Original article

A comparative study of the physico-chemical properties affecting the organoleptic quality of fresh and thermally treated yellow tomato ecotype fruit

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Summary In recent years, yellow commercial tomatoes have attracted great interest from consumers. The goal of this work was to characterise the parameters of three yellow genotypes that affect the fruit quality, in comparison with those of a red fruit genotype. Compared to the other genotypes, the GiaGiù ecotype was characterised as having the highest titratable acidity, organic acids content and pectin content before and after a thermal treatment simulating industrial pasteurisation. Most of the analysed parameters influence the taste and aroma of fresh fruit and processed products, particularly the high glutamic acid content measured in the GiaGiù ecotype. This genotype was also distinctive for its higher pectin content, which influences the texture. These features might allow the development of new food products that require a specific viscosity, such as sauces and ketchup. Interestingly, the beneficial properties of GiaGiù were preserved after thermal processing.

Keywords Brix, consistency, glutamic acid, pectin, reducing sugars, *Solanum lycopersicum*, total acidity, yellow tomatoes.

Introduction

Tomato (*Solanum lycopersicum*) is the second most important source of nourishment with a total production of approximately 162 million tons *per* year worldwide. Its consumption has increased with the development of processed products, such as juices, sauces and purees (FAOSTAT 2014). In the last few years, new commercial products have been offered to fresh tomato market consumers, including tomatoes with a wide range of fruit colours. Among these, yellow tomatoes have attracted much interest, and the demand for both fresh consumption and cooking purposes has increased.

It should be emphasised that not all yellow tomatoes exhibit the same organoleptic properties because they belong to different genotypes and geographical origins, which greatly influence the fruit flavour and aroma. Therefore, a quality evaluation of the new yellow fruit genotypes is required to better understand their performance in the fresh or processing markets. Indeed, many genetic and environmental factors can affect the technological and organoleptic quality of tomatoes (Carli *et al.*, 2011). Ripening of tomatoes is characterised by the softening of the fruit, an increase in the respiration rate, ethylene production and the synthesis of acids and sugars (Opara *et al.*, 2012). Most biochemical compounds derived from these processes influence the flavour characteristics of the fresh fruits. Many commercial products are obtained from processing tomatoes; therefore, it is important to also evaluate the quality traits after the thermal treatment required for processing. Two essential quality properties for processing tomatoes are the pH and titratable acidity. The pH of tomatoes is mainly associated with the acid content of the fruit and influences the flavour of the tomato products, which is a composite of the taste and aroma that are affected by both physiological and chemical characteristics. Citric acid is the most abundant acid in tomatoes and the main contributor to the total titratable acidity (Anthon & Barrett, 2012), but glutamic and malic acids also contribute. Glutamic acid is an amino acid present in tomatoes at levels comparable to that of citric acid, and it may also be an important factor affecting tomato flavour. Other important contributors to tomato flavour are soluble

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solids that are predominantly sugars. The main free sugars of commercial varieties of tomatoes are reducing sugars, and the quantity of sucrose is negligible. However, fructose has a large impact on the sweetness perception (Tieman *et al.*, 2012). The polysaccharides determine the texture of fruit (Lahaye *et al.*, 2013), which can be affected by industrial processing. In fact, after tomatoes are homogenised, the enzymes pectin methylesterase (PME) and polygalacturonase (PG) become extremely active, causing rapid pectin breakdown. To avoid this enzymatic loss of pectin, the majority of tomatoes are rapidly heated to $T > 90$ °C to thermally inactivate PMEs and PGs. Indeed, the hydrolysis of pectin is an important issue for tomato processors because the loss of pectin reduces the tomato viscosity (Moelants *et al.*, 2013). Processing tomato cultivars are known to vary in the pectin content, and cultivars with an high pectin content generally produce hot-break juices with high viscosities (Anthon & Barrett, 2012).

