International Journal of Food Science +Technology

Original article

Improved antioxidant properties and sustainability of whole-fruit yellow tomato puree

Fabiana Pizzolongo,* Giovanni Sorrentino, Salvatore Graci, Amalia Barone & Raffaele Romano

Department of Agricultural Sciences, University of Napoli Federico II, Piazza Carlo di Borbone, 80055 Portici (Napoli), Italy

(Received 2 August 2024; Accepted in revised form 23 August 2024)

Summary In this study, a new process was proposed to make the yellow tomato puree more sustainable, avoiding any waste during production and including peels and seeds in it. In addition, as raw material tomatoes grown without irrigation and fertilisation procedures were used to increase the sustainability. With respect to a traditional puree, the whole-fruit yellow tomato puree contained more β-carotene and polyphenols, exhibiting greater antioxidant capacity, and showed greater consistency due to the high content of pectin in peels. Moreover, a higher content of glutamic acid, responsible for the umami taste, was detected particularly in products from GiaGiù ecotype. Sensory analysis assessed that whole-fruit yellow tomato puree has good acceptability and consumers preferred it for the texture. In conclusion, the whole-fruit yellow tomato puree is not only a sustainable product but can be also used as an excellent ingredient in food formulation with antioxidant properties.

Keywords Bioactive compounds, food processing, glutamic acid, polyphenols, storage, β-carotene.

Introduction

Tomato (*Solanum lycopersicum* L.) is among the most economically important horticultural crop species worldwide, second only to potato (Saeed *et al.*, 2014; Pishgar-Komleh *et al.*, 2017).

Yellow tomato cultivars are attracting much interest among consumers as fresh products or ingredients for cooking purposes.

Several yellow tomato varieties are currently available in Italian markets. Most of these varieties are hybrids because compared with pure lines, they frequently exhibit heterosis in terms of yield-related, pathogen resistance, and fruit quality traits (Mishra *et al.*, 2021). However, because of the pedoclimatic, cultural, and political differences among Italian environments, many tomato ecotypes have been selected from farmers based on their high performances in specific areas of the country, thus increasing consumer demand (Sacco *et al.*, 2020; Farinon *et al.*, 2022). Among these varieties, 'GiaGiù', an autochthonous cultivar from the Campania region in southern Italy, is of considerable interest for its interesting organoleptic and nutritional qualities (Sacco *et al.*, 2013; Ruggieri *et al.*, 2014). Compared with the other genotypes, the GiaGiù ecotype contains the highest content of titratable acid, organic acids (particularly glutamic acid), and pectin. The chemical–physical properties are preserved even after heat treatment, as reported by Raiola *et al.* (2018).

Through these features, yellow tomatoes can be successfully used to produce juices, sauces, and purees with specific viscosities and taste. Tomato consumption, in fact, has increased in recent years with the development of new processed products (Raiola *et al.*, 2018; Chabi *et al.*, 2024). Tomatoes contain 93–96% water on average. All other components represent the dry matter (4–7%). The latter contains soluble and insoluble organic compounds and mineral salts. Soluble organic compounds are mainly sugars and organic acids. Insoluble organic compounds are mainly pectin and cellulose. Soluble sugars, organic acids, free amino acids, and salts contribute to the taste of tomatoes, while pectin affects the consistency (Causse *et al.*, 2010; Raiola *et al.*, 2018). Among the amino acids, glutamic acid is of great importance from both functional and organoleptic perspectives. It was studied from several authors that have highlighted its relationship with the total sugar content, consumer acceptability of fruit, and umami taste (Carli *et al.*, 2011; Zhang *et al.*, 2015; Raiola *et al.*, 2018). The genotype strongly affects the amount of this compound (Cebolla-Cornejo *et al.*, 2011). GiaGiù cultivar exhibited a high content of glutamic acid (Raiola *et al.*, 2018) and

*Correspondent: Tel: +390812539447; e-mail: fabiana.pizzolongo@unina.it

doi:10.1111/ijfs.17569

its specific trait may explain the unique flavour of this yellow genotype (Moschetti, 2016). Pectin content influences the viscosity that is an important feature for many food products, and therefore, new food processing techniques have been emphasised to reduce pectin degradation during processing and adverse effects on texture (Christiaens *et al*., 2012; Raiola *et al*., 2018). The breaking temperature strongly affects the content of pectin and the consistency of the product during tomato processing (Anthon & Barrett, 2012). Fruit genotypes with a high pectin content, such as GiaGiu, may contain a higher amount of this compound after natural degradation during processing (Raiola *et al*., 2018).

During traditional tomato puree processing, seeds, peels and small amounts of pulp are discarded as waste, but they still contain valuable nutritional compounds. The waste composition for dried fruit was as follows: 35–55% seeds (containing hemicellulose, cellulose, lignin, and lipids), 30–60% peels (containing cutin, pectin, hemicellulose, and cellulose) and 0–15% pulp (containing cellulose, hemicellulose, and lignin), as reported by Casa *et al*. (2021). In addition, tomato peels are a valuable source of carotenoids, which are important antioxidant sources (Gheonea *et al*., 2020). Tomato peels also contain flavonolic glycosides (quercetin and kaempferol) in concentrated form (Savatović *et al*., 2012; Nour *et al*., 2018; Lu *et al*., 2019). Tomato seeds have a high content of bioactive compounds, such as polyphenols, carotenoids, proteins, minerals, fibre and oil (Szabo *et al*., 2019).

The waste from the traditional tomato puree process results in the loss of important resources and represents an environmental issue. Moreover, the rational disposal of tomato waste is an economic problem. From a sustainable point of view, waste management is a moral challenge for society (Lu *et al*., 2019).

With the goal of developing new and environmentally friendly tomato purees, in this work, we created a new type of yellow tomato puree by utilising whole fruits, not excluding peels and seeds. Two types of cultivars, GiaGiù and hybrid were used to produce whole-fruit yellow tomato puree. Chemical composition, antioxidant properties, and sensory parameters were monitored during storage for 6 months at 25 °C, the temperature commonly used in grocery stores for tomato purees.

Materials and methods

Raw materials

The yellow tomatoes used in this study consisted of two Italian cultivars from the Campania Region: the miniplum F_1 combination with indeterminate plant habitus (Hybrid) and the GiaGiù ecotype, which was previously phenotypically characterised by Graci *et al*. (2022). Both cultivars were purchased by Gaetano Romano farm located in Somma Vesuviana (Naples, Italy). The plants were transplanted to an open field during the first week of April and cultivated according to a randomised design with 30 plants per replicate and three replicates in 2022. The plants were grown without irrigation or fertilisation. The tomato fruits were harvested during the first week of July from the second to the fourth truss. All tomato samples were subjected to subsequent physicochemical analysis and were processed within 7 days from collection.

Tomato puree

Both tomato cultivars were processed to generate whole tomato puree and traditional tomato puree according to the procedures reported in Fig. 1.

