Nutritional quality of orange tomatoes for fresh consumption and processing products

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Abstract

In Argentina, commercial tomatoes for fresh consumption as well for processed products traditionally have red fruits. Although other fruit colors (yellow, purple) are present in the "cherry" types, orange tomatoes for direct consumption or for the industry are not used. Our aim was to contribute to the diversification of the tomato market by generating cultivars of different colors and non-traditional fruit characteristics. Field comparative trials during several cycles at the Institute of Horticulture (FCA-UNCuyo, Mendoza) allowed the selection of two cultivars with good agronomic performance, productivity and fruit quality: cultivar 1, with determinate growth, three to five fruits per cluster, pear-shaped fruit with mammillate tip, orange, jointless; and cultivar 2, with indeterminate growth, three to five fruits per cluster, oval-shaped fruit, deep orange, jointless or with non-functional pedicel articulation. Fruits of the two varieties have good internal and external color, adequate pericarp thickness, homogeneous maturation, and fruits adapted to manual and mechanical concentrated harvest. Mature fresh fruits were characterized by physical and chemical traits including total polyphenols, lycopene and β-carotene content, and antioxidant activity, showing an interesting nutritional composition and different antioxidant properties. Using mature fruits, a marmalade was produced at the Pilot Processing Industry (FCA-UNCuyo, Mendoza), and its nutritional composition as well as its phytochemical contribution (polyphenols, lycopene and β-carotene) and antioxidant activity were determined. Finally, a consumer panel considered the aspect, color and odor of the marmalade attractive and expressed great acceptability of the new product. The marmalade had great acceptance and constitutes an interesting product with excellent nutritional value that could also provide part of the required antioxidant compounds in human diets. At present, the orange marmalade is commercialized locally by the Agronomy Faculty with significant acceptance by consumers. Orange tomato varieties have excellent nutritional properties and sensorial characteristics for direct consumption and for industrial processed products.

Keywords: orange tomatoes, antioxidants, processing products, sensorial qualities

INTRODUCTION

A better understanding of a healthy diet generates consumers' demand for products that, besides having good nutritional content, are beneficial to physical well-being. Currently, great attention is focused on the potential of certain foods that promote health, improve body condition and contribute to decreasing the risk of chronic non-transmissible diseases (obesity, diabetes or cancer) and cardiovascular diseases (Liu, 2003; Silveira Rodríguez et al., 2003). A functional food, in addition to its intrinsic nutritional value, has beneficial effects on one or more selective functions of the organism that improve healthiness, reduce the risk of disease, or both (Moreno, 2012). Functional foods have "bioactive compounds" or "phytochemicals", molecules of plant origin with beneficial action for health, encompassing nutrients or other substances that are able to act on some physiological mechanisms of the

human body (Fernández-Ruiz et al., 2007). Fresh tomatoes and their processing products are excellent sources of bioactive molecules, particularly carotenoids and polyphenols (Weisburger, 1999), which confer not only nutritional value but also beneficial health properties (Story et al., 2010; Cruz Bojórquez et al., 2013). The protective effects of tomato are mainly due to the antioxidant properties of these compounds (Finkel and Holbrook, 2000; Fernández-Ruiz et al., 2007), related to their ability to capture active oxygen, principally lycopene, with a greater ability to capture free radicals (Periago et al., 2001). Protective mechanisms of cardiovascular diseases involve antioxidant activity, anti-platelet activity, protection of the endothelium and antiatherogenic effects (Laquatra et al., 2005). Furthermore, the main mechanisms that prevent cancer are antioxidant activity, activation of apoptosis, decrease in cell proliferation and reduction of angiogenesis and metastasis (Kirsh et al., 2006; Palomo et al., 2010 a, b). Another protective effect of tomato compounds is reduction of total cholesterol and LDL levels and increase of the HDL level, with less effect on triglycerides (Palomo et al., 2010 a, b).

