1   **Microwave flow and conventional heating effects on the physicochemical**

2   **properties, bioactive compounds and enzymatic activity of tomato puree**

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13

14   **ABSTRACT**

15   **BACKGROUND: Thermal processing causes a number of undesirable changes in**

16   **physicochemical and bioactive properties of tomato products. Microwave (MW)**

17   **technology is an emergent thermal industrial process that offers a rapid and**

18   **uniform heating, high energy efficiency, and high overall quality of the final**

19   **product. The main quality changes of tomato puree after a pasteurization at 96 ± 2**

20   **ºC for 35 s, provided by a semi industrial continuous microwave oven (MWP)**

21   **under different doses (low power/long time to high power/short time) or by**

22   **conventional method (CP) were studied.**

23   **RESULTS: The results showed that all heat treatments reduced color quality, total**

24   **antioxidant capacity and vitamin C, with a greater reduction in CP than in MWP.**

25   **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.

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

61 color parameters, viscosity and enzymatic activity of a tomato puree after CP and MWP

62 using different doses (powers and times) of processing.

63

64 **2. MATERIALS AND METHODS**

65

66 **2.1. Plant materials**

67 Tomato *(Lycopersicum esculentum* Mill., Moneymaker cv.*)* were grown in greenhouse

68 under Mediterranean climate (Mazarrón, Murcia, Spain). They were harvested

69 according to commercial maturity stage, obtaining 4.73 ± 0.07 ºBrix and 44.94 ± 0.19

70 hº. Fruits free from defects and with a similar visual appearance were blended with a

71 commercial thermomix (Vorwerk Elektrowerke, Model TM 31-1, France) in order to

72 obtain a puree.

73

74 **2.2. Thermal treatment**

75 600 mL of puree samples were heated in the above cited thermomix (conventional

76 pasteurization, (CP). Alternatively, samples for each MW pasteurization (MPW)

77 treatment were placed in 3 tempered and extra resistant MW glasses were used

78 (Hostelvia, Vicrila, Leioa, Spain). These glass beakers, containing each one 200 mL of

79 tomato puree was treated in an innovative semi-industrial prototype of continuous MW

80 oven (Sairem Ibérica S.L. SI-MAQ0101, Barcelona, Spain) with a power control from 0

81 to 3,000 W (Fig. 1). Based on our preliminary studies several appropriate

82 temperature/time combinations of MWP were selected with following conditions:

83   Low power/long time (390 W/848 s, 510 W/805 s, 770 W/460 s), medium

84 power and time (980 W/848 s, 1,640 W/805 s, 1,700 W/230 s) and high power/short

85 time (1,900 W/180 s, 2,700 W/160 s and 3,150 W/150 s). In both CP and MWP

86   processing the final temperature in all the treatments was $96 \pm 2°C$ and they remained at

87   this temperature for 35 s.

88   After both kinds of pasteurization, the samples were packaged aseptically into

89   plastic tubes and rapidly cooled (5 °C) with an ice-water bath and then analyzed before

90   (control) and after thermal treatments. For each heating method, the full experiment was

91   conducted independently three times, each one constituting a repetition which was

92   analysed.

93

94   **2.3. Analysis and quality determination**

95   *Physical quality analysis*

96   Color: The color of the samples was monitored by photo-colorimeter (Minolta CR-300,

97   Ramsey, NJ, USA). Color was expressed as Hunter L**,** a**,** b*and hue angle ($h^o = \tan^{-1} b*/a*$).

98   $^{1}b*/a*$).

99   Viscosity: Viscous flow tests were determined in triplicate with a controlled shear

100 rate/stress rheometer (AR G-2, TA Instruments, U.K) at 20 °C. Viscous flow tests were

101 performed by using a shear rate range between 1 and 100 s^{-1}.

102

103 *2.3.2 Chemical quality attributes*

104 Titratable acidity (TA), soluble solids content SSC and pH were analyzed as described

105 by Aguayo et al.[12]

106

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

108 TPC was measured following by Swain and Hillis[13] method using a Multiscan plate

109 reader (Tecan Infinite M200, Männedorf, Switzerland). TPC was expressed as mg

110 chlorogenic acid equivalents (ChAE) kg^{-1} fresh weight (FW).

111   TAC was assessed using the Ferric Reducing Antioxidant Power (FRAP)

112   technique[14] with the same device as for TPC. Results were expressed as mg ascorbic

113   acid equivalent (AAE) kg^{-1} (FW).

