Microwave flow and conventional heating effects on the physicochemical properties, bioactive compounds and enzymatic activity of tomato puree

Journal Science Food Agriculture. 97(3): 984-990. doi: 10.1002/jsfa.7824.

Mitra Arjmandi[a,b,c], Mariano Otón[c], Francisco Artés[b,c], Francisco Artés-Hernández[b,c], Perla A. Gómez[c] and Encarna Aguayo[b,c*] **e-mail: encarna.aguayo@upct.es*

[a]*College of Agriculture and Natural Resources. University of Tehran. Iran.*

[b]*Postharvest and Refrigeration Group - Universidad Politécnica de Cartagena (UPCT). Paseo Alfonso XIII, 48. 30203 Cartagena, Murcia, Spain.*

[c]*Institute of Plant Biotechnology. UPCT. Campus Muralla del Mar, 30202 Cartagena, Murcia, Spain.*

ABSTRACT

BACKGROUND: Thermal processing causes a number of undesirable changes in physicochemical and bioactive properties of tomato products. Microwave (MW) technology is an emergent thermal industrial process that offers a rapid and uniform heating, high energy efficiency, and high overall quality of the final product. The main quality changes of tomato puree after a pasteurization at 96 ± 2 ºC for 35 s, provided by a semi industrial continuous microwave oven (MWP) under different doses (low power/long time to high power/short time) or by conventional method (CP) were studied.

RESULTS: The results showed that all heat treatments reduced color quality, total antioxidant capacity and vitamin C, with a greater reduction in CP than in MWP. On the other hand, use of a MWP, in particular, high power/short time (1900

W/180 s, 2700 W/160 s and 3150 W/150 s) enhanced the viscosity, lycopene extraction and decreased the enzyme residual activity better than with CP samples. For tomato puree, polygalacturonase was the more thermos resistant enzyme, and could be used as an indicator of pasteurization efficiency.

CONCLUSION: MWP was an excellent pasteurization technique that provided tomato puree with improved nutritional quality, reducing process times compared to the standard pasteurization process.

Keywords*:* Carotenoids; Viscosity; Vitamin C; Thermal treatment; Smoothie.

1. INTRODUCTION

Tomato (*Lycopersicon esculentum* L.) is widely grown around the world and becoming increasingly popular, both fresh and processed. Tomato and tomato products have very high levels of bioactive compounds such as carotenoids, especially lycopene, followed by β-carotene[1]. Dietary intake of tomatoes and tomato products containing lycopene, has been shown to reduce the risk of prostate cancer.[2] Processed products contain more lycopene than fresh foods because thermal treatment causes transformation of the *trans* isomers in *cis* form.[3]

All tomato products are usually prepared by thermal processing for inactivating natural degrading enzymes and microorganisms that may cause unwanted modification during their storage.[4] But this processing causes a number of undesirable changes in physicochemical properties of products and must be applied without compromising food safety, nutritional quality and shelf life.[5,6] MW technology is an emergent thermal industrial process to achieve this purpose. It enhances microbial destruction and help to maintain the product quality.[7] In comparison with conventional heating methods, the industrial MW oven offers a rapid and relatively uniform heating, high energy efficiency, reduced space utilization, precise process control, fast start-up, shutdown conditions and high overall quality and safety of the final product. [6,8] Several studies have assessed the safety as well as nutrient loss associated with MW cooking, and antioxidant activity of strawberry and kiwifruit apuree.[9,10] Additionally, high-power/short-time MW processes reduced the adverse thermal degradation in food quality while ensuring food safety because of the nutrient characteristics of product being more sensitive to time than to temperature.[11] In this way, the aim of the present work was to investigate quality parameter changes such as vitamin C, lycopene, β-carotene, total phenolics content (TPC), and total antioxidant capacity (TAC), as well as

color parameters, viscosity and enzymatic activity of a tomato puree after CP and MWP using different doses (powers and times) of processing.

2. MATERIALS AND METHODS

2.1. Plant materials

Tomato *(Lycopersicum esculentum* Mill., Moneymaker cv.*)* were grown in greenhouse under Mediterranean climate (Mazarrón, Murcia, Spain). They were harvested according to commercial maturity stage, obtaining 4.73 ± 0.07 ºBrix and 44.94 ± 0.19 hº. Fruits free from defects and with a similar visual appearance were blended with a commercial thermomix (Vorwerk Elektrowerke, Model TM 31-1, France) in order to obtain a puree.

2.2. Thermal treatment

600 mL of puree samples were heated in the above cited thermomix (conventional pasteurization, (CP). Alternatively, samples for each MW pasteurization (MPW) treatment were placed in 3 tempered and extra resistant MW glasses were used (Hostelvia, Vicrila, Leioa, Spain). These glass beakers, containing each one 200 mL of tomato puree was treated in an innovative semi-industrial prototype of continuous MW oven (Sairem Ibérica S.L. SI-MAQ0101, Barcelona, Spain) with a power control from 0 to 3,000 W (Fig. 1). Based on our preliminary studies several appropriate temperature/time combinations of MWP were selected with following conditions:

Low power/long time (390 W/848 s, 510 W/805 s, 770 W/460 s), medium power and time (980 W/848 s, 1,640 W/805 s, 1,700 W/230 s) and high power/short time (1,900 W/180 s, 2,700 W/160 s and 3,150 W/150 s). In both CP and MWP

processing the final temperature in all the treatments was 96 ± 2°C and they remained at this temperature for 35 s.

After both kinds of pasteurization, the samples were packaged aseptically into plastic tubes and rapidly cooled (5 °C) with an ice-water bath and then analyzed before (control) and after thermal treatments. For each heating method, the full experiment was conducted independently three times, each one constituting a repetition which was analysed.

2.3. Analysis and quality determination

Physical quality analysis

Color: The color of the samples was monitored by photo-colorimeter (Minolta CR-300, Ramsey, NJ, USA). Color was expressed as Hunter L*****, a*****, b*****and hue angle ($h^o = \tan^{-1} b^*/a^*$).