Briefly, after the tomatoes were washed for 5 min with water, they were divided in two aliquots of 2 kg.

The first 2 kg – aliquot was placed into a machine that cooks food in a vacuum state (Roboqbo, Bentivoglio, Bologna, Italy) to obtain the whole tomato puree. The rotating system was set at 3000 ***g***, and the vacuum was set at −850 mbar. Under these conditions, the hot-break thermal treatment was set at 92 °C for 3 min, and homogenisation was carried out at 90 °C for 5 min.

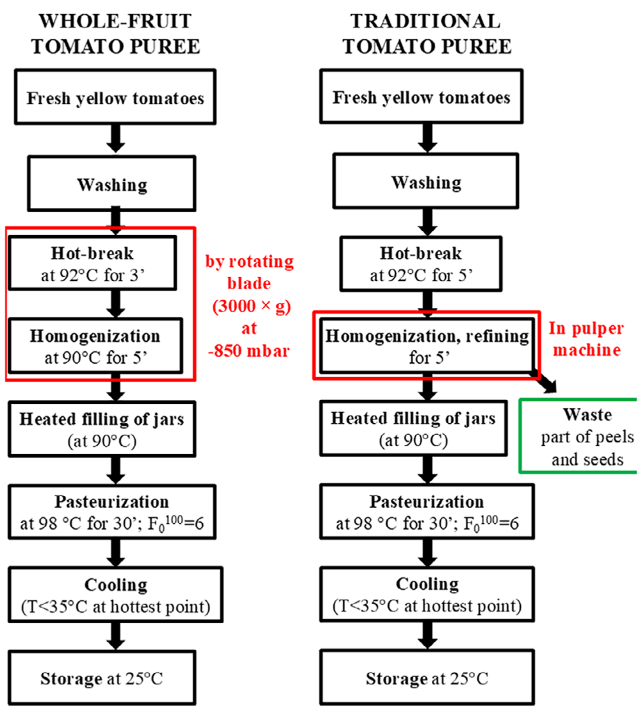

Figure 1 Flow sheet of the whole-fruit puree and the traditional puree process applied to Hybrid and GiaGiù yellow tomatoes.

The second 2 kg – aliquot was subjected to heat treatment (92 °C for 5 min) and refined in a pulper to obtain a traditional puree excluding peels and seeds.

Glass jars were filled with 500 g of tomato puree (whole-fruit and traditional) and subsequently vacuum-sealed. The jars were pasteurised at 100 °C for 10 min in water, cooled, and stored at 25 °C for 6 months.

All samples were subjected to chemical analysis after 1 day (t0) and 6 months of storage (t6).

Dry weight

This parameter was determined as reported by Romano *et al.* (2020b). It represents the total solids and was calculated as the percentage of total solid weight/sample fresh weight.

Total soluble solids

This parameter was determined by using a portable refractometer from SperScientific (Scottsdale, AZ, USA) according to the official method as reported by Romano *et al.* (2020b). The values were expressed in °Brix, which is defined as the concentration (%) of total soluble solids in solution when measured at 20 °C.

pH

This parameter was carried out by a Crison Basic 20+ pH meter (Barcelona, Spain) according to the official method as reported by Romano *et al.* (2020b).

Titratable acidity

This parameter was determined according to the official method as reported by Romano *et al.* (2020b). It was expressed as the percentage of citric acid monohydrate weight/sample fresh weight.

Reducing sugars

This parameter was determined on diluted and filtered samples by Fehling's method according to the official method as reported by Romano *et al.* (2020b). The results were estimated as the percentage of reducing sugar weight/sample fresh weight.

Analytical index

The analytical index was calculated for fresh tomatoes as $(R^2 * Z)/(a * 10)$, where R is the total soluble solids (°Brix), Z is the reducing sugar content (%), and a is the titratable acidity (%) as reported by Marini & Balestrieri (1990).

Moisture

This parameter was determined in a hot air oven at 60 °C until a constant weight was reached according to the official method as reported by Romano *et al.* (2020b). The results were calculated as the weight/weight percentage of water (% w/w).

Viscosity

This parameter was measured in processed tomatoes according to the Bostwick method (Raiola *et al.*, 2018) using a Bostwick LS100 consistometer. The results were expressed as Bostwick degree (cm/30 s).

Extractions of hydrophilic and lipophilic fractions

The two fractions, hydrophilic and lipophilic were obtained according to Raiola *et al.* (2016).

For the hydrophilic extraction, 30 mL of methanol was added to 3 g of samples of fresh tomatoes or purees (70% methanol). The mixture was centrifuged at 3500 ***g*** using a PK 131 (ALC International Srl, Milano, Italy) for 10 min, and the supernatant (hydrophilic fraction) was stored at −20 °C until total phenolic compound, organic acid, ABTS, FRAP, and DPPH assays were performed.

The pellet was subjected to further extractions to obtain the lipophilic fraction. It was subjected three times to extraction with 16 mL of a solution of acetone/hexane (40/60, v/v) using an Ultraturrax 115VAC IKA T 25 high-speed homogeniser (Cole-Parmer, Vernon Hills, IL, USA). The mixture was centrifuged at 3500 ***g*** for 5 min according to a modified procedure reported by Zouari *et al.* (2014). The supernatant phases (lipophilic fraction) were collected and stored at −20 °C until the determination of total carotenoids, ABTS, and FRAP assays.

Total carotenoids

Total carotenoids were determined in the lipophilic fraction under reduced light conditions. The extracted fat, taken with hexane, was suitably diluted after reading with a Shimadzu UV 1601 spectrophotometer (Milan, Italy) at a wavelength of 471 nm for total carotenoids (expressed as β-carotene eq.), 475 nm for β-carotene and 502 nm for lycopene (Luterotti *et al.*, 2015).

The absorbance value is derived from the respective concentration by applying the Lambert-Beer equation, using a molar extinction coefficient of 3150 dL g^{-1}*cm for hexane for lycopene, 2049 dL g^{-1}*cm for β-carotene and 2049 dL g^{-1}*cm for total carotenoids (expressed as β-carotene eq.). The results were calculated as mg/100 g of sample fresh weight (mg/100 g fw).

Organic acids

The organic acids were determined by using the method described by Manzo *et al.* (2018) with slight modifications as reported by Raiola *et al.* (2018). High-performance liquid chromatography (HPLC) analysis were performed on extracts diluted to 30% w/v h deionised water, filtered through a 0.45 nm filter. The results were expressed as mg/100 g of sample fresh weight (mg/100 g fw).

Total polyphenols

The total phenolic content in the hydrophilic fraction was determined by the Folin–Ciocalteu assay with modifications reported by Sacco *et al.* (2019) and Rigano *et al.* (2014). The standard curve was obtained in the range of 0–70 μg mL^{-1} gallic acid. The results were expressed as mg gallic acid equivalents (GAE)/100 g of sample fresh weight (mg/100 g fw).

