



Peach fruit quality on the fresh market: A long-term evaluation series from Northern Italy is pushing the overturn of commercial standards within the mass-supply chain

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ABSTRACT

Commercial peach fruit quality standards mainly rely on visual and fruit size attributes, often unpredictable or unrelated to organoleptic pleasantness. Hence, surveys on consumers' continuously reports a poor fresh internal quality of peaches as the main cause of a widespread disaffection. In addition, the consistent adoption of similar selection criteria among main breeding programs hampers a marked improvement of enhanced flavour. This eight-years study reported the quality analysis of 52 peach cultivars sold across several mass-supply chain channels (the so-called 'Organized Large-Scale Retail Distribution', GDO), describing the current landscape of marketed peaches in Italy. In addition to the evaluation of external and internal quality parameters, a group of experienced panelists performed a sensory evaluation at commercial ripening ('ready-to-buy' stage) and after shelf-life ('ready-to-eat') to complement analytic determination and further investigate its relationship with human perception. Overall, soluble solid content (SSC) resulted inconsistent and generally low over the years of assessment, particularly in early and mid-season cultivars. This evidence negatively impacted panelists' pleasantness that, in turn, appeared strongly dependent on taste sensorial experience and, above all, on aroma and sweetness perception. In particular, aroma tended to be poorly perceived with SSCs below 12 %, while a significant superior preference occurred with SSC above 14 % and a BrimA index above 27. The almost negligible effect of shelf-life on SSC emphasized the largest effect of the pre-harvest conditions for this feature. Accordingly, this study endorses an impelling improvement of the agronomic practices currently adopted and, hopefully, a reorganization of the whole peach retailers' distribution chain to really meet consumers' preferences.

1. Introduction

Peach [*(Prunus persica* L. (Batsch.))] is the stone fruit crop mostly grown worldwide, from Canada to New Zealand, for both fresh consumption and canning industry (FAOSTAT, 2021). Decades of stagnant or declining peaches fresh consumption have been challenging growers, retailers and exporters in many countries such as Italy, Spain, Greece and the USA, leading to a global impasse (FAOSTAT, 2021; USDA-NASS, 2021). Apart from the competitions of other fresh fruit (e.g. kiwifruit, bananas, apples and tropical fruit) now available year-round and an increased vulnerability of peach production in some important growing areas (i.e. late frost damages or insufficient chilling accumulation), some

researches have tried to clarify the main drivers of consumers' purchasing habits for developing marketing strategies and lifting up the consumption (Kelley et al., 2016; Zhou et al., 2018; Christofides et al., 2022). Price, origin and trademark (such as the Protected Geographical Indications in the European Union), cultivar label, pomological type, outward appearance and intrinsic features, etc. have been associated to the heterogeneity of consumers' preferences and purchasing habits. However, their specific importance widely varies depending on the study, country and/or socio-demographics characteristics. For example, experienced fruit quality-oriented consumers (i.e. preference for higher sweetness and flavor perception without considering important the other attributes) represents the main group in the USA (Zhou et al.,

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2018). Cross-cultural differences are also evident between Italian and UK consumers: the former mainly driven by cultivar labelling and the latter by organoleptic qualities and price (Christofides et al., 2022).

In spite of a personal purchasing attitude within each country, a poor intrinsic quality of peaches sold on the market still remains the main bottleneck and popularly advocated as the primary reason of this falling trend in *per capita* consumption worldwide (Clareton, 2000; Crisosto, 2002; Crisosto et al., 2006a, 2006b; Manganaris et al., 2022). A systematic assessment of fruit quality (FQ) throughout markets and sales points have been rarely reported for the currently available cultivars (Crisosto, 2002; Crisosto and Crisosto, 2005; Crisosto et al., 2006b). A categorization of cultivars into organoleptic groups -defined according to consumer's acceptance- has been advanced to establish reliable targets within each group in order to increase consumption (Crisosto et al., 2006a, 2006b; Cano-Salazar et al., 2012).

The mass-supply chain system can take advantages from the development of some fixed and universal quality indexes in stone fruit trading (such as flesh firmness higher than 27–35 N; Crisosto, 2002) to avoid bruising and decay problems in post-harvest handlings. Nevertheless, setting such analytical parameters, without considering the coeval effect of other features (e. g. total sugar content *etc.*) on the organoleptic pleasantness, does not ensure a reliable minimum FQ standard and often appears detrimental to consumers' appreciation and market life (Crisosto et al., 2006b).

Consumers' fresh FQ definition has moved over years from prioritizing visual and physical attributes (such as bright full red peel color, fuzzy or smooth skin respectively in peach and nectarine, flesh firmness and round/flat shape) to embedding organoleptic (i.e., sugars, acids and volatile organic compounds), sensorial perception and health-promoting profile (minerals such as potassium and magnesium, vitamins and bioactive compounds such as cyanidin 3-glucoside) (Crisosto and Tonutti, 2015; Cantin et al., 2010; Reig et al., 2013; Olmstead et al., 2015; Minas et al., 2018; Reig et al., 2023). Although fruit appearance seems to be the primary purchase-drivers in the store, several surveys have highlighted a disappointing eating experience of consumers once consumed at home (Kays, 1999; Crisosto, 2002; Infante et al., 2009; Olmstead et al., 2015).

Overall flavor perception is shaped by the individual contribution of taste, odor and texture, each stimulating distinct sensory receptors. However, these elements interact with each other and combine within the human mouth, creating a unified sensory experience (Noble, 1996; Simon et al., 2006; Rolls, 2019). Certainly, several attributes can compensate each other in sensory perception, perfecting the final flavor and eating pleasantness (Crisosto, 2002; Crisosto and Crisosto, 2005). In terms of taste, consumers' degree of liking for 'in store' peaches were found to be highly varied, ranging from a strong preference for either sour or sweet taste to a balanced appreciation of both (Crisosto et al., 2006a, 2006b). Previous evidences have confirmed a tricky relationship between sweet and sour taste, as consumers' acceptance greatly varied across cultivars (other sensory quality attributes can interact), maturity degree and countries. Despite these differences, a greater consensus was observed for peaches with a medium-to-high sweetness, a balanced sourness and a prominent 'peach' aroma (Colaric et al., 2005; Crisosto and Crisosto, 2005; Crisosto et al., 2006a; Infante et al., 2008a; Delgado et al., 2013; Crisosto and Tonutti, 2015; Crisosto et al., 2016; Farina et al., 2019).

In peach, accurate chemical predictors of sweetness and sourness intensity are respectively the total soluble solids content (SSC, measured as total grams of SSC dissolved in 100 mL of solution and commonly expressed as percentage or Brix degrees, "°Brix") -mainly reflecting the sugars profile- and the total acidity level (evaluated by titratable acidity as g L⁻¹ of malic acid or pH) with the relative pattern of the most abundant organic acids (malate, citrate and quinate) (Biester, 1925; Moing et al., 1998; Colaric et al., 2005; Crisosto and Crisosto, 2005; Kanayama et al., 2005; Reig et al., 2013; Baccichet et al., 2021). Previous studies reported a wide SSC variability (from about 12–19 % or

"°Brix") within a set of peach and nectarine cultivars at commercial ripening and a potential SSC accumulation over 20 % in some breeding materials, leading to question the minimum commercial standard of 8 % (or "°Brix") imposed by the UNECE (Commission Implementing Regulation 2021/1890/EU; Cantin et al., 2010; Font i Forcada et al., 2014; Reig et al., 2013; Petruccioli et al., 2023). In this wake, several previous studies have already suggested to raise the minimum SSC to 10–12 %, with slight variations accounting for fruit type (peach or nectarine), flesh color and maturity date (Kader, 1997; Clareton, 2000; Ventura et al., 2000; Hilaire, 2003). Concerning titratable acidity (TA), at least in Western countries, breeding has moved toward the selection of low-acid type (indicatively, with acidity lower than 5–6 g L⁻¹ and/or pH above 4), especially in early-ripening cultivars where both SSC and percentage of dry matter are lower, and sourness perception can impact more the degree of liking (Dirlewanger et al., 1998; Hernández Mora et al., 2017; Baccichet et al., 2021; da Silva Linge et al., 2021).

The intrinsic perishability of the drupe and post-harvest handlings further affect the organoleptic quality, in particular the storage at low temperature (between 2 and 7.6 °C) that can induce chilling injury or internal breakdown (i.e. mealy fruit texture and flesh browning) depending from a complex interaction among cultivar, ripening degree and storage temperature/length (Crisosto et al., 1999; Lurie and Crisosto, 2005; Diehl et al., 2013; Tanou et al., 2017). Indeed, the decay of eating quality in nectarines destined to distant fresh markets is one of the main problems for off-season exporters (Infante et al., 2008b).

Diversification has been an important breeding trend to expand the harvest season with more than four months between the extra-early and very-late ripening cultivars in some locations (Bassi et al., 1988; Byrne, 2002; Batlle et al., 2012; Cos-Terrer et al., 2012; Cantin et al., 2017). Nevertheless, a neglected and often unpredictable FQ occurs along the whole season, even if a higher 'in store' consumers' acceptance was concomitant with mid-season cultivars (Crisosto et al., 2006b).

Patenting novel peach cultivars with outstanding organoleptic properties remains a primary objective in breeding programs around the world (Byrne, 2002). However, peach varietal renovation suffers from the restricted –and sometimes unexplored– germplasm resources available and from the retailer's demand of certain 'Big Top'-like features (Zaiger Genetics Inc., California) such as full red skin color and slow-softening texture (Ghani et al., 2011; Font i Forcada et al., 2012). Ironically, breeders yearly release novel cultivars but fruit tend to be marketed anonymously and pooled together in bins under similar basic attributes (skin and flesh color, presence of fuzziness or fruit size), instead of emphasizing the organoleptic profile (Fideghelli et al., 1998; Okie et al., 2008; Iglesias and Echeverría, 2009; Minas et al., 2018). Peach industry seems to lack a disciplined marketing strategy aimed at rewarding the premium FQ of novel cultivars and the promotion campaigns often lead to price depreciation of superior quality fruit. Indeed, the peach trade still seems far from establishing a solid system based on branded club cultivars such as Pink Lady® and Kanzi® in apple, with Ondine™ for flat peaches and Dimple® for mini-nectarines as the only two European brands at the moment.

This study evaluated a total of 52 peach cultivars from 2011 to 2021 to summarize the influence of several FQ parameters on taste immediately at the commercial ripening (ready-to-buy) and after five days of shelf-life at 20 °C (ready-to-eat) in order i) to provide a medium-term and data-driven overview of the analytic and sensory quality of peach sold on some Italian selling points, ii) to report the scarce efforts in unlocking this questionable quality of peaches sold across the mass-supply channels (the Italian Organized Large-Scale Retail Distribution, GDO) and iii) to compellingly overturn the minimum selection criteria for suiting the consumer's taste in forthcoming years.

2. Materials and methods

2.1. Plant material and sample collection

This study encompassed a total of 20 peach (12 white-flesh, 7 yellow-flesh and 1 canning peach) and 32 nectarine cultivars (24 yellow-flesh and 8 white-flesh) mostly belonging to Occidental breeding-derived material (Supplementary Table 1). Fruit samples were retrieved by several mass-supply selling points (i.e. the Italian Organized Large-Scale Retail Distribution, GDO) located in Emilia-Romagna region (Northern Italy) and committed to 'ASTRA' service company (Agency for Technological Experimentation and Agri-environmental Research in Faenza, Ravenna, Italy). For 6 out of the 52 cultivars analyzed, fruit samples were provided for two different years. In addition, for eight cultivars, fruit samples were provided by two or three different retailer's chains in the same year (Supplementary Table 1 and Supplementary Figure 1). A total of sixty fruit per each sample were provided at commercial ripening ('ready-to-buy' stage) with indication of harvest date (expressed as Julian Day, JD). Although not detailed, during the period between harvest and delivery (on average less than seven days), fruit were exposed to cold storage at 0–1 °C according to the standard protocols for peach post-harvest handlings adopted by sorting centers and the Italian GDO. After a preliminary assessment for the presence of external defects and uniform size, fruit were randomly subdivided into two equal batches of thirty fruit: the first analyzed briefly upon arrival ('ready-to-buy' stage) and the other stored for five days at 20 °C to mimic the typical shelf-life period and conditions in the store ('ready-to-eat' stage).

