuged; the procedure was done three consecutive times, and the three filtrated supernatants were combined to obtain a volume of 100 mL of extract. Glucose and fructose were analyzed with a high performance liquid chromatography system equipped with a pump (Beckman 110B, Fullerton, CA, USA), an injector (Hewlett Packard Serie 1100, Palo Alto, CA, USA), a refractive index detector (Beckman 156, Fullerton, CA, USA), and a 250 mm × 4.6 mm Luna NH2 column (Phenomenex, Torrance, CA, USA). Results are expressed as g/100 g fw. Glutamic acid was determined by an enzymatic test (Boehringer Mannheim/R, Biopharm)). Each analysis was repeated twice (2 technical replicates).

2.2.3. Sensory Analysis

Trained Panel Evaluations

Limited by the panel's evaluation capacity, for descriptive sensory analyses we selected the 10 genotypes (5 fresh market/5 cherry, Table 1) with the greatest economic importance in the area of study (Catalonia, Spain). The panel evaluated samples from a total of 20 phenotypes: one from each genotype grown in the soilless/glass-greenhouse environment and one from each genotype grown in the soil/open-air environment. Each phenotype was evaluated in triplicate, the samples being randomly distributed across the tasting sessions. The panel comprised 9 expert panelists with more than 10 years of experience in sensory analysis of tomato [38,39]. All sensory sessions took place in individual booths meeting the standards set out by the International Organization for Standardization [40]. In each session, panelists evaluated a maximum of 5 samples. For all the samples, panelists evaluated 4 taste-related traits (sweetness, acidity, taste intensity, odor intensity) in homogenates from 5 blended fruits and 3 texture-related traits (skin perception, mealiness, and firmness) in longitudinal slices for the fresh market type and in fruit halves for the cherry type [41,42]. For the cherry genotypes, two additional texture-related traits (juiciness and explosiveness) were evaluated [41] because they are considered to have an important impact on consumer acceptance. Panelists rated the traits on a 100 mm semi-structured scale with the left extreme corresponding to the lowest intensity (score = 0) and the right extreme corresponding to the highest intensity (score = 10).

Consumer Test

Two consumer surveys (one for the cherry group and one for the fresh market group) were held in a public vegetable market in Barcelona on 2 consecutive days; a total of 210 consumers (50% in each group) participated (gender: 42% men, 58% women; age: <20 years 12%, 21–40 years 31%, 41–60 years 42%, >60 years 15%, education level: primary school 10%, secondary school 26%, university degree 64%; frequency of tomato consumption: every day 35%, 3–4 times per week 47%, 1–2 times per week 17%, 1–3 times per month 1%; preferred ripeness for consumption: breaker 22%, red ripe 78%; consumption period: seasonal 14%, all year 86%; access to home-grown tomatoes: grow in their own garden 17%, grown by friends 31%, no access to recently harvested tomatoes 52%). Tomato samples were presented in a monadic sequential, using a Latin square design to avoid effects of order and first position. Consumers evaluated 4 of the 5 accessions evaluated by the trained panel, but only the greenhouse-grown phenotypes (Table 1). Fewer samples were presented to consumers to avoid sensory fatigue, which can appear when untrained individuals consider a high number of samples [43]. Consumers were presented greenhouse-grown phenotypes because this growing environment is less sensitive to climatic and edaphic fluctuations. We adapted the protocol proposed by Sinesio et al. [44]

to obtain consumers' ratings on a scale (0–5) for odor intensity, taste intensity, and purchase preference ("would you buy this tomato?"). Consumers were served half tomatoes (fresh market type) or 3 whole fruits (cherry) to analyze.

2.3. Statistical Analysis

The whole experiment comprised 9 chemical, 5 morphological, and 12 sensory traits (Figure 1). To analyze chemical and morphological traits, we used a three-way analysis of variance (ANOVA) considering the factors commercial group, environment, and accession within the group, as well as all the interactions. To analyze the trained sensory panel's scores, we used an ANOVA considering the factors commercial group, environment, accession within the group, panelist, and all the interactions. All factors were considered fixed. For significant factors, differences among mean values were estimated by the Student-Newman-Keuls test, at a significance level of $p \leq 0.05$. To compare the diversity between cherry and fresh market groups, we elaborated boxplots for the main chemical and morphological traits. To assess the correlations between the trained panel's evaluations of sensory traits and the chemical and morphological variables, we used Pearson's correlation coefficient. To assess chemical and sensory variables underlying consumer preferences, we used principal component analysis (PCA). We used SPSS (v.12.0, SPSS Inc., Chicago, IL, USA) for univariate analyses (ANOVA, mean separation) and R (R core team 2017; PCAmethods and Ellipse packages) for multivariate (PCA) analyses.