The aim of this work was to characterise three yellow tomato genotypes for the major parameters of the internal fruit quality, such as the pH and organic acids, soluble solids and reducing sugars content, in comparison with a red fruit tomato genotype. Because these genotypes might be used for fresh consumption and as canned tomatoes, the quality traits were evaluated before and after the thermal treatment usually applied in the agri-food industry for tomato processing. Following all the analyses, a best performing genotype, GiaGiù, was identified for its quality traits, mainly for the high acid and pectin contents in the fruit. These traits highlighted in GiaGiù might also correlate with the culinary properties, which render it a novel genotype for specific gastronomic applications.

Materials and methods

Plant material and processing

Plant material consisted of four tomato genotypes (GiàGiù, Vesuvio 2001, 284 and M-4, coded E40, E48, E87 and E92, respectively): E40 and E48 are two Italian ecotypes originating in the Campania Region, and E87 and E92 are two Bolivian landraces. E40, E87 and E92 have yellow mature fruits, whereas E48 is a red tomato. They belong to a tomato germplasm collection available at the Department of Agricultural Sciences, University of Naples Federico II. Additional details on the genotypes are available in the Lab Archives repository hosted at https://doi.org/10.6070/h4tt4nxn. The plants were cultivated according to a randomised design with three replicates (10 plants/replicate) in an experimental field located in Acerra (Naples, Italy) in the year 2015. Four-week-old seedlings were transplanted to an open field at the end of April after germinating in a plateau with sterile soil in a greenhouse. The plants were grown following the standard irrigation and fertilisation procedures adopted in the Campania cultivation area until harvesting at the end of July. Each sample consisted of 20 fruits per plot harvested at full yellow or red ripen stage, as used in the industry. The tomatoes were processed according to a classical thermal treatment. Briefly, after washing for 5 min with water, a part of the tomatoes was passed through a pulper to obtain a puree. Glass jars were filled to 60% with whole tomatoes and 40% puree and subsequently vacuum-sealed. The filled jars were pasteurised at 100 °C for 60 min in water and then cooled. Three jars for each genotype were collected and analysed. Both fresh whole fruit and processed samples were homogenised using a Fimar FRI150 blender and kept at −80 °C until the analyses.

Determination of pH

The determination of pH was carried out by a pH meter (Crison Basic 20) according to the instructions supplied by the manufacturer.

Determination of the total solids

The determination of the total solids was carried out by drying 3 g of homogenised in a stove at 70 °C, until the complete elimination of water. The content was calculated as percentage of total solids weight/sample fresh weight.

Determination of the total soluble solids

The determination of the total soluble solids was carried out using a portable refractometer from Sper Scientific. The values were expressed in °Brix, which is defined as the concentration (%) of total soluble solids in solution when measured at 20 °C.

Determination of the reducing sugars

The reducing sugars were determined by Fehling's method (Official Italian Methods, 1989) on diluted and filtered samples. The parameter was calculated as percentage of reducing sugars weight/sample fresh weight.

Determination of the titratable acidity

The total acidity was determined as described in the Official Italian Methods of 1989. The parameter was expressed as percentage of citric acid monohydrate weight/sample fresh weight.

Determination of the organic acids

The organic acid content was determined according to the method reported by Flores *et al.* (2012) with slight modifications. Extracts were diluted to 30% w/v with deionised water, filtered through a 0.45 nm filter and submitted to high-performance liquid chromatography (HPLC) analysis. Citric, malic, glutamic, succinic, tartaric and oxalic acids were identified by comparing their retention times to those of the standards (Sigma, St. Louis, MO, USA). The results were expressed as mg/100 g. The HPLC analysis was performed on a HPLC Agilent 1100 Series system equipped with a diode array detector using a 20-μL sample injection loop. UV detection was performed at 210 nm. A reversed-phase column, Spherisorb S5 ODS2 (5 μm, 250 × 4.6 mm; Waters Corporation, Milford, USA), was used, and the elution was carried out under isocratic conditions using water acidified with orthophosphoric acid (pH 2.1) as the mobile phase at a flow rate of 0.6 mL min^{-1} for 45 min.