114

115   *Total vitamin C*

116   The ascorbic acid (AA) determination was performed as described by Falagán et al.[15] 10

117   mL of puree were mixed with 10 mL of a solution containing 45 g L^{-1} of

118   metaphosphoric acid and 7.2 g L^{-1} of DTT (DL-1, 4-dithiotreitol). The mixture was

119   centrifuged at $22,100 \times g$ for 15 min at 4 °C (Eppendrof, AG 22331, Germany). The

120   analysis of vitamin C was carried out by HPLC (Waters 2695, Detector UV-V 2687,

121   Milford, USA). Detection was performed with an UV-visible spectrophotometer

122   (Hewlet Packard, Model 8453, Columbia, USA) at 260 nm. Vitamin C was quantified

123   through a calibration curve made with AA standards and results were expressed as mg

124   (AA) kg^{-1} FW.

125

126   *Carotenoids*

127   Carotenoids were measured according to the method of Nagata and Yamashita[16] with

128   the slight modifications. 5 mL of smoothie were mixed with 20 mL acetone-hexane

129   (4:6). Two phases separated and the upper phase was taken for lycopene and β-carotene

130   measurements at 663, 645, 505 and 453 nm in a UV-visible spectrophotometer (Hewlet

131   Packard, Model: 8453, Columbia, EEUU). Lycopene and β-carotene were calculated

132   according to the following equations:

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

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

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

136

Peroxidase (POD)

POD activity was measured using the method described by Elez-Martínez et al.[17] 0.009

mL enzyme extract, 0.243 mL of phosphate buffer 0.05 M, 0.018 mL of phenildiamina

(10 g kg^{-1}), and 0.009 mL of H_2O_2 (15 g kg^{-1}) in a 96-well polystyrene flat-bottom plate.

The absorbance was measured at 509 nm for 10 min at 25 °C by using the multiscan

plate reader cited above.

143

Pectin methylesterase (PME)

PME activity was determined according to Ratneret et al.[18] with slight modifications. A

2.5 mL simple of puree was homogenized with 10 mL of sodium chloride 0.2 M. After

filtering the homogenate by cheesecloth, 2.5 mL of it was mixed with 15 mL pectin (10

g L^{-1}). This solution was adjusted to pH 7.0 with 1N NaOH and the pH was kept at 7.0

during 10 min using 0.01 N NaOH. One PME U can be expressed as the amount of

enzyme that produces 1 nmol of acid per minute at pH 7.0 and 22 °C.

151

Polygalacturonase (PG)

PG activity was measured according to Aguiló-Aguayo et al.[4] with slight modifications.

2 mL of sample was homogenized two times in 15 and 10 mL of cold acetone for 30

and 15 min, respectively. The supernatant was again decanted and replaced with 5 ml of

tris hydroxylmethyl aminomethane buffer (0.2 M), pH 7.0, including 0.5 g L^{-1} of

sodium metabisulfite, 10 g L^{-1} PVPP and 1M NaCl. The extraction was carried out

during 2 h in an orbital shaker (Stuart, Staffordshire, UK) at $200 \times g$ in darkness inside a

polystyrene box with ice at 4 °C. The homogenate was centrifuged at $20,000 \times g$ for 15

min at 4 °C. The supernatant was used as enzyme extract. The PG activity was

161 quantified according to Gross.[19] The substrate was constituted of 0.6 mL of a solution

162 containing 4 g L^{-1} (w/v) polygalacturonic acid in 0.05 M sodium acetate buffer (pH 4.5)

163 and the reaction was carried out by adding 0.15 mL of enzyme extract, followed by

164 incubation at 37 °C for 10 min with shaker of 30 rpm. The reaction was stopped with 2

165 mL of 10 mM borate buffer at pH 9 and 0.4 mL of 10 g L^{-1} (w/v) cyanoacetamide. The

166 mixture was put in a boiling water bath (100 °C) for 10 min and then chilled by ice. 200

167 µL of extraction was put in a 96-well polystyrene flat-bottom plate the well. The

168 absorbance of samples was measured. The absorbance was read at 276 nm using the

169 same device as for POD at 22 °C. The quantity of reducing groups formed was

170 determined using a calibration curve made with D-galacturonic acid and the enzyme

171 activity was expressed as mM of galacturonic acid released per min. One unit (U) of PG

172 activity was defined as the amount of enzyme that yielded 1 mM of reducing groups per

173 min.