Viscosity: Viscous flow tests were determined in triplicate with a controlled shear rate/stress rheometer (AR G-2, TA Instruments, U.K) at 20 °C. Viscous flow tests were performed by using a shear rate range between 1 and 100 s^{-1}.

2.3.2 Chemical quality attributes

Titratable acidity (TA), soluble solids content SSC and pH were analyzed as described by Aguayo et al.[12]

Total phenolic compounds (TPC) and total antioxidant activity (TAC)

TPC was measured following by Swain and Hillis[13] method using a Multiscan plate reader (Tecan Infinite M200, Männedorf, Switzerland). TPC was expressed as mg chlorogenic acid equivalents (ChAE) kg^{-1} fresh weight (FW).

TAC was assessed using the Ferric Reducing Antioxidant Power (FRAP) technique[14] with the same device as for TPC. Results were expressed as mg ascorbic acid equivalent (AAE) kg^{-1} (FW).

Total vitamin C

The ascorbic acid (AA) determination was performed as described by Falagán et al.[15] 10 mL of puree were mixed with 10 mL of a solution containing 45 g L^{-1} of metaphosphoric acid and 7.2 g L^{-1} of DTT (DL-1, 4-dithiotreitol). The mixture was centrifuged at 22,100 × *g* for 15 min at 4 °C (Eppendrof, AG 22331, Germany). The analysis of vitamin C was carried out by HPLC (Waters 2695, Detector UV-V 2687, Milford, USA). Detection was performed with an UV-visible spectrophotometer (Hewlet Packard, Model 8453, Columbia, USA) at 260 nm. Vitamin C was quantified through a calibration curve made with AA standards and results were expressed as mg (AA) kg^{-1} FW.

Carotenoids

Carotenoids were measured according to the method of Nagata and Yamashita[16] with the slight modifications. 5 mL of smoothie were mixed with 20 mL acetone-hexane (4:6). Two phases separated and the upper phase was taken for lycopene and β-carotene measurements at 663, 645, 505 and 453 nm in a UV-visible spectrophotometer (Hewlet Packard, Model: 8453, Columbia, EEUU). Lycopene and β-carotene were calculated according to the following equations:

$$\text{Lycopene} = -0.0458\ A_{663} + 0.204\ A_{645} + 0.372\ A_{505} - 0.0806\ A_{453}$$

$$\beta\text{-carotene} = 0.216\ A_{663} - 1.22\ A_{654} - 0.304\ A_{505} + 0.452\ A_{453}$$

Results were expressed as mg lycopene or β-carotene kg^{-1} FW.

136

137 *Peroxidase (POD)*

138 POD activity was measured using the method described by Elez-Martínez et al.[17] 0.009
139 mL enzyme extract, 0.243 mL of phosphate buffer 0.05 M, 0.018 mL of phenildiamina
140 (10 g kg^{-1}), and 0.009 mL of H_2O_2 (15 g kg^{-1}) in a 96-well polystyrene flat-bottom plate.
141 The absorbance was measured at 509 nm for 10 min at 25 °C by using the multiscan
142 plate reader cited above.

143

144 *Pectin methylesterase (PME)*

145 PME activity was determined according to Ratneret et al.[18] with slight modifications. A
146 2.5 mL simple of puree was homogenized with 10 mL of sodium chloride 0.2 M. After
147 filtering the homogenate by cheesecloth, 2.5 mL of it was mixed with 15 mL pectin (10
148 g L^{-1}). This solution was adjusted to pH 7.0 with 1N NaOH and the pH was kept at 7.0
149 during 10 min using 0.01 N NaOH. One PME U can be expressed as the amount of
150 enzyme that produces 1 nmol of acid per minute at pH 7.0 and 22 °C.

151

152 *Polygalacturonase (PG)*

153 PG activity was measured according to Aguiló-Aguayo et al.[4] with slight modifications.
154 2 mL of sample was homogenized two times in 15 and 10 mL of cold acetone for 30
155 and 15 min, respectively. The supernatant was again decanted and replaced with 5 ml of
156 tris hydroxylmethyl aminomethane buffer (0.2 M), pH 7.0, including 0.5 g L^{-1} of
157 sodium metabisulfite, 10 g L^{-1} PVPP and 1M NaCl. The extraction was carried out
158 during 2 h in an orbital shaker (Stuart, Staffordshire, UK) at 200 × *g* in darkness inside a
159 polystyrene box with ice at 4 °C. The homogenate was centrifuged at 20,000 × *g* for 15
160 min at 4 °C. The supernatant was used as enzyme extract. The PG activity was

quantified according to Gross.[19] The substrate was constituted of 0.6 mL of a solution containing 4 g L^{-1} (w/v) polygalacturonic acid in 0.05 M sodium acetate buffer (pH 4.5) and the reaction was carried out by adding 0.15 mL of enzyme extract, followed by incubation at 37 °C for 10 min with shaker of 30 rpm. The reaction was stopped with 2 mL of 10 mM borate buffer at pH 9 and 0.4 mL of 10 g L^{-1} (w/v) cyanoacetamide. The mixture was put in a boiling water bath (100 °C) for 10 min and then chilled by ice. 200 µL of extraction was put in a 96-well polystyrene flat-bottom plate the well. The absorbance of samples was measured. The absorbance was read at 276 nm using the same device as for POD at 22 °C. The quantity of reducing groups formed was determined using a calibration curve made with D-galacturonic acid and the enzyme activity was expressed as mM of galacturonic acid released per min. One unit (U) of PG activity was defined as the amount of enzyme that yielded 1 mM of reducing groups per min.

For all analysis, each of the three replicates was analyzed by triplicate.