Calcium determination

Five grams of sample was decomposed into ash at 500 °C. The ash was then dissolved in 0.01 N nitric acid and atomised into the air–acetylene flame of an atomic absorption spectrometer, Pinnacle 900F (Perkin Elmer, Massachusetts, USA). The wavelength of the spectrometer was set at 422.7 nm. An appropriate calibration curve was obtained from standard solutions from 1 μg mL^{-1} to 5 μg mL^{-1}. The mean of the absorbance values was calculated, and the mean of the absorbance value of the blank solution was subtracted. The results were expressed as mg/100 g.

Determination of the consistency

The tomato consistency was measured by the Bostwick method (Marsh *et al.*, 1980) using a Bostwick LS100 consistometer. The results were reported in Bostwick (cm/30 s).

Determination of the pectin content

The pectin determination was carried out after the samples were treated with pectate lyase (Megazyme-Pectin identification kit) for 30 min and read spectrophotometrically at 235 nm. The results were expressed as a percentage of the weight of pectins/sample fresh weight.

Determination of the analytical index

The values of the total soluble solids, reducing sugar content and titratable acidity were converted into the analytical index (AI), which was calculated as AI: $(R^2*Z)/(a*10)$ where R is the total soluble solids (°Brix), Z is the reducing sugars content (%), and a is the titratable acidity (%). The AI expresses the quality of the fruit (good quality when AI > 25, Marini & Balestrieri, 1990).

Statistical analysis

The three biological replicates of the samples were analysed in triplicate. Quantitative parameters were expressed as the mean value ± standard error (SE). Differences among the unprocessed and processed samples were determined using SPSS (Statistical Package for Social Sciences) Package 6, version 15.0 (SPSS Inc., Chicago, IL, USA). Two-way ANOVA ($P < 0.05$) was used to test the effect of the genotypes, treatments and their interactions on the mean values of the analysed traits. The differences among the genotypes for each parameter were determined by Tukey's test at a significance level of 0.05. Principal component analysis (PCA) was carried out using the R platform.

Results

In this work, analyses were carried out to evaluate the organoleptic qualities of four tomato genotypes. The samples consisted of three yellow tomato genotypes and one with red fruit. The chemical–physical parameters measured before and after processing are reported in Table 1. Before processing, the pH values varied from 4.26 to 4.43 in E40 and E48, respectively; the pH values showed minimal variations after processing. Regarding the total soluble solids, we found the lowest mean level in E87 (6.42 °Brix) and the highest levels in E92 (7.75 °Brix) before heat treatment. After treatment, we observed a general decrease in °Brix with the exception of the E48 genotype. The total solids ranged from 7.03% to 7.79% in E48 and E92, respectively, before processing and showed the highest level in E48 (8.68%) after processing. The consistency was measured using a Bostwick consistometer, which indicates the speed a viscous liquid runs along a slope. The results showed the highest mean level in E87 (19.83 Bostwick), which represents the sample with the lowest consistency. The lowest level was observed for E40 (13.17 Bostwick), indicating that this genotype had the highest viscosity. After processing, we observed a general decrease. The data also revealed that the highest content of pectin was in E40 both before (1.58%) and after (1.66%) processing.

The reducing sugars content (Table 2) had the lowest amount in E87, which was equal to 2.97%, and the highest level in E92 at 3.33%. After thermal processing, a slight increase was observed in E40 and in E48, whereas a decrease was reported in E92. Table 2 also

Table 1 Mean and standard error of the chemical–physical parameters in the four tomato genotypes analysed before and after processing. The letters indicate the significance of variations observed among genotypes (Tukey's test, $P < 0.05$) before (normal font) and after (italic font) the thermal treatment.