2.2. Fruit quality analyses

The two batches of fruit ('ready-to-buy' and 'ready-to-eat' stages) were further randomly divided into two equal pools of twenty fruit destined respectively to quality-related analyses and sensorial evaluations. Maturity date (meant as commercial ripening day) was expressed as Julian Day (JD). Fruit shape (flat/round), fruit type (peach/nectarine), fruit weight (expressed as grams, g) and flesh color (yellow/white) were also recorded. Ground skin color was measured for each drupe with a Konica Minolta Chroma Meter (CR-400, Konica Minolta Sensing Inc., Japan) instrument calibrated on the white porcelain plate provided by the producer. Coordinates of L^* (i.e., a lightness coefficient ranging from 0 = black to 100 = white), a^* (i.e., a scale of redness to greenness ranging from -60 = true green to +60 = true red) and b^* (i.e., a scale of yellowness to blueness ranging from -60 = true blue to +60 = true yellow) components from CIELAB color space model were determined around the equatorial region of fruit cheek. Fruit skin over-color was visually assessed and expressed as a ratio value ranging from 0 (no over-color) to 1 (full red over-color). Fruit maturity degree was assessed through i) visual and manual inspection; ii) chlorophyll content, estimated by I_{AD} index with a DA-Meter portable device (Sintèleia; Ziosi et al., 2008) and iii) flesh firmness (expressed as N), by GÜSS Fruit Texture Analyser (destructive method) penetrometer equipped with an 8 mm metal plunger set at speed of 1 ~ 40 mm sec⁻¹ after removing a 1.5 cm portion of the skin from the middle of one fruit cheek. Total SSC (intended as the total grams of soluble solids dissolved in a final solution of 100 mL) was estimated from few fruit juice drops using a 53000 C hand-held digital refractometer (T.R. Turoni, Italy) and expressed as percentage. TA (calculated as both grams of malic acid per liter of sample juice and pH) was measured in twenty biological replicates of the flesh juice made using a blender after the complete skin removal. TA was determined by titrating 10 g of flesh sample with 0.1 N of NaOH to pH 8.1 using a DL-50 auto-titrator instrument (Mettler-Toledo, Italy). TA value in g L⁻¹ of malic acid has been used as the preferred unit for expressing acidity, since it likely provided a more accurate prediction of the acid's impact on flavor compared to pH. This is because titratable acidity measures both bound and free hydrogen ions in solution (Sadler

and Murphy, 2010). Ratio between SSC (measure converted appropriately into g L⁻¹) and TA (in g L⁻¹) was defined as BrimA index. Fruit weight and color-related measurements were only recorded at ready-to-buy stage.

2.3. Sensorial analyses

Sensory analyses followed the quantitative descriptive analysis method (QDA) and ISO guidelines involving a team of fourteen experienced and trained panelists. Descriptive sensory evaluations were conducted in isolation booths under normal indoor lighting as previously reported (Baccichet et al., 2024). Panelists evaluated the perceived fruit textural attributes (i.e. firmness, juiciness, mealiness) and flavor-related perceptions (i.e. aroma, astringency, bitterness, BrimA intensity - i.e. prevalence of sweetness over acidity-, fruitiness, sourness and sweetness) using a hedonic scale (from 0 to 9) with the minimum liking threshold set at 5. Then, panelists were asked to rate the overall visual, olfactory, textural and taste pleasantness with the corresponding degree of liking.

2.4. Statistical analysis

All statistical analyses were performed using R software (v. 4.1.3) in the interface of RStudio (v. 1.4.1717).

Replicated measurements for each cultivar were averaged for all the analyses except for some elaborations showing the overall variability across samples for some parameters (SSC, TA, BrimA index and overall pleasantness) which includes all 66 observations. Distribution range (minimum, maximum, mean and median values) for maturity date (MD), chlorophyll content (DA), skin over-color, fruit weight and pH were represented at 'ready-to-buy' stage (Supplementary Figure 2) using *ggplot2* package (v. 3.4.3). Ground skin color of each cultivar was visualized on a xyz Cartesian plane (Supplementary Figure 4) using *plotly* package (v. 4.10.3). Mean and standard deviation were calculated for the analytical fruit features (SSC, TA and BrimA index; Supplementary Table 3). Analytical and sensory data distribution was checked for normality assumption through Shapiro-Wilk's test (p -value ≤ 0.05) leading to perform non-parametric statistics tests. Peach cultivars were ranked basing on the MD class of frequency as very-early (≤ 140 JD; VE), early (156–169 JD; E), mid-season (173–194 JD; MS), late mid-season (198–211 JD; LMS), late-season (215–234 JD; LS) and very late-season (238–257 JD; VLS). Kruskal-Wallis's test (p -value ≤ 0.05) and Dunn's multiple pairwise *post-hoc* test were performed to compare data of each analytical and sensory parameter among MD classes (Figs. 1, 2, 5 and 6; Supplementary Figs. 3, 5, 6, 7, 9, 10 and 11; Supplementary Table 5) using *ggstatsplot* (v. 0.12.1) or computed with *stats* (v. 4.1.3) and then plotted using *ggplot2* (v. 3.4.3) packages. To evaluate the relationships among the analytical parameters (Supplementary Table 4) and between attributes and sensory ratings (Fig. 4), Spearman's correlation coefficients were estimated respectively in *Hmisc* (v. 5.0–1) and in *metan* package (v. 1.18.0). To investigate the effect (p -value ≤ 0.05) of storage condition on DA (Supplementary Figure 12), flesh firmness (Fig. 7-C and D), TA (Supplementary Figure 13), SSC (Supplementary Figure 14) and BrimA index (Fig. 7-A and B) among cultivars and then among MD ranks, a linear model was carried out in *stats* package (v. 4.1.3). Cultivar- and MD-related variability for the analyzed-parameter between ready-to-buy (F) and ready-to-eat (S) was depicted as line-plot and box-plot, respectively, using *ggplot2* (v. 3.4.3). Treatment effect was significant at p -value ≤ 0.05 and the average range of variation ($\mu_F - \mu_S$) was reported for each FQ parameter. A multiple linear regression analysis was performed on the overall pleasantness score (Fig. 3-A). For the tested predictor, t -statistics (t -score) discriminated the significant (p -value ≤ 0.05) associations with visual, taste, textural and olfactory evaluation. R-squared values were estimated on the 52 cultivars to disjoint the sensory qualities entity contributing to the final taste response by panelists (Fig. 3-C).

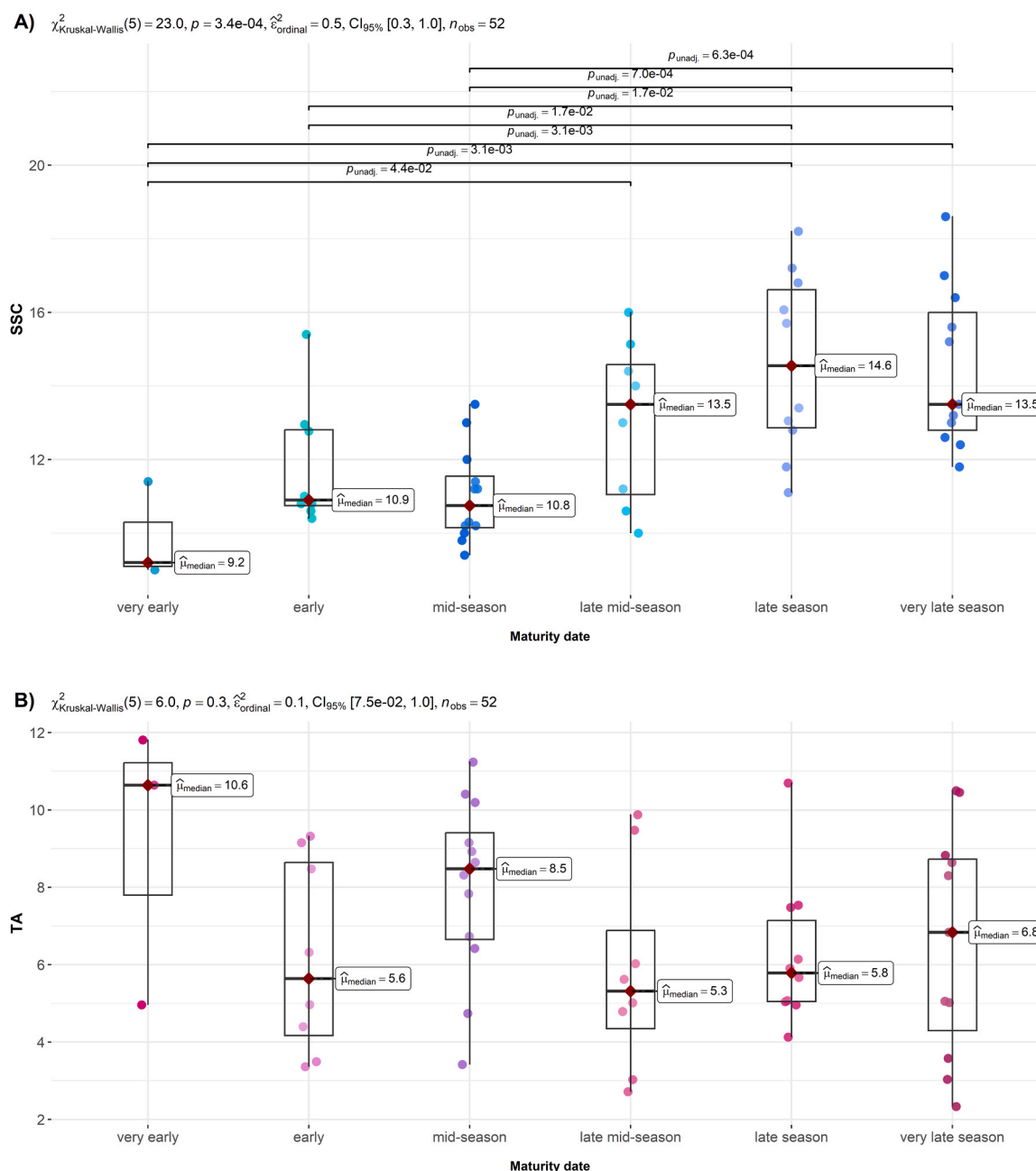


Fig. 1. Distribution of soluble solid content (SSC) and titratable acidity (TA) level along the maturity date calendar in 52 unique peach cultivars at ‘ready to buy’ stage. SSC (in A) and TA (in B) values widely differed among the six peach maturity date groups. SSC was measured as total SSC content dissolved in a final 100 mL of flesh juice (in %). TA level was preferentially expressed as g L^{-1} of malic acid. Differences were tested for statistical significance using Kruskal-Wallis’s non-parametric test and Dunn’s multiple pairwise *post-hoc* test. Only significant ($p\text{-value} \leq 0.05$) comparisons were reported on the top of the plot as bars. Across and within year replicated measurements for the 52 unique cultivars were averaged. Maturity date had a positive effect on the total SSC as very-early, early and mid-season cultivars significantly differed from the other late ripening groups. TA did not show a significant maturity date-dependency.

3. Results

3.1. Cultivars and fruit quality characterization at ready-to-buy stage

The peach materials characterized in this study likely indicated the most popular cultivars grown in Italian orchards (Supplementary Table 1) over eight years (from 2011 to 2021; Supplementary Figure 1). The whole cultivars collection covered most of the marketing season in Italy (Supplementary Figure 2-A) starting from ‘Sagittaria’ (II decade of May) and closing with ‘Romagna 3000’ (II decade of September). Among the six commercially-harvested groups defined in this study (i.e. very-early, early, mid-season, late mid-season, late season and very-late

season), most of the cultivars fell into the late mid-season group (mean value of about 200 JD), the peak of Italian production.

Fruit weighted on average 178.5 g (Supplementary Figure 2-D), equivalent to the commercial standard class of A size (from 135 to 180 g or from 67 to 73 mm diameter according to ‘UNECE STANDARD FFV-26’). Flat peaches (seven cultivars) significantly confirmed their intrinsic lower weight (range of 75.4–150.5 g) than rounded ones (Supplementary Figure 3-A). In turn, rounded peaches were significantly affected by maturity date (MD) (Supplementary Figure 3-B): the early ripening ‘Sagittaria’ (137 JD) and ‘Garcima’ (140 JD) weighted almost 100 g less than late ripening cultivars ‘Alexa’ (256 JD), ‘LateFair’ (255 JD) and ‘Romagna 3000’ (257 JD).