2.4. Statistical analysis

Data were analyzed in a randomized design with three replicates per treatment. Data were subjected to one-way analysis of variance ($p \leq 0.05$) using Statgraphic Plus 5.1, Manugistic Inc, Rockville, MD, USA). Mean values were compared by multiple range least significant difference test to identify significant differences among treatments. A Pearson's correlation analysis was performed to corroborate relationships between specific parameters.

3. RESULTS AND DISCUSSION

Color

186 The effects of thermal treatment on tomato puree color are shown in Table 1. L* values
187 decreased after any thermal treatment. The lowest L* reduction was obtained using high
188 MW power/short time dose of processing. This reduction was only of 5.6% using 3,150
189 W/150 s compared to unheated samples. In this same trend, hº increased in samples
190 thermally treated being higher in CP than in MWP treated under high power/short time,
191 indicating a changing of color from red to orange. Lower h° is preferred as the best
192 color properties in tomato.[20] Results in this experiment showed that the use of MWP
193 was able to keep the tomato puree color better than CP. The results agree with results
194 obtained in orange juice[21] and kiwi fruit puree[10] treated by MW. The main red colored
195 tomato pigment is *trans* lycopene and smaller amounts of *cis*-isomers (yellow colored
196 pigment in tomato) and other carotenoids. In this case, Pearson correlation coefficient
197 showed a positive correlation between the amount of lycopene and redness (a*) of
198 treated samples (0.758). Thermal processing leads to isomerization of lycopene from
199 *trans* to *cis*-form[3] and since the redness of tomato depends on the level of *trans*-
200 lycopene[22] therefore, severe thermal treatment leads to decreasing of the redness.
201
202
203 *Viscosity*
204 This is an important quality attribute to determine the overall quality of processed
205 tomato products which is influenced by the presence of pectin and inactivation of PME
206 and PG after thermal treatment.[23,24] From a rheological point of view, tomato puree can
207 be considered as a weak gel[23] and its viscosity is not stable and influenced by changing
208 the degree of shear rate. The effect of MWP and CP on tomato puree viscosity (shown
209 in low shear rate) is presented in Fig. 2. There was an increase (p<0.05) in the viscosity
210 of the samples when pasteurized by both methods compared to unheated puree. The

MWP, in particular, high power combined with low time, provided the higher viscosity compared to CP and unheated samples. For low shear rates, the viscosity value ranged from 81.73 to 53.54 Pa.s for MWP puree compared to 43.85 Pa.s CP and 21.33 Pa.s for CP and unheated samples, respectively. This viscosity decreased for higher shear rates and reached 4 and 2.5 Pa.s in all treatments, at a shear rate of 100 s^{-1}. Due to disruption of the samples treated cell wall during thermal treatment, the soluble pectin could be increased. In the current research and several other studies, an increase in viscosity of tomato products was found with increasing pectin content.[25,26] On the other hand, different inactivation levels of PME and PG during pasteurization of puree as well as varietal characteristics and the maturity stage of fruits at processing have an influence on the viscosity.[27] According to our results, the reduction of PME and PG activity by both thermal treatment methods lead to increased viscosity.

SSC, pH and TA

The SSC range between 4.73 and 5.27 ºBrix, pH values 4.11 to 4.26 and TA had a mean of 0.37% in unheated and heated samples without significant differences (data not shown). The literature reported that temperature and treatment time had no effect on pH and °Brix of CP orange juice.[28]

TPC

The initial TPC in fresh tomato puree was 424 ChAE mg kg^{-1} (Table 2). The range from 268 to 523 mg kg^{-1} reported for different tomato juices.[29] In this work, after any heat treatment the TPC was in the range between 430.6 and 441.2 ChAE mg kg^{-1} without significant difference between unheated or heated treatments. Similarly to our results it was reported a non-significant enhancement of TPC after CP at 90 °C for 30 or 60 s in

236 tomato juice[30]. Since POD is involved in the oxidative degradation of phenolic TPC[31],
237 inactivation of POD avoids degradation of TPC during thermal processing. Also the
238 slight TPC enhancement could be attributed to the disruption of cell wall during
239 heating, therefore making phenolics more accessible for extraction.[5]
240
241 *TAC*
242 The TAC was influenced by type of heating and decreased significantly (p<0.05)
243 compared to unheated samples Table 2. As previously reported, TAC in MW treated
244 tomatoes or tomato paste[32] or watermelon juice[33] is strongly decreased by heating. In the
245 current work initial TAC in unheated samples was 725.2 mg AAE kg^{-1}. The highest
246 TAC degradation (around 28%) was found in the CP treated puree, whereas this level
247 was only 6% in MWP samples treated by highest power/short time of processing. These
248 results showed that at similar temperature (96 ± 2 °C) MWP maintained a better TAC
249 than CP. In the same way, Stratakos et al.[34] reported the TAC, in heated tomato juice
250 was higher for MWP compared to the CP at 85 °C. TAC depends on the extract and the
251 intensity of the heating applied to tomato samples.[35] In our results, the highest power
252 (1,900 to 3,150 W) combined with shorter duration (180 to 150 s) maintained the TAC
253 better than low power (390 to 770 W) combined with higher duration (848 to 460 s).
254 Arslan et al.[36] found that MW drying at 700 W offered a lower TAC destruction than
255 MW at 200 W. In summary, when comparing the efficacy of the MWP versus CP,
256 advantage for keeping the TAC of tomato puree was found, in particular, using highest
257 power and lowest time.
258
259 *Vitamin C*

The vitamin C amount in MWP and CP purees is presented in Table 2. Vitamin C content in fresh tomato is between 80 and 163 mg kg^{-1} FW [37], depending on the cultivar, the cultivation conditions and ripening stage.[38] The vitamin C was degraded by 40% in CP, whilst in MWP puree was only 10% (highest power/short time) to 28% (low power/long time) showing that vitamin C of puree was maintained better by MWP than by CP. Similar results were obtained for strawberry puree showing that degradation of vitamin C in MWP (90 °C for 7 or 10 s) samples was from 4 to 22%, while achieving 62% by CP.[9] After MW treatment of potato[39], spinach[40] and apricot[41] the total AA content decreased with increasing processing time at a constant temperature. Decreasing of vitamin C occurs just after heating because this vitamin is very sensitive to heat.[42]