Carotenoids are a class of more than 600 naturally occurring pigments synthesized by plants, algae, and photosynthetic bacteria. Their main biological function is organ coloration and uptake of light during the photosynthetic process, as well as photoprotective effects that inhibit the spread of oxygen and other free radicals (Vershinin, 1999). In tomatoes, the most important carotenoids are lycopene, responsible for red color fruits, and β-carotene, which produces orange pigmentation and is considered a provitamin A carotenoid. β-Carotene can be converted by the human body to retinol, while lycopene cannot be converted and does not have vitamin A activity (Perveen et al., 2015). Liposoluble carotenoids must be released from the food matrix and require the presence of fat in a meal in order to be absorbed intestinally. Heat treatment of vegetables appears to improve the bioavailability of carotenoids in many foods by promoting cell wall breakdown, and contributes to increase their antioxidant and anticancer properties. Heat cooking transforms the *trans*-lycopene present in plant tissues to the *cis* form, which enhances its bioavailability in human body (Cruz Bojórquez et al., 2013). Processed tomato products present three to four times more absorption than fresh tomatoes, hence the importance of their consumption (Ordóñez et al., 2009).

Phenolic compounds are considered secondary metabolites of plants, with different chemical structures and functions related to growth, reproduction, and defensive processes against pathogens, predators or ultraviolet radiation (Oroian and Escriche, 2015). Phenolic compounds are bioactive phytochemicals mainly through their antioxidant properties related to prevention of cardiovascular disease, since they have vasodilatory effects, antithrombotic and anti-inflammatory properties and are involved in the prevention of some types of cancer by intervening in cellular detoxification systems (Tomás-Barberán, 2003). The beneficial effects depend on the quantity consumed and their bioavailability (Bravo-Lozar, 2012). In tomato, the most important phenolic compounds are naringenin, rutin, coumaric acid, quercetin, chlorogenic acid and caffeic acid (Vallverdú-Queralt et al., 2011; Di Paola Naranjo et al., 2016) and can range from 259.15 to 498.60 mg kg^{-1} fresh weight (Martínez-Valverde et al., 2002; Podsedek et al., 2003; Zhou and Yu, 2006). These values vary depending on the time of year, the type of sample, tomato cultivar, and cultivation management (Toor et al., 2006; Bravo-Lozar, 2012; Di Paola Naranjo et al., 2016). There are conflicting results on the effect of processing on phenolic compounds in tomatoes. Several studies claim that industrial processing can produce both a decrease and an increase of phenolic compounds, depending on the type of heat treatment. Processing causes rupture of the cell structure, which allows better extraction of compounds from the array of food (Bravo-Lozar, 2012).

In Argentina, mainly tomato cultivars with red fruits are traditionally used for fresh consumption and processing.

Tomato bioactive properties have been mainly studied in red-fruited cultivars. The main objective of our research was to evaluate fruit quality of two different orange-fruited tomato cultivars and determine antioxidant compounds (lycopene, β-carotene and polyphenols) and antioxidant activity in fresh fruits and processing products.

MATERIALS AND METHODS

Field trials with two orange-fruit cultivars were established at the Horticultural Institute of the Agronomy Faculty, National University of Cuyo, Mendoza, Argentina (33°00'S, 68°52'E, 912 m a.s.l.), cultivar 1, with determinate growth, and cultivar 2, with indeterminate growth. Fruits were harvested at physiological maturity, determined by color and soluble solid content, and chemical composition (lycopene, β-carotene and total polyphenol content) and antioxidant activity were assessed.

In order to assess antioxidant activity, six different fruits from each cultivar were harvested from different sectors of the plot, preserved on ice and immediately chopped, frozen in liquid nitrogen and stored in a freezer at -80°C in individual plastic boxes until sample processing. Frozen samples were ground in an electrical mill previously cooled with liquid nitrogen until a homogeneous fine tomato powder was obtained. Ground samples were stored in a freezer at -80°C in 50-mL polypropylene tubes until sample analysis.

Antioxidant detection and quantification were performed on lipophilic and hydrophilic extracts obtained by the method proposed by Toor and Savage (2005). Lycopene and β-carotene were determined on the lipophilic extract using a UV-visible spectrophotometer (Shimadzu MultiSpec – 1501). Absorbances for lycopene were detected at 503 nm and for β-carotene at 478 nm, and used to calculate the concentration of each pigment (Porter and Anderson, 1967). All samples were analyzed in triplicate.

Total polyphenol (TP) content of hydrophilic extracts was measured by the Folin-Ciocalteu (FC) method in accordance with the technique employed by Arnous et al. (2001), with minor modifications. The absorbance was read at 750 nm, and total polyphenol concentration was calculated from a calibration curve, using gallic acid as a standard. Results were expressed as mg gallic acid equivalents (GAE) 100 g^{-1} fresh weight. All samples were analyzed in triplicate.