	Sample	pH	Total soluble solids (°Brix)	Total solids (% w/w)	Consistency (Bostwick cm/30 sec)	Pectin (% w/w)
Pre-processing	E40	4.26 ± 0.03^{a}	7.61 ± 0.09^{bc}	7.42 ± 0.09^{a}	13.17 ± 0.28^{a}	1.58 ± 0.05^{c}
	E48	4.43 ± 0.02^{b}	7.15 ± 0.12^{b}	7.03 ± 0.28^{a}	18.17 ± 0.27^{b}	1.47 ± 0.01^{ab}
	E87	4.40 ± 0.03^{b}	6.42 ± 0.12^{a}	7.45 ± 0.02^{a}	19.83 ± 0.26^{b}	1.40 ± 0.02^{a}
	E92	4.37 ± 0.01^{b}	7.75 ± 0.03^{c}	7.79 ± 0.03^{a}	14.83 ± 0.27^{a}	1.54 ± 0.01^{bc}
Post-processing	E40	4.37 ± 0.01^{a}	6.95 ± 0.05^{b}	7.76 ± 0.03^{b}	12.17 ± 0.29^{a}	1.66 ± 0.05^{c}
	E48	4.36 ± 0.01^{a}	7.81 ± 0.01^{c}	8.68 ± 0.09^{c}	13.33 ± 0.29^{a}	1.62 ± 0.05^{b}
	E87	4.42 ± 0.02^{a}	6.60 ± 0.10^{b}	7.56 ± 0.04^{b}	12.83 ± 0.28^{a}	1.61 ± 0.05^{ab}
	E92	4.41 ± 0.01^{a}	6.05 ± 0.05^{a}	6.96 ± 0.11^{a}	15.17 ± 0.28^{b}	1.56 ± 0.07^{a}

Table 2 Mean and standard error of reducing sugars content and titratable acidity (percentage weight/weight) in the four tomato genotypes analysed before and after processing. The ratio of total sugars/titratable acids and the analytical index (AI) are also reported. The letters indicate the significance of variations observed among genotypes (Tukey's test, $P < 0.05$) before (normal font) and after (italic font) the thermal treatment.

	Sample	Reducing sugars (% w/w)	Titratable acidity (%w/w)	Reducing sugars/titratable acids	Analytical index (AI)
Pre-processing	E40	3.13 ± 0.05^{a}	0.63 ± 0.02^{c}	4.97	28.73
	E48	3.04 ± 0.09^{a}	0.42 ± 0.02^{a}	7.24	37.41
	E87	2.97 ± 0.08^{a}	0.48 ± 0.02^{ab}	6.19	25.49
	E92	3.33 ± 0.02^{a}	0.53 ± 0.02^{b}	6.28	38.09
Post-processing	E40	3.32 ± 0.01^{b}	0.34 ± 0.01^{b}	9.76	47.87
	E48	3.60 ± 0.03^{c}	0.33 ± 0.01^{b}	10.91	66.28
	E87	3.46 ± 0.04^{b}	0.24 ± 0.05^{a}	14.42	64.04
	E92	3.18 ± 0.02^{a}	0.24 ± 0.05^{a}	13.25	48.71

reports the values for the titratable acidity, the total sugars/total acids ratio and the analytical index (AI). The titratable acidity was the lowest in E48 (0.42%) and the highest in E40 (0.63%) before processing, and after processing, a significant reduction was observed for all the genotypes. The ratio between the reducing sugars and total acids ranged from 4.97 in E40 to 7.24 in E48, and after processing, it increased from 48% in E48 to 137% in E87. An analogous trend was found for the analytical index (AI). Although it varied among the genotypes, and also before and after the treatment, all were classified as good genotypes (AI > 25). Table 3 shows the organic acids and calcium content measured by HPLC. Malic acid, which is an index of freshness, was on average the most abundant in E40 (331.18 mg/100 g) and less abundant in E87 (199.19 mg/100 g). Processing decreased the content of this compound from 1.8% in E87 to 12.7% in

Table 3 Mean and error standard of organic acids (mg/100 g) and calcium (mg/100 g) content in the four tomato genotypes analysed before and after processing. The letters indicate the significance of variations observed among genotypes (Tukey's test, $P < 0.05$) before (normal font) and after (italic font) the thermal treatment.