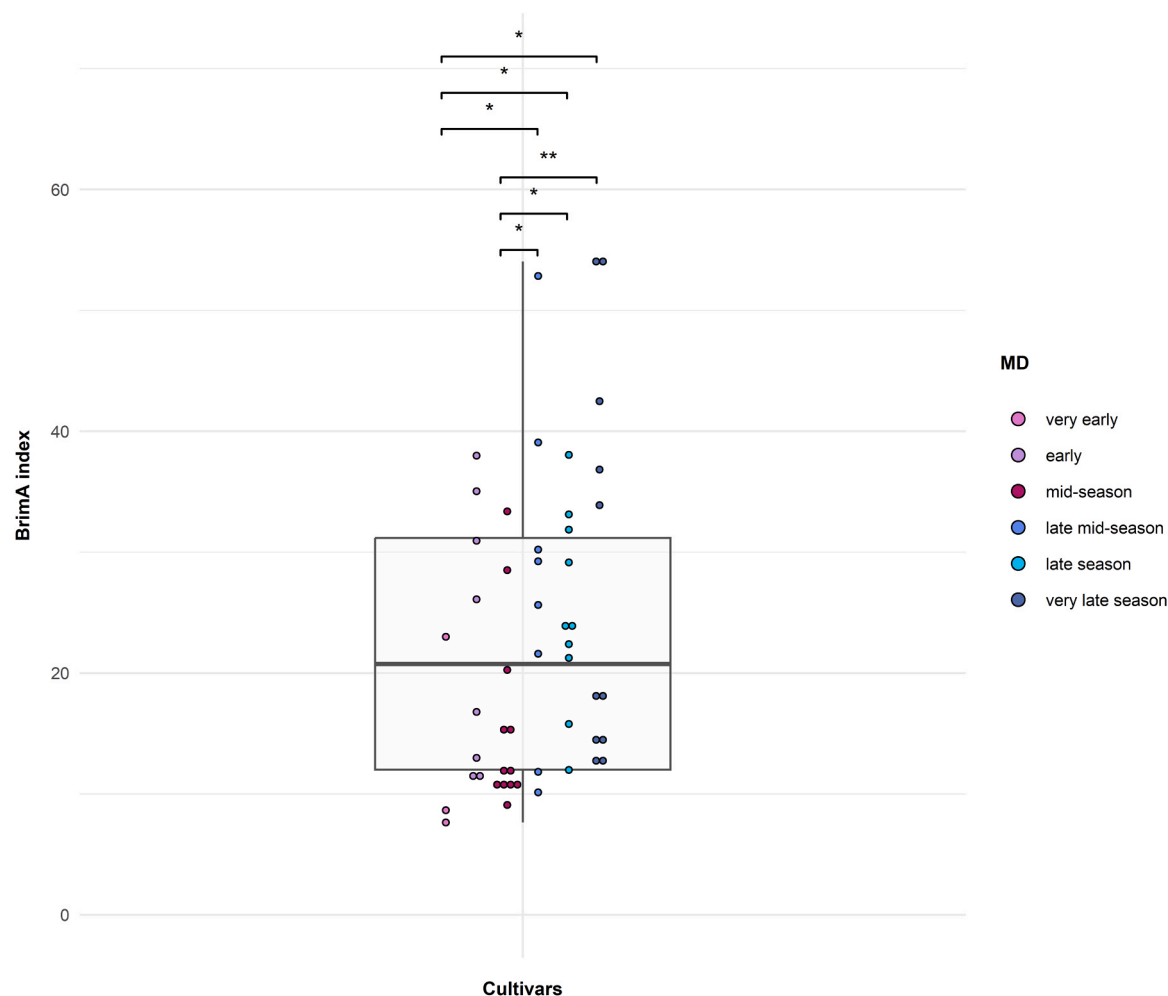


Fig. 2. Distribution of the ratio (BrimA index) between soluble solid content and titratable acidity level in 52 peach cultivars at ‘ready to buy’ stage. BrimA index was calculated as the absolute content ratio between soluble solid (SSC, converted in g L^{-1}) and titratable acidity (TA in g L^{-1} of malic acid) in fruit samples at ‘ready-to-buy’ stage. Box-plot depicts the overall distribution on the whole dataset of 52 cultivars while colored points corresponds to each maturity date class distribution. Differences were tested for statistical significance using Kruskal-Wallis’s non-parametric test and Dunn’s multiple pairwise *post-hoc* test. Comparisons were significant at $p\text{-value} \leq 0.05$ (* significant at the 5 % level, ** significant at the 1 % level, *** significant at the 0.1 % level). Across and within year replicated measurements for the 52 cultivars were averaged. Significant differences occurred in the BrimA index along the maturity date calendar at ‘ready-to-buy’ stage with the maximum value of 54 in ‘Saturnia’ and ‘Kewina’, two very late ripening cultivars.

At ‘ready to buy’ stage (F), flesh firmness was in the retailers’ commercial standards, since most of the cultivars ranged between 40 and 60 N (Supplementary Figure 2-E). Based on I_{AD} values (averaging 0.55), most of the cultivars were at the lower limit of pre-climacteric phase, although this index was positively but poorly correlated with firmness (ρ of 0.36; Supplementary Table 2), indicating that both measurements are complementary but not interchangeable. Skin color showed similar values across cultivars ($\rho = 0.70$ between a^* and b^* parameter; Supplementary Table 2 and Supplementary Figure 4), with no significant differences (Kruskal Wallis’s test outputs with $p\text{-value} > 0.05$) in red shades ($\rho = 0.29$ between L^* and a^* ; Supplementary Table 2). The percentage of skin over-color was quite extensive, reaching an average covering of over 70–80 % of the surface in most cultivars (Supplementary Figure 2-C).

Soluble solid content (SSC), titratable acidity (TA) and their balance (BrimA index) showed a high range of variability, both considering average values of each cultivar or the whole set of observations. At cultivars level, SSC varied from a minimum of 9 % in ‘Garcima’ to over 18 % in ‘Tourmaline’, while TA from 2.3 g L^{-1} in Kewina to 11.8 in ‘Garcima’ (Supplementary Table 1). MD was the main discriminant factor for SSC, being positively and highly correlated with its level ($\rho = 0.62$; Supplementary Table 2). In this wake, very early (mean of 9.9 and

median of 9.2 %), early (mean of 11.8 and median of 10.9 %) and mid-season (mean of 11 and median of 10.8 %) cultivars significantly differentiated from the other late ripening ones (around 14 %) (Fig. 1-A). Conversely, TA did not show a significant MD-dependency ($p\text{-value} > 0.05$; Fig. 1-B), as expected from the strong effect of cultivar’s genetic background on this trait. Significant differences occurred in the ratio between SSC and TA (BrimA index) along the MD calendar, reaching a maximum of about 54 in ‘Saturnia’ and ‘Kewina’, two very late ripening cultivars (Fig. 2).

In general, across samples and years, SSC values were quite low, with an overall mean of 12.5 % (Supplementary Table 3 and Supplementary Figure 5-A), in turn affecting BrimA index (with average values below 24) and only partially compensated by the medium-low TA of many samples (Supplementary Figure 5-B and 6-A).

3.2. Overall sensory perception at ready-to-buy stage

The overall eating pleasantness showed an inconsistent trend over years (Supplementary Figure 6-B and Supplementary Table 3), mostly depending on unsatisfactory taste-related properties ($t\text{-score}$ in the linear model: 14.16; Fig. 3-A) rather than olfactory, visual and textural features ($t\text{-scores}$: 4.09, 2.64 and 3.27, respectively). However, sensory

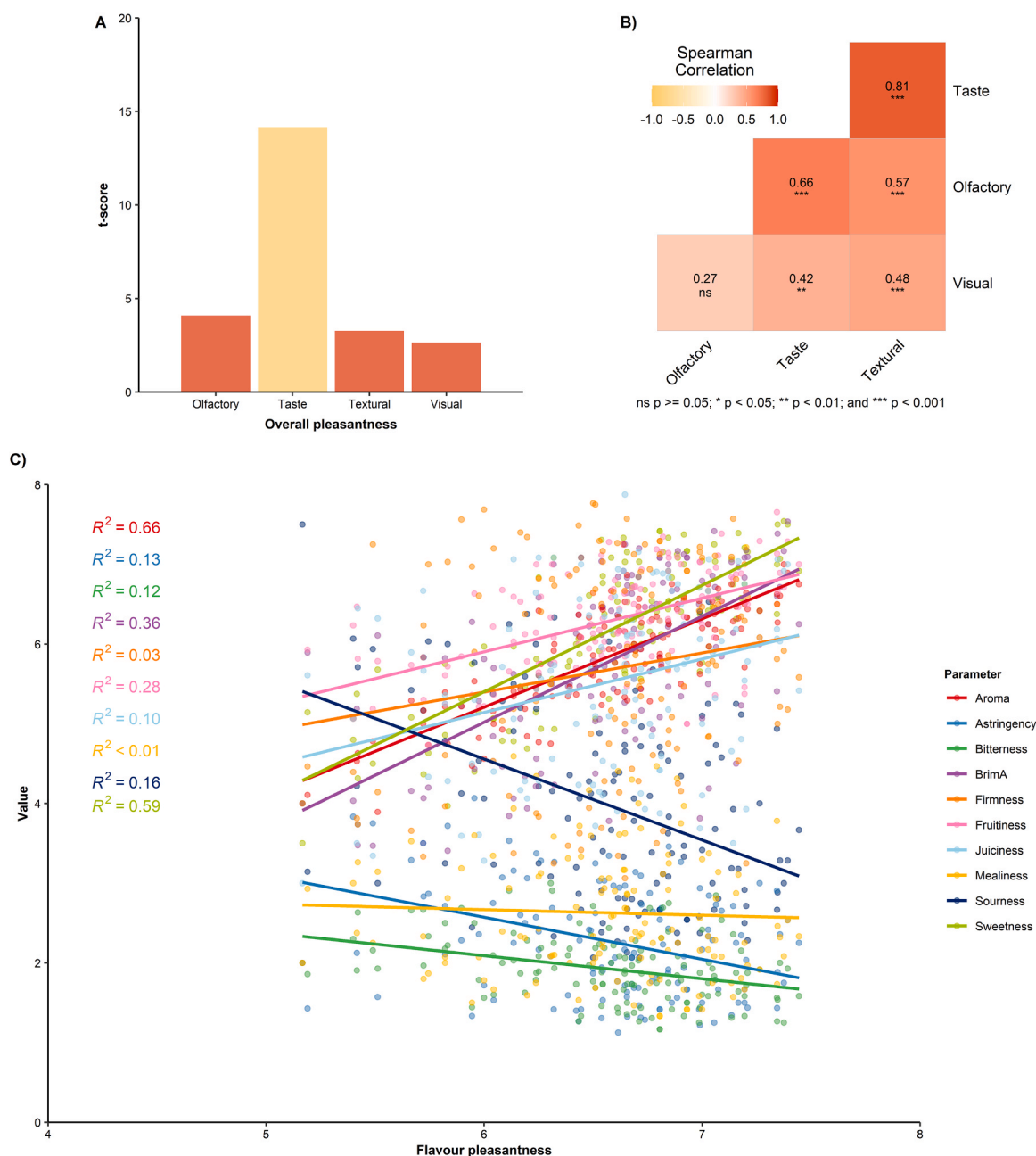


Fig. 3. Multiple linear regression analysis and Spearman's correlation test on olfactory, taste, textural and visual pleasantness ratings. Multiple linear regression model was performed on the whole peach sensorial outputs estimating the *t-score* (on y axis) of each pleasantness-related parameter (A). All *t*-scores were significant at p -value ≤ 0.05 . B) Spearman's correlation test at p -value ≤ 0.05 . C) Multiple linear regression model on flavor-related parameters. Replicated measurements and sensory scores for each cultivar were averaged across years. Most of the eating pleasantness depended on taste (*t-score* of 14.16) rather than olfactory (*t-score* of 4.09), visual (*t-score* of 2.64) and textural features (*t-score* 3.27). Among the parameters, visual pleasantness seemed the unique almost unrelated to the others.

results pinpointed a strong and significant (p -value ≤ 0.05) relationship between textural properties ($\rho = 0.81$; Fig. 3-B) and olfactory scent ($\rho = 0.66$), emphasizing their synergic effect on flavor perception. Visual pleasantness seemed almost unrelated to the other parameters (Fig. 3-B). At flavor level (Fig. 3-C and Supplementary Table 4), an enhanced sensation of sweetness and aroma (R -squared of 0.59 and 0.66, respectively) appeared as the most important parameters in panelists' eating experience. Conversely, sourness slightly decreased the pleasant 'peach' flavor. No significant variation in panelists' degree of liking were detected for the other organoleptic parameters evaluated (Supplementary Table 4).

Among flesh textural properties, multiple linear regression analysis ranked juiciness as the most pleasant type, often coupled to a superior

peach flavor, although no significant differences were found for this parameter among cultivars' groups (Supplementary Figure 7-C).