In vitro antioxidant activity was measured using both the Trolox equivalent antioxidant capacity (TEAC) assay and the ferric-reducing ability of plasma (FRAP) assay. The TEAC assay was performed in accordance with Re et al. (1999), with minor modifications. The $ABTS^{\bullet+}$ radical was produced by the oxidation of 7 mM ABTS with potassium persulfate (2.45 mM final concentration) dissolved in water. The mixture was allowed to stand in the dark at room temperature for 12-16 h before use, and then the $ABTS^{\bullet+}$ solution was diluted with phosphate-buffered saline (PBS) at pH 7.4 and equilibrated at 30°C to give an absorbance of 0.70±0.02 at 734 nm. Twenty-five microliters of sample extract in an appropriate dilution or Trolox standard was mixed with 1 mL diluted $ABTS^{\bullet+}$ solution, vortexed for 10 s, and the absorbance measured at 734 nm after 4 min of reaction at 30°C. The results were obtained by interpolating the absorbance on a calibration curve obtained with Trolox (0.03-0.50 mM) and were expressed as mmol Trolox equivalent 100 g^{-1} fresh weight. All samples were analyzed in triplicate. The FRAP assay was performed in accordance with Benzie and Strain (1996), with minor modifications. Working FRAP reagent was prepared as required by mixing 25 mL acetate buffer (300 mM, pH 3.6), 2.5 mL 10 mM 2,4,6-tris(2-pyridyl)-S-triazine (TPTZ) and 2.5 mL 20 mM $FeCl_3.6H_2O$. One hundred microliters of sample extract was added to 3 mL FRAP reagent, and the absorbance was measured at 593 nm after incubation at room temperature for 6 min, using the FRAP reagent as a blank. The results were obtained by interpolating the absorbance on a calibration curve obtained with Trolox (0.03-1.00 mM) and were expressed as mmol Trolox equivalent 100 g^{-1} fresh weight. All samples were analyzed in triplicate.

Statistical analysis was performed to determine significant differences (α=0.05) in the phytochemical composition and antioxidant activity in fresh fruits of the two cultivars using Student's *t*-test (Di Rienzo et al., 2013).

Thirty fruits of each cultivar were randomly harvested to determine physical and chemical variables: potential acidity was measured with a potentiometer calibrated with buffers (pH 4 and 7); acidity was assessed by neutralization with sodium hydroxide (NaOH 0.1 M) and phenolphthalein; soluble solids were determined by refractometry expressed in Brix grade corresponding to the amount of sucrose present in the sample; moisture was established by sample desiccation at 105°C until constant weight and total solids by

difference between fresh and dry weight (CITEF, 1987).

The marmalade was produced at the Pilot Processing Industry (FCA-UNCuyo, Mendoza). Mature fruits with intense orange color and firm pericarp were harvested, weighed and washed and their pH and sugar content were controlled with a potentiometer and refractometer, respectively. Fruits were treated for 30 s in boiled water (98°C), immediately immersed in cold water (20°C) and peeled. Tomato pulp was chopped into small pieces and weighed to estimate the amount of each ingredient (sucrose 80%; glucose 10%; vanilla essence 0.03%; citric acid 0.25%) needed to produce the marmalade. Pulp was concentrated slowly by heating, and one-third of the sugars and acid were added. When the mixture reached 45 °Brix, the rest of the ingredients were incorporated. Marmalade was ready when tomato pulp had the adequate consistency and sugar concentration (65 °Brix). The vanilla essence was incorporate at the end, and marmalade was distributed in 500-mL crystal flasks that were sterilized by heat to preserve the final product. The nutritional composition as well as the phytochemical content (polyphenols, lycopene and β-carotene) and antioxidant activity of the marmalade were established. Finally, acceptability of the new product was assessed by a written questionnaire about sensorial qualities (color, flavor, texture, etc.) that was completed by 131 consumers, representing 50% of each gender, and different age ranges. Statistical analyses were made to describe characteristics of fresh fruits, marmalade, and consumer preferences (Di Rienzo et al., 2013).

RESULTS

Both cultivars showed good agronomic performance, productivity and quality of fruit. Cultivar 1 showed determinate growth, with four or five basal branches, three to four inflorescences per branch, three to four fruits per inflorescence, fruits 7-8 cm long and 4-5 cm wide, 80-90 g, pear-shaped with a small mammillate tip, orange, and jointless. Cultivar 2 showed indeterminate growth, three or four vigorous branches, five to eight inflorescences per branch, with three to five fruits per inflorescence, fruits 7-8 cm long and 4-5 cm wide, 70-80 g, oval or ovate, dark orange, jointless or with non-functional pedicel articulation. Fruits of the two varieties had good internal and external color, adequate pericarp texture and thickness (7-10 mm), homogeneous maturation, and adapted to manual and mechanical concentrated harvest.