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

175

176 *2.4. Statistical analysis*

177 Data were analyzed in a randomized design with three replicates per treatment. Data

178 were subjected to one-way analysis of variance ($p \leq 0.05$) using Statgraphic Plus 5.1,

179 Manugistic Inc, Rockville, MD, USA). Mean values were compared by multiple range

180 least significant difference test to identify significant differences among treatments. A

181 Pearson's correlation analysis was performed to corroborate relationships between

182 specific parameters.

183

184 **3. RESULTS AND DISCUSSION**

185 *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, h° 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

211 MWP, in particular, high power combined with low time, provided the higher viscosity

212 compared to CP and unheated samples. For low shear rates, the viscosity value ranged

213 from 81.73 to 53.54 Pa.s for MWP puree compared to 43.85 Pa.s CP and 21.33 Pa.s for

214 CP and unheated samples, respectively. This viscosity decreased for higher shear rates

215 and reached 4 and 2.5 Pa.s in all treatments, at a shear rate of $100 \ s^{-1}$. Due to disruption

216 of the samples treated cell wall during thermal treatment, the soluble pectin could be

217 increased. In the current research and several other studies, an increase in viscosity of

218 tomato products was found with increasing pectin content.[25,26] On the other hand,

219 different inactivation levels of PME and PG during pasteurization of puree as well as

220 varietal characteristics and the maturity stage of fruits at processing have an influence

221 on the viscosity.[27] According to our results, the reduction of PME and PG activity by

222 both thermal treatment methods lead to increased viscosity.

223

224 *SSC, pH and TA*

225 The SSC range between 4.73 and 5.27 ºBrix, pH values 4.11 to 4.26 and TA had a mean

226 of 0.37% in unheated and heated samples without significant differences (data not

227 shown). The literature reported that temperature and treatment time had no effect on pH

228 and °Brix of CP orange juice.[28]

229

230 *TPC*

231 The initial TPC in fresh tomato puree was 424 ChAE mg kg^{-1} (Table 2). The range from

232 268 to 523 mg kg^{-1} reported for different tomato juices.[29] In this work, after any heat

233 treatment the TPC was in the range between 430.6 and 441.2 ChAE mg kg^{-1} without

234 significant difference between unheated or heated treatments. Similarly to our results it

235 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*

260 The vitamin C amount in MWP and CP purees is presented in Table 2. Vitamin C

261 content in fresh tomato is between 80 and 163 mg kg^{-1} FW [37], depending on the cultivar,

262 the cultivation conditions and ripening stage.[38] The vitamin C was degraded by 40% in

263 CP, whilst in MWP puree was only 10% (highest power/short time) to 28% (low

264 power/long time) showing that vitamin C of puree was maintained better by MWP than

265 by CP. Similar results were obtained for strawberry puree showing that degradation of

266 vitamin C in MWP (90 °C for 7 or 10 s) samples was from 4 to 22%, while achieving

267 62% by CP.[9] After MW treatment of potato[39], spinach[40] and apricot[41] the total AA

268 content decreased with increasing processing time at a constant temperature. Decreasing

269 of vitamin C occurs just after heating because this vitamin is very sensitive to heat.[42]

270

271 *Carotenoids*

272 The lycopene levels ranged from 15.94 in unheated to 20.07 mg kg^{-1} in MWP puree

273 (Table 2), being slightly but significantly enhanced by both heating methods in

274 particular samples treated under high power MWP doses compared to CP samples.

275 Since it is the main carotenoid responsible for the intense redness of the tomato, its level

276 is considered as a quality index.[44] Heating leads to isomerization of lycopene from

277 trans-form to cis-form and a more efficient extraction from the matrix by breaking down

278 cell walls, therefore making lycopene more accessible.[45] Temperature kinetics play an

279 important role in lycopene bio-accessibility as rapid heating of tomato puree can lead to

280 higher accessibility compared to a slow temperature increase.[46] In this experiment, we

281 can add that even if obtaining the same final temperature of pasteurization, the kinetic

282 of MWP power doses is also very important and the combination of highest power/short

283 time of processing improved the lycopene content. On the contrary, other authors found

284 that the lycopene content was stable in tomatoes under different thermal treatments.[47,23]

285　For the cells that were not disrupted during the puree preparation, such as tomato skin

286　cells, a longer heating time or higher temperature may be needed to disrupt the cell