Carotenoids

The lycopene levels ranged from 15.94 in unheated to 20.07 mg kg^{-1} in MWP puree (Table 2), being slightly but significantly enhanced by both heating methods in particular samples treated under high power MWP doses compared to CP samples. Since it is the main carotenoid responsible for the intense redness of the tomato, its level is considered as a quality index.[44] Heating leads to isomerization of lycopene from trans-form to cis-form and a more efficient extraction from the matrix by breaking down cell walls, therefore making lycopene more accessible.[45] Temperature kinetics play an important role in lycopene bio-accessibility as rapid heating of tomato puree can lead to higher accessibility compared to a slow temperature increase.[46] In this experiment, we can add that even if obtaining the same final temperature of pasteurization, the kinetic of MWP power doses is also very important and the combination of highest power/short time of processing improved the lycopene content. On the contrary, other authors found that the lycopene content was stable in tomatoes under different thermal treatments.[47,23]

For the cells that were not disrupted during the puree preparation, such as tomato skin cells, a longer heating time or higher temperature may be needed to disrupt the cell walls sufficiently to release all the lycopene from cells.[48] These authors showed that long-time/low temperature and short-time/high temperature can have the same effects on the tomato matrix. Also, the lycopene remains relatively stable during food processing, except at high temperature or long heating time.[43]

The β-carotene content was also affected by heating method, and increased after pasteurization compared to unheated samples (Table 2). The raw tomato had the lowest β-carotene content (6.76 mg kg^{-1}). This value increased to reach 7.37 and 9.60 mg kg^{-1}in CP and MWP, respectively. It has been reported that there is an enhanced bioavailability of carotenoids after heat treatment in tomato[49] and pumpkin[50] when compared to fresh sample. As explained with lycopene content, heat treatment might improve β-carotene bioavailability by breaking down of the cellulose structure of the plant cell walls.[51]

Enzyme activity

POD is responsible for enzymatic browning and can lead to reduction in nutritive quality, color, and flavor in many plant foods, being a common indicator of enzyme inactivation because of its high thermal stability.[4] Both thermal treatments reduced the POD activity in tomato puree (Table 3). In comparison to CP, highest MWP power combined with short time of processing induced a higher decrease of POD activity. A similar POD inactivation has been reported at 90 °C for 30 or 60 s in apple juice.[52]

PME and PG are the most important enzymes affecting the processed tomato quality playing an important role in the pectin degradation in the primary cell wall and middle lamella.[53] PME also leads the pectin chain to be susceptible to more pectin

degradation by PG reducing the tomato viscosity.[54] Consequently PME and PG inactivation is needed to avoid quality losses.

In this experiment, MWP decreased the PME residual activity better than CP (Table 3). PME activity was significantly affected by the highest power/short time MWP treatment (12%). Similarly, in the current work, PME inactivation in orange juice was faster by MW heating than by CP.[21,55] In most industrial uses the PME residual activity remaining below 10% guarantees the tomato quality and shelf-life.[4]

The PG is present in tomato as PG_1 (thermo-stable form), inactivated at 90 °C, 5 min and PG_2 (thermo-labile form), inactivated at 65 °C, 5 min.[54,56] The PG activity decreased as a function of thermal treatment (Table 3). The major reduction (71%) was found in MWP at 3,150 W/150 s, whereas only 52 and 55%inactivation was reached at 390 W/848 s and CP, respectively. The high PG activity after all treatments could be attributed to the presence of PG_1 and prolonged heating leads to complete inactivation of PG.[57] Results in the present study indicated that MWP might improve PME and PG inactivation through high power and reduced processing time more than with CP. According to Pearson coefficient, there was a negative correlation between residual PG and PME enzyme activity and viscosity of treated smoothies (-0.895 and -0.876, respectively). This correlation showed that the viscosity strongly was influenced by the reduction in PG and PME enzyme activity[4].

As reported in fruit purees and strawberry puree, the POD activity in tomato puree was better inactivated than PG and PME in a microwaved product.[57] For this tomato puree, PG was the more thermo- resistant enzyme, and could be used as an indicator of pasteurization efficiency.

CONCLUSION

Physicochemical properties of tomato puree, especially color, were greatly influenced by heat treatments. MWP was able to preserve tomato puree redness, one of the major quality indicators, better than CP. Generally, MWP induced an enrichment of health-promoting compounds, leading to more retention of antioxidant capacity and vitamin C and enhancing lycopene content. PME and PG enzyme activities were highly decreased by MWP, in particular when high power/short time doses were used, resulting in a better viscosity. For all these reasons the semi-industrial continuous MW heating method studied, using high power combined with short processing time, could be recommended as an emergent pasteurization technique for maintaining quality of tomato puree.

ACKNOWLEDGEMENTS

This work was financially supported by MINECO-FEDER (AGL2013-48830-C2-1-R).

REFERENCES

1 Khachik F, Carvalho L, Bernstein PS, Muir GJ, Zhao DY, and Katz NB, Chemistry distribution, and metabolism of tomato carotenoids and their impact on human health. *J Exp Biol* **227**: 845-851 (2002).

2 Fleshner N and Agarwal S, Serum and tissue lycopene and biomarkers of oxidation in prostate cancer patients: a case-control study. *Nutr Cancer* **33**(2):159-64 (1999).

3 Boileau TWM, Boileau AC, and Erdman JW Jr, Bioavailability of all-trans and cis-isomers of lycopene. *Exp Biol Med* **227**: 914-919 (2002).

4 Aguiló-Aguayo I., Fortuny SR, and Belloso OM, Comparative study on color, viscosity and related enzymes of tomato juice treated by high-intensity pulsed electric fields or heat. *Eur Food Res Technol* **227**:559-606 (2008).