Antioxidant activity by ABTS+

Hydrophilic and lipophilic fractions of fresh tomatoes and purees were submitted to the 2,2′ azino-bis (3-ethylbenzthiazoline-6-sulfonic acid) ($ABTS^{•+}$) radical cation decolorisation assay to measure the free radical scavenging capacity as described by Bianchi *et al.* (2023). The decolorisation resulting from cation reduction by antioxidants in the sample was measured at 734 nm using a UV-1601PC UV–visible scanning spectrophotometer (Shimadzu). Trolox (6 hydroxy-2,5,7,8-trimethyl-chroman-2-carboxylic acid) (0–15 μM) was used for the standard curve. The results were expressed as Trolox equivalent (TE) μmol /100 g of sample fresh weight (μmol TE/100 g fw).

Antioxidant assay by FRAP

Determination of ferric-reducing antioxidant power (FRAP) was conducted according to Fuentes *et al.* (2013). The FRAP reagent preparation and the incubation conditions used were those reported by Fuentes *et al.* (2013). Trolox was used for the standard curve. The results were expressed as Trolox equivalent (TE) μmol /100 g of sample fresh weight (μmol TE/100 g fw).

Antioxidant assay by DPPH

The hydrophilic fraction of fresh tomatoes and purees was submitted to the 2,2-diphenyl-1-picrylhydrazyl (DPPH·) assay. The test is based on the scavenging activity of this free radical dissolved in methanol and was performed as described by Espinosa-Pardo *et al.* (2017), with some modifications. The results were expressed as Trolox equivalent (TE) μmol/100 g of sample fresh weight (μmol TE/100 g fw).

Acceptability test

The acceptability test was carried out on the tomato puree according to Lavelli *et al.* (2014) with some modifications. Ninety-four consumers (18–65 years old) participated in the test. Briefly they were asked to evaluate the overall acceptability, the texture, and the colour liking in a hedonic scale ranging from 1 to 9 (extremely disliked = 1, extremely liked = 9). Samples of 20 g puree were served at 40 °C in randomised order in coded plastic 40 mL-cups.

Colour measurement

The colour of tomato puree was determined using a colorimeter (Chroma Meter, model CR-300; Minolta, Osaka, Japan). The samples were poured into 90 cm diameter Petri dishes and L^* (lightness), a^* (green-red direction), and b^* (blue-yellow direction) colour parameters were recorded.

Statistical analysis

Three purees from the two tomato varieties and the two processing methods were produced. Each measurement was performed in triplicate, and the results were reported as the average values (± standard deviations). The data were submitted to analysis of variance (ANOVA) and Tukey's test ($P \leq 0.05$) by using XLSTAT software version 2023 (Addinsoft, New York, NY, USA).

Results and discussion

Tomato puree process

Figure 1 shows the process of pureeing the yellow whole tomato, which was reported and compared with the traditional process. In both types, the hot-break process at 92 °C was applied. Through this process, the enzymes pectin methyl esterase, endopolygalacturonase, and exopolygalacturonase were completely inactivated, and a consistent paste was obtained. If a coldbreak process (<66 °C) was used, these enzymes were partially inactivated, and a puree with low consistency was obtained (Krebbers *et al.*, 2003).

The main difference between the two processes was that, first, the whole tomatoes were simultaneously heated at 92 °C in a vacuum at −850 mbar and then were finely homogenised in a rotating blade system at 3000 ***g***. The whole processed tomatoes (including peels and seeds) were placed in the jars, and no waste was produced. In the traditional process, the hot-break and the homogenisation steps were carried out separately in the presence of air. After refining, some of the peels and seeds were discarded as waste.

Preliminary analysis of fresh and processed tomatoes

In Table 1, preliminary analyses of fresh tomatoes, whole-fruit, and traditional puree from the Hybrid (H) and GiaGiu (G) cultivars after 1 day (t0) and 6 months (t6) of storage are reported.

The parameters were all significantly different for fresh tomatoes. The values of dry matter, total soluble solids and reducing sugars in the hybrid cultivar (12.12%, 9.47 °Brix and 5.94%, respectively) were greater than those in GiaGiù. These parameters, particularly total soluble solids (which are the sum of sugars, acids and other minor components) are economically valuable for the processing tomato industry since small increases of these parameters can significantly increase yield. Acidity is the most important quality parameter because it influences the thermal processing conditions required for producing safe tomato puree. Acidity was greater in the GiaGiù samples (0.94%) than in the hybrid samples (0.87%), and the pH decreased. There is an inverse relationship between pH and titratable acidity, although sometimes the relationship is inaccurate (Wasim & Singh, 2015). These results correspond with previous studies (Raiola *et al.*, 2018) in which this cultivar was found to have greater acidity than other yellow tomato ecotypes because of its high glutamic acid content. The analytical indices obtained by converting the values of the total soluble solids, reducing sugar content and titratable acidity were 61 and 42 in the Hybrid and GiaGiù media, respectively. In both cases, a value greater than 25 indicates good quality of the fruit (Marini & Balestrieri, 1990). Therefore, even though the tomatoes were grown without water and fertilisers, they have good technological characteristics.

Regarding the puree, the dry matter content and total soluble solids ranged from 12.40% to 10.50% and from 9.80 to 9.20 °Brix, respectively, in whole tomato puree (Table 1). Both parameters were greater than those of traditional puree due to the presence of peels and seeds in the first type of puree, which contributed to increased dry matter and °Brix values. No significant differences between the cultivar and during storage were found for either type of puree. Similar to that in fresh tomatoes, the sugar content at t0 was significantly greater in whole tomato puree from hybrids (6.40%) than in whole tomato puree from GiaGiù (5.20%). The content slightly decreased during storage, possibly because it was involved in reactions such as the Maillard reaction. However, the sugar content of whole tomato puree was greater (6.40–4.72% vs. 5.00–3.46%) than that of traditional puree. The pH values were not significantly different among the samples at t0 and decreased in GiaGiù whole tomato puree during storage from 4.31 at t0 to 4.15 at t6. Similarly, the titratable acidity at t0 was significantly greater for the GiaGiù samples (0.68–0.94%) than the Hybrid samples (0.49–0.72%). In addition, the titratable acidity was greater in whole tomato puree than in traditional puree from both cultivars. This could result from the presence of fatty acids in seeds that are included in the whole tomato. The consistency, which is measured in °Bostwick as the speed (cm/30 s) at which a viscous liquid runs along a slope, was generally lower (range 9.50–11.50 °Bostwick) in whole tomato puree samples with higher pectin contents in their peels (lower Bostwick consistency values, higher viscosity). Several studies (Moelants *et al.*, 2013)

Table 1 Dry matter (%), total soluble solids (°Brix), pH, titratable acidity (%), reducing sugars (%) and viscosity (°Bostwick) in fresh tomatoes, whole-fruit and traditional yellow tomato puree obtained from Hybrid (H) and GiaGiù (G) cultivar after 1 day (t0) and 6 months (t6) of storage