3.3. Visual and textural-related fruit quality and perception at ready-to-buy stage

Spearman's test revealed a high correlation ($\rho = 0.74$) between firmness and its sensory perception at 'ready-to-buy' stage (F) (Fig. 4). Mealiness and juiciness were moderate in firmer fruit (ρ of -0.47 and -0.54 , respectively; Fig. 4). Flesh firmness (Supplementary Figure 7-A), juiciness (Supplementary Figure 7-C) and mealiness (Supplementary Figure 7-D) did not vary significantly across cultivars or harvesting calendar (p -value > 0.05). Notably, mealiness perception ranked well

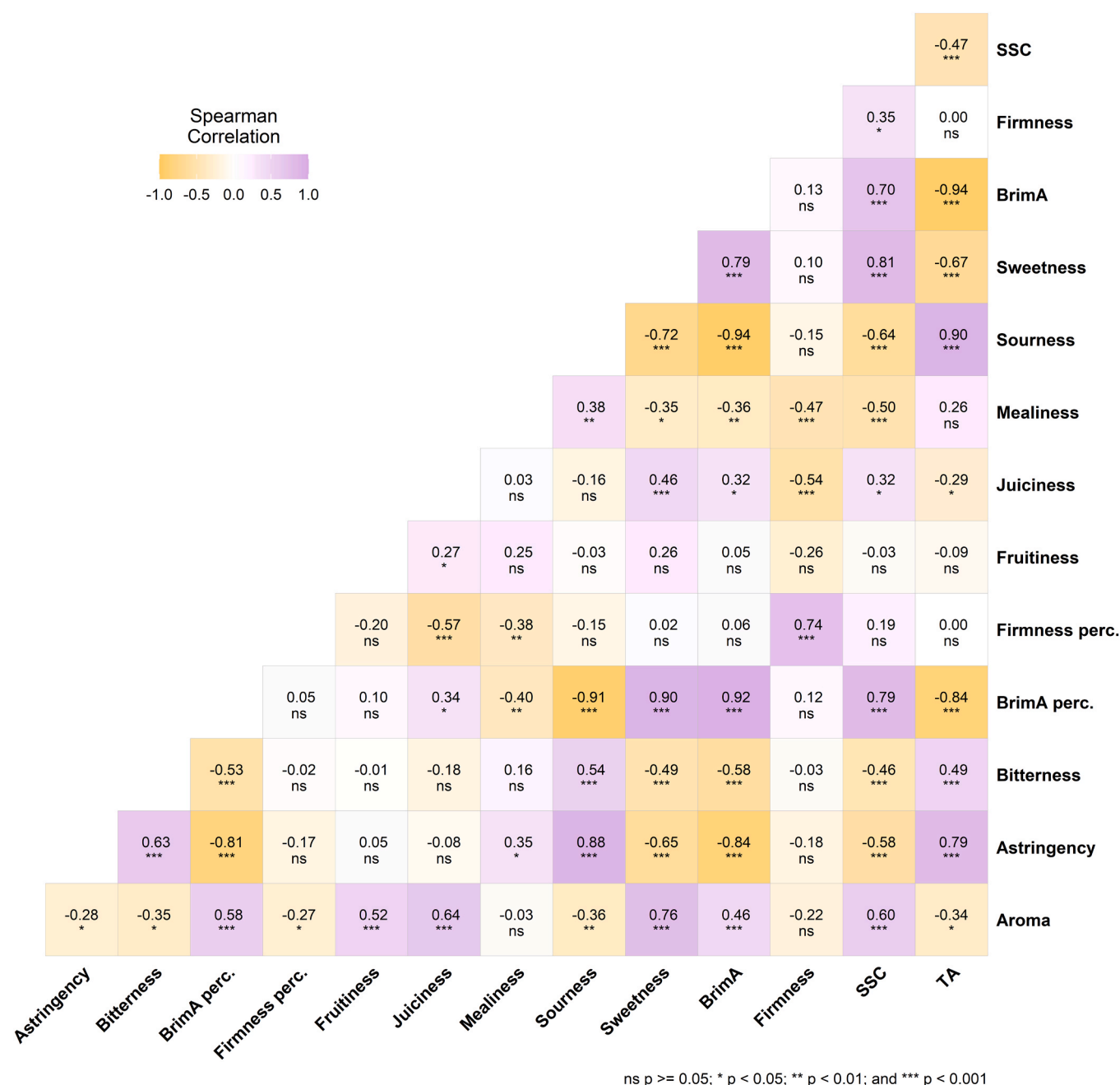


Fig. 4. Spearman's correlation test among the quality-related features and sensory perceptions at 'ready-to-buy' stage. Evaluation of physico-chemical parameters (Firmness, BrimA index, SSC and TA) and sensory perceptions. Across and within year replicated measurements for the 52 unique cultivars were averaged. Correlations were significant at p -value ≤ 0.05 (* significant at the 5 % level, ** significant at the 1 % level, *** significant at the 0.1 % level and 'ns' not significant). Abbreviations: *BrimA*, absolute content ratio between soluble solids and titratable acidity; *SSC*, soluble solids content (%); *TA*, titratable acidity (g L^{-1} of malic acid); *perc.*, perception.

below (panelists' ratings between 1.5 and 3.5) the minimum threshold set. However, panelists tended to perceive nectarines as firmer than peaches (Supplementary Figure 7-B), regardless of the inclusion of a canning cultivar ('Baby Gold 6').

3.4. Organoleptic quality and sensorial perception at ready-to-buy stage

Spearman's correlation analysis between pomological and sensory attributes at 'ready-to-buy' stage (F) corroborated SSC and TA as strong predictors of sweetness ($\rho = 0.81$) and sourness ($\rho = 0.90$) perception, respectively (Fig. 4). Conversely, no relationship was found between skin color-related parameters and internal fruit features (SSC, TA and

BrimA index; Supplementary Table 2). This is particularly true for many recently breed cultivars, almost equally (Supplementary Figure 2_C) and fully-over colored long before the full physiological maturity stage (Supplementary Figure 8).

At taste level, panelists confirmed a sweeter perception in late and very late-ripening cultivars (Fig. 5-A and Supplementary Table 5) while sourness prevailed in the very-early and mid-season groups (Fig. 5-B and Supplementary Table 5). The gap occurring between the variability in TA and sourness could be clarified by an increase of astringency ($\rho = 0.79$) and bitterness ($\rho = 0.49$) sensations, albeit both were under the minimum perception threshold (Supplementary Figure 9-C and 9-D). Astringency and bitterness seemed to prolong the sour taste in fruit with

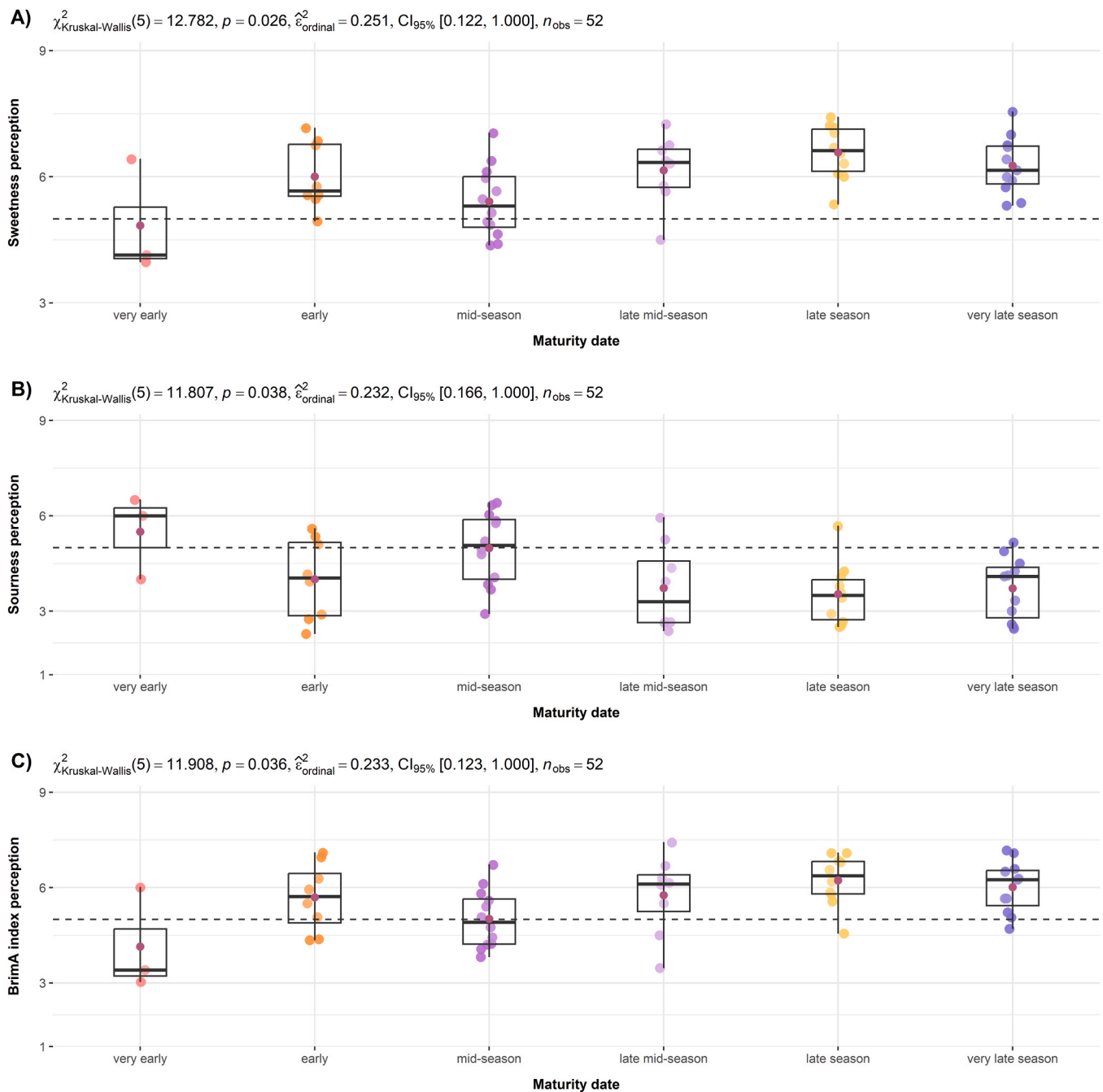


Fig. 5. Distribution of panelists' taste perception of sweetness, sourness and BrimA index among the six cultivars maturity date groups at 'ready-to-buy' stage. Sweetness (in A), sourness (in B) and BrimA index (in C) perception differences were significant at $p\text{-value} \leq 0.05$ (* significant at the 5 % level, ** significant at the 1 % level, *** significant at the 0.1 % level) based on Kruskal-Wallis's non-parametric test and Dunn's multiple pairwise *post-hoc* test. The panelists' hedonic scale ranged between 0 and 9 with the minimum acceptable threshold set at 5 (dashed line). A sweeter perception occurred in late and very late-ripening cultivars. Sourness prevailed in the very-early and mid-season groups. BrimA index mirrored the perceptions of sweet and sour taste, with a neglected and higher values in very-early and late ripening groups, respectively.

higher TA level and an unbalanced ratio between SSC and TA (BrimA index). BrimA perception was strongly consistent with the instrumental analysis ($\rho = 0.92$), revealing an almost equally dependence on TA ($\rho = -0.84$) and SSC ($\rho = 0.79$). Conversely, analytical measurement of BrimA correlated to TA ($\rho = -0.94$ versus $\rho = 0.70$) more than SSC, stressing the complex multisensory interactions that give rise to the human flavor experiences (Fig. 4).

A pleasant aroma perception occurred regardless of MD, although the median of very early and mid-season cultivars positioned around 5 (i.e. the minimum acceptable threshold set in panelists' sensory

analysis), respectively (Supplementary Figure 9-B). Aroma perception poorly and negatively correlated to TA ($\rho = -0.34$; Fig. 4) explaining the not significant differences observed between the low (2–4 g L⁻¹ of malic acid), medium (5–6 g L⁻¹ of malic acid), medium-high (7–8 g L⁻¹ of malic acid) and high (more than 9 g L⁻¹ of malic acid) acid cultivars (Supplementary Figure 10-A). This result -and the evidence that aromatic scent increased in fruit with the BrimA index above 21 (Supplementary Figure 10-B)- suggests a primary sensorial dependence on SSC ($\rho = 0.60$; Fig. 4; Fig. 6). Out of the five groups (Fig. 6), panelists experienced a more pleasant and enhanced aromatic hint from SSC

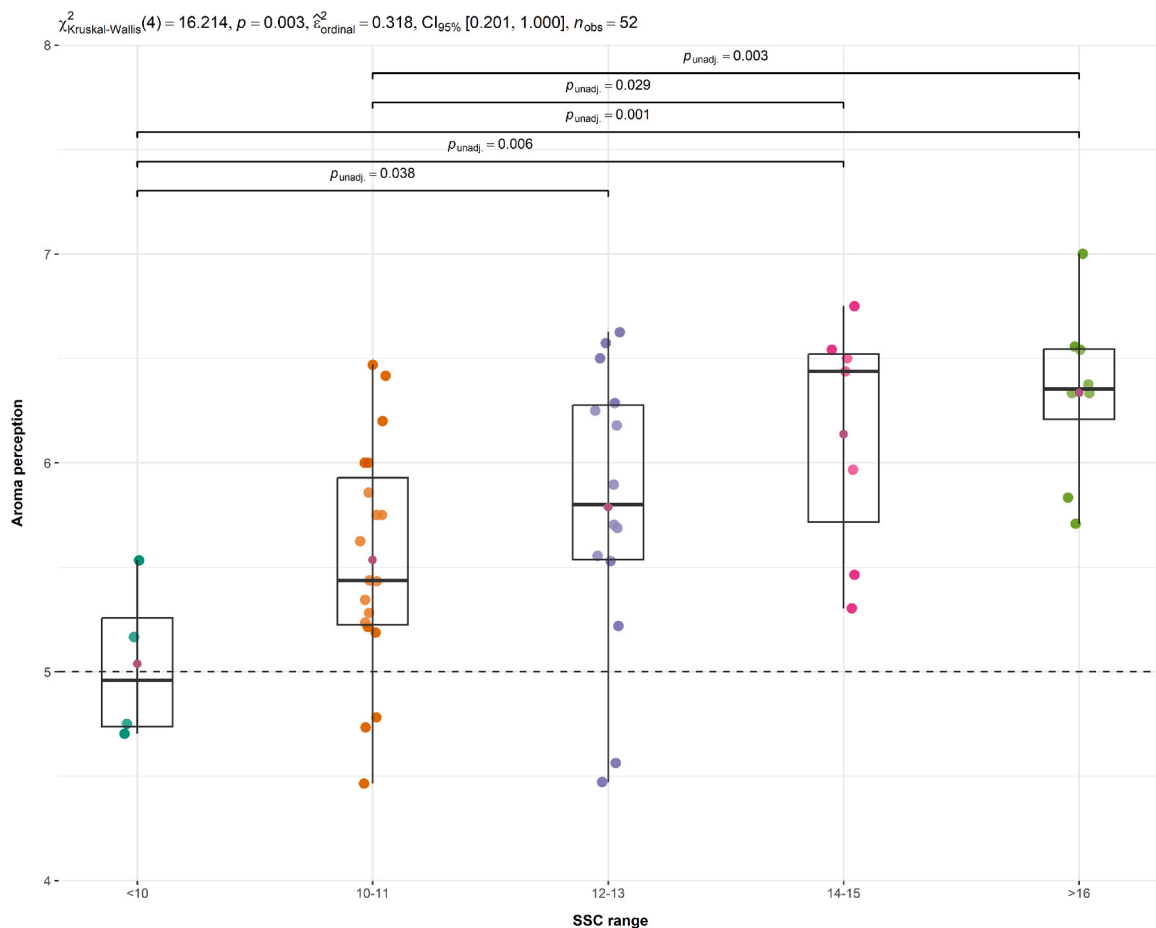


Fig. 6. Relationship between soluble solid content range and perception of aroma intensity at ‘ready to buy’ stage. Five box-plots report the distribution of cultivars within each soluble solid content (SSC in %) group. The panelists’ hedonic scale set the minimum liking threshold at 5 (dashed line). Differences were tested for statistical significance using Kruskal-Wallis’s non-parametric test and Dunn’s multiple pairwise *post-hoc* test. Comparisons were significant at $p\text{-value} \leq 0.05$ (* significant at the 5 % level, ** significant at the 1 % level, *** significant at the 0.1 % level). Panelists experienced an enhanced aromatic perception in drupes with a SSC above 12 %.