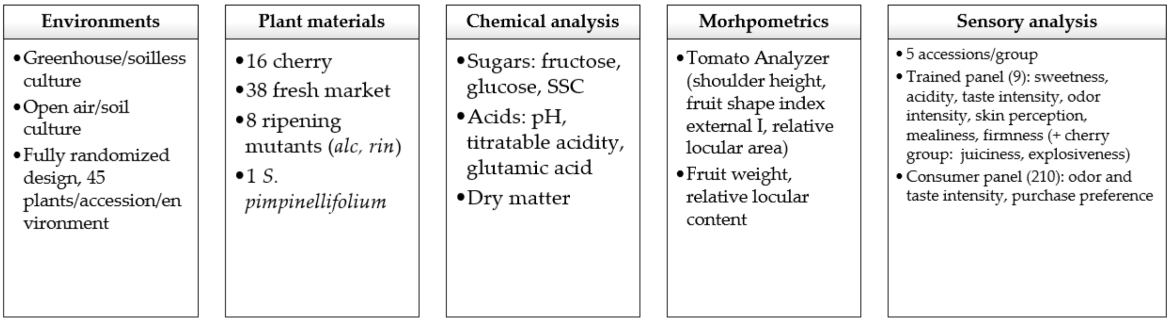

Figure 1. Graphical scheme with the experimental design and traits studied.

3. Results

3.1. Chemical Traits

Significant differences between the groups (cherry, fresh market, ripening mutants (*alc*, *rin*), and *S. pimpinellifolium*) were found for all the chemical traits except pH (Table 2). Cherry had the most different chemical profile, yielding significantly higher values for reducing sugars (fructose, glucose), glutamic acid, SSC, and dry matter than the fresh market tomatoes and the ripening mutants. The values of fructose and glucose for the *S. pimpinellifolium* accession (LA2904, TGRC) were lower than for cherry but higher than for the other groups; this accession had the highest values of SSC, TA, and dry matter. The *alc* ripening mutant had significantly higher SSC, TA, and dry matter than fresh market and *rin*. Few differences were found between fresh market and the *rin* ripening mutant, except in glutamic acid (significantly lower in *rin*) and TA (significantly higher in *rin*).

Table 2. Differences between tomato commercial groups for chemical traits. At the bottom, significance of the factors considered in the ANOVA (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns not significant). Within columns, different letters indicate significant differences (Student-Newman-Keuls test, at $p < 0.05$). SSC, soluble solids content; TA, titratable acidity.

	Fructose (g/100 g fw)		Glucose (g/100 g fw)		Glutamic Acid (g/100 g fw)		pH		SSC (°Brix)		TA (g Citric Acid/100 g fw)		Dry Matter (%)	
Cherry	2.75	a	2.72	a	0.27	a	4.20	-	7.88	b	0.38	c	9.44	b
Fresh market	1.60	c	1.52	c	0.16	b	4.40	-	5.18	d	0.33	d	6.19	d
Ripening mutant (*alc*)	1.69	c	1.52	c	0.19	b	4.29	-	5.76	c	0.46	b	6.98	c
Ripening mutant (*rin*)	1.61	c	1.55	c	0.09	c	4.34	-	4.99	d	0.39	c	6.31	d
S. pimpinellifolium	2.01	b	1.78	b			4.32	-	8.40	a	0.70	a	12.70	a
Environment (E)	***		***		ns		ns		*		ns		**	
Group (G)	***		***		***		ns		***		***		***	
G*accession (A)	***		***		***		ns		***		***		***	
G*E	***		***		ns		ns		***		***		***	
G*E*A	***		**		ns		ns		*		***		*	

Apart from the differences between the groups, significant differences among accessions were found within groups for all traits (Table S1). Besides higher values for the chemical traits studied, cherry had much greater intra-varietal diversity in both environments than fresh market tomato, despite the lower number of accessions assayed for this group (cherry, $n = 16$; fresh market, $n = 38$; Figure 2), as shown by the higher coefficients of variation (CV) in the cherry group compared to the fresh market group for fructose (1.6-fold), glucose (1.5-fold), pH (1.4-fold), SSC (2.1-fold), and dry matter (1.7-fold). Some cherry accessions had very high sugar content (e.g., EA03306, Angelle, VESLB01) with concentrations of fructose and glucose above 3.2 g/100 g fw. By contrast, the accession in the fresh market group with the highest sugar content, Garden Gem, had only 2.3 g/100 g fw fructose and 2.1 g/100 g fw glucose.