	Sample	Malic acid	Citric acid	Glutamic acid	Succinic acid	Tartaric acid	Oxalic acid	Calcium
Pre-processing	E40	331.18 ± 0.47^{d}	400.92 ± 0.29^{d}	566.67 ± 4.62^{d}	15.00 ± 0.40^{a}	60.11 ± 0.13^{c}	2.78 ± 0.08^{a}	10.90 ± 0.42^{a}
	E48	240.45 ± 0.53^{c}	265.95 ± 0.41^{a}	409.05 ± 2.86^{c}	18.17 ± 0.47^{a}	50.74 ± 1.21^{b}	2.11 ± 0.35^{a}	10.70 ± 0.17^{a}
	E87	199.19 ± 0.48^{a}	315.93 ± 0.29^{b}	366.73 ± 4.60^{b}	17.63 ± 3.32^{a}	35.61 ± 1.81^{a}	4.03 ± 0.09^{b}	9.80 ± 0.09^{a}
	E92	210.93 ± 0.09^{b}	342.82 ± 0.07^{c}	315.73 ± 4.09^{a}	12.53 ± 0.34^{a}	32.77 ± 0.45^{a}	3.05 ± 0.06^{ab}	9.19 ± 1.04^{a}
Post-processing	E40	297.52 ± 0.10^{d}	382.86 ± 0.30^{d}	261.04 ± 1.91^{d}	25.86 ± 1.33^{c}	68.41 ± 0.41^{c}	0.85 ± 0.03^{b}	10.14 ± 0.11^{b}
	E48	271.06 ± 0.14^{c}	295.82 ± 0.40^{a}	246.23 ± 0.61^{c}	25.82 ± 0.33^{c}	63.88 ± 0.85^{b}	0.02 ± 0.02^{a}	17.28 ± 0.20^{c}
	E87	195.56 ± 0.09^{a}	314.57 ± 0.38^{b}	170.30 ± 2.58^{b}	18.95 ± 0.14^{b}	40.63 ± 0.67^{a}	1.09 ± 0.01^{c}	6.91 ± 0.47^{a}
	E92	206.40 ± 1.86^{b}	379.56 ± 0.25^{c}	132.23 ± 0.30^{a}	12.44 ± 0.01^{a}	42.93 ± 0.62^{a}	1.26 ± 0.01^{d}	8.05 ± 0.02^{a}

E48. Regarding citric acid, in the fresh fruit, the mean levels ranged from 265.95 mg/100 g in E48 to 400.92 mg/100 g in E40. The amount of this acid was preserved after the heat treatment and did not show significant variations. Glutamic acid was the highest in E40 (566.67 mg/100 g) and the lowest in E92 (315.73 mg/100 g). The processing strongly impacted the content of this compound with reductions of 39.8% and 58.1% in E48 and E92, respectively, and E40 always exhibited the highest level. The amount of succinic acid ranged between 12.53 (in E92) and 18.17 mg/100 g (in E48). A general increase ranging from 7.4% (in E87) to 72.4% (in E40) was found after the thermal treatment. Regarding tartaric acid, the values ranged from 32.77 mg/100 g in E92 to 60.11 mg/100 g in E40, and a general increase was seen after processing, ranging from 13.8% in E40 to 31% in E92.

Finally, the amount of oxalic acid was 2.11 and 4.03 mg/100 g in E48 and E87, respectively. A significant reduction was detected after thermal treatment. For the calcium levels, the highest amount was found in E40 (10.90 mg/100 g), and the lowest level was detected in E87 and E92. After the heat treatment, a general reduction ranging from 6.9% to 29.4% in E40 and E87 was found, whereas an increase of 61.49% was detected in E48.

To verify the effects of the genotype, treatment and their interactions on the differences observed in all the results from our analyses, a two-way ANOVA test was carried out, at a significance level of $P < 0.05$. Apart from the reducing sugars ($P = 0.374$), the four genotypes significantly differed for all the traits, as well as the two treatments (before and after processing), which were not significantly different only for calcium content ($P = 0.438$). In addition, a clear effect of the interaction between the genotype and the treatment was observed for all the traits studied. Therefore, the performances of the four genotypes relating to the evaluated traits varied in an unpredictable way before and after treatment. To compare the genotype performances for all the analysed traits, the statistical significance of the observed differences was determined by the Tukey's post hoc test. The tests regarding the chemical–physical traits (Tables 1 and 2) evidenced a clear distinction in the groups for the total soluble solids, total solids and pectin content. For the data related to all the organic acids evaluated (Table 3), four significantly different groups were observed for the main acids (malic, citric and glutamic acids) and the highest levels of five acids were recorded for the genotype E40.