Analysis of antioxidants (Table 1) showed significant differences between the cultivars; the amount of lycopene and total polyphenols were higher in cultivar 2. The content of β-carotene was similar in the two cultivars. In contrast, in red-fruit cultivars, the content of lycopene expressed in mg 100 g^{-1} fresh sample is quite variable, being reported as between 0.88 and 4.20 (Periago et al., 2001), 4.59±0.704 (Candelas-Cadillo et al., 2005) and 1.8-6.5 (Martínez-Valverde et al., 2002). Both orange-fruited cultivars had less lycopene than red cultivars. The amount of β-carotene in mg 100 g^{-1} fresh sample in orange cultivars was higher than in red-fruit cultivars, which have been reported to contain 0.17±0.088 (Candelas-Cadillo et al., 2005), 0.104±0.013 (Zapata et al., 2007), and 1.18 (Minoggio et al., 2003). These differences demonstrate that lycopene is the predominant pigment in red fruits, while β-carotene is the principal compound in orange fruits. For total polyphenols, the amount found in fruits of orange cultivars was significantly higher than that reported in red-fruit cultivars, at between 15.7 and 20.14 mg GAE 100 g^{-1} fresh sample (Toor et al., 2006) and a mean of 18.46±3.47 mg GAE 100 g^{-1} fresh sample (Zapata et al., 2007).

Antioxidant activity measured with the Trolox equivalent antioxidant capacity (TEAC) was similar in lipophilic and hydrophilic extracts in both cultivars (Table 2), while significant differences were found with the iron reduction assay (FRAP), the indeterminate cultivar having almost three times the antioxidant activity, in agreement with a larger amount of total polyphenols (Table 2). These results might reflect the chemical nature of the antioxidant compounds.

Table 1. Lycopene, β-carotene and total polyphenols found in determinate (cultivar 1) and indeterminate (cultivar 2) cultivars. Different letters indicate significant differences (α=0.05). Values are means ± standard deviation.

Cultivar	Lycopene (mg 100 g^{-1} sample)	β-Carotene (mg 100 g^{-1} sample)	Total polyphenols (mg GAE 100 g^{-1} sample)
Cultivar 1	0.615±0.15a	2.014±0.23c	129.527±16.00d
Cultivar 2	0.827±0.13b	1.841±0.26c	224.332±73.64e

Table 2. Antioxidant activity determined in milliequivalent (meq) Trolox 100 g^{-1} sample. Different letters indicate significant differences (α=0.05). Values are means ± standard deviation.

Cultivar	TEAC lipophilic	TEAC hydrophilic	FRAP
Cultivar 1	0.0388±0.022a	0.5090±0.122b	0.1016±0.039c
Cultivar 2	0.0501±0.025a	0.6095±0.130b	0.3913±0.204d

Comparing the two orange cultivars, the indeterminate cultivar had a better lycopene profile and total polyphenols, similar amount of β-carotene, and greater antioxidant activity. Fruit characteristics of the indeterminate cultivar were evaluated before processing (Table 3). The soluble solids value revealed an adequate amount of sugar, around 5.3 °Brix, while acidity expressed in citric acid, around 0.7%, was less than the quantity needed (1.4%) to give good jellification of the marmalade (Coronado and Roaldo, 2001) with an optimum pH of 3.1.

Table 3. Physical and chemical properties of fresh fruits of the indeterminate cultivar. Values are means ± standard deviation.

Property	Amount
Moisture (%)	93.72±0.01
°Brix	5.3±0.3
Acidity (citric acid g %)	0.44±0.06
pH	4.28±0.21
Dry weight (%)	6.3±0.008

During marmalade processing, it was necessary to incorporate citric acid to adjust acidity and pH. Tomato fruits were weighed during the different processing steps, and efficiency of 93% was established, taking into account incorporation of sucrose and glucose, where loss was mainly due to fruit heating and peeling. Antioxidants were determined in the marmalade (Table 4), and, compared with other products made with red-fruit tomatoes (Periago et al., 2001), it has less lycopene, but 3- to 5-fold more β-carotene. For example, in red tomato sauce, the amount of lycopene is 15.2 mg 100 g^{-1} and β-carotene is 0.3 mg 100 g^{-1}.