Samples	Cultivar	Time of storage	Dry matter (%)	Total soluble solids (°Brix)	Reducing sugar (%)	pH	Titratable acidity (%)	Viscosity (°Bostwick)
Fresh tomatoes	H	t0	12.12 ± 0.00^{a}	9.47 ± 0.42^{a}	5.94 ± 0.21^{a}	4.09 ± 0.02^{a}	0.87 ± 0.03^{b}	
	G	t0	11.20 ± 0.00^{b}	8.67 ± 0.12^{b}	5.35 ± 0.13^{b}	4.02 ± 0.01^{b}	0.94 ± 0.03^{a}	
Whole-fruit puree	H	t0	12.40 ± 0.85^{a}	9.80 ± 0.28^{a}	6.40 ± 0.41^{a}	4.25 ± 0.01^{b}	0.72 ± 0.01^{e}	9.50 ± 0.54^{de}
	H	t6	12.00 ± 1.41^{ab}	9.45 ± 0.07^{a}	4.72 ± 0.01^{c}	4.31 ± 0.01^{a}	0.83 ± 0.01^{d}	10.45 ± 0.07^{cd}
	G	t0	11.10 ± 1.13^{ab}	9.20 ± 0.57^{a}	5.20 ± 0.47^{b}	4.31 ± 0.01^{a}	0.94 ± 0.04^{c}	10.00 ± 0.04^{de}
	G	t6	10.50 ± 0.71^{b}	9.40 ± 0.28^{a}	4.95 ± 0.01^{b}	4.15 ± 0.01^{c}	1.11 ± 0.01^{b}	$11.50 \pm 0.71b^{cd}$
Traditional puree	H	t0	8.40 ± 0.57^{d}	7.20 ± 0.28^{b}	4.12 ± 0.23^{cd}	4.27 ± 0.03^{b}	0.49 ± 0.04^{f}	9.00 ± 0.06^{e}
	H	t6	9.00 ± 1.41^{d}	8.00 ± 0.28^{ab}	3.46 ± 0.03^{d}	4.15 ± 0.07^{bc}	1.43 ± 0.01^{a}	13.05 ± 0.21^{a}
	G	t0	8.10 ± 0.42^{d}	6.80 ± 0.28^{b}	4.70 ± 0.49^{cd}	4.23 ± 0.04^{b}	0.68 ± 0.03^{e}	10.30 ± 0.16^{cde}
	G	t6	8.50 ± 0.71^{d}	7.00 ± 0.14^{b}	5.00 ± 0.21^{bc}	4.23 ± 0.00^{b}	1.04 ± 0.01^{bc}	12.50 ± 0.00^{ab}

[a–e]Different letters in the same column indicate statistically significant differences ($P < 0.05$).

reported an increase in the serum viscosity of tomato products with increasing pectin content. Considering the storage time, the traditional puree showed higher °Bostwick values after 6 months for pectin degradation processes, such as depolymerisation (Moelants *et al.*, 2013). A similar trend was observed for the Hybrid and Giagiù cultivars. This result indicates that compared with traditional puree, whole tomato puree can be better stored because their consistency is preserved.

Carotenoids, organic acids and polyphenols

The content of carotenoids in fresh and processed tomatoes was investigated (Table 2). The main carotenoid detected was β-carotene. Lycopene was detected in trace amounts (<0.1 mg/100 g fw). In fresh tomatoes, the content was 0.33–0.44 mg/100 g fw, and the value of the hybrid cultivar was significantly greater than that of GiaGiù. These results correspond well with those of Georgé *et al.* (2011), who detected 0.3 mg/100 g fw in cultivar 6205, Séminis, a yellow tomato.

For the processed tomatoes, the concentrations ranged from 0.69 to 1.44 and 0.19 to 0.61 mg/100 g fw for the whole tomato and traditional puree, respectively. With respect to fresh tomatoes, the range increased for whole tomatoes but not for traditional purees, probably because different processing parameters were used (hot-break, ultrahomogenisation, and vacuum). Similar results were obtained by other authors (Pénicaud *et al.*, 2011), who reported increased levels of cis-β-carotene when processed tomatoes underwent hot-break processing. In addition, the use of a vacuum during the process can prevent the oxidation and loss of β-carotene. The higher β-carotene content in whole tomato fruits than in traditional puree fruits is mainly related to the presence of peel, which is included in whole tomato puree fruits rather than wasted. Peels and seeds are important sources of natural carotenoids (Strati & Oreopoulou, 2014). The amount of β-carotene increased during storage in all samples except in GiaGiù whole-fruit puree. This result occurred due to the simultaneous isomerisation and degradation of β-carotene, which may lead to inconsistent changes or slight increases in concentration (Lin & Chen, 2005).

Glutamic acid was the most abundant organic acid and was detected at concentrations ranging from 415 to 561 and 48 to 207 mg/100 g fw in fresh and processed tomatoes, respectively (Table 2). This compound produces the fifth taste, which is known as the umami taste. The values were greater for fresh GiaGiù tomatoes and decreased for processed samples of both cultivars, corresponding with the findings of Raiola *et al.* (2018). The parameters used during the processing strongly impacted the content of this acid, with reductions of more than 60% at t0. Similar to fresh tomatoes, processed tomatoes from GiaGiù (both types) contained more glutamic acid than those of the hybrid products. With respect to processing, glutamic acid was more abundant in the whole tomato process than in the traditional process. During the 6 months of storage, the values were stable in the processed GiaGiù samples (from 207 to 202 and 133 to 139 mg/100 g fw in the whole and traditional puree samples, respectively), but they strongly decreased in the processed hybrid puree samples, with values of 48 and 59 mg/100 g fw in the whole and traditional puree samples, respectively. This loss can occur during processing due to oxidation or reactions with other food components. Glutamic acid is an amino acid, and during thermal treatment, it can react with the reducing sugars, of which hybrid is more effective than GiaGiù. A

Table 2 Carotenoids, main organic acids (glutamic and ascorbic acid), and total polyphenols of fresh tomatoes, whole-fruit, and traditional yellow tomato puree obtained from hybrid (H) and GiaGiù (G) cultivar after 1 day (t0) and 6 months (t6) of storage