Finally, to better understand the variations among the genotypes in all the observed traits, a PCA analysis was carried out using the data set recorded before and after the thermal treatment. The PCA analysis (Fig. 1a) describing the properties of the fresh tomatoes showed that the genotypes exhibited different chemical properties, which allowed us to clearly distinguish each of them. For component D1, which explained 52.2% of the variability and described the contribution of the total acidity, consistency and pectin, total sugars/total acids and glutamic acid contents, a high degree of similarity was observed between E87 and E48. Regarding component D2, which explained 32.4% of the variability and described the contribution of the reducing sugar content, analytical index, and calcium and glutamic acid contents, more similarity was observed between E40 and E87. After thermal processing (Fig. 1b), the PCA analysis indicated that component D1 explained 63.9% of the variability and the contribution of the glutamic acid content, °Brix, total acidity and pectin content, whereas D2 explained 23.2% of the variability due to the AI contribution and reducing sugar content. For the D1 component, more similarity was observed between E48 and E40, whereas for the D2 component, E48 and E87 were the most similar. The PCA analysis allowed us to clearly discriminate the four analysed genotypes, which were distributed in four different chart squares. It also indicated that the genotype E40 was characterised by the highest content of glutamic acid, total acidity and pectin, which is positively correlated with consistency and negatively correlated with the Bostwick values. The parameters that characterise E40 are those that mainly influence the taste and aroma, and these properties are mostly preserved after the heat treatment.

Discussion

The four genotypes analysed in this study were derived from a wide collection of landraces available to our laboratory and previously characterised for many morphological (Sacco *et al*., 2015) and nutritional quality traits (Ruggieri *et al*., 2014). The three yellow genotypes were also characterised for antioxidant content before and after processing (Raiola *et al*., 2016). After processing, they also showed a cytotoxic effect towards cancer cells, thus revealing their potential use for the production of tomato-based functional foods. In addition to their nutritional value, these genotypes should also have good organoleptic qualities, and therefore, we reported here the evaluation of the physical and biochemical traits known to influence consumer acceptability of both the fresh and processed tomatoes. The yellow fruit genotypes were compared with the red fruit ecotype Ves2001 (E48), which represents a traditional Italian fruit typology (the Vesuvio type) and is characterised by a particular flavour and taste due to its genomic constitution and cultivation in a volcanic area (Carli *et al*., 2009). This ecotype has been previously characterised at morphological,