360 5 Martínez-Hernández GB, Artés-Hernández F, Perla A Gómez PA, Artés F, Quality
361 changes after vacuum-based and conventional industrial cooking of kailan-
362 hybrid broccoli throughout retail cold storage. *LWT- Food Sci Technol* **50**: 707-
363 714 (2013).
364 6 Zhang M, Tang J, Mujumdar A, and Wang S, Trends in microwave-related drying of
365 fruits and vegetables. *Trends Food Sci Technol* **17**: 524-534 (2006).
366 7 Esteve MJ, Frigola A, Martorell L, and Rodrigo C, Kinetics of ascorbic acid
367 degradation in green asparagus during heat processing. *J Food Prot* **61**: 1518-
368 1521 (1998).
369 8 Puligundla P, Abdullah SA, Choi W, Jun S, Oh SE, and Ko S, Potentials of
370 Microwave Heating Technology for Select Food Processing Applications - a
371 Brief Overview and Update. *J Food Process Technol* 4: 1-9 (2013).
372 9 Marszalek K, Mitek M, and Skapska S, Effect of continuous flow microwave and
373 conventional heating on the bioactive compounds, color, enzyme activity,
374 microbial and sensory quality of strawberry puree. *Food Bioprocess Tech*
375 **8**:1864-1876 (2015).
376 10 Benlloch-Tinoco M, Igual M, and Salvador A, Quality and acceptability of
377 microwave and conventionally pasteurized kiwifruit puree. *Food Bioprocess*
378 *Tech* **7**:3282-3292 (2014).
379 11 Teixeira AA, Simulating thermal food processes using deterministic models. In:
380 "Thermal Food Processing: New Technologies and Quality Issues" (ed. Wen-
381 Sun D) CRC press, PP. 98 (2012).
382 12 Aguayo E, Escalona VH and Artés F, Quality of minimally fresh processed Cucumis
383 melo var. saccharinus as improved by controlled atmosphere. *Eur J Hort Sci*
384 **72**: 39-45 (2007).

385 13 SwainT, and Hillis WE, The phenolic constituents of *Prunus domestica*. The
386 quantitative analysis of phenolic constituents. *J Sci Food Agric* **10**: 63-68.
387 (1959).
388 14 Benzie IFF, and Strain JJ, Ferric reducing antioxidant power assay: direct measure
389 of total antioxidant activity of biological fluids and modified version for
390 simultaneous measurement of total antioxidant power and ascorbic acid
391 concentration. *Methods Enzymol* **299**: 15-27 (1999).
392 15 Falagán N, Artés F, Gómez PA, Artés-Hernández F, Pérez-Pastor A, de la Rosa JM,
393 and Aguayo E, Combined effects of deficit irrigation and fresh-cut processing on
394 quality and bioactive compounds of nectarines. *Hort Sci (Prague)* **42**: 125-131
395 (2015).
396 16 Nagata M, Yamashita I, Simple method for simultaneous determination of
397 chlorophyll and carotenoids in tomato fruit. *J Jpn Soc Food Sci* **39**: 926-928
398 (1992).
399 17 Élez-Martínez P, Soliva-Fortuny RC, and Martín-Belloso O, Comparative study on
400 shelf life of orange juice processed by high intensity pulsed electric fields or heat
401 treatments. *Eur Food Res Tech* **222**: 321-329 (2006).
402 18 Ratner A, Goren R, and Monseline SP, Activity of pectin esterase and cellulase in
403 the abscission zone of citrus leaf explants. *J Plant Physiol* **44**: 1717-1723
404 (1969).
405 19 Gross KC, A rapid and sensitive spectrophotometric method for assaying
406 polygalacturonase using 2-cyanoacetamide. *J Hortic Sci* **17**: 933-934 (1982).
407 20 Sacilik K, The thin-layer modelling of tomato drying process. *Agric Conspec Sci* **72**:
408 343-349 (2007).

21 Cinquanta L, Albanese D, Cuccurullo G, and Di Matteo M,Effect on orange juice of batch pasteurization in an improved pilot-scale microwave oven. *J Food Sci* **75**: 46-50 (2010).

22 Dutta C, Chowdhury BR, Chakraborty R, and Raychaudhuri U, Incorporation of turmeric-lime mixture during the preparation of tomato puree. *Afr J* Biotechnol **6**: 795-798 (2007).

23 Sánchez MC, Valencia C, Ciruelos A, Latorre A, and Gallegos C, Rheological properties of tomato paste: Influence of the addition of tomato slurry. *J Food Sci* **68**: 551-554 (2003).

24 Kaur C, George B, Deepa N, Jaggi S, and Kapoor HC, Viscosity and quality of tomato juice as affected by processing methods. *J Food Qual* **30**: 864-877 (2007).

25 Luh BS, Sarhan MA, and Wang Z, Pectins and fibers in processing tomatoes. *Food Tecnol Aust* **36**: 70-73 (1984).

26 Errington N, Tucker GA, and Mitchell JR, Effect of genetic down-regulation of polygalacturonase and pectin esterase activity on rheology and composition of tomato juice. *J Sci Food Agric* **76**: 515-519 (1998).

27 Dale KB, Okos MR, and Nelson PE, Concentration of tomato products: analysis of energy saving process alternatives. *J Food Sci* **47**:1853-1858 (1984).

28 Kim HB, and Tadini CC, Effect of different pasteurization conditions on enzyme inactivation of orange juice in pilot-scale experiments. *J Food Process Eng* **22**: 395-403 (1999).

29 Odriozola-Serrano I, Soliva-Fortuny R, and Martín-Belloso, O, Changes of health-related compounds throughout cold storage of tomato juice stabilized by thermal

or high intensity pulsed electric field treatments. *Innov Food Sci Emerg Technol* **9**: 272-279 (2008).