above 12 %. Undeniably, other factors affected the aroma variability perceived within each SSC group (as witnessed by the variance spread within the range of 10–13 %).

In relation to the four pomological peach type (peach or nectarine, yellow and white flesh), variability of sweetness, BrimA index and aroma was not informative and always positioned above the minimum threshold set at 5 (Supplementary Figure 11-A, 11-B and 11-C). Also, neither fruit type (peach/nectarine) nor shape (flat/round) seemed to influence the aromatic intensity (Supplementary Figure 10-C and D). The pomological classification appeared as useful as only a purchase’s driver in mass-supply selling system and not for ensuring a higher degree of liking at taste level.

At odor level, perception of fruitiness intensity varied with the fruit type, revealing peaches (mostly white-fleshed) as more fragrant than nectarines ($Z\text{-score}$ of 2.67; Supplementary Figure 11-D and Supplementary Table 5) but unaffected by maturity period (Supplementary Figure 9-A).

3.5. Effect of shelf-life (ready-to-eat stage) on fruit internal quality

Fruit internal quality was re-evaluated after a shelf-life of 5 d at 20 °C (‘ready to eat’, S) (Supplementary Figure 12A). Ripening speed ($\mu_F - \mu_S$) was cultivar-dependent (e. g., ‘Garcima’ and ‘Sagittaria’ versus ‘Alma 2’, ‘Parabelle’, Saturnia’ and ‘Lami Dolza 3’; Supplementary Figure 12-A) and mostly evident in the very early maturity group (Supplementary Figure 12-B). Loss of firmness varied among cultivars (Fig. 7-C),

probably depending on flesh texture types (melting, non-melting, slow-softening) but not specifically evaluated in this study. An average loss ($\mu_F - \mu_S$) of firmness of 27.2 N was observed during five days of shelf-life (i.e. comparison between ‘ready to buy’ and ‘ready to eat’ stages; Fig. 7-C). Worth mentioning, a greater decrease of firmness occurred in late mid-season, late and very-late ripening cultivars (Fig. 7-D).

Changes occurring during shelf-life lead to an almost negligible deterioration of taste-related perception (astringency, sourness, sweetness and sweet-sour balance) –and hence metabolites– that could explain the strong and positive correlation coefficients found (ρ from 0.85 to 0.93; Table 1). The almost negligible variability observed for TA (Supplementary Figure 13-A), SSC (Supplementary Figure 14-A) and BrimA index (Fig. 7-A), as well as across the MD groups (Supplementary Figure 13-B and Supplementary Figure 14-B), could be related to sampling. In contrast, shelf-life tend to moderately reduce aroma and fruitiness intensity (ρ of -0.56 and -0.50 , respectively; Table 1).

4. Discussion

This study summarized eight-years data collected on fruit quality (FQ) across 66 samples from 52 peach cultivars sold across the mass-supply chain (the so-called ‘Organized Large-Scale Retail Distribution’, GDO) in Northern Italy, with the aim of giving a reliable and cutting-edge glimpse of peaches traded along the harvesting calendar. A combined analytical and sensorial evaluation of several FQ features was adopted, hopefully to support peach industry.

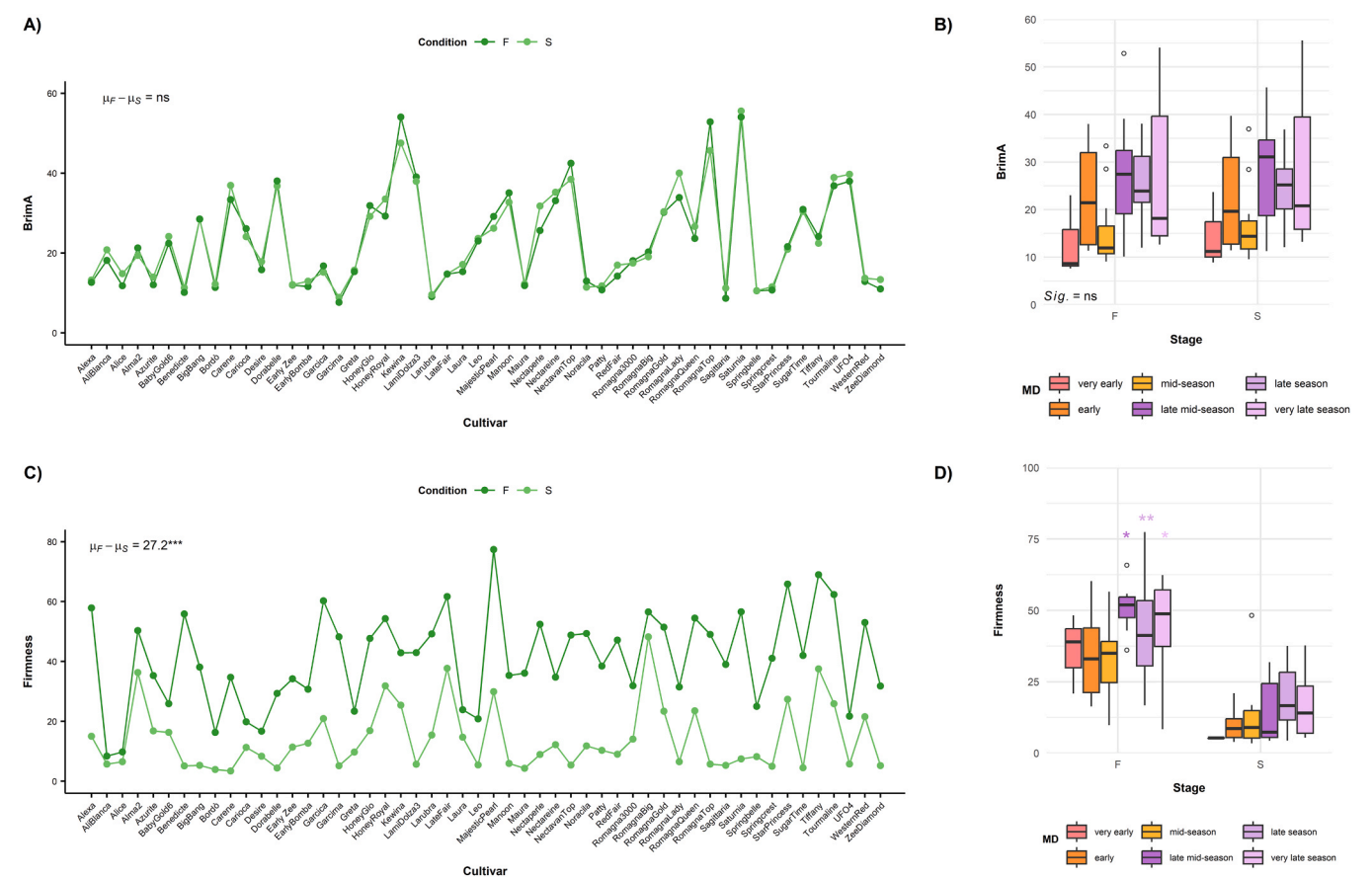


Fig. 7. Effect of shelf-life on BrimA index and flesh firmness. Comparisons of BrimA index and flesh firmness (expressed as N) between ‘ready-to-buy’ (F) and ‘ready-to-eat’ stages (five days of storage at 20 °C, S). The effect was evaluated on each cultivar (in A and C) and maturity date group (in B and D). The average variation ($\mu_F - \mu_S$) is reported in each plot when significant at p -value ≤ 0.05 (* significant at the 5 % level, ** significant at the 1 % level, *** significant at the 0.1 % level and ‘ns’ not significant). Across and within year replicated measurements for the 52 unique cultivars were averaged.

Table 1
Spearman’s test correlation matrix among the quality attributes evaluated on 52 peach cultivars at ‘ready-to-buy’ and ‘ready-to-eat’ stages. Only the quality attributes significantly perceived by panelists were tested and reported in this table. The correlation coefficients are significant when p -value ≤ 0.05 (* significant at the 5 % level, ** significant at the 1 % level, *** significant at the 0.1 % level).

		READY-TO-EAT									
		Aroma	Astringency	Bitterness	BrimA index perception	Firmness perception	Fruitiness	Juiciness	Mealiness perception	Sourness	Sweetness
READY-TO-BUY	Aroma	0.56***									
	Astringency		0.89***								
	Bitterness			0.57***							
	BrimA index perception				0.90***						
	Firmness perception					0.58***					
	Fruitiness						0.50***				
	Juiciness							0.66***			
	Mealiness perception								0.51***		
	Sourness									0.93***	
	Sweetness										0.85***

The Italian GDO is a complex system as it includes distributors, wholesalers and retailers (super and hypermarkets). Notably, the GDO model is the most widespread selling channel in Italy (84 % *versus* 16 % of the small retailers; [Ismea-NielsenIQ, 2024](#)) and, thus, highly representative of the peach market in general. As a multi-faceted trait, FQ involves intrinsic pre- and post-harvest factors balanced with socio-economic, marketing and customer aspects ([Musacchi and Serra, 2018](#)). GDO model play an important role in the shaping of peach

quality, strongly influencing maturity indices and market’s acceptability criteria. Firmness and appearance were confirmed to be the main commercial priority target, as deduced by the consistent values of flesh firmness (40–60 N), size (from 135 to 180 g or from 67 to 73 mm) and the compliance of external features (particularly the absence of defects and homogenous skin color). Firmness is a critical index for fruit shelf life as it affects resistance to mechanical damage during handling, transport and storage ([Crisosto and Valero, 2008](#); [Di Miceli et al., 2012](#)).

A complementarity but not interchangeability between firmness and chlorophyll content was observed (Supplementary Table 2), confirming the need of testing both indices in each cultivar to establish a proper harvest time and predict the potential shelf-life at retailers' level (Crisosto, 2002). Skin color is another commonly adopted maturity indices in stone fruit (Esti et al., 2002; Crisosto et al., 2003; Minas et al., 2018; Silva et al., 2021; Crisosto, 2023). Nevertheless, intensity and coverage of red over-color was similar for most of the analyzed peach cultivars, and weakly correlated to ripening degree, in contrast to older varieties (Crisosto, 1994; Kader, 1997). A plausible explanation relies on the very early development of red-skin coverage, a characteristic of almost all recently released cultivars, which tend to mask the background color at the onset of ripening (Supplementary Figure 8) (Crisosto, 1994; Crisosto et al., 1995; Iglesias and Echeverría, 2009; Cantín et al., 2010). This evidence might discourage the adoption of this parameter as a reliable harvesting criterion, albeit easily recognizable in orchards (Infante et al., 2009).