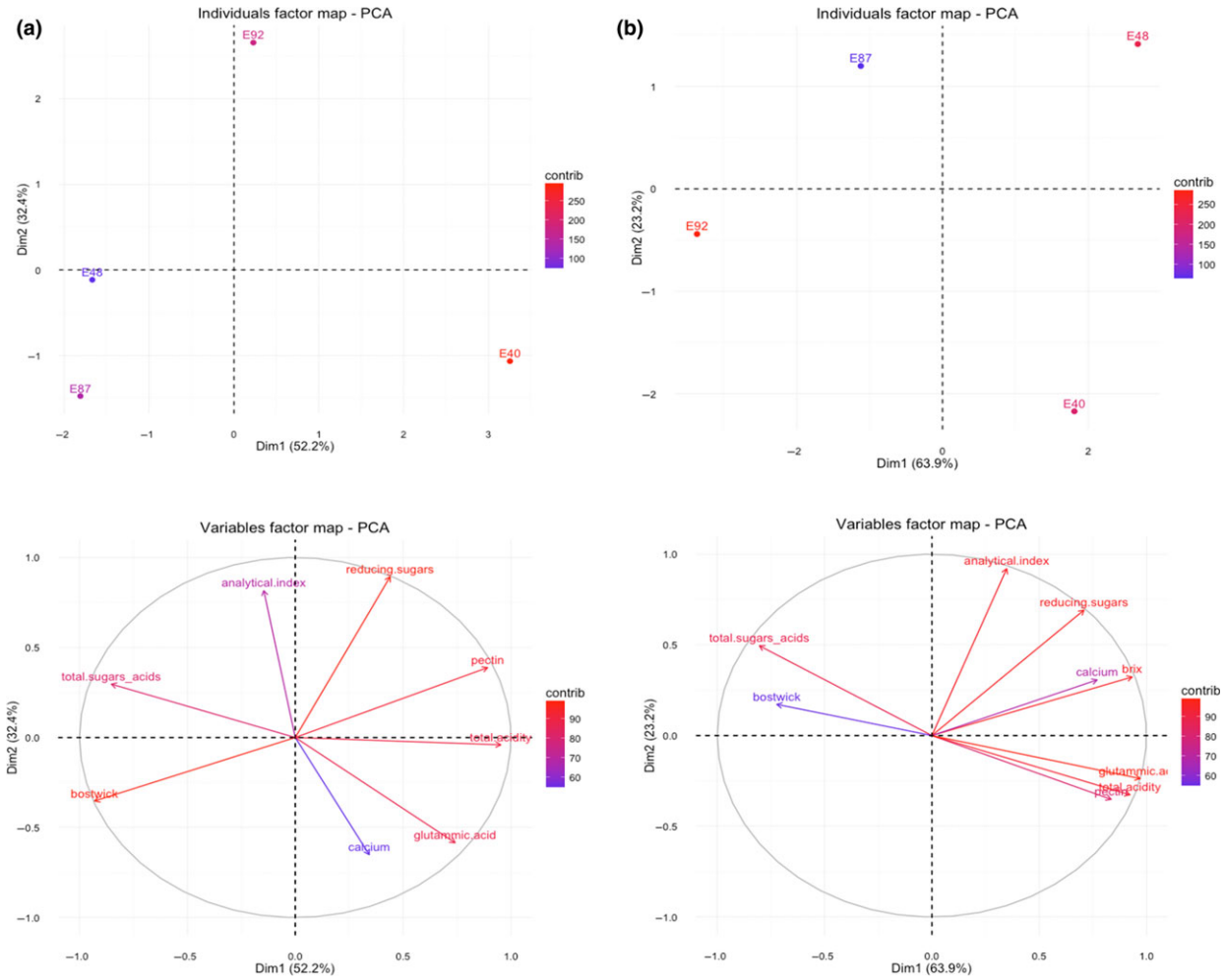

Figure 1 Principal component analysis (PCA) of quality parameters evaluated on fruits of the four analysed genotypes before (a) and after (b) the thermal treatment.

biochemical, molecular (Ercolano *et al.*, 2008) and sensorial levels (Carli *et al.*, 2011), and therefore, it constitutes a good control for evaluating the organoleptic qualities of the three yellow genotypes that exhibit a similar fruit typology. Most of the parameters evaluated in the present work were consistently variable among the four genotypes, and their values were significantly affected by the thermal treatment, as expected.

The three main characteristics that affect the organoleptic quality of fresh tomato fruit and the processed products are the acidity, soluble sugars and consistency. The molecules influencing these features have different chemical–physical characteristics and might change the sensorial perception. Sugars, organic acids, free amino acids and salts are the main compounds contributing to tomato taste. In particular, sweetness and sourness are related to the sugar and acid contents, respectively, and they also contribute to the overall aroma (Causse *et al.*, 2010). The specific sweet–sour taste of tomato is due to the presence of the sugars and organic acids. Approximately 50% of the total solids is composed of sugars, mostly the reducing sugars, glucose and fructose. Positive correlations between the sweetness, reducing sugar content and soluble solids have also been observed (Tieman *et al.*, 2012). The tested genotypes showed a higher content of total soluble solids than values reported in the literature. For example, Pratta *et al.* (2011) found levels ranging between 3.79 and 6.61 (°Brix) in sixteen analysed recombinant inbred lines, whereas Ercolano *et al.* (2008) measured from 4.10 to 5.50 °Brix in a group of 16 Italian ecotypes. Aguirre & Cabrera (2012) analysed 30 types of cherry tomatoes and