Table 4. Lycopene, β-carotene and total polyphenols in 100 g marmalade. Values are means ± standard deviation.

Lycopene (mg 100 g^{-1} sample)	β-Carotene (mg 100 g^{-1} sample)	Total polyphenols (mg GAE 100 g^{-1} sample)
1.2614±0.1975	0.9702±0.0837	256.29±15.79

During processing, the amount of β-carotene decreased by 34%, while lycopene and total polyphenols increased by 90 and 42%, respectively (Figures 1 and 2).

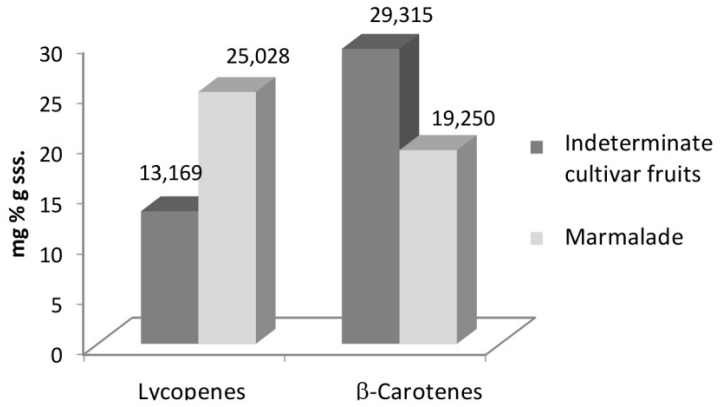

Figure 1. Lycopenes and β-carotenes (mg 100 g^{-1} sample) determined in fresh fruits and marmalade.

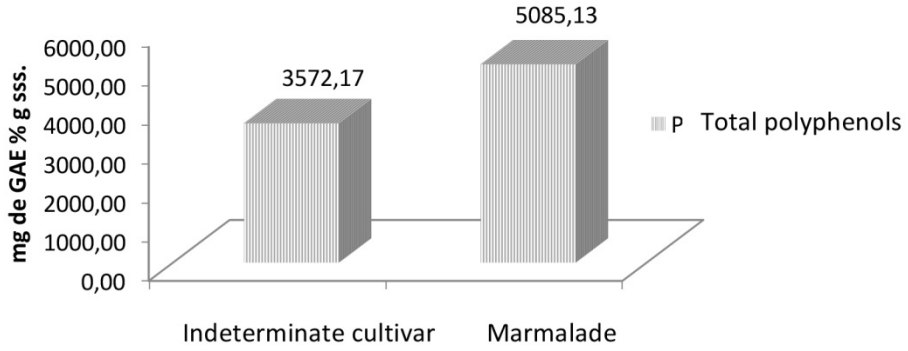

Figure 2. Total polyphenols content (mg GAE 100 g^{-1} sample) determined in fresh fruits and marmalade.

Antioxidant activity determined in the marmalade by TEAC, in the lipophilic and hydrophilic extracts, was higher than in the initial product, while FRAC decreased by 12% (Figure 3).

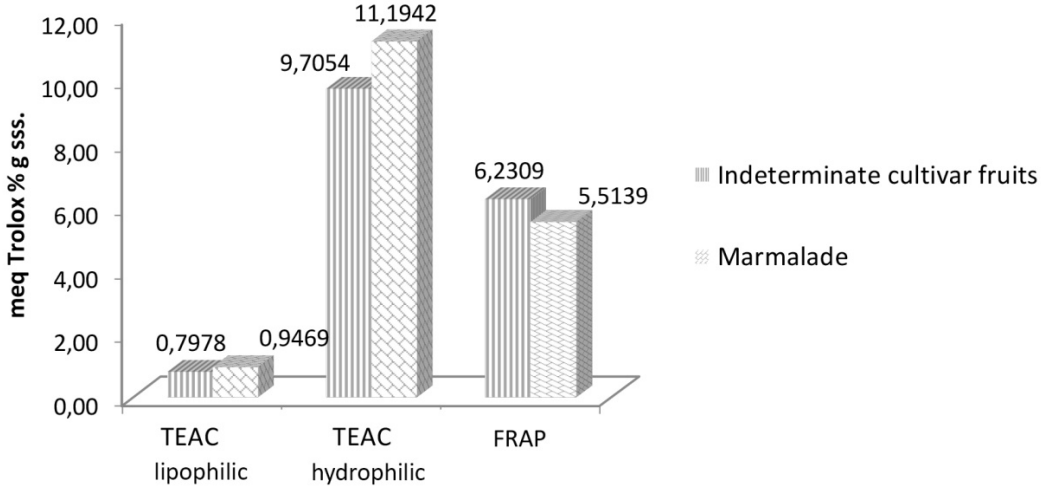

Figure 3. Antioxidant activity (meq Trolox 100 g^{-1} sample) in fresh fruits and marmalade.