3.2. Morphology

The commercial classes cherry and fresh market are mainly defined by fruit morphological traits (size). Although size and shape are perceived by sight and can thus be considered visual sensory traits, we consider them in a separate section because the measurements were made instrumentally. Cherry tomatoes are basically defined by the small size of the fruit (in the present study, mean 19.6 g) (Table 3). All the cherry accessions had high fruit height/width ratios (fruit shape index external I descriptor from the Tomato Analyzer); thus, we observed no flat fruits (Figure 2). Furthermore, cherry accessions had low values for shoulder height (i.e., low degree of shoulder depression). By contrast, fresh market accessions varied widely on these traits, with shoulder shapes from flat to strongly depressed. In cherry tomatoes, the proportion of locular tissue was 16.2% when assessed by weight (g locule/fruit weight) (range 10.1–26.4%) and 44.8% when assessed by area (locular area/total area, measured in the transversal slice) (range 42.4–50.4%). These values are similar to those obtained for the fresh market group, although the range of variation in this group was higher for both traits (16.9% (3.7–26.2%) by weight; 45.0% (33.1–81.2%) by area). The wild relative *S. pimpinellifolium* had a much higher proportion of locular tissue than the rest of the collection when assessed by weight (36.8%), but these differences were not observed when assessed by area.