The strong relationship between FQ perception and analytical parameters corroborates the sensory capacity of experienced panelists as a good and reliable yardstick. The sensory preference for taste over the visual, textural and olfactory pleasantness, contrast with main GDO targets, prioritizing appearance and firmness (Di Miceli et al., 2012; Taiti et al., 2021). Visual pleasantness appeared to be unrelated from the organoleptic one (Fig. 3-B), unhinging skin color as a top-notch feature in peach and unlike most of recently released apple cultivars (Musacchi and Serra, 2018). Results also emphasized a large inconsistency of taste-related properties in fruit sold along the mass-supply channels, regardless of the minimum quality standard criteria set. This aspect may, therefore, contribute to increasing consumers' skepticism toward purchasing peaches. Panelists' significantly discriminated cultivars in terms of aroma, astringency, firmness, sourness, sweetness and sweetness-sourness ratio (BrimA) perception. Flavor pleasantness strictly depended on sweetness (taste) and aroma (retro-nasal perception), corroborating previous evidences on peach and other stone fruit (Colaric et al., 2005; Crisosto and Crisosto, 2005; Montevecchi et al., 2012; Rolls, 2019; Taiti et al., 2021; Baccichet et al., 2023; Crisosto, 2023). Either sourness or astringency negatively contributed to a pleasant panelists' eating experience. A sourer and more astringent taste perception occurred in very-early cultivars, also approaching the limit of minimum acceptable SSC (about 9.2 %) (Fig. 1 and Fig. 5). In this harvest group, the imbalance between acids and sugars (BrimA of 8.7 *versus* 19.9 in very-late ripening cultivars) probably failed to produce a sensorial stimulus strong enough to exceed the minimum threshold perceivable at receptor level in the mouth. Among the taste-related features, analyses of panelists' overall pleasantness highlighted the aroma as a key trait, regardless of the maturity period. Even if analytic determination of aromatic volatiles (VOCs, such as γ -hexalactone, γ -octalactone, γ -decalactone, δ -decalactone, Z-3-Hexenyl acetate and Hexyl acetate; Wang et al., 2009; Eduardo et al., 2013; Bianchi et al., 2017) was not performed in this study, their synthesis relies on a myriad of metabolic pathways (terpenoid, phenylpropanoid, fatty acids etc.; Schwab et al., 2008; Ortiz et al., 2010; Lara et al., 2020), affected by genotype, fruit ripening degree, environmental conditions and post-harvest handlings (Aubert and Milhet, 2007; Eduardo et al., 2013; Bianchi et al., 2017; Pott et al., 2019). All these aspects have limited a comprehensive characterization in peach germplasm available over years. However, human perception of aroma integrates multiple receptors stimuli (taste stimuli from oral cavity, odor from sniffing or inhaling through the mouth and aroma from retro-nasal smell) from hundreds of VOCs simultaneously and it also interacts with taste to create the final flavor (Noble, 1996; Delgado et al., 2013; Crisosto and Tonutti, 2015). The poor advancement in linking the qualitative VOCs profiles to the human sensorial perception and/or preference validates the reliability of panelists' judgment in this study. Additionally, our results confirmed a larger aromatic intensity with SSCs at least above 12–13 %. Previous studies reported e-nose as a useful tool for checking

fruit ripening degree, predicting sensory quality perception along shelf-life and segregating individuals, but not for confirming the occurrence of specific VOCs within a peach cultivar (Di Natale et al., 2001; Benedetti et al., 2008; Infante et al., 2008a; Infante et al., 2011; Cano-Salazar et al., 2012; Zhang et al., 2008). Although various destructive and non-destructive methods are available to quantify aromas, such as gas chromatography-mass spectrometry (GC-MS), electronic nose, solid-phase microextraction (SPME), FTIR/ NIRS spectroscopy, none of them currently possess the reliability and cost-effectiveness required for widespread application in the pre- and post-harvest monitoring of the aromatic profile (Sneath and Persaud, 2002).

The evidence that panelists perceived a stronger 'fruity' perception in peaches than in nectarines, either of white or yellow flesh, might be further explored to unbundle other factors – maybe cultivars specific- in determining the final flavor. Among the whole sensory perceptions on internal features, panelists detected a scarcer juiciness in firmer fruit at 'ready-to-buy' stage (Fig. 4), a different behavior from apples (Harker et al., 2003; Harker et al., 2006). A higher juiciness could facilitate the contact between soluble metabolites and the sensory receptors in the mouth and on the tongue. Also, firmness and mealiness (both included within the textural properties) were the unique moderately affected by shelf-life (correlation coefficients of about 0.55). The higher loss of firmness observed in late mid-season, late and very-late ripening cultivars seems pointing out the goals toward which the forthcoming breeding targets should be addressed to overcome the rapid fruit perishability. From the release of 'Big Top' nectarine (a mid-season cultivar in Northern Italy), the slow-softening trait has progressively becoming a characteristic of newly released cultivars (Olmstead et al., 2015; Ciacciulli et al., 2018), until almost completely saturating the fresh market. However, a US survey clearly distinguished young consumers (ages 18–24) who preferred crisp and firm peaches from older consumers (ages 51–65) who liked a melting-texture, but without exploring their familiarity with different flesh textures (Olmstead et al., 2015). As a result, consumers might be somewhat confused by purchasing fruit at 'ready to buy' stage that become 'ready to eat' after some days, even if slow-softening peaches keeps a firm flesh longer after harvest (Fig. 7C). Apart from the limited number of canning peaches (only 'Baby Gold 6') within our panel, the higher firmness perception detected in nectarines rather than in peaches requires further studies specifically accounting for different textures.

The importance of SSC, both alone and in relation to the acidity, is one of the key aspects that emerge from the study. In contrast with the minimum acceptable standard of 8 % (or "Brix" in the published requirements) set by UNECE (UNECE STANDARD FFV-26, 2023), panelists showed a preference concurrently with an SSC of at least 14 % (Fig. 1-A), a threshold similar to other previous consumers' surveys (Crisosto and Crisosto, 2005; Crisosto et al., 2006b; Montevecchi et al., 2012; Crisosto and Tonutti, 2015; Delgado et al., 2013). A reduced acidity level, when not balanced by adequate SSC, seems to generate a false sweetness perception in panelists, leading to the 'flat taste' frequently described by consumers. The strong consistency of SSC (Supplementary Figure 14), TA (Supplementary Figure 13) and BrimA index (Fig. 7-A) emphasized the irreversible consequence of not achieving organoleptic features prior to harvest, a topic already discussed in several temperate fruit tree crops (Crisosto et al., 1997; Manganaris et al., 2008; Stanley et al., 2014; Di Vittori et al., 2018; Musacchi and Serra, 2018; Anthony and Minas, 2022). This evidence seems to further support the overturn of the minimum taste-related standard currently imposed to peach trade sector within EU countries for lifting up the consumption.

Undeniably, the increase of SSC is challenging in stone fruit, both for breeders and growers (Crisosto and Crisosto, 2005; Crisosto et al., 2006b; Montevecchi et al., 2012; Crisosto and Tonutti, 2015; Delgado et al., 2013). Average SSC values observed across samples (ranging on average around 12 %) appeared significantly below the genetical

potential of these and other recently patented cultivars, as deduced from SSC level usually reported by cultivar testing trials or germplasm evaluation (Reig et al., 2013; Font i Forcada et al., 2014; Baccichet et al., 2021). Furthermore, the significant fluctuations within and between years (in part explained by the different harvesting periods) highlight another major concern for consumers: the unpredictable and inconsistent quality of the fruit. At the genetic level, it is evident that early-season cultivars have a lower potential for SSC accumulation compared to medium and late-ripening ones, albeit the correlation between maturity date and effect was more moderate ($p = 0.62$) than previously reported ($p = 0.86$; Baccichet et al., 2021). Whether it is possible to ameliorate the trade-off between early ripening and high SSC accumulation remains a topic of debate, since early maturing cultivars are constrained by their shorter developmental periods, which limits sugar accumulation. Thus, although SSC continues to be a highly important trait for breeders and still a focus of selection, it is now clear that the bottleneck originates at the orchard management level (Manganaris et al., 2022). In particular, crop load, nutrition and maturity degree at harvest are key agronomic factors in the regulation of fruit SSC accumulation potential. Currently adopted practices aims to maximize yield (by setting high fruit loads), size (high nutrient availability, particularly water and nitrogen) and post-harvest storability (very early harvesting): all practices that hinder the accumulation of SSC levels necessary to meet consumer expectations. A quality-driven control of fruit-load is instrumental to reduce fruit-to-fruit competition for photosynthates and increase dry mass or SSC level, as widely demonstrated by several thinning studies (Grossman and DeJong, 1995; Marini, 2003; Anthony and Minas, 2021). Curiously, two spring frosts in 2021 deeply affecting yield in most of the Emilia-Romagna growing areas can explain the higher SSC in samples assessed during this season (Supplementary Figure 5_A). Considering that the current profitability of peach production is largely determined by high yields per hectare, reconciling productivity and quality would require a re-asset of the existing remuneration methods across the GDO in order to move towards a 'rewarding quality production' strategy. Similarly, a premature harvest can also contribute to reduce SSC accumulation, with differences of more than 2 % for I_{AD} values moving from 1 to 0.5 (Bonora et al., 2013). However, the I_{AD} and firmness values observed in this study do not seem to indicate an excessively early harvest. Clearly, pushing indices toward more advanced ripening stages is still challenging, due to the complexity of logistic chain. Particularly for highly perishable fruit like peaches, reducing the lag time from harvest to retail is a current objective of many post-harvest innovations (such as robotic harvesting, industrial packing machinery and automated sorting and grading systems), including storage technologies (Hayat et al., 2024). At breeding level, the exploitation of particular textures, such as the stony-hard trait, might become a solution for extending the ripening on-tree and delaying harvest, allowing fruit to accumulate higher SSC (over 17 %) without affecting shelf-life (Giovannini et al., 2006; Liverani et al., 2017; Bassi and Foschi, 2021). Certainly, great efforts should be undertaken in the forthcoming years to move improve the aromatic features of stony-hard cultivars to fit with an adequate consumers' degree of liking (Ceccarelli et al., 2019).

5. Conclusions

This study emphasized the significant shortcomings in minimum quality standards acceptable for peach market, prioritizing attributes scarcely correlated to human satisfactory eating experience. This study did not claim a specific cultivar but aimed to provide a broad overview of the peaches marketed in Italian mass-supply channels (GDO). The findings showed that visual qualities were unrelated to organoleptic pleasantness, being sweet taste and aromatic intensity the greater predictors of the overall pleasantness. Among quality traits, largest preference occurred with an SSC of 14 %, with minimal impact of shelf-life on this parameter. While greater flesh firmness at commercial ripening is

one of the major standard for GDO acceptance, it appeared detrimental for eating experience. These findings underscore the need for a comprehensive overhaul of the peach trading system at GDO's level, including the development of novel ideotypes as well as pre- and post-harvest strategies. While consumer surveys were not conducted in this study, the results lay the groundwork for future research, which could provide further insights into optimizing peach quality for better consumer satisfaction.

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CRediT authorship contribution statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.postharvbio.2025.113460.

Data availability

Data will be made available on request.

References

- Anthony, B.M., Minas, I.S., 2021. Optimizing peach tree canopy architecture for efficient light use, increased productivity and improved fruit quality. *Agronomy* 11 (10), 1961. <https://doi.org/10.3390/agronomy11101961>.
- Anthony, B.M., Minas, I.S., 2022. Redefining the impact of preharvest factors on peach fruit quality development and metabolism: a review. *Sci. Hortic.* 297. <https://doi.org/10.1016/j.scienta.2022.110919>.
- Aubert, C., Milhet, C., 2007. Distribution of the volatile compounds in the different parts of a white-fleshed peach (*Prunus persica* L. Batsch). *Food Chem.* 102 (1), 375–384. <https://doi.org/10.1016/j.foodchem.2006.05.030>.
- Baccichet, I., Chiozzotto, R., Bassi, D., Gardana, C., Cirilli, M., Spinardi, A., 2021. Characterization of fruit quality traits for organic acids content and profile in a large peach germplasm collection. *Sci. Hortic.* 278. <https://doi.org/10.1016/j.scienta.2020.109865>.

