

Inactivation of *Listeria monocytogenes* using water bath heat treatment in vacuum packed ricotta salata cheese wedges

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1 **Inactivation of *Listeria monocytogenes* using water bath heat treatment in vacuum packed**
2 **ricotta salata cheese wedges**

3

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16

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22

23 **ABSTRACT:** Ricotta salata cheese is frequently contaminated on the surface with *L.*
24 *monocytogenes*. Water bath heat treatment in vacuum packed whole ricotta salata cheese wheels
25 demonstrated to be effective in inactivating *L. monocytogenes*. However the risk of cross
26 contamination in ricotta salata wedges is increased during cheese cutting. Therefore, the
27 effectiveness of heat treatment in ricotta salata wedges has to be demonstrated conducting a new
28 validation study. In the present study nine different time temperature combinations, 75°C, 85°C and
29 90°C applied for 10 min, 20 min and 30 min each, were tested on artificially contaminated ricotta
30 salata cheese wedges. The extent of the lethal effect on *L. monocytogenes* was assessed one day and
31 30 days after the application of the hot water bath treatment. Five out of nine combinations, 75°C
32 for 30 min, 85°C for 20 and 30 min and 90°C for 20 and 30 min, demonstrated to meet the process
33 criteria of at least 5 log reduction. Sensory analyses were also conducted in order to account for the
34 potential impact on sensory features of ricotta salata wedges which showed no significant
35 differences between treatments.

36

37 **Keywords:** *Listeria monocytogenes*, Whey cheese, Post-lethality treatment, Sensory properties.

38

39 **Practical Application:**

40 The present study allowed to select water bath heat treatments of vacuum packed ricotta salata
41 wedges effective to reduce *L. monocytogenes* contamination. Such treatments can be successfully
42 applied by food business operator to meet compliance with microbiological criteria through the
43 designated shelf-life.

44

45 **Introduction**

46 Ricotta salata is a whey protein cheese largely produced in Sardinia (Italy) using the whey
47 remaining after the production of sheep's milk cheeses, mainly Pecorino Romano PDO (protected

48 denomination of origin). After filtration and pre-heating at temperature of 60-70°C, the whey is
49 heated in open kettles under gentle agitation for about 30 min to temperature of 85-90°C. As
50 consequence of whey protein coagulation, the curd starts floating on the surface and then is scooped
51 into perforated plastic hoops lined with cheesecloth. In order to increase drainage, the curd is
52 pressed for approximately 24 hours. Ricotta is salted by dry salting or by brine-salting and dried in
53 storage rooms under controlled temperature (10-12°C) and humidity for 10-15 days. The final
54 moisture of the product depends on its intended use, usually 53-55% if intended for grating and
55 between 55-60% if is to be consumed as such. Traditionally ricotta salata is a cylindrical shaped
56 wheel (ricotta “*Toscanella*”) with an average weight of approximately 3 kg, pH of 6.1-6.9, aw of
57 0.940-0.970, fat of 28-33%, protein of 14-23% and NaCl of 3-4% (Spanu and others 2012; Spanu
58 and others 2013; Spanu and others 2015a). Ricotta salata wheels are individually packed in vacuum
59 bags as a whole or after cutting into smaller wedges of ca. 200-300 g. Wedges are shaped as
60 triangular prisms with height, width and length of ca. 3.5 cm, 8.5 cm and 12 cm, respectively. The
61 shelf-life of the product differs from one business operator to another, but it usually ranges between
62 few weeks up to several months at refrigeration temperature. Despite the application of good
63 hygiene practices together with the application of procedures based on the HACCP principles
64 during manufacturing, recalls of ricotta salata produced in Sardinia due to *Listeria monocytogenes*
65 contamination have been reported in recent years (RASFF 2008; CDC 2012). Raw milk and whey
66 can be excluded as the origin of the contamination in consideration of heat treatments usually
67 applied during cheese making (i.e. thermization and pasteurization) and whey protein coagulation
68 (Buazzi and others 1992; Casadei and others 1998; ICMSF 1996; Villani and others 1996). *L.*
69 *monocytogenes* contamination in ricotta salata is generally limited to the product surfaces and
70 origins from the processing environment. Previous studies reported a prevalence of *L.*
71 *monocytogenes* in ricotta salata rind of ca. 20% (Pintado and Malcata, 2000; Lioliou and others
72 2001; Ibba and others 2013; Spanu and others 2015b). Contamination of ricotta salata is rarely

73 observed in the inner paste and is generally a consequence of flaws in the application of production
74 hygiene procedures (Spanu and others 2015a). Cutting ricotta salata wheels into smaller portions
75 and repacking for retail sale can expose the product to cross-contamination originating from utensils
76 used to cut the cheese, thus increasing the risk of *L. monocytogenes* contamination. Previous
77 investigation demonstrated a *L. monocytogenes* growth potential in contaminated ricotta salata
78 wheels of ca. $5 \log_{10} \text{ cfu g}^{-1}$ on the rind during the first two months of storage at refrigeration
79 temperature (Spanu and others 2012). This represents a serious concern in such product, since
80 ricotta salata does not have an actual rind and it is generally assumed to be whole edible. There is
81 evidence that food business operator cannot demonstrate compliance with microbiological food
82 safety criteria of 10^2 cfu g^{-1} at the time of consumption set by European Commission (EC)
83 Regulation No. 2073/2005 throughout the shelf-life. This issue is even more stringent considering
84 that ricotta salata is largely exported in North America where the limit recommended by FDA is
85 more restrictive, requiring the absence in 25 g.