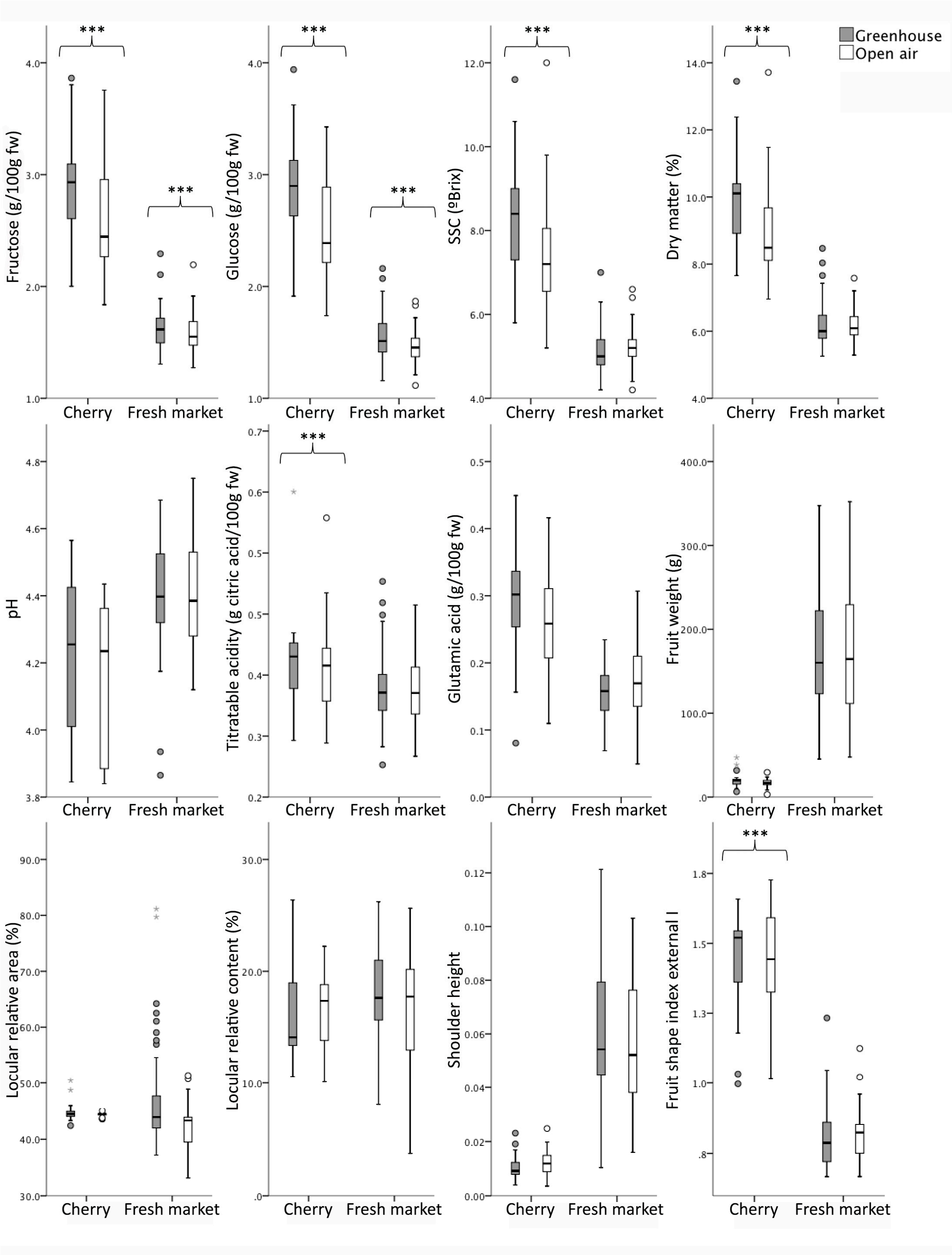

Figure 2. Genetic diversity within cherry and fresh market tomatoes for the most important chemical and morphological traits, and comparison between greenhouse and open-air cultivation. For the boxplots, ° and * represent extreme values more than 1.5×, and 3.5×, respectively, of the interquartile range of the box, which contains the middle 50% of the records. Significant differences between environments for each group are signaled above a bracket (significance levels, *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$).

Table 3. Differences between tomato commercial groups for morphological traits. At the bottom, significance of the factors considered in the ANOVA (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns not significant). Within columns, different letters indicate significant differences (Student–Newman-Keuls test, at $p < 0.05$). SSC, soluble solids content; TA, titratable acidity.

Group	Fruit Weight (g)		Fruit Shape Index External I		Shoulder Height		Relative Locular Content (%)		Relative Locular Area (%)	
Cherry	19.6	d	1.43	a	0.01	c	16.2	b	44.8	-
Fresh market	184.2	a	0.82	c	0.06	a	16.8	b	45.8	-
Ripening mutant (*alc*)	90.3	c	0.83	c	0.05	b	17.7	b	45.7	-
Ripening mutant (*rin*)	148.3	b	0.81	c	0.07	a	17.3	b	45.5	-
S. pimpinellifolium	1.3	e	0.96	b	0.01	c	36.8	a	45.7	-
Environment (E)	ns		ns		ns		ns		ns	
Group (G)	***		***		***		***		ns	
G*accession (A)	***		***		***		***		***	
G*E	ns		ns		ns		ns		ns	
G*E*A	ns		ns		ns		ns		ns	

3.3. Sensory Profile

To determine differences between the sensory profiles of cherry and fresh market tomatoes and to investigate the relationship between sensory and chemical traits, we used sensory quantitative descriptive analysis by trained panelists in a subset of the accessions (Table 1). The panel's discriminatory ability was very high: few significant panelist*accession and panelist*environment interactions were identified (1 in 14 in fresh market; 6 in 20 in cherry), so ratings were highly consistent between panelists [45]. The sensory intensity of the individual traits measured differed between the cherry and fresh market groups, cherry accessions yielding significantly higher scores for sweetness, acidity, and taste intensity, and lower scores for odor intensity, mealiness, and firmness (Table 4). Nevertheless, the accession within group factor was significant for all the sensory traits; in other words, the sensory intensity scores for some fresh market accessions overlapped those of cherry accessions for individual traits. For instance, for sweetness and taste intensity, Egara and Montgrí were not significantly different from the lowest scored accessions in the cherry group (Ornella, HA110331), although they had significantly lower scores than the highest scoring cherry accessions (Angelle, MiniStar, and HA12046). A similar pattern was observed for the remaining sensory traits.

Table 4. Differences between cherry and fresh market tomatoes for sensory traits. Within columns, different letters indicate significant differences (Student-Newman-Keuls test, at $p < 0.05$).

	Sweetness	Acidity	Taste Intensity	Odor Intensity	Skin Perception	Mealiness	Firmness	Juiciness	Explosiveness
Cherry	6.8 a	6.1 a	5.3 a	2.0 b	7.2 -	1.2 b	2.3 b	8.3 -	6.7 -
Fresh market	4.3 b	5.3 b	4.7 b	5.6 a	7.3 -	3.8 a	4.5 a	-	-

To understand sensory differences between the two groups considering all the sensory space, we performed a PCA with all the quantitative sensory data (Figure 3). The plots drawn from the first three principal components (PC1-PC2 74.2% of the total variation; PC1-PC3 71.9%) shows a clear separation between the two groups, distinguishing cherry tomatoes for higher scores in taste-related traits and fresh market tomatoes for higher scores in odor, firmness, and mealiness. Skin perception is the only sensory trait that does not contribute to the separation between the groups. The slight overlap between the two groups means that although the variation between the groups can overlap for individual traits, when the entire sensory space is considered, cherry and fresh market tomatoes are highly different.