30 Odriozola-Serrano I, Soliva-Fortuny R, Hernandez-Jover T, and Martin-Belloso O, Carotenoid and phenolic profile of tomato juices processed by high intensity pulsed electric fields compared with conventional thermal treatments. *Food Chem* **112**:258-266 (2009).

31 Amiot JM, Fleuriet A, Cheynier VC, and Nicolas J, Phenolic compounds and oxidative mechanisms in fruit and vegetables. In: Tomas-Barberán FA, and Robins RJ. (eds). Phytochemistry of fruit and vegetables. *Proc Phytochem Lett* (Oxford) **41**: 51-85 (1997).

32 Kaur C, Khurdiya DS, Pal RK, and Kapoor HC, Effect of microwave heating and conventional processing on the nutritional qualities of tomato juice. *J Food Sci Technol* **36**:331-333 (1999).

33 Tarazona-Díaz MP, and Aguayo E, Influence of acidification, pasteurization, centrifugation and storage time and temperature on watermelon juice quality. *J Sci Food Agric* **93**:3863-3869 (2013).

34 Stratakos ACh., Delgado-Pando G., Linton M., Patterson MF., and Koidis A, Industrial scale microwave processing of tomato juice using a novel continuous microwave system. *Food Chem* **190**: 622-628 (2015).

35 Jacob K, García-Alonso FJ, Ros G, and Periago MJ, Stability of carotenoids, phenolic compounds, ascorbic acid and antioxidant capacity of tomatoes during thermal processing. *Arch Latinoam Nutr* **60**:192-198 (2010).

455 36 Arslan D, and Özcan MM, Drying of tomato slices: changes in drying kinetics,
456 mineral contents, antioxidant activity and color parameters. CyTA- *J Food*
457 **9**:229-236 (2011).
458 37 Frusciante L, Carli P, Ercolano MR, Pernice R, Di Matteo A, Fogliano V, and
459 Pellegrini N, Antioxidant nutritional quality of tomato. *Mol Nutr Food Res* 51:
460 609-617 (2007).
461 38 Capanoglu E, Beekwilder J, Boyacioglu D, De Vosb RCH, and Hall RD, The Effect
462 of industrial food processing on potentially health-beneficial tomato
463 antioxidants. *Int J Food Sci Technol* **50**: 919-930 (2010).
464 39 Khraisheh MAM, McMinn WAM, and Magee TRA, Quality and structural changes
465 in starchy foods during microwave and convective drying. *Food Res Int* **37**: 497-
466 503 (2004).
467 40 Ozkan IA, Akbudak B, and Akbudak N, Microwave drying characteristics of
468 spinach. *J Food Eng* **78**: 577-583 (2007).
469 41 Karatas F, and Kamisli F, Variations of vitamins (A, C and E) and MDA in apricots
470 dried in IR and microwave. *J Food Eng* **78**: 662-668 (2007).
471 42 Leoni, C, Improving the nutritional quality of processed fruits and vegetables: the
472 case of tomatoes, *in Fruit and Vegetable Processing: Improving Quality*. Jongen
473 W, Ed., Woodhead Publishing Ltd and CRC Press, LLC., Cambridge, pp. 83-
474 122 (2002).
475 43 Dewanto V, Wu X, Adom K, and Liu R, Thermal processing enhances thenutritional
476 value of tomatoes by increasing the total antioxidant activity. *J Agric Food*
477 *Chem* **50**:3010-3014 (2002).
478 44 Zeb A, and Mehmood S, Carotenoids contents from various sources and their
479 potential health applications. *Pak J Nutr* **3**: 199-204 (2004).

480 45 Shi J, Maguer M, Kakuda Y, Liptay A, and Niekamp F, Lycopene degradation and
481 isomerization in tomato dehydration. *Food Res Int* **32**: 15-21 (1999).
482 46 Page D, Van Stratum E, Degrou A, and Renard CMGC, Kinetics of temperature
483 increase during tomato processing modulate the bioaccessibility of lycopene.
484 *Food Chem* **135**: 2462-2469 (2012).
485 47 Graziani G, Pernice R, Lanzuise S, Vitaglione P, Anese M, and Fogliano V, Effect of
486 peeling and heating on carotenoid content and antioxidant activity of tomato and
487 tomato–virgin olive oil systems. *Eur Food Res Technol* **216**:116-121 (2003).
488 48 Shi J, Dai Y, Kakuda Y, Mittal G, and Xue SJ, Effect of heating and exposure to
489 light on the stability of lycopene in tomato puree. *Food Control* **19**: 514-520
490 (2008).
491 49 Stahl W, and Sies H, Uptake of lycopene and its geometrical isomers is greater from
492 heat-processed than from unprocessed tomato juice in humans. *J Nutr* **122**:
493 2161-2166 (1992).
494 50 Azizah AH, Wee KC, Azizah O, and Azizah M, Effect of boiling and stir frying on
495 total phenolics, carotenoids and radical scavenging activity of pumpkin
496 (*Cucurbita moschato*). *Int Food Res J* **16**: 45-51(2009).
497 51 Van het Hof KH, de Boer BCJ, Tijburg LBM, Lucius BRHM, Zijp I, West CE,
498 Hautvast JGAJ, and Weststrate JA, Carotenoid bioavailability in humans from
499 tomatoes processed in different ways determined from the carotenoid response in
500 the triglyceride-rich lipoprotein fraction of plasma after a single consumption
501 and in plasma after four days of consumption. *J Nutr* **130** : 1189-1196 (2000).
502 52 Cañumir JA, Celis JE, Brujin J, and Vidal L, Pasteurization of apple juice by using
503 microwaves. *LWT- J Food Sci* **35**:389-392 (2002).