- Baccichet, I., Tagliabue, G.A., da Silva Linge, C., Tura, D., Chiozzotto, R., Bassi, D., Cirilli, Marco, 2023. Sensory perception of citrate and malate and their impact on the overall taste in apricot (*Prunus armeniaca* L.) fruits. *Sci. Hortic.* 321. <https://doi.org/10.1016/j.scienta.2023.112266>.
- Baccichet, I., Da Silva Linge, C., Tagliabue, A.G., Chiozzotto, R., Tura, D., Bassi, D., Cirilli, M., 2024. Phenotypic characterization and quality perception of unsulfurated dried apricots in a panel of European cultivars and breeding selections. *Sci. Hortic.* 331. <https://doi.org/10.1016/j.scienta.2024.113095>.
- Bassi, D., Gambardella, M., Negri, P., 1988. Date of ripening and two morphological fruit traits in peach progenies. II Int. Peach Symp. 254, 59–66. <https://doi.org/10.17660/ActaHortic.1989.254.9>.
- Bassi, D., Foschi, S., 2021. A new introduction from the Italian MAS.PES peach breeding program: 'Maissa', a stony hard flat peach. *Acta Hortic.* 1304, 83–88. <https://doi.org/10.17660/ActaHortic.2021.1304.13>.
- Battle, I., Fontich, C., Lozano, L., Iglesias, I., Reig, G., Alegre, S., Echeverría, G., de Heralde, F., Clavería, E., Dolcet-Sanjuan, R., Carbó, J., Bonany, J., Maillard, A., Maillard, L., 2012. The peach breeding program IRTA-ASF: aiming for high fruit quality. *Acta Hortic.* 940, 75–78. <https://doi.org/10.17660/ActaHortic.2012.940.8>.
- Benedetti, S., Buratti, S., Spinardi, A., Mannino, S., Mignani, I., 2008. Electronic nose as a non-destructive tool to characterise peach cultivars and to monitor their ripening stage during shelf-life. *Postharvest Biol. Technol.* 47 (2), 181–188. <https://doi.org/10.1016/j.postharvbio.2007.06.012>.
- Bianchi, T., Weesepeol, Y., Koot, A., Iglesias, I., Eduardo, I., Gratacós-Cubarsí, M., Guerrero, L., Hortós, M., van Ruth, S., 2017. Investigation of the aroma of commercial peach (*Prunus persica* L. Batsch) types by Proton Transfer Reaction-Mass Spectrometry (PTR-MS) and sensory analysis. *Food Res Int* 133–146. <https://doi.org/10.1016/j.foodres.2017.05.007>.
- Biester, A.M., 1925. Carbohydrate studies. I. Relative sweetness of pure sugars. *Am. J. Physiol.* 73, 387–400. <https://doi.org/10.1001/jama.1925.02670130039014>.
- Bonora, E., Stefanelli, D., Costa, G., 2013. Nectarine fruit ripening and quality assessed using the index of absorbance difference (IAD) in planta. *Int. J. Agron.* 1–9. <https://doi.org/10.1155/2013/242461>.
- Byrne, D.H., 2002. Peach breeding trends: a worldwide perspective. *Acta Hortic.* (592), 49–59. <https://doi.org/10.17660/ActaHortic.2002.592.5>.
- Cano-Salazar, J., Echeverría, G., Crisosto, C.H. And, Lopez, L., 2012. Cold-storage potential of four yellow-fleshed peach cultivars defined by their volatile compounds emissions, standard quality parameters and consumers acceptance. *J. Agric. Food Chem.* 60, 1266–1282. <https://doi.org/10.1021/jf204126m>.
- Cantín, C., Crisosto, C.H., Ogundiwin, E.A., Gradziel, T., Torrents, J., Moreno, M.A., Gogorcena, Y., 2010. Chilling injury susceptibility in an intra-specific peach [*Prunus persica* (L.) Batsch] progeny. *Postharvest Biol. Technol.* 58, 79–87. <https://doi.org/10.1016/j.postharvbio.2010.06.002>.
- Cantín, C., Fontich, C., Battle, I., Iglesias, I., Dolcet-Sanjuan, R., Alegre, S., Carbó, J., Bonany, J., Maillard, A., Maillard, L., 2017. The joint IRTA-ASF peach breeding program: outstanding quality fruit adapted to the Mediterranean conditions. *Acta Hortic.* 1172, 151–154. <https://doi.org/10.17660/ActaHortic.2017.1172.29>.
- Ceccarelli, Alessandro, Farneti, Brian, Frisina, Christine, Allen, David, Donati, Irene, Cellini, Antonio, Costa, Guglielmo, Spinelli, Francesco, Stefanelli, Dario, 2019. Harvest maturity stage and cold storage length influence on flavour development in peach fruit. *Agronomy* 9. <https://doi.org/10.3390/agronomy9010010>.
- Christofides, Sarah R., Setarehnejad, Anita, Fairchild, Ruth, Muzzalupo, Innocenzo, Bruno, Leonardo, Muto, Antonella, Chiappetta, Adriana, Bitonti, Maria B., Müller, Carsten T., Rogers, Hilary J., et al., 2022. Cross-cultural differences between Italian and UK consumer preferences for 'Big Top' nectarines in relation to cold storage. *Foods* 11. <https://doi.org/10.3390/foods11162424>.
- Ciacchi, A., Cirilli, M., Chiozzotto, R., Attanasio, G., Da Silva Linge, C., Pacheco, I., Rossini, L., Bassi, D., 2018. Linkage and association mapping for the slow softening (SWS) trait in peach (*P. persica* L. Batsch) fruit. *Tree Genet. Genomes* 14. <https://doi.org/10.1007/s11295-018-1305-6>.
- Clareton, M., 2000. Peach and nectarine production in France: Trends, consumption, and perspectives. In: *Summaries of the Prunus Breeders Meeting*, 2000. Embrapa Clima Temperado, Pelotas, Brazil, pp. 83–91.
- Colaric, M., Veberic, R., Stampar, F., Hudina, M., 2005. Evaluation of peach and nectarine fruit quality and correlations between sensory and chemical attributes. *J. Sci. Food Agric.* 85, 2611–2616. <https://doi.org/10.1002/jsfa.2316>.
- Cos-Terrer, J., Carrillo-Navarro, A., García, F., Frutos, D., López, G., Pérez, M., Guevara, A., 2012. Peach and nectarine breeding program IMIDA-NOVAMED S.L., to obtain new varieties adapted to the region of Murcia. *Acta Hortic.* 962, 45–49. <https://doi.org/10.17660/ActaHortic.2012.962.4>.
- Crisosto, C.H., 1994. Stone fruit maturity indices: a descriptive review. *Postharvest N. Inf.* 5 (6), 65N–68N.
- Crisosto, C.H., Mitchell, F.G., Johnson, S., 1995. Factors in fresh market stone fruit quality. *Postharvest News Inf.* 6 (2), 17N–21N.
- Crisosto, C.H., Johnson, R.S., DeJong, T., Day, K.R., 1997. Orchard factors affecting postharvest stone fruit quality. *HortScience* 32, 820–823.
- Crisosto, C.H., Mitchell, F.G., Ju, Z., 1999. Susceptibility to chilling injury of peach, nectarine, and plum cultivars grown in California. *HortScience* 34, 1116–1118. <https://doi.org/10.21273/HORTSCI.34.6.1116>.
- Crisosto, C.H., 2002. How do we increase peach consumption? *Acta Hortic.* 592, 601–605. <https://doi.org/10.17660/ActaHortic.2002.592.82>.
- Crisosto, C.H., Crisosto, G.M., Metheny, P., 2003. Consumer acceptance of 'Brooks' and 'Bing' cherries is mainly dependent on fruit SSC and visual skin color. *Postharvest Biol. Technol.* 28 (1), 159–167. [https://doi.org/10.1016/S0925-5214\(0\)02173-4](https://doi.org/10.1016/S0925-5214(0)02173-4).
- Crisosto, C.H., Crisosto, G.M., 2005. Relationship between ripe soluble solids concentration (RSSC) and consumer acceptance of high and low acid melting flesh peach and nectarine [*Prunus persica* (L.) Batsch] cultivars. *Postharvest Biol. Technol.* 38 (3), 239–246. <https://doi.org/10.1016/j.postharvbio.2005.07.007>.
- Crisosto, C.H., Crisosto, G.M., Echeverría, G., Puy, J., 2006a. Segregation of peach and nectarine (*Prunus persica* (L.) Batsch) cultivars according to their organoleptic characteristics. *Postharvest Biol. Technol.* 39 (1). <https://doi.org/10.1016/j.postharvbio.2005.09.007>.
- Crisosto, C.H., Crisosto, G., Neri, F., 2006b. Understanding tree fruit quality based on consumer acceptance. *Acta Hortic.* 712, 183–190. <https://doi.org/10.17660/ActaHortic.2006.712.18>.
- Crisosto, C.H., Valero, D., 2008. Harvesting and postharvest handling of peaches for the fresh market. In: Layne, D., Bassi, D. (Eds.), *The Peach: Botany, Production and Uses*. CAB International, Wallingford, UK, pp. 575–596.
- Crisosto, C., Tonutti, P., 2015. Innovations in peach postharvest research and storage technology. *Acta Hortic.* 1084, 821–828. <https://doi.org/10.17660/ActaHortic.2015.1084.111>.
- Crisosto C.H., Crisosto G.M. and Bermejo J.R. (2016). Applying non-destructive sensors to improve fresh fruit consumer satisfaction and increase consumption. *Acta Hortic.* Volume 1119, XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): International Symposia on Abscission Processes in Horticulture and Non-Destructive Assessment of Fruit Attributes. DOI: 10.17660/ActaHortic.2016.1119.31.
- Crisosto, C.H., 2023. Establishing a consumer quality index for fresh plums (*Prunus salicina* Lindell). *Horticulturae* 9 (6), 682. <https://doi.org/10.3390/horticulturae9060682>.
- da Silva Linge, C., Cai, L., Fu, W., Clark, J., Worthington, M., Rawandoozi, Z., et al., 2021. Multi-locus genome-wide association studies reveal fruit quality hotspots in peach genome. *Front. Plant Sci.* 12. <https://doi.org/10.3389/fpls.2021.644799>.
- Delgado, C., Crisosto, G.M., Heymann, H., Crisosto, C.H., 2013. Determining the primary drivers of liking to predict consumers' acceptance of fresh nectarines and peaches. *J. Food Sci.* 78. <https://doi.org/10.1111/1750-3841.12063>.
- Di Miceli, C., Inglese, P., Infante, R., 2012. Instrumental and sensory evaluation of eating quality of peaches and nectarines. *Acta Hortic.* 962, 473–480. <https://doi.org/10.17660/ActaHortic.2012.962.64>.
- Di Natale, C., Macagnano, A., Martinelli, E., Proietti, E., Paolesse, R., Castellari, L., Campani, S., D'Amico, A., 2001. Electronic nose based investigation of the sensorial properties of peaches and nectarines. *Sens. Actuators B: Chem.* 77 (s 1–2), 561–566. [https://doi.org/10.1016/S0925-4005\(0\)01705-5](https://doi.org/10.1016/S0925-4005(0)01705-5).
- Di Vittori, L., Mazzoni, L., Battino, M., Mezzetti, B., 2018. Pre-harvest factors influencing the quality of berries. *Sci. Hortic.* 233, 310–322. <https://doi.org/10.1016/j.scienta.2018.01.058>. ISSN 0304-4238.
- Diehl, D.C., Sloan, N.L., Bruhn, C.M., Simonne, A.H., Brecht, J.K., Mitcham, E.J., 2013. Exploring produce industry attitudes: relationships between postharvest handling, fruit flavor, and consumer purchasing. *HortTechnology* 23. <https://doi.org/10.21273/HORTTECH.23.5.642>.
- Dirlwanger, E., Pronier, V., Parvery, C., Rothan, C., Guy, A., Monet, R., 1998. Genetic linkage map of peach. *Theor. Appl. Genet.* 97, 888–895. <https://doi.org/10.1007/s001220050969>.
- Eduardo, I., Chietara, G., Pirona, R., Pacheco, I., Troglio, M., Banchi, E., Bassi, D., Rossini, L., Vecchiotti, A., Pozzi, C., 2013. Genetic dissection of aroma volatile compounds from the essential oil of peach fruit: QTL analysis and identification of candidate genes using dense SNP maps. *Tree Genet. Genomes* 9, 189–204. <https://doi.org/10.1007/s11295-012-0546-z>.
- Esti, M., Cinquanta, L., Sinesio, F., Moneta, E., Di Matteo, M., 2002. Physicochemical and sensory fruit characteristics of two sweet cherry cultivars after cool storage. *Food Chem.* 76 (4), 399–405. [https://doi.org/10.1016/S0308-8146\(0\)01231-X](https://doi.org/10.1016/S0308-8146(0)01231-X).
- FAOSTAT, (www.faostat.org).
- Farina, V., Lo Bianco, R., Mazzaglia, A., 2019. Evaluation of late-maturing peach and nectarine fruit quality by chemical, physical, and sensory determinations. *Agriculture* 9 (9). <https://doi.org/10.3390/agriculture9090189>.
- Fideghelli, C., Della Strada, G., Grassi, F., Morico, G., 1998. The peach industry in the world: present situation and trend. *Acta Hortic.* 465, 29–40. <https://doi.org/10.17660/ActaHortic.1998.465.1>.
- Font i Forcada, C., Gogorcena, Y., Moreno, M.A., 2012. Agronomical and fruit quality traits of two peach cultivars on peach-almond hybrid rootstocks growing on Mediterranean conditions. *Sci. Hortic.* 140, 157–163. <https://doi.org/10.1016/j.scienta.2012.04.007>.
- Font i Forcada, C., Gradziel, T.M., Gogorcena, Y., Moreno, M.A., 2014. Phenotypic diversity among local Spanish and foreign peach and nectarine [*Prunus persica* (L.) Batsch] accessions. *Euphytica* 197, 261–277. <https://doi.org/10.1007/s10681-014-1065-9>.
- Ghani, A., Negrini, N., Morgutti, S., Baldin, F., Nocito, F.F., Spinardi, A., Mignani, I., Bassi, D., Cocucci, M., 2011. Melting of 'Big Top' nectarine fruit: some physiological, biochemical, and molecular aspects. *J. Am. Soc. Hortic. Sci.* 136 (1), 61–68. <https://doi.org/10.21273/JASHS.136.1.61>.
- Giovannini, D., Liverani, A., Merli, M., Brandi, F., 2006. Breeding strategies to improve peach fruit quality. *Acta Hortic.* 713, 107–112. <https://doi.org/10.17660/ActaHortic.2006.713.12>.
- Grossman, Y.L., DeJong, T.M., 1995. Maximum fruit growth potential following resource limitation during peach growth. *Ann. Bot.* 75 (6), 561–567. <https://doi.org/10.1006/anbo.1995.1059>.
- Harker, F.R., Lau, K., Gunson, F.A., 2003. Juiciness of fresh fruit: a time-intensity study. *Postharvest Biol. Technol.* 29, 55–60. [https://doi.org/10.1016/S0925-5214\(0\)02173-4](https://doi.org/10.1016/S0925-5214(0)02173-4).
- Harker, F.R., Amos, R.L., Echeverría, G., Gunson, F.A., 2006. Influence of texture on taste: insights gained during studies of hardness, juiciness and sweetness of apple fruit. *J. Food Sci.* 71 (2). <https://doi.org/10.1111/j.1365-2621.2006.tb08925.x>.