287　walls sufficiently to release all the lycopene from cells.[48] These authors showed that

288　long-time/low temperature and short-time/high temperature can have the same effects

289　on the tomato matrix. Also, the lycopene remains relatively stable during food

290　processing, except at high temperature or long heating time.[43]

291　　　The β-carotene content was also affected by heating method, and increased after

292　pasteurization compared to unheated samples (Table 2). The raw tomato had the lowest

293　β-carotene content (6.76 mg kg^{-1}). This value increased to reach 7.37 and 9.60 mg kg^{-1}in

294　CP and MWP, respectively. It has been reported that there is an enhanced

295　bioavailability of carotenoids after heat treatment in tomato[49] and pumpkin[50] when

296　compared to fresh sample. As explained with lycopene content, heat treatment might

297　improve β-carotene bioavailability by breaking down of the cellulose structure of the

298　plant cell walls.[51]

299

300　*Enzyme activity*

301　POD is responsible for enzymatic browning and can lead to reduction in nutritive

302　quality, color, and flavor in many plant foods, being a common indicator of enzyme

303　inactivation because of its high thermal stability.[4] Both thermal treatments reduced the

304　POD activity in tomato puree (Table 3). In comparison to CP, highest MWP power

305　combined with short time of processing induced a higher decrease of POD activity. A

306　similar POD inactivation has been reported at 90 °C for 30 or 60 s in apple juice.[52]

307　　　PME and PG are the most important enzymes affecting the processed tomato

308　quality playing an important role in the pectin degradation in the primary cell wall and

309　middle lamella.[53] PME also leads the pectin chain to be susceptible to more pectin

310 degradation by PG reducing the tomato viscosity.[54] Consequently PME and PG

311 inactivation is needed to avoid quality losses.

312 In this experiment, MWP decreased the PME residual activity better than CP

313 (Table 3). PME activity was significantly affected by the highest power/short time

314 MWP treatment (12%). Similarly, in the current work, PME inactivation in orange juice

315 was faster by MW heating than by CP.[21,55] In most industrial uses the PME residual

316 activity remaining below 10% guarantees the tomato quality and shelf-life.[4]

317 The PG is present in tomato as PG_1 (thermo-stable form), inactivated at 90 °C, 5

318 min and PG_2 (thermo-labile form), inactivated at 65 °C, 5 min.[54,56] The PG activity

319 decreased as a function of thermal treatment (Table 3). The major reduction (71%) was

320 found in MWP at 3,150 W/150 s, whereas only 52 and 55% inactivation was reached at

321 390 W/848 s and CP, respectively. The high PG activity after all treatments could be

322 attributed to the presence of PG_1 and prolonged heating leads to complete inactivation

323 of PG.[57] Results in the present study indicated that MWP might improve PME and PG

324 inactivation through high power and reduced processing time more than with CP.

325 According to Pearson coefficient, there was a negative correlation between residual PG

326 and PME enzyme activity and viscosity of treated smoothies (-0.895 and -0.876,

327 respectively). This correlation showed that the viscosity strongly was influenced by the

328 reduction in PG and PME enzyme activity[4].

329 As reported in fruit purees and strawberry puree, the POD activity in tomato

330 puree was better inactivated than PG and PME in a microwaved product.[57] For this

331 tomato puree, PG was the more thermo- resistant enzyme, and could be used as an

332 indicator of pasteurization efficiency.

333

334 **CONCLUSION**

335 Physicochemical properties of tomato puree, especially color, were greatly influenced

336 by heat treatments. MWP was able to preserve tomato puree redness, one of the major

337 quality indicators, better than CP. Generally, MWP induced an enrichment of health-

338 promoting compounds, leading to more retention of antioxidant capacity and vitamin C

339 and enhancing lycopene content. PME and PG enzyme activities were highly decreased

340 by MWP, in particular when high power/short time doses were used, resulting in a

341 better viscosity. For all these reasons the semi-industrial continuous MW heating

342 method studied, using high power combined with short processing time, could be

343 recommended as an emergent pasteurization technique for maintaining quality of

344 tomato puree.