			Carotenoids (mg/100 g fw)	Organic acids (mg/100 g fw)		
Samples	Cultivar	Time of storage	β-Carotene	Glutamic acid	Ascorbic acid	Total polyphenols (mg GAE/100 g fw)
Fresh tomatoes	H	t0	0.44 ± 0.06[a]	415.48 ± 12.10[b]	54.37 ± 6.84[a]	79.01 ± 11.28[a]
	G	t0	0.33 ± 0.03[b]	561.96 ± 7.93[a]	50.60 ± 5.29[a]	61.79 ± 3.03[a]
Whole-fruit puree	H	t0	0.69 ± 0.03[a]	157.82 ± 6.51[b]	29.12 ± 0.44[b]	84.07 ± 1.13[b]
	H	t6	1.44 ± 0.62[a]	48.41 ± 2.37[e]	3.05 ± 0.01[c]	77.74 ± 0.04[c]
	G	t0	0.70 ± 0.01[a]	207.26 ± 2.83[a]	32.39 ± 0.25[ab]	91.24 ± 1.47[a]
	G	t6	0.66 ± 0.31[a]	202.71 ± 1.07[a]	2.50 ± 0.42[c]	58.96 ± 0.00[f]
Traditional puree	H	t0	0.19 ± 0.03[c]	126.70 ± 4.38[d]	23.41 ± 1.40[b]	79.82 ± 0.37[c]
	H	t6	0.45 ± 0.07[bc]	59.81 ± 0.54[e]	2.30 ± 1.63[c]	75.71 ± 0.01[cd]
	G	t0	0.22 ± 0.04[c]	133.40 ± 2.12[c]	23.97 ± 0.55[b]	72.65 ± 2.26[de]
	G	t6	0.61 ± 0.01[b]	139.87 ± 0.44[c]	2.66 ± 0.40[c]	50.68 ± 0.00[g]

[a–g]Different letters in the same column indicate statistically significant differences ($P < 0.05$).

similar trend was also observed for sugar content during storage.

The ascorbic acid concentration was in the range of 54–50 mg/100 g fw, without statistically significant differences between the hybrid and fresh GiaGiù tomatoes. These values were greater than those reported by Georgé *et al.* (2011) (17.1 mg/100 g fw) and Simonne *et al.* (2007) (35.0–44.8 mg/100 g fw) for yellow tomatoes. As expected, the content strongly decreased in both processed samples (23–32 mg/100 g fw) and after 6 months of storage (2–3 mg/100 g fw). Ascorbic acid is highly sensitive to elevate temperatures and various processing conditions.

The total polyphenol (TPC) content in fresh tomatoes was 61–79 mg GAE/100 g fw for the GiaGiù and hybrid cultivars. It increased significantly after whole tomato thermal processing at t0 (up to 91 and 84 in GiaGiù and hybrid, respectively) and after traditional thermal processing at t0 (up to 72 in GiaGiù). This increase may result from the increased release of phenolics from the matrix due to thermal treatment. Our results are consistent with the findings of Kamiloglu *et al.* (2014) and Bugianesi *et al.* (2004), who also noted that cooking improved the TPC content and the bioaccessibility of chlorogenic acid, one of the main phenolic compounds in tomatoes. In all processed samples, the TPC decreased during the 6 months of storage. Comparing the two types of puree at the same storage time, the TPC was greater in whole tomatoes than in traditional puree. This is because peels, which are rich in polyphenols, are present in the first type.

Hydrophilic and lipophilic antioxidant activity

Antioxidant activity represents the capacity of food extracts to delay oxidation processes. The activity of both the lipophilic and hydrophilic fractions was determined by the free radical scavenging ABTS and ferric ion-reducing FRAP assays (Table 3). In addition, hydrophilic fraction was also submitted to DPPH assay.

The antioxidant activity of lipophilic extracts from tomato purees is mainly due to β-carotene, which is a lipophilic molecule well known for its antioxidant properties and its ability to act as a quencher of singlet oxygen and reactive free radicals (Polyakov *et al.*, 2001; Polívka & Sundström, 2004; Sandhiya & Zipse, 2022). The lipophilic ABTS values in fresh tomatoes (48–45 μmmol TE/100 g fw) were similar to those found in the Albertovské žluté yellow tomato variety (6.2 μmmol TE/g of dry matter) studied by Kotíková *et al.* (2011). The TE was in the range of 142–180 μmmol TE/100 g fw in whole tomato puree, which was significantly greater than that of traditional peeds (112–172 μmmol TE/100 g fw); this increase was due to the presence of β-carotene in the peels and high percentages of unsaturated fatty acids in the seeds (Romano *et al.*, 2020a). Both the whole and traditional hybrid purees exhibited significantly greater values than those of GiaGiù. This result is consistent with the finding that the highest β-carotene content was detected in the hybrid cultivar. The difference was not confirmed by the FRAP test, which ranged from 5.7 to 4.8 and from 13 to 39 μmmol TE/100 g fw in fresh and processed tomatoes, respectively, without significant differences. Both the ABTS and FRAP values increased in the processed tomatoes due to thermal treatment. The increase during heating may result from an increase in the bioavailability of the main antioxidant substances and was also reported by Dewanto *et al.* (2002).

The hydrophilic antioxidant activity of the samples is mainly related to the polyphenol content. The ABTS

Table 3 Antioxidant activity (ABTS and FRAP assay) in the lipophilic and hydrophilic fractions of fresh tomatoes, whole-fruit, and traditional yellow tomato puree obtained from hybrid (H) and GiaGiù (G) cultivar after 1 day (t0) and 6 months (t6) of storage

			Antioxidant activity in lipophilic fraction (μmol TE/100 g fw)		Antioxidant activity in hydrophilic fraction (μmol TE/100 g fw)	
Samples	**Cultivar**	**Time of storage**	**ABTS**	**FRAP**	**ABTS**	**FRAP**
Fresh tomatoes	H	t0	48.38 ± 8.40^{a}	5.71 ± 1.31^{a}	308.32 ± 3.13^{a}	37.51 ± 3.01^{a}
	G	t0	45.55 ± 2.76^{a}	4.81 ± 1.66^{a}	290.23 ± 5.49^{b}	24.38 ± 2.32^{b}
Whole-fruit puree	H	t0	166.94 ± 4.24^{ab}	14.47 ± 3.14^{d}	624.46 ± 9.90^{b}	95.06 ± 1.27^{d}
	H	t6	180.37 ± 0.06^{a}	36.55 ± 0.46^{ab}	659.25 ± 12.74^{a}	246.64 ± 3.15^{b}
	G	t0	142.54 ± 4.38^{d}	21.17 ± 3.28^{cd}	300.36 ± 4.38^{d}	96.89 ± 1.56^{d}
	G	t6	158.28 ± 3.09^{bc}	39.88 ± 0.18^{a}	343.59 ± 2.37^{c}	257.43 ± 2.03^{a}
Traditional puree	H	t0	146.45 ± 5.23^{cd}	17.45 ± 2.12^{cd}	596.54 ± 9.48^{b}	58.58 ± 1.74^{e}
	H	t6	172.34 ± 2.63^{a}	18.39 ± 3.19^{cd}	617.49 ± 2.78^{b}	193.17 ± 0.43^{c}
	G	t0	112.14 ± 3.11^{e}	13.60 ± 3.73^{d}	261.54 ± 4.81^{e}	60.81 ± 1.23^{e}
	G	t6	139.59 ± 2.89^{d}	27.17 ± 0.41^{bc}	294.92 ± 5.71^{d}	196.55 ± 5.32^{c}

[a–e]Different letters in the same column indicate statistically significant differences ($P < 0.05$).

values were 308 and 290 μmmol TE/100 g fw in the hydrophilic fraction in fresh tomatoes and were notably greater than those found in the Albertovské žluté yellow tomato variety (27 μmmol TE/g of dry matter) studied by Kotíková *et al.* (2011). The hydrophilic fraction increased in processed tomatoes due to the increase in the bioavailability of antioxidant substances during thermal treatment. These substances were in the range of 300–659 μmmol TE/100 g fw in whole tomato puree and were significantly greater than those found in traditional methods (261–617 μmmol TE/100 g fw). The results were correlated with the higher TPC values found in the whole tomato puree. The results were confirmed by the FRAP assay, which revealed higher values in whole tomato puree (95–257 μmmol TE/100 g fw) than in traditional puree (58–196 μmmol TE/100 g fw), with the highest value (257 μmmol TE/100 g fw) in GiaGiù whole tomato puree stored for 6 months. The values of the processed hybrid tomatoes measured by ABTS were significantly greater than those measured by GiaGiù, but no statistically significant differences were detected by FRAP. The DPPH results followed the same tendency as those of the previous tests and showed values very close to those of ABTS (Table S1).