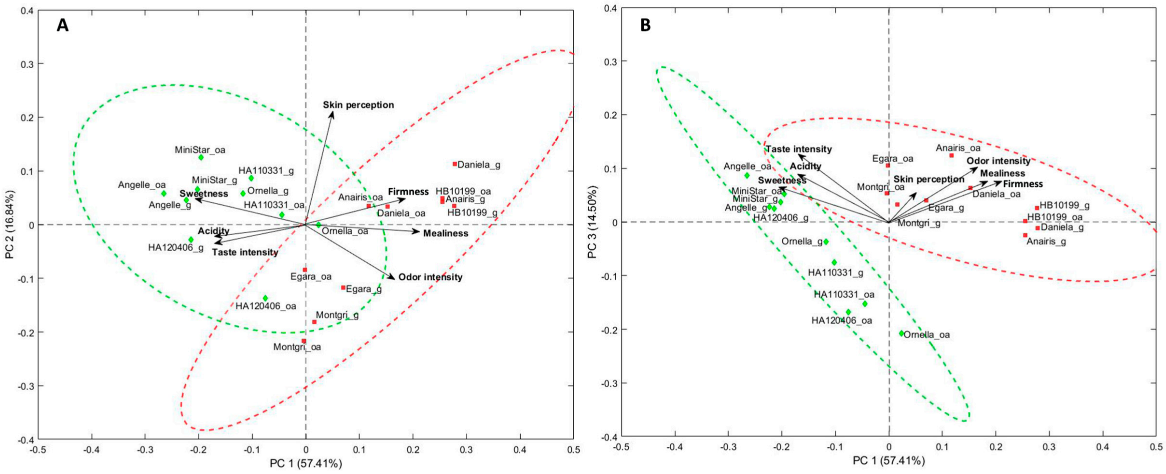

Figure 3. Plot from the three first principal components in the PCA estimated from sensory data (**A**), PC-PC2; (**B**), PC1-PC3. Green points = cherry; red points = fresh market. The dashed lines represent the 95% confidence ellipses for each varietal group (cherry, fresh market). Growing environment is signaled as "g" (greenhouse) or "oa" (open air).

3.4. Cultivation Effect

Environment (greenhouse/open air) had a significant impact on dry matter and sugar content (SSC, fructose, glucose), and had no effect on acids (glutamic acid, pH, TA) (Table 2). In general, greenhouse treatment had a positive impact on sugars and dry matter, although the group*environment interaction was significant for all these traits, signaling that the effect was not consistent across the different groups. The in depth analysis within cherry and fresh market groups revealed that cherry accessions were more sensitive to the greenhouse conditions, as for instance fructose, glucose, dry matter, and TA were significantly higher in this environment (Figure 2). For the fresh market group, environment affected only fructose and glucose content, the greenhouse treatment yielding higher concentrations in this group.

Morphological traits were much less affected by growing conditions. The environment factor was significant only for fruit shape index external I trait, although the cherry and fresh market intra-group analysis revealed that the environment affected only the cherry group, where values were significantly with the greenhouse treatment (Figure 2). For the remaining traits, environment was not significant.

The environment had a pronounced effect on taste-related traits, but did not affect texture (Table 5). Sweetness and taste intensity were significantly affected in both cherry and fresh market, although in opposite senses: greenhouse cultivation increased intensity in cherry accessions but decreased intensity in fresh market accessions. Nevertheless, significant accession*environment interactions were detected, signaling that the environmental effect on the sensory profile is highly dependent on the genotype. Acidity (fresh market) and juiciness (cherry) were also affected by the environment.

Table 5. Effect of greenhouse vs. open-air cultivation on the sensory traits of cherry and fresh market tomatoes. Within each group and for each trait, different letters indicate significant differences (Student-Newman-Keuls test, at $p < 0.05$; ns, not significant). & indicates a significant accession*environment interaction ($p < 0.05$) within each group.

	Sweetness		Acidity		Taste Intensity		Odor Intensity		Skin Perception	
Fresh type										
Open air	4.6 &	a	5.8	a	5.3	a	5.6	ns	7.3	ns
Greenhouse	4.0 &	b	4.7	b	4.4	b	5.8	ns	7.4	ns
Cherry										
Open air	6.2 &	b	6.0	ns	4.8 &	b	1.8	ns	7.1	ns
Greenhouse	7.6 &	a	6.2	ns	5.6 &	a	1.9	ns	7.5	ns
	Mealiness		**Firmness**		**Juiciness**		**Explosiveness**			
Fresh type										
Open air	3.7	ns	4.6	ns						
Greenhouse	3.9	ns	4.5	ns						
Cherry										
Open air	1.4	ns	2.4	ns	7.8	b	6.4	ns		
Greenhouse	1.4	ns	2.2	ns	8.5	a	6.8	ns		