345

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348

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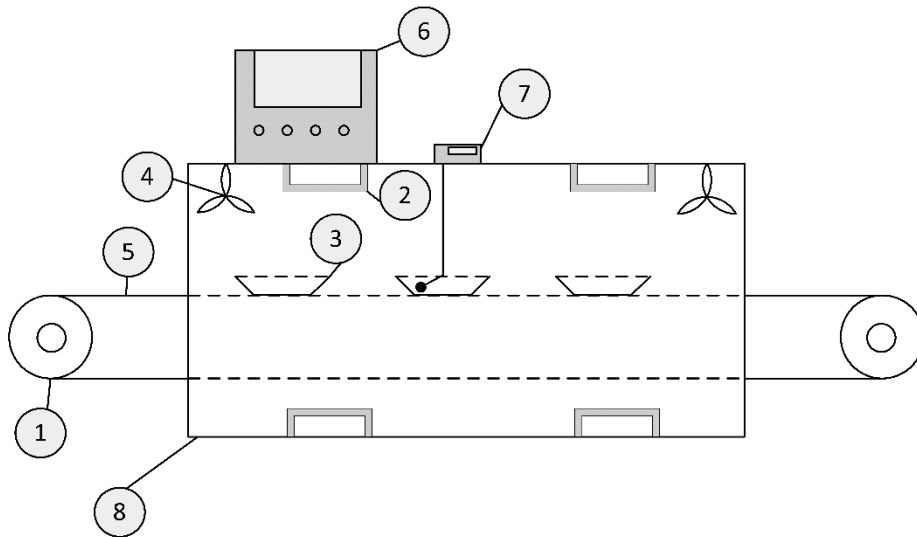
Figure 1. Semi-industrial microwave oven, process diagram.

1.- Motor

2.- Magnetron

3.- Sample

4.- Fan
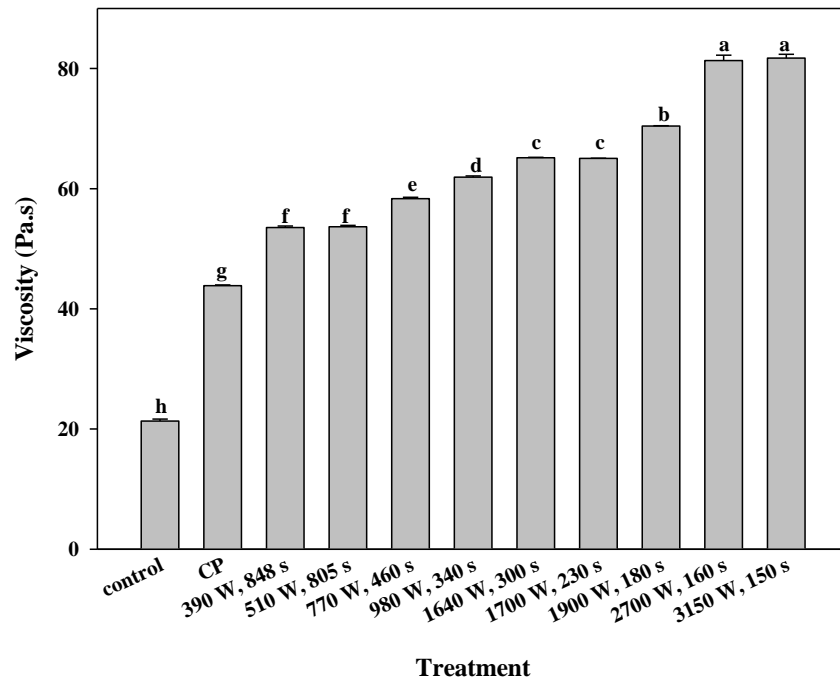
5.- Conveyor belt

6.- Control process

7.- Fiber optical temperature sensor

8.- Microwave chamber

533

Figure 2. Viscosity in unheated (control), conventional (CP) and microwave (MWP)

pasteurized tomato puree. Different letters indicate significant differences among mean

values ($p<0.05$).

537

Table 1. Color changes in unheated (control), conventional (CP) and microwave (MWP)

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

Values are mean $\pm$ 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.

544 **Table 2.** Total antioxidant capacity (TAC, mg AAE kg^{-1}), total phenolic compound (TPC, ChAE mg kg^{-1}),

545 Vitamin C (mg kg^{-1}), lycopene and β carotene (mg kg^{-1}) in unheated (control), conventional (CP) and

546 microwave pasteurized (MWP) tomato puree.

	Treatment	TAC	TPC	Vitamin C	Lycopene	β-carotene
MWP	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}
Doses	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}
Low	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}
Low	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}
Medium	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}
Medium	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}
High	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}
High	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}

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