The ABTS and FRAP antioxidant activities measured in the hydrophilic fraction were greater than those measured in the lipophilic fraction. This result is similar to the findings of Cano *et al.* (2003), Kotíková *et al.* (2011) and Toor & Savage (2005), who reported lower antioxidant activity of lipophilic antioxidants.

Considering the storage time, the antioxidant activity measured by all the assays significantly increased during the 6 months, indicating that antioxidant substances were released during storage.

Sensory analysis

The acceptability test was performed on puree samples to detect if the different processing, the storage time and types of cultivars could affect the pleasantness perceived by consumers. In Table 4 is reported the liking test estimating the overall acceptability, the texture and colour liking. The overall acceptability was on average 8 (very much liked) for all samples except for traditional puree stored for 6 months that received a score of 7. The texture was better in whole-fruit puree (7.7–8.3) than in traditional (7.1–7.7). This parameter is correlated to the particle sizes of puree and can be influenced by the processing (Moelants *et al.*, 2013). In the new process, the homogenisation by rotating blade at 3000 ***g*** determined small particles that are preferred by consumers. Also, the colour can be influenced by the processing (Lavelli & Torresani, 2011), but in our case, no differences were found by consumers with all samples receiving the score of ~ 8. The colour was well preserved during the new process because it was carried out under a vacuum. This finding was confirmed by the colour measurements (Table 4) that showed no significant differences among the samples for all the parameters (L^*, a^* and b^*) recorded. In conclusion, the new product, the whole-fruit puree, was particularly appreciated by consumers for its texture.

Conclusion

The process we proposed to make the whole-fruit yellow tomato puree allowed us to easily include seeds and peels in the puree. The new type of puree showed improved antioxidant capacity due mainly to β-carotene and polyphenols contained in seeds and peels. Compared with traditional puree, it also exhibited greater consistency for the high content of pectin in peels and a higher content of glutamic acid. Its chemical parameters were well preserved after storage at room temperature of 25 °C for 6 months.

Both the yellow cultivars used, Hybrid and Giagiù, well suited to being processed, with GiaGiù exhibiting a higher content of glutamic acid, which is responsible for the umami taste.

Table 4 Acceptability test (overall acceptability, texture, and colour liking) and colour measurement (L^*, a^* and b^*) of whole-fruit and traditional yellow tomato puree obtained from Hybrid (H) and GiaGiù (G) cultivar after 1 day (t0) and 6 months (t6) of storage

			Acceptability test			Colour measurement		
Samples	**Cultivar**	**Time of storage**	**Overall acceptability**	**Texture liking**	**Colour liking**	L^*	a^*	b^*
Whole-fruit puree	H	t0	7.91 ± 0.29^a	8.22 ± 0.42^a	7.91 ± 0.29^a	45.5 ± 7.3^a	7.1 ± 2.7^a	22.8 ± 4.9^a
	H	t6	7.87 ± 0.34^a	7.74 ± 0.45^b	7.87 ± 0.34^a	41.4 ± 5.3^a	6.9 ± 2.6^a	21.0 ± 4.8^a
	G	t0	7.74 ± 0.45^a	8.30 ± 0.47^a	8.00 ± 0.30^a	46.8 ± 6.0^a	7.2 ± 2.5^a	22.9 ± 4.7^a
	G	t6	7.70 ± 0.47^a	7.70 ± 0.47^b	7.83 ± 0.39^a	44.6 ± 5.2^a	7.1 ± 2.8^a	21.8 ± 4.9^a
Traditional puree	H	t0	7.70 ± 0.47^a	7.70 ± 0.47^b	7.83 ± 0.49^a	44.5 ± 6.9^a	7.0 ± 2.6^a	22.0 ± 4.6^a
	H	t6	7.17 ± 0.39^b	7.13 ± 0.34^c	7.70 ± 0.47^a	40.3 ± 5.3^a	6.8 ± 2.8^a	20.8 ± 4.8^a
	G	t0	7.78 ± 0.42^a	7.22 ± 0.42^c	7.87 ± 0.46^a	45.4 ± 6.9^a	7.1 ± 2.3^a	21.1 ± 4.3^a
	G	t6	7.22 ± 0.42^b	7.17 ± 0.39^c	7.74 ± 0.54^a	44.1 ± 5.7^a	7.0 ± 2.8^a	21.0 ± 4.8^a

[a–c]Different letters in the same column indicate statistically significant differences ($P < 0.05$).

Sensory analysis assessed that the whole-fruit yellow tomato puree has good acceptability during all the storage time and consumers preferred it for the texture.

Considering that the puree process avoided any waste and that fruits were grown without irrigation and any fertilisers, the environmental pollution was reduced, making the whole-fruit yellow tomato puree a sustainable product.

Moreover, given the antioxidant properties and the peculiar consistency and taste, the whole-fruit yellow tomato puree can be used as an excellent ingredient in food formulation.

Acknowledgments

This study was part of the project PSR 'Sviluppo e valorizzazione della filiera sostenibile del pomodorino giallo Giagiu' CUP B98H19005160008. Open access publishing facilitated by Universita degli Studi di Napoli Federico II, as part of the Wiley - CRUI-CARE agreement.

Author contributions

Fabiana Pizzolongo: Conceptualization; formal analysis; supervision; writing – original draft; writing – review and editing; investigation. **Giovanni Sorrentino:** Formal analysis; writing – review and editing; data curation. **Salvatore Graci:** Writing – review and editing; software; validation. **Amalia Barone:** Project administration; validation; resources; funding acquisition. **Raffaele Romano:** Conceptualization; methodology; validation; visualization.

Conflict of 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 article.

Ethical approval

Ethics approval was not required for this research.

Peer review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ijfs.17569.

Data availability statement

Data will be made available on request.

References

Anthon, G.E. & Barrett, D.M. (2012). Pectin methylesterase activity and other factors affecting pH and titratable acidity in processing tomatoes. *Food Chemistry*, **132**, 915–920.