3.5. Consumer Test

A multivariate analysis of consumers' ratings, sensory panel analysis, and chemical analysis of fresh market and cherry accessions grown in the greenhouse found that the two first principal components accounted for 60% (PC1) and 22% (PC2) of the total variation for the fresh market group (Figure 4a) and 59% (PC1) and 28% (PC2) for the cherry group (Figure 4b). In the fresh market group, consumers' perception of taste intensity was the main factor driving purchase preference, and this perception strongly correlated with the trained panel's scores on sweetness and taste intensity. By contrast, consumers' perception of odor intensity was not important for final purchase preference; this trait is related with the acid content of the fruit. For the cherry tomato group, there were strong correlations among the three traits scored by consumers. Of all the chemical and sensory data considered in the analysis, juiciness was the most important trait driving purchase preference. The chemical traits glutamic acid, TA, and pH and the panel's rating of sweetness and acidity were also grouped with purchase preference. With regard to texture attributes, skin perception, firmness and mealiness seem to affect consumer acceptance for fresh market tomatoes negatively, while firmness is a negative trait for the cherry type.

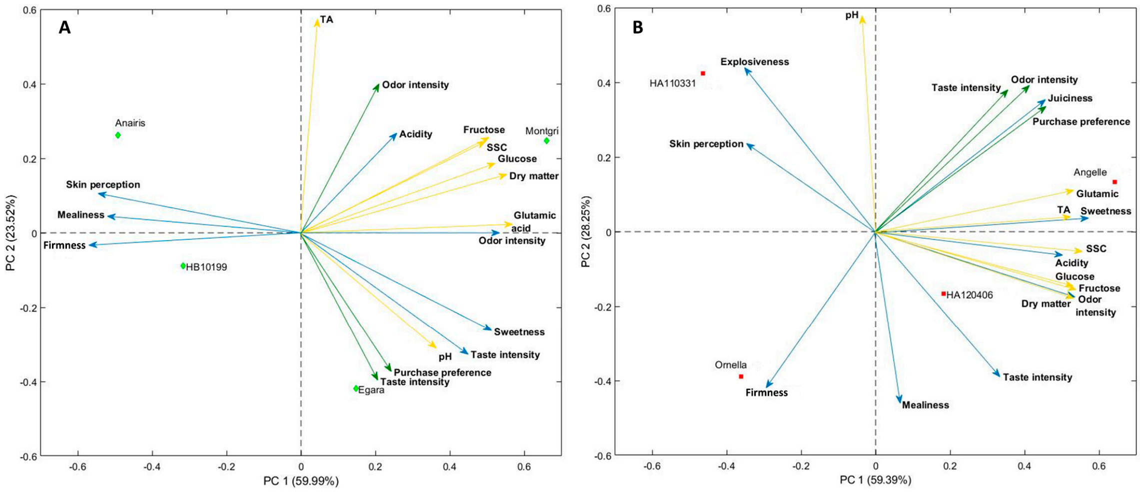

Figure 4. Plot of the two first principal components in the PCA estimated from sensory-panel, chemical, and consumer data on (**A**) fresh market and (**B**) cherry commercial groups. The type of variable is indicated in yellow (chemical), blue (trained panel), and green (consumer test) colors.

3.6. Correlations

Using a trained panel to guide breeding for sensory traits strongly limits the number of samples that can be evaluated and the amount of phenotypic variation that can be explored. Thus, to look for genetic or genotypic relationships between sensory traits and instrumentally measurable characteristics, we used genotypic correlation analysis (correlations between mean phenotypic values of the accessions for each chemical, morphological, and sensory trait). Considering that cherry and fresh market tomatoes have different genetic backgrounds, we analyzed the data from each group separately (Table S2). Despite the lower number of accessions from the cherry group studied (n = 16 for chemical and morphology traits and n = 5 for sensory traits vs. n = 38 for chemical and morphological traits and n = 5 for sensory traits in fresh market), many more statistically significant correlations were found within the cherry group: fructose, glucose, glutamic acid, SSC, titratable acidity, and dry matter were highly and positively correlated with one another, and these traits were negatively correlated with fruit weight. The sensory traits sweetness and taste intensity were positively correlated with the amounts of reducing sugars, dry matter, and SSC, but also with the total content of acids (titratable acidity) and glutamic acid. These correlations were very strong ($r > 0.90$), signaling that the chemical profile can be a good predictor of the sensory profile in the cherry group.