504 53 Wu J, Gamage TV, Vilkhu KS, Simons LK, and Mawson R, Effect of thermos
505 sonication on quality improvement of tomato juice. *Innov Food Sci Emerg*
506 *Technol* **9**: 186-195 (2008).
507 54 López P, Sánchez AC, Vercet A, and Burgos J, Thermal resistance of tomato
508 polygalacturonase and pectinmethylesterase at physiological pH. *Z Lebensm*
509 *Unters Forsch* **204**:146-150 (1997).
510 55 Tajchakavit S, and Ramaswamy HS, Thermal vs. microwave in activation kinetics of
511 pectin methylesterase in orange juice under batch mode heating conditions. *J*
512 *Food Sci Technol* **30**: 85-93 (1997).
513 56 Rodrigo D, Cortes C, Clynen E, Schoofs L, Ann Van Loey AV, and Hendrickx M,
514 Thermal and high-pressure stability of purified polygalacturonase and
515 pectinmethylesterase from four different tomato processing varieties. *Food Res*
516 *Int* **39**, 440-448 (2006).
517 57 Fachin D, Van Loey AM, Nguyen BL, Verlent I, Indrawati I and Hendrickx ME,
518 Inactivation kinetics of polygalacturonase in tomato juice. *Innov Food Sci*
519 *Emerg Technol* **4**: 135-142 (2003).
520

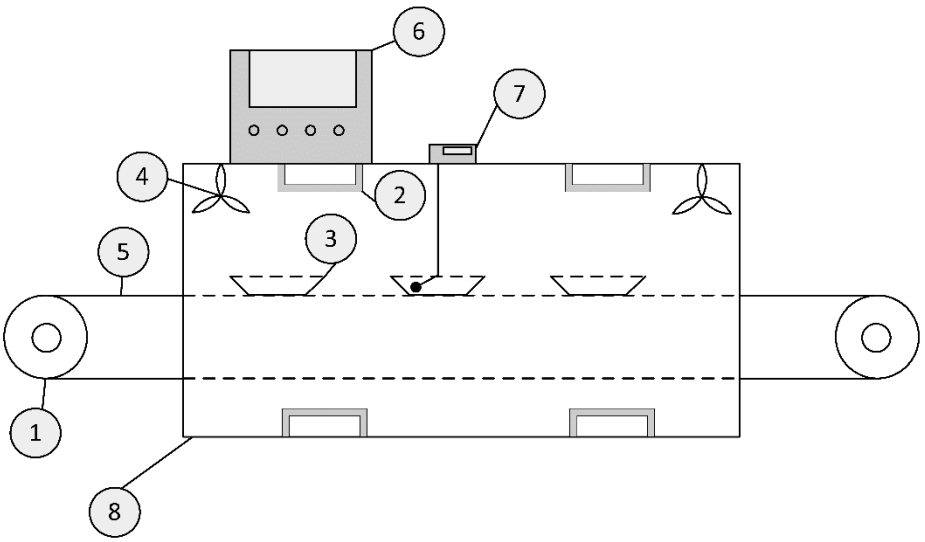

Figure 1. Semi-industrial microwave oven, process diagram.

1.- Motor

2.- Magnetron

3.- Sample

4.- Fan

5.- Conveyor belt

6.- Control process

7.- Fiber optical temperature sensor

8.- Microwave chamber

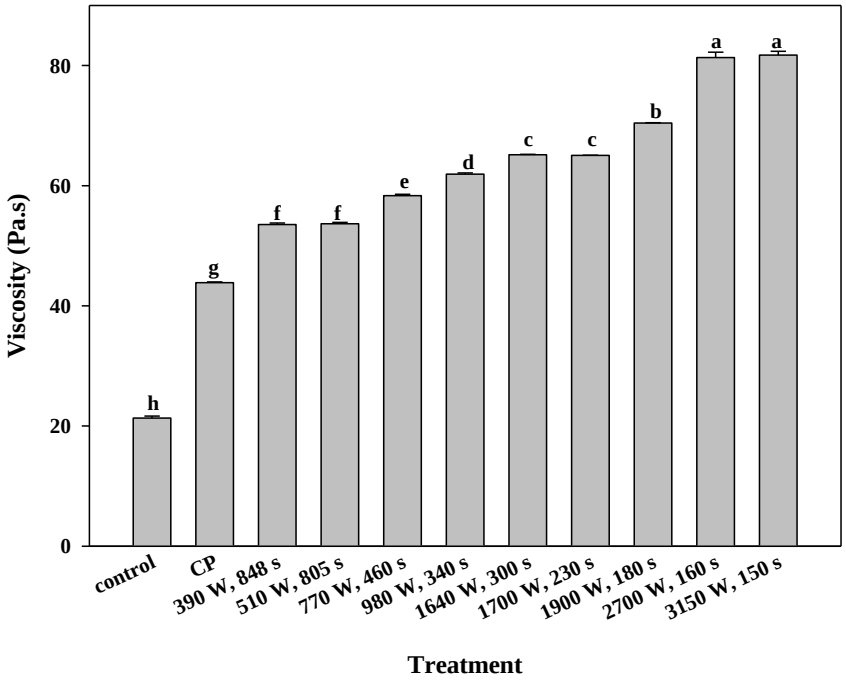

Figure 2. Viscosity in unheated (control), conventional (CP) and microwave (MWP) pasteurized tomato puree. Different letters indicate significant differences among mean values (p<0.05).

538 **Table 1.** Color changes in unheated (control), conventional (CP) and microwave (MWP)
539 pasteurized tomato puree

	Treatments	L*	Hue angle
MWP	Untreated	39.60 ± 0.17^{a}	44.94 ± 0.19^{d}
Doses	CP	33.00 ± 0.38^{f}	48.44 ± 0.10^{a}
Low	390 W-848 s	35.36 ± 0.12^{e}	48.70 ± 0.80^{a}
	510 W-805 s	35.80 ± 0.12^{de}	47.45 ± 0.19^{ab}
	770 W-460 s	35.84 ± 0.22^{de}	47.03 ± 0.23^{abc}
Medium	980W-340 s	36.38 ± 0.41^{cd}	46.61 ± 0.50^{abc}
	1640 W-300 s	36.39 ± 0.37^{cd}	46.18 ± 0.64^{abc}
	1700 W-230 s	36.82 ± 0.40^{bc}	45.67 ± 0.86^{bc}
High	1900 W-180 s	36.93 ± 0.14^{bc}	45.45 ± 0.27^{bc}
	2700 W-160 s	37.08 ± 0.09^{bc}	45.12 ± 0.60^{bc}
	3150 W-150 s	37.36 ± 0.25^{b}	45.06 ± 0.19^{c}

540 Values are mean ± standard error (n=3). Different letters in the same column indicate significant differences among
541 mean values of different treatments ($p < 0.05$). ¨ns¨ means there are no significant differences. Low MWP: Microwave
542 pasteurization at low power and long time. Medium MWP: Microwave pasteurization at medium power and medium
543 time. High MWP: Microwave pasteurization at high power and short time.