Bianchi, A.R., Vitale, E., Guerretti, V. *et al.* (2023). Antioxidant characterization of six tomato cultivars and derived products destined for human consumption. *Antioxidants*, **12**, 761.

Bugianesi, R., Salucci, M., Leonardi, C. *et al.* (2004). Effect of domestic cooking on human bioavailability of naringenin, chlorogenic acid, lycopene and β-carotene in cherry tomatoes. *European Journal of Nutrition*, **43**, 360–366.

Cano, A., Acosta, M. & Arnao, M.B. (2003). Hydrophilic and lipophilic antioxidant activity changes during on-vine ripening of tomatoes (*Lycopersicon esculentum* mill.). *Postharvest Biology and Technology*, **28**, 59–65.

Carli, P., Barone, A., Fogliano, V., Frusciante, L. & Ercolano, M.R. (2011). Dissection of genetic and environmental factors involved in tomato organoleptic quality. *BMC Plant Biology*, **11**, 58.

Casa, M., Miccio, M., De Feo, G. *et al.* (2021). A brief overview on valorization of industrial tomato by-products using the biorefinery cascade approach. *Detritus*, **15**, 31–39.

Causse, M., Friguet, C., Coiret, C. *et al.* (2010). Consumer preferences for fresh tomato at the European scale: a common segmentation on taste and firmness. *Journal of Food Science*, **75**, S531–S541.

Cebolla-Cornejo, J., Roselló, S., Valcárcel, M., Serrano, E., Beltrán, J. & Nuez, F. (2011). Evaluation of genotype and environment effects on taste and aroma flavor components of Spanish fresh tomato varieties. *Journal of Agricultural and Food Chemistry*, **59**, 2440–2450.

Chabi, I.B., Zannou, O., Dedehou, E.S. *et al.* (2024). Tomato pomace as a source of valuable functional ingredients for improving physicochemical and sensory properties and extending the shelf life of foods: a review. *Heliyon*, **10**, e25261.

Christiaens, S., Van Buggenhout, S., Houben, K., Chaula, D., Van Loey, A.M. & Hendrickx, M.E. (2012). Unravelling process-induced pectin changes in the tomato cell wall: an integrated approach. *Food Chemistry*, **132**, 1534–1543.

Dewanto, V., Wu, X., Adom, K.K. & Liu, R.H. (2002). Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. *Journal of Agricultural and Food Chemistry*, **50**, 3010–3014.

Espinosa-Pardo, F.A., Nakajima, V.M., Macedo, G.A., Macedo, J.A. & Martínez, J. (2017). Extraction of phenolic compounds from dry and fermented orange pomace using supercritical CO_2 and cosolvents. *Food and Bioproducts Processing*, **101**, 1–10.

Farinon, B., Picarella, M.E., Siligato, F., Rea, R., Taviani, P. & Mazzucato, A. (2022). Phenotypic and genotypic diversity of the tomato germplasm from the Lazio region in Central Italy, with a focus on landrace distinctiveness. *Frontiers in Plant Science*, **13**, 931233. https://doi.org/10.3389/fpls.2022.931233

Fuentes, E., Carle, R., Astudillo, L. *et al.* (2013). Antioxidant and antiplatelet activities in extracts from green and fully ripe tomato fruits (*Solanum lycopersicum*) and pomace from industrial tomato processing. *Evidence-based Complementary and Alternative Medicine*, **2013**, 867578.

Georgé, S., Tourniaire, F., Gautier, H., Goupy, P., Rock, E. & Caris-Veyrat, C. (2011). Changes in the contents of carotenoids, phenolic compounds and vitamin C during technical processing and lyophilisation of red and yellow tomatoes. *Food Chemistry*, **124**, 1603–1611.
This study provides new data on the impact of thermal processing on carotenoids, total polyphenols, and vitamin C in a yellow tomato cultivar. It was cited to compare the content of β-carotene and acid ascorbic found in our samples.

Gheonea, I., Aprodu, I., Enachi, E. *et al.* (2020). Investigations on thermostability of carotenoids from tomato peels in oils using a kinetic approach. *Journal of Food Processing and Preservation*, **44**, e14303.

Graci, S., Olivieri, F. & Barone, A. (2022). Phenotypic and genotypic characterization to authenticate and trace a high-quality yellow tomato ecotype through the processing chain. *Scientia Horticulturae*, **306**, 111449.

Kamiloglu, S., Demirci, M., Selen, S., Toydemir, G., Boyacioglu, D. & Capanoglu, E. (2014). Home processing of tomatoes (*Solanum lycopersicum*): effects on in vitro bioaccessibility of total lycopene, phenolics, flavonoids, and antioxidant capacity. *Journal of the Science of Food and Agriculture*, **94**, 2225–2233.

Kotíková, Z., Lachman, J., Hejtmánková, A. & Hejtmánková, K. (2011). Determination of antioxidant activity and antioxidant content in tomato varieties and evaluation of mutual interactions between antioxidants. *LWT-Food Science and Technology*, **44**, 1703–1710.

In this study, hydrophilic and lipophilic antioxidant activity in varieties of tomatoes was determined. It was cited to compare our results.

Krebbers, B., Matser, A.M., Hoogerwerf, S.W., Moezelaar, R., Tomassen, M.M. & van den Berg, R.W. (2003). Combined high-pressure and thermal treatments for processing of tomato puree: evaluation of microbial inactivation and quality parameters. *Innovative Food Science & Emerging Technologies*, **4**, 377–385.

Lavelli, V. & Torresani, M.C. (2011). Modelling the stability of lycopene-rich by-products of tomato processing. *Food Chemistry*, **125**, 529–535.

Lavelli, V., Harsha, P.S., Torri, L. & Zeppa, G. (2014). Use of winemaking by-products as an ingredient for tomato puree: the effect of particle size on product quality. *Food Chemistry*, **152**, 162–168.

In this study a consumer test was performed on tomato purees having varying particle sizes. It is included in our research because it provides a solid basis to whom compare our sensory results.

Lin, C.H. & Chen, B.H. (2005). Stability of carotenoids in tomato juice during storage. *Food Chemistry*, **90**, 837–846.

Lu, Z., Wang, J., Gao, R., Ye, F. & Zhao, G. (2019). Sustainable valorisation of tomato pomace: a comprehensive review. *Trends in Food Science & Technology*, **86**, 172–187.

Luterotti, S., Bicanic, D., Marković, K. & Franko, M. (2015). Carotenes in processed tomato after thermal treatment. *Food Control*, **48**, 67–74.

Manzo, N., Pizzolongo, F., Meca, G., Aiello, A., Marchetti, N. & Romano, R. (2018). Comparative chemical compositions of fresh and stored Vesuvian PDO "Pomodorino Del Piennolo" tomato and the Ciliegino variety. *Molecules*, **23**, 2871.

Marini, D. & Balestrieri, F. (1990). Analisi chimica dei prodotti alimentari. Athena Pr Milano. ISBN: 88-85211-01-1.