In the fresh market group, fewer correlations were found among the chemical traits. The most important difference with the cherry group is the lack of significant correlations between glutamic acid and fructose, glucose, SSC, and dry matter. Fruit weight seems to have less impact on chemical composition in the fresh market group, as we identified only one significant correlation (with dry matter, $r = -0.601$). Finally, the correlations between sensory traits and chemical profile yielded less interesting results, as sweetness and taste intensity were correlated only with fructose ($r = 0.915$ and $r = 0.897$, respectively), and acidity was correlated only with titratable acidity ($r = 0.918$).

Locular relative content (measured as the % of fruit weight that corresponds to the locular tissue) and locular relative area (measured as the % of the transversal area that corresponds to the locule) were not correlated, signaling that the variable calculated by the Tomato Analyzer offers no good predictions of the relative contribution of each tissue to total fruit weight. Moreover, these two variables that describe the internal structure of the fruit were not correlated with any of the chemical or sensory variables, signaling that the internal structure of the fruit has a low impact on fruit quality traits. Only the locular relative content was negatively correlated with fruit weight ($r = -0.492$) in the fresh market group, which can be a consequence of the higher contribution of septa and pericarp in large and multilocular fruits.

4. Discussion

Various studies have reported data about the composition of fresh market and cherry tomatoes [11,16,17,27], although much less information is available about the variability within each group and how it is expressed in commercial growing environments (open air/soil culture; greenhouse/soilless culture). Our results corroborate that cherry tomatoes have higher concentrations of sugars (fructose, glucose, SSC), dry matter, glutamic acid, and TA [16,17,46,47]. Although differences in TA were slight between cherry (mean value 0.38 g citric acid/100 g fw) and fresh market (0.33 g citric acid/100 g fw), the range of variation among accessions was much wider for cherry tomatoes (0.24–0.74 g citric acid/100 g fw vs. 0.20–0.50 g citric acid/100 g fw for fresh market). Similarly, in addition to higher mean concentrations of other chemical analytes, the cherry group's variability for fructose, glucose, pH, SSC, and dry matter was 1.4-fold to 2.1-fold higher than in the fresh market group.

Fresh market tomatoes had low levels of and less variability for glucose (coefficient of variation (CV) 13%; range 1.12–2.16 g/100 g fw), fructose (CV 12%; range 1.27–2.34 g/100 g fw), SSC (CV 9%; range 4.2–7.0 °Brix), and dry matter (CV 10%; range 5.3–8.5%), values that are similar to those reported in the literature [11]. Accessions of the ripening mutants *rin* and *alc* in homozygosis had distinct chemical profiles differing from the fresh market group in all chemical traits except glucose, fructose, and pH, especially higher TA in *alc* mutants and lower glutamic acid in *rin* mutants. The *S. pimpinellifolium* accession had the highest mean values for SSC, titratable acidity, and dry matter; its values for reducing sugars were situated between those found for cherry and fresh market, although for all these traits some cherry accessions overlapped with *S. pimpinellifolium*. Blanca et al. [4] point out that the cherry group comprises accessions with different phylogenetic origins (*S. pimpinellifolium, S. lyc.* var. *cerasiforme, S. lyc.* var. *lycopersicum*); thus, the high SSC and dry matter content in some cherry accessions can be caused by the presence of *S. pimpinellifolium* alleles that affect these traits positively, such as *Lin5* and *SSC11.1*, which were negatively selected during domestication [14].

The main criterion for classifying tomatoes into the cherry and fresh market groups is fruit size; cherry is characterized by small fruits (here, mean weight 19.6 g) and fresh market by large fruits (here, mean weight 184.2 g). Although most of the other morphological descriptors analyzed did not differ significantly between the two groups, cherry accessions were characterized by high fruit height/width ratios (i.e., fruit shape index external I) and high values for the shoulder height descriptor. Thus, we identified no flat fruits with depressed shoulders in the cherry group, although there are old-varieties with this form. New fruit shapes and colors were positively selected during the domestication and diversification of tomato [9]; consequently, the fresh market group is characterized by high diversity for fruit external appearance traits. Nevertheless, it seems that the internal structure was not affected, as the proportion of the different tissues (locule/pericarp) of the fruit was similar in the cherry (mean locular relative content 16.2%, CV 26%, range 10.1–26.4%) and fresh market groups (16.9%, CV 29%, 3.7–26.2%). This trait has been scarcely studied [48], and our study provides novel data about the range of variation within the two main commercial groups. Pericarp and locular tissues have different chemical compositions, with the pericarp having higher concentrations of reducing sugars and lower concentrations of acids (TA, citric, and malic acid) [47,48]. Despite these differences between the compositions of the tissues, we found no correlations between the relative contribution of each tissue and the chemical composition of the fruit, suggesting that this trait would not be useful for indirect selection for quality in tomato.