reported levels of °Brix ranging between 4.04 and 6.70. Because the main components of soluble solids are sugars and acids and the levels of reducing sugar are not significantly different among fresh fruit of our four genotypes, we hypothesised that the acidic component is more relevant in determining the higher soluble solids observed in the analysed genotypes. Indeed, the four genotypes exhibited a high variability of organic acid content in the pre- and post-processing tomatoes. Interestingly, the GiàGiù (E40) ecotype showed the highest levels of all the organic acids analysed, except for oxalic acid. Citric and malic acids are the organic acids that contribute most to the typical taste of tomato fruit. Cebolla-Cornejo *et al.* (2011) analysed the taste- and aroma-related compounds in a number of genotypes grown in a screenhouse and open field. These authors reported levels of citric acid similar to those found in our study, although we detected higher levels of malic and glutamic acids. Glutamic acid is an amino acid with a large importance from both functional and organoleptic points of view. Various authors have also highlighted the role of glutamic acid and its ratio to the total sugar content in fruit acceptability and umami taste (Carli *et al.*, 2011; Zhang *et al.*, 2015). The amount of this compound is strongly genotype dependent (Cebolla-Cornejo *et al.*, 2011). The levels of glutamic acid we detected were significantly higher than those reported by Zgola-Grześkowiak & Grześkowiak (2012) who found a mean of 153.2 mg/100 mL in yellow tomato juice. Among our genotypes, the consistently higher level of glutamic acid observed in E40 exceeded the values observed by Casals Missio *et al.* (2015) in 23 tomato accessions. This specific trait exhibited by GiaGiù might explain the particular flavour of this yellow genotype. Also, our values for succinic and tartaric acids were significantly higher than those previously reported (Oms-Oliu *et al.*, 2011). Finally, oxalic acid plays an important role from a nutritional point of view because it is a dicarboxylic acid that forms insoluble salts with bivalent cations, such as calcium, reducing the bioavailability of this metal (Nakata, 2012). Calcium bioavailability depends on the ratio of oxalic acid to calcium, because at high levels it cannot be assimilated by the human body. Based on the observed values, all the samples represent a good source of calcium. Related to the main chemical parameters influencing taste and aroma, the PCA analysis noted that, both before and after thermal treatment, the genotype GiaGiù preserves the same specific traits, i.e. a high titratable acidity and glutamic acid and pectin contents. The high content of glutamic acid might influence the taste of yellow fresh fruits of the genotype GiaGiù (Ferraro *et al.*, 2012), and this attribute enhances its culinary properties, as already evidenced by various chefs when used GiaGiù for preparing pasta and pizza (Moschetti, 2016; the chefs Raffaele Ferriere and Giuseppe Pignalosa, personal communications). The second relevant difference between the genotype GiaGiù and the other three genotypes analysed was the pectin content, which was significantly higher. This compound greatly affects fruit softening (Paniagua *et al.*, 2014) and its viscosity before and after the thermal treatment. Viscosity is a very important characteristic for many food products, and therefore, attention has been paid to novel food-processing techniques to reduce the negative effects of processing on pectin degradation and texture changes (Christiaens *et al.*, 2012). Indeed, the break temperature used in tomato processing strongly impacts the pectin content and the product consistency (Anthon & Barrett, 2012). Genotypes showing an high pectin content in the fruit, such as GiaGiù, might guarantee a higher content of this compound after the degradation that naturally occurs during processing. Because the cell wall polysaccharide composition and structure are highly variable in different tomato lines previously studied (Lahaye *et al.*, 2013), we hypothesised that these chemical and structural variations might also occur among the yellow tomatoes here analysed. However, more detailed investigations are required to verify this hypothesis. In future, the detailed analyses carried out in this work might be a basis for selecting new genotypes with specific taste characteristics that are more suitable for processing, focusing on the genotypic effect and on technologies to achieve better performances after cooking and processing.

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Author Contributions

Raiola A., Pizzolongo F. and Barone A. wrote the manuscript, Manzo N. and Montefusco I. carried out the analyses. Spigno P. grew the tomato samples. Romano R. and Barone A. designed the study and interpreted the results. All the authors revised the manuscript.

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