Mishra, A., Nandi, A., Thriveni, V., Das, S., Mohanty, I.C. & Pattanayak, S.K. (2021). Heterosis in tomato (*Solanum lycopersicum*) hybrids for growth, yield and quality traits. *Pharmaceutical Innovation*, **10**, 220–229.

Moelants, K.R.N., Jolie, R.P., Palmers, S.K.J. *et al*. (2013). The effects of process-induced pectin changes on the viscosity of carrot and tomato sera. *Food and Bioprocess Technology*, **6**, 2870–2883.

Moschetti, G. (2016). *Lo Cunto de li Maccarune, Ovvero Settantacinque Ricette per Perocchiusi, Accuorti e Scialacquoni*. Napoli: Libreria Dante & Descartes.

Nour, V., Corbu, A.R., Rotaru, P., Karageorgou, I. & Lalas, S. (2018). Effect of carotenoids, extracted from dry tomato waste, on the stability and characteristics of various vegetable oils. *Grasas y Aceites*, **69**, e238.

Pénicaud, C., Achir, N., Dhuique-Mayer, C., Dornier, M. & Bohuon, P. (2011). Degradation of β-carotene during fruit and vegetable processing or storage: reaction mechanisms and kinetic aspects: a review. *Fruits*, **66**, 417–440.

Pishgar-Komleh, S.H., Akram, A., Keyhani, A. *et al*. (2017). Variability in the carbon footprint of open-field tomato production in Iran-a case study of Alborz and East-Azerbaijan provinces. *Journal of Cleaner Production*, **142**, 1510–1517.

Polívka, T. & Sundström, V. (2004). Ultrafast dynamics of carotenoid excited states−from solution to natural and artificial systems. *Chemical Reviews*, **104**, 2021–2072.

Polyakov, N.E., Leshina, T.V., Konovalova, T.A. & Kispert, L.D. (2001). Carotenoids as scavengers of free radicals in a Fenton reaction: antioxidants or pro-oxidants? *Free Radical Biology and Medicine*, **31**, 398–404.

Raiola, A., Del Giudice, R., Monti, D.M., Tenore, G.C., Barone, A. & Rigano, M.M. (2016). Bioactive compound content and cytotoxic effect on human cancer cells of fresh and processed yellow tomatoes. *Molecules*, **21**, E33.

Raiola, A., Pizzolongo, F., Manzo, N. *et al*. (2018). A comparative study of the physico-chemical properties affecting the organoleptic quality of fresh and thermally treated yellow tomato ecotype fruit. *International Journal of Food Science & Technology*, **53**, 1219–1226.

In our previous study, we found that the GiaGiu ecotype showed higher titratable acidity, organic acids content, and pectin than other genotypes. It was cited to justify why this ecotype was chosen to produce the whole-fruit yellow tomato puree.

Rigano, M.M., Raiola, A., Tenore, G.C. *et al*. (2014). Quantitative trait loci pyramiding can improve the nutritional potential of tomato (*Solanum lycopersicum*) fruits. *Journal of Agricultural and Food Chemistry*, **62**, 11519–11527.

Romano, R., Aiello, A., Pizzolongo, F., Rispoli, A., De Luca, L. & Masi, P. (2020a). Characterisation of oleoresins extracted from tomato waste by liquid and supercritical carbon dioxide. *International Journal of Food Science & Technology*, **55**, 3334–3342.

Romano, R., De Luca, L., Manzo, N., Pizzolongo, F. & Aiello, A. (2020b). A new type of tomato puree with high content of bioactive compounds from 100% whole fruit. *Journal of Food Science*, **85**, 3264–3272.

Ruggieri, V., Francese, G., Sacco, A. *et al*. (2014). An association mapping approach to identify favourable alleles for tomato fruit quality breeding. *BMC Plant Biology*, **14**, 337.

Sacco, A., Greco, B., Matteo, A.D., Stefano, R.D. & Barone, A. (2013). Evaluation of tomato genetic resources for response to water deficit. *American Journal of Plant Sciences*, **2013**, 131–145.

Sacco, A., Raiola, A., Calafiore, R., Barone, A. & Rigano, M.M. (2019). New insights in the control of antioxidants accumulation in tomato by transcriptomic analyses of genotypes exhibiting contrasting levels of fruit metabolites. *BMC Genomics*, **20**, 43.

Sacco, A., Cammareri, M., Vitiello, A. *et al*. (2020). Italian traditional tomato varieties: a focus on the campania region. *I Congrés de la Tomaca Valenciana: La Tomaca Valenciana d'El Perelló*, 179–193. https://doi.org/10.4995/TOMAVAL2017.2017.6526

Saeed, A., Nadeem, H., Amir, S. *et al*. (2014). Genetic analysis to find suitable parents for development of tomato hybrids. *Life Science Journal*, **11**, 30–35.

Sandhiya, L. & Zipse, H. (2022). Conformation-dependent antioxidant properties of β-carotene. *Organic & Biomolecular Chemistry*, **20**, 152–162.

Savatović, S., Ćetković, G., Čanadanović-Brunet, J. & Djilas, S. (2012). Tomato waste: a potential source of hydrophilic antioxidants. *International Journal of Food Sciences and Nutrition*, **63**, 129–137.

Simonne, A.H., Fuzeré, J.M., Simonne, E., Hochmuth, R.C. & Marshall, M.R. (2007). Effects of nitrogen rates on chemical composition of yellow grape tomato grown in a subtropical climate. *Journal of Plant Nutrition*, **30**, 927–935.

Strati, I.F. & Oreopoulou, V. (2014). Recovery of carotenoids from tomato processing by-products – a review. *Food Research International*, **65**, 311–321.

Szabo, K., Diaconeasa, Z., Cătoi, A.-F. & Vodnar, D.C. (2019). Screening of ten tomato varieties processing waste for bioactive

components and their related antioxidant and antimicrobial activities. *Antioxidants*, **8**, 292.
Toor, R.K. & Savage, G.P. (2005). Antioxidant activity in different fractions of tomatoes. *Food Research International*, **38**, 487–494.
Wasim, S.M. & Singh, J.P. (2015). Compositional alterations in tomato products during storage. *Research Journal of Chemistry and Environment*, **19**, 82–87.
Zhang, Y., Pan, Z., Venkitasamy, C., Ma, H. & Li, Y. (2015). Umami taste amino acids produced by hydrolyzing extracted protein from tomato seed meal. *LWT-Food Science and Technology*, **62**, 1154–1161.
Zouari, I., Salvioli, A., Chialva, M. *et al.* (2014). From root to fruit: RNA-Seq analysis shows that arbuscular mycorrhizal symbiosis may affect tomato fruit metabolism. *BMC Genomics*, **15**, 221.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Antioxidant activity by DPPH assay in the hydrophilic fraction of fresh tomatoes, whole-fruit and traditional yellow tomato puree obtained from Hybrid (H) and GiaGiù (G) cultivar after 1 day (t0) and 6 months (t6) of storage.