Differences in sensory traits between cherry and fresh market tomatoes have been widely highlighted, but few studies have quantified these differences [16]. On average, the cherry group had higher sweetness, acidity, and taste intensity and lower odor intensity, mealiness, and firmness than fresh market tomatoes, but accessions from the two groups overlapped considerably on some traits (Table 4). However, when the complete sensory space was considered, the differences between the two groups were evident (Figure 3). The lower odor intensity in cherry accessions can be explained by differences in the volatile composition [19], but also by cherry tomatoes' much lower surface area, which means that less volatilization occurs when the fruit is cut; Serrano-Megías et al. [31] found a positive correlation between fruit size and odor intensity. Moreover, cherry tomatoes have a different textural profile, being less mealy and firm, although these traits are probably not perceived due to the small size of the fruit (cherry tomatoes are more characterized by juiciness and explosiveness, as they are usually eaten whole).

Tomato fruit quality is highly affected by environmental conditions [11], and most of the quality traits are highly polygenic and show low heritability [18,26]. Our study considered the effects of growing conditions on fruit quality at the chemical, morphological, and sensory levels. Sugars, SSC, and dry matter were significantly affected by the growing conditions, but the variables related with the acid fraction of the fruit (glutamic acid, titratable acidity, pH) were not. Panthee et al. [26] found that acid traits such as titratable acidity had higher heritability in comparison with sugars. Morphological traits were much less affected by the environment, and only the height/width ratio was affected in the cherry group. However, the magnitude of the group*environment interactions was high for all the traits, signaling that the environmental effect and its direction were not consistent throughout all groups. This should be taken into account in plant breeding programs to obtain varieties with better sensory properties [26,49,50].

In the cherry group, the greenhouse environment yielded higher values for reducing sugars, SSC, dry matter, and titratable acidity, significantly increasing sweetness and taste intensity and thereby improving the sensory profile. Together with juiciness, sweetness seems to be the most important sensory trait influencing consumer purchase preference in this group. As in other studies [29,33], we found several significant positive correlations between chemical composition (sugars and acids) and sensory traits (sweetness, acidity, and taste). Considering the high diversity for chemical composition in this group, selection for sugar and acid content (especially glutamic acid as a taste enhancer) can be an efficient way to breed tastier cherry tomatoes.

By contrast, in the fresh market group, we found fewer correlations between chemical and sensory traits, probably due to the lower variability for chemical composition in this group. Consumers are positively influenced by sweetness and taste intensity, which in our study were positively correlated with fructose (r = 0.915, and 0.897, respectively), but not with glucose. In tomato, fructose has twice the sweetening power of glucose [51], and breeding for higher fructose content or higher fructose/glucose ratio has been proposed as a strategy to increase consumer acceptance [52]. Moreover, we did not observe the widely reported negative correlation between fruit weight and sugar content [21,25] in the fresh market group, indicating that an increase in sugar content should not affect the fruit size negatively. Nevertheless, in the fresh market group chemical composition seems a less efficient tool for breeding for sensory profile, as prediction models in this group for sensory traits are highly complex, involving volatile and non-volatile compounds [29] and their interaction [28]. Thus, descriptive sensory analyses continue to be the most reliable tool, as evidenced by the strong correlations between the trained panel's assessments and consumer preferences. Perhaps the difficulties in handling trained panels in breeding for sensory traits explains the scant progress to date toward satisfying consumers' demands.

5. Conclusions

Although the literature defines cherry and fresh market tomato groups solely by their fruit size [8], the different farmer-selection pressures and modern breeding ideotypes applied in each group has provoked several other differences between them, including some differences regarding consumers' preferences. From a sensory point of view, cherry tomato seems much more close to the consumer's ideotype, and the high variability for chemical composition in this group enables to use sugar and acid content as markers for breeding tastier tomatoes. In the case of the fresh market group, the relationships between consumer acceptance and chemical composition are much more complex. Moreover in this group the sugar and acid content variability is much lower, implying the need to use sensory analysis in plant breeding programs for fruit quality. Although from a commercial point of view the limits between cherry and fresh market groups are more or less clear, it is necessary to clarify this issue by developing a more detailed definition of each group, in order to standardize scientific studies.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/9/1/9/s1, Table S1: Mean values per accessions for the chemical and morphological traits studied. At the bottom, least significant difference ($p < 0.05$) between means; Table S2: Pearson genotypic correlations between chemical, morphological, and sensory traits within the fresh market (upper part) and cherry (lower part) groups, using mean values per genotype of all available data. Significance levels: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

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