Table 2. Total antioxidant capacity (TAC, mg AAE kg^{-1}), total phenolic compound (TPC, ChAE mg kg^{-1}), Vitamin C (mg kg^{-1}), lycopene and β carotene (mg kg^{-1}) in unheated (control), conventional (CP) and microwave pasteurized (MWP) tomato puree.

	Treatment	TAC	TPC	Vitamin C	Lycopene	β-carotene
MWP Doses	Untreated	725.2 ± 0.17^{a}	424.0 ± 0.47^{ns}	100.0 ± 0.02^{a}	15.94 ± 0.86^{e}	6.76 ± 0.90^{ns}
	CP	519.4 ± 0.25^{g}	430.6 ± 0.02^{ns}	59.8 ± 0.02^{g}	17.19 ± 0.88^{de}	7.37 ± 0.06^{ns}
Low	390 W-848 s	559.1 ± 0.40^{f}	430.0 ± 0.36^{ns}	72.4 ± 0.06^{f}	17.66 ± 0.07^{cd}	9.08 ± 0.04^{ns}
	510 W-805 s	559.5 ± 0.25^{f}	430.7 ± 0.35^{ns}	72.4 ± 0.02^{f}	17.98 ± 0.22^{cd}	9.11 ± 0.63^{ns}
	770 W-460 s	560.8 ± 0.43^{f}	430.7 ± 0.37^{ns}	73.5 ± 0.06^{f}	17.99 ± 0.15^{cd}	9.08 ± 0.53^{ns}
Medium	980W-340 s	578.8 ± 0.44^{e}	431.7 ± 0.37^{ns}	77.4 ± 0.01^{e}	18.05 ± 0.12^{cd}	9.49 ± 0.50^{ns}
	1640 W-300 s	615.9 ± 0.23^{d}	432.6 ± 0.40^{ns}	87.0 ± 0.08^{d}	18.15 ± 0.21^{bcd}	9.54 ± 0.21^{ns}
	1700 W-230 s	619.6 ± 0.37^{d}	433.1 ± 0.63^{ns}	88.1 ± 0.03^{cd}	18.47 ± 0.07^{bcd}	9.56 ± 0.10^{ns}
High	1900 W-180 s	663.1 ± 0.20^{c}	440.3 ± 0.33^{ns}	89.0 ± 0.05^{bc}	19.17 ± 0.36^{abc}	9.57 ± 0.34^{ns}
	2700 W-160 s	682.6 ± 0.38^{b}	441.1 ± 0.41^{ns}	89.5 ± 0.04^{b}	19.60 ± 0.07^{ab}	9.56 ± 0.12^{ns}
	3150 W-150 s	682.7 ± 0.47^{b}	441.2 ± 0.39^{ns}	89.8 ± 0.06^{b}	20.07 ± 0.12^{a}	9.60 ± 0.14^{ns}

Values are mean ± standard error (n=3). Different letters in the same column indicate significant differences among mean values of different treatments ($p<0.05$). ¨ns¨ means there are no significant differences. Low MWP: Microwave pasteurization at low power and long time. Medium MWP: Microwave pasteurization at medium power and medium time. High MWP: Microwave pasteurization at high power and short time.

Table 3. Residual activity (%RA) of peroxidase (POD), pectin methylesterase (PME), and polygalacturonase (PG) in unheated (control), conventional (CP) and microwave (MWP) pasteurized tomato puree.

	Treatments	POD	PME	PG
MWP Doses	Untreated	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}
	CP	15.99 ± 0.55^{b}	19.57 ± 0.10^{b}	55.77 ± 0.44^{b}
Low	390 W-848 s	15.90 ± 0.61^{b}	16.97 ± 0.15^{c}	52.05 ± 0.29^{c}
	510 W-805 s	15.80 ± 0.49^{b}	16.48 ± 0.10^{c}	49.43 ± 0.37^{d}
	770 W-460 s	15.32 ± 0.29^{b}	16.29 ± 0.13^{c}	48.33 ± 0.60^{de}
Medium	980W-340 s	14.81± 0.33^{b}	16.16 ± 0.05^{c}	47.97 ± 0.27^{e}
	1640 W-300 s	14.03 ± 0.78^{c}	16.13 ± 0.06^{d}	32.06 ± 0.56^{f}
	1700 W-230 s	13.66 ± 0.94^{c}	16.02 ± 0.03^{de}	32.84 ± 0.50^{f}
High	1900 W-180 s	12.95 ± 0.64^{cd}	15.02 ± 0.22^{de}	32.80 ± 0.52^{f}
	2700 W-160 s	12.26 ± 0.52^{d}	14.99 ± 0.07^{de}	30.51 ± 0.56^{g}
	3150 W-150 s	11.72 ± 0.82^{e}	14.65 ± 0.10^{e}	29.22 ± 0.52^{g}

Values are mean ± standard error (n=3). Different letters in the same column indicate significant differences among mean values of different treatments ($p < 0.05$). Low MWP: Microwave pasteurization at low power and long time. Medium MWP: Microwave pasteurization at medium power and medium time. High MWP: Microwave pasteurization at high power and short time.