The marmalade had an adequate nutritional content as well as energetic value for commercialization (Table 5). A portion of 20 g (a tablespoon) has an energetic value of 49

kcal/208 kJ, and this amount is equivalent to 2% of a normal diet of 2000 kcal or 8400 kJ.

Table 5. Marmalade nutritional composition (g 100 g^{-1} fresh product).

Compound	Quantity
Proteins	0.72 g
Carbohydrates	59.79 g
Total fat	0.59 g
Ashes	0.13 g
Humidity	37.57 g
Fiber	1.20 g
Sodium	28 mg
Energetic value	247.35 kcal/1038.87 kJ

In order to assess acceptance of the product, 131 consumers (50.38% female and 49.62% male) representing different ages, 1) 15% less than 20 years; 2) 22% between 21 and 30 years; 3) 15% between 31 and 40 years; 4) 15% 41 and 50 years; 5) 18% between 51 and 60; and 6) 15% more than 61 years, answered a questionnaire. The majority (55%) expressed that would like to consume the product three or more than five times a week, while 45% preferred to eat the product less than three times a week. The results of the acceptance test showed that 27% of the consumers greatly liked the marmalade, 54% considered it a good product, 14% slightly liked it, and 3% did not like or disliked it and only 2% disliked it. In summary, the product was highly accepted by 95% of the consumers and, when preferences were analyzed by gender, 99% of males (65) and 91% of females (66) liked it. Regarding acceptance by consumers considering the six age categories, 57% of people between 51 and 60 years old greatly liked the marmalade, while 20% of people in each of the other five categories had the same opinion. The marmalade was considered as a good product by consumers older than 60 years (65%), followed by people between 20 and 30 years (61%), less than 20 years (55%), between 31 and 40 years (55%), between 41 and 50 years (55%) and between 51 and 60 years (35%). Only three people (2.3%) disliked the product. Furthermore, the majority (86%) expressed their intention to buy the product, with a higher preference by males (91%) than by females (82%). Consumers were also questioned about organoleptic qualities of the marmalade, and 94% considered its external characteristics very attractive, nice orange amber color (91.6%) and aroma (80.15%). It is interesting than consumers did not associate the marmalade color (84.73%) and odor (48.85%) with a tomato product, but with a peach marmalade. Almost 52% of consumers considered that seeds made marmalade attractive, while the other 48% disliked the presence of seeds but emphasized that they did not notice them when they consumed the product.

A frequent comment by consumers was that other kinds of products prepared with orange tomatoes such as sauces, ketchup, or acre-sweet puree for meat dishes, could have similar acceptance to the marmalade.

CONCLUSIONS

Both orange tomato cultivars had acceptable agronomic performance, productivity and fruit quality, with good internal and external color, adequate pericarp texture and thickness, homogeneous maturation, and adapted to manual and mechanical concentrated harvest. Antioxidant composition revealed large amounts of β-carotene, a bioactive compound precursor of vitamin A, and also high levels of polyphenols, but less content of lycopene when compared with red tomatoes. The marmalade had an interesting antioxidant profile and an increment of antioxidant activity determine by TEAC. The quantities of lycopene and polyphenols increased, while β-carotene decreased, when compared with fresh fruits; nevertheless, a larger amount of antioxidant was determined in the marmalade. Nutritional composition as well as functional compounds (polyphenols, lycopene and β-

carotene) and antioxidant properties of the marmalade allow it to be classified as a healthy product suitable for commercialization. The consumer panel expressed great acceptance of the new product; more than 95% liked it, and considered the marmalade aspect, color and odor attractive. Finally, the majority expressed an intention to purchase the marmalade and suggested that other processing products should be elaborated with orange tomatoes. Marmalade constitutes a healthy product, mainly due to its provitamin A content and antioxidant activity, does have significate amount of fats and has low sodium levels. Orange fruits have excellent nutritional and sensorial characteristics for direct consumption and for products of industrial interest.

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