- Hayat, U., Li, W., Bie, H., Liu, S., Guo, D., Cao, K., 2024. An overview on post-harvest technological advances and ripening techniques for increasing peach fruit quality and shelf life. *Horticulturae* 10 (4). <https://doi.org/10.3390/horticulturae10010004>.
- Hernández Mora, J.R., Micheletti, D., Bink, M., et al., 2017. Integrated QTL detection for key breeding traits in multiple peach progenies. *BMC Genom.* 18 (404). <https://doi.org/10.1186/s12864-017-3783-6>.
- Hilaire, C., 2003. The peach industry in France: State of art, research and development. In: Marra, F., Sottile, F. (Eds.), *First Mediterranean Peach Symposium*. Panuzzo Prontostampa, Caltanissetta: Agrigento, Italy, pp. 27–34.
- Iglesias, I., Echeverría, G., 2009. Differential effect of cultivar and harvest date on nectarine colour, quality and consumer acceptance. *Sci. Hortic.* 120, 41–50. <https://doi.org/10.1016/j.scienta.2008.09.011>.
- Infante, Espiñeira R., Meneses Alvarado, C., Predieri, S., 2008a. Sensory quality performance of two nectarine flesh typologies exposed to distant market conditions. *J. Food Qual.* 31, 526–535. <https://doi.org/10.1111/j.1745-4557.2008.00217.x>.
- Infante, R., Farcuh, M., Meneses, C., 2008b. Monitoring the sensorial quality and aroma through an electronic nose in peaches during cold storage. *J. Sci. Food Agric.* 88, 2073–2078. <https://doi.org/10.1002/jsfa.3316>.
- Infante, R., Meneses, C., Crisosto, C.H., 2009. Preconditioning treatment maintains taste characteristic perception of ripe 'September Sun' peach following cold storage. *Int. J. Food Sci. Technol.* 44, 1011–1016. <https://doi.org/10.1111/j.1365-2621.2008.01864.x>.
- Infante, R., Rubio, P., Meneses, C., Contador, L., 2011. Ripe nectarines segregated through sensory quality evaluation and electronic nose assessment. *Fruits* 66 (2), 109–119. <https://doi.org/10.1051/fruits/2011020>.
- ISMEA-NielsenIQ, (www.ismeamercati.it).
- Kader, A.A., 1997. Fruit maturity, ripening, and quality relationships. *Acta Hortic.* 485. <https://doi.org/10.17660/ActaHortic.1999.485.27>.
- Kays, S.J., 1999. Preharvest factors affecting appearance. *Postharvest Biol. Technol.* 15, 233–247. [https://doi.org/10.1016/S0925-5214\(9\)8088-X](https://doi.org/10.1016/S0925-5214(9)8088-X).
- Kelley, K.M., Primrose, R., Crassweller, R., Hayes, J.E., Marini, R., 2016. Consumer peach preferences and purchasing behavior: a mixed methods study. *J. Sci. Food Agric.* 96, 2451–2461. <https://doi.org/10.1002/jsfa.7365>.
- Lara, M.V., Bonghi, C., Famiani, F., Vizzotto, G., Walker, R.P., Drincovich, F., 2020. Stone fruits as biofactories of phytochemicals with potential roles in human nutrition and health. *Front. Plant Sci.* 11. <https://doi.org/10.3389/fpls.2020.562252>.
- Liverani, A., Brandi, F., Quacquarelli, I., Sirri, S., Giovannini, D., 2017. Advanced stony-hard peach and nectarine selections from CREA-FRF breeding program. *Acta Hortic.* 1172, 219–224. <https://doi.org/10.17660/ActaHortic.2017.1172.41>.
- Lurie, S., Crisosto, C.H., 2005. Chilling injury in peach and nectarine. *Postharvest Biol. Technol.* 37 (3), 195–208. <https://doi.org/10.1016/j.postharvbio.2005.04.012>.
- Kanayama, Y., Kogawa, M., Yamaguchi, M., Kanahama, K., 2005. Fructose content and the activity of fructose - related enzymes in the fruit of eating - quality peach cultivars and native - type peach cultivars. *J. Jpn. Soc. Hort. Sci.* 74 (6), 431–436. <https://doi.org/10.2503/jjshs.74.431>.
- Manganaris, G.A., Vicente, A.R., Crisosto, C.H., 2008. Effect of pre-harvest and post-harvest conditions and treatments on plum fruit quality. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 3. <https://doi.org/10.1079/PAVSNNR20083009>.
- Manganaris, G.A., Minas, I., Cirilli, M., Torres, R., Bassi, D., Costa, G., 2022. Peach for the future: a specialty crop revisited. *Sci. Hortic.* 305. <https://doi.org/10.1016/j.scienta.2022.111390>.
- Marini, R.P., 2003. Peach fruit weight, yield, and crop value are affected by number of fruiting shoots per tree. *HortScience* 38 (4), 512–514. <https://doi.org/10.21273/HORTSCI.38.4.512>.
- Minas, I.S., Tanou, G., Molassiotis, A., 2018. Environmental and orchard bases of peach fruit quality. *Sci. Hortic.* 235, 307–322. <https://doi.org/10.1016/j.scienta.2018.01.028>.
- Moing, A., Svanella, L., Rolin, D., Gaudillère, M., Gaudillère, J., Monet, R., 1998. Compositional changes during the fruit development of two peach cultivars differing in juice acidity. *J. Am. Soc. Hortic. Sci.* 123 (5), 770–775. <https://doi.org/10.21273/JASHS.123.5.770>.
- Montecchini, G., Vasile, S.G., Masino, F., Bignami, C., Antonelli, A., 2012. Physical and chemical characterization of *Pescabivona*, a Sicilian white flesh peach cultivar [*Prunus persica* (L.) Batsch]. *Food Res. Int.* 45, 123–131. <https://doi.org/10.1016/j.foodres.2011.10.019>.
- Musacchi, S., Serra, S., 2018. Apple fruit quality: overview on pre-harvest factors. *Sci. Hortic.* 234, 409–430. <https://doi.org/10.1016/j.scienta.2017.12.057>.
- Noble, A.C., 1996. Taste-aroma interactions. *Trends Food Sci. Technol.* 7 (12), 439–444. [https://doi.org/10.1016/S0924-2244\(9\)96044-3](https://doi.org/10.1016/S0924-2244(9)96044-3).
- Okie, W.R., Bacon, T., Bassi, D., 2008. Fresh market cultivar development. In: Layne, D. R., Bassi, D. (Eds.), *The peach – Botany, Production and Uses*. CAB International, pp. 139–174.
- Olmstead, M.A., Gilbert, J.L., Colquhoun, T.A., Clark, D., Kluson, R., Moskowitz, H.R., 2015. In pursuit of the perfect peach: consumer-assisted selection of peach fruit traits. *HortScience* 50 (8), 1202–1212. <https://doi.org/10.21273/HORTSCI.50.8.1202>.
- Ortiz, A., Jordi Graell, M., López, L., Echeverría, G., Lara, I., 2010. Volatile ester-synthesising capacity in 'Tardibelle' peach fruit in response to controlled atmosphere and 1-MCP treatment. *Food Chem.* 123 (3), 698–704. <https://doi.org/10.1016/j.foodchem.2010.05.037>.
- Petrucelli, R., Bonetti, A., Giaccheri, L., Ieri, F., Ganino, T., Faraloni, C., 2023. Evaluation of the fruit quality and phytochemical compounds in peach and nectarine cultivars. *Plants (Basel)* 12 (8). <https://doi.org/10.3390/plants12081618>.
- Pott, D.M., Osorio, S., Vallarino, J.G., 2019. From central to specialized metabolism: an overview of some secondary compounds derived from the primary metabolism for their role in conferring nutritional and organoleptic characteristics to fruit. *Front. Plant Sci.* 10. <https://doi.org/10.3389/fpls.2019.00835>.
- Reig, G., Iglesias, I., Gatiús, F., Alegre, S., 2013. Antioxidant capacity, quality, and anthocyanin and nutrient contents of several peach cultivars [*Prunus persica* (L.) Batsch] grown in Spain. *J. Agric. Food Chem.* 61 (26), 6344–6357. <https://doi.org/10.1021/jf401183d>.
- Reig, G., Cisneros-Zevallos, L., Costa, G., Crisosto, C.H., 2023. Peach fruit quality: components, composition, and nutritional and health benefits. In: Manganaris, G., Costa, G., Crisosto, C. (Eds.), *Peach*. CAB International.
- Rolls, E.T., 2019. Taste and smell processing in the brain. *Smell and Taste* 97–118. <https://doi.org/10.1016/B978-0-444-63855-7.00007-1>.
- Sadler, G.D., Murphy, P.A., 2010. pH and Titratable Acidity. *Food Analysis*. Springer, Boston, MA. https://doi.org/10.1007/978-1-4419-1478-1_13.
- Schwab, W., Davidovich-Rikanati, R., Lewinsohn, E., 2008. Biosynthesis of plant-derived flavor compounds. *Plant J.* 54, 712–732. <https://doi.org/10.1111/j.1365-3113.2008.03446.x>.
- Silva, V., Pereira, S., Vilela, A., Bacelar, E., Guedes, F., Ribeiro, C., Silva, Gonçalves, B., 2021. Preliminary insights in sensory profile of sweet cherries. *Foods* 10 (3). <https://doi.org/10.3390/foods10030612>.
- Simon, S.A., de Araujo, I.E., Gutierrez, R., Nicoletti, M.A.L., 2006. The neural mechanisms of gustation: a distributed processing code. *Nat. Rev. Neurosci.* 7, 890–901. <https://doi.org/10.1038/nrn2006>.
- Sneath, R.W., Persaud, K.C., 2002. Correlating electronic nose and sensory panel data. *Handb. Mach. Olfaction* 377–397. <https://doi.org/10.1002/3527601597.ch15>.
- Stanley, J., Marshall, R., Tustin, S., Woolf, A., 2014. Preharvest factors affect apricot fruit quality. *Acta Hortic.* 10 (58), 269–276. <https://doi.org/10.17660/ActaHortic.2014.1058.31>.
- Taiti, C., Costa, C., Petrucci, W.A., Luzzietti, L., Giordani, E., Mancuso, S., Nencetti, V., 2021. Are peach cultivars used in conventional long food supply chains suitable for the high-quality short markets? *Foods* 10 (6). <https://doi.org/10.3390/foods10061253>.
- Tanou, G., Minas, I.S., Scossa, F., Belghazi, M., Xanthopoulou, A., Ganopoulos, I., Madesis, P., Fernie, A., Molassiotis, A., 2017. Exploring priming responses involved in peach fruit acclimation to cold stress. *Sci. Rep.* 7, 11358. <https://doi.org/10.1038/s41598-017-11933-3>.
- USDA-NASS, (www.nass.usda.gov).
- Ventura, M., Sama, A., Minguzzi, A., Lazoni, S., Sansavini, S., 2000. Ottimizzazione del carico di frutti per migliorare la produzione e la qualità delle nettarine 'Supercrimson' e 'Venus'. In: Sansavini, S. (Ed.), *XXIV Italian Peach Meeting*. MDM, Cesena, Italy, pp. 173–176.
- Wang, Y.J., Yang, C.X., Li, S.H., Yang, L., Wang, Y.N., Zhao, J.B., Jiang, Q., 2009. Volatile characteristics of 50 peaches and nectarines evaluated by HP-SPME with GC-MS. *Food Chem.* 116, 356–364. <https://doi.org/10.1016/j.foodchem.2009.02.004>.
- Zhang, H., Chang, M., Wang, J., Ye, S., 2008. Evaluation of peach quality indices using an electronic nose by MLR, QPST and BP network. *Sens. Actuators B: Chem.* 134, 332–338. <https://doi.org/10.1016/j.snb.2008.05.008>.
- Zhou, R., Yue, C., Zhao, S., Gallardo, R.K., McCracken, V., Luby, J.J., McFerson, J.R., 2018. Using market segmentation analysis to identify consumer preferences for fresh peach attributes. *HortScience horts* 53 (11), 1664–1668. <https://doi.org/10.21273/HORTSCI.53.11.1664>.
- Ziosi, V., Noferini, M., Fiori, G., Tadiello, A., Trainotti, L., Casadoro, G., Costa, G., 2008. A new index based on vis-spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biol. Technol.* 49 (3), 319–329. <https://doi.org/10.1016/j.postharvbio.2008.01.017>.