86 Post-process decontamination procedures are widely used in ready to eat food industry to reduce the
87 risk of *L. monocytogenes* contamination in packaged products (Zhu and others 2005). These include
88 methods such as thermal pasteurization, irradiation and high-pressure referred to as post-lethality
89 treatments since they are applied to the final product or sealed package of product in order to reduce
90 or eliminate the level of pathogens resulting from contamination from post-lethality exposure (FSIS
91 2014; Spanu and others 2014). To describe the overall effect of a control measure on a specific
92 hazard at a step it is used the term *performance criterion* (PC), which is defined as: the effect in
93 frequency and/or concentration of a hazard in a food that must be achieved by the application of one
94 or more control measures to provide or contributes to an food safety objectives or appropriate level
95 of protection, as applicable (CAC, 2004).

96 Hot water bath treatments applied in whole ricotta salata cheese wheels have been previously
97 proven to be effective in reducing *L. monocytogenes* contamination on the rind up to $5\text{-}6 \log_{10} \text{ cfu}$

98 g⁻¹ (Spanu and others 2015a). However, a thermal treatment should take into account several factors
99 such as temperature-time combination, microbiological profile, composition and product size and
100 weight (Doyle and others 2001; Ray 2004; Sofos 2002; Yen and others 1991).

101 Effectiveness of the immersion of portioned vacuum packed ricotta salata in hot water bath needs to
102 be validated with an ad hoc study.

103 The aim of the present study was to evaluate the efficacy of hot water bath treatment on the
104 reduction of *L. monocytogenes* in artificially contaminated ricotta salata wedges. Nine different
105 temperature-time combinations were compared in order to identify the process criteria required to
106 deliver a 5 log reduction of *L. monocytogenes* concentration. The impact of post-lethality treatments
107 on sensory properties of ricotta salata has been also evaluated. Inactivation of *L. monocytogenes*
108 was assessed 24 hours and 30 days after the treatment. The suitable treatment combination will be
109 selected to conduct a successive shelf -life study to assess compliance of treated ricotta salata
110 wedges for the designated durability.

111

112 **Materials and methods**

113

114 *Ricotta salata samples*

115 A local cheese-making plant supplied 465 vacuum packed ricotta salata wedges, obtained from the
116 whey remaining after the production of sheep milk cheeses. Ricotta salata samples belonged to 3
117 different production batches (155 from each batch). Ricotta salata wedges were transported and
118 stored at refrigeration temperature (4±2°C) until use for the experiment within 24 h. Part of ricotta
119 salata wedges (inoculated units) were artificially contaminated with *L. monocytogenes* while
120 another part (uninoculated units) was not contaminated. Inoculated units included ricotta salata
121 samples submitted to heat treatment, or experimental units (EUs), used to assess the efficacy of the
122 treatment and positive controls (PCs), used to check for the inoculum level. Uninoculated samples

123 included blank samples (BLs), used to evaluate the level of natural contamination of ricotta salata
124 with *L. monocytogenes*; sensory units (SEs) used to evaluate sensory properties after heat treatment;
125 composition units (CUs) samples used for the determination of intrinsic properties (pH and aw) and
126 composition (moisture, fat and proteins). Detailed description of the number of ricotta salata
127 wedges included in each of the sample types is showed in table 1.

128

129 *Artificial contamination*

130 The artificial contamination of EUs and PCs ricotta salata wedges was conducted according to the
131 Technical Guidance document prepared by the EU Community Reference Laboratory (CRL) for *L.*
132 *monocytogenes* (Beaufort and others 2014). In the preparation of the inoculum was used a mixture
133 of 5 *L. monocytogenes* strains composed by the reference strain ATTC 19111 (serovar 1/2a)
134 obtained from American Type Culture Collection (Manassas, VA, USA) and by other four wild-
135 type strains (respectively serotypes 1/2a, 1/2b, 1/2c and 4b), previously recovered from the cheese-
136 making plant environments or from ricotta salata. Selection of strains and preparation of the
137 inoculum have been previously described (Spanu and others 2015a). The target level of
138 contamination was $5 \log_{10} \text{ cfu g}^{-1}$ of rind, which was obtained spraying ricotta salata wedges with 2
139 mL of inoculum at a concentration of 10^7 cfu mL^{-1} . The concentration of the inoculum was
140 confirmed by plate count on Trypticase Soy Agar (TSA, Biolife, Milan, Italy). The whole surface of
141 ricotta salata wedges was evenly sprayed using an atomizer. Before ricotta salata samples were
142 individually vacuum packed in shrink bags (Criovac Cook-In HT-3000, Sealedair Ltd., St Neots,
143 UK) a holding period of 15 min at room temperature was allowed to let the inoculum attach (Health
144 Canada, 2012). Vacuum packed ricotta salata wedges were then stored in cold room at $4 \pm 2^\circ\text{C}$ until
145 further analyses. The inoculum was performed under a microbiological safety cabinet and the
146 operator worn protection devices.

147

148 *Heat treatment and testing times*

149 Independent trials were conducted for each of the three production batches. The post-lethality
150 treatment was performed by immersion of vacuum packed ricotta salata wedges in a stainless steel
151 vat containing hot water. Nine different temperature-time conditions were tested: 75°C, 85°C and
152 90°C applied for 10 min, 20 min and 30 min each. Ricotta salata samples used for each treatment
153 condition are reported in table 1. Once treated, in order to firm up ricotta salata wedges, the samples
154 were immersed for approximately 2 hours in iced water and then stored at 4±2°C until analysis. The
155 testing times (T) were: T₀ which was the day of the artificial contamination and heat treatment; T₁
156 and T₃₀ which were respectively 24 hours and 30 days after heat treatment. At T₀ were analyzed
157 PCs to assess if the level of contamination was effectively 10⁵ log₁₀ cfu g⁻¹ and BLs to check for
158 eventual natural contamination of ricotta salata with *L. monocytogenes*. The EUs and CUs were
159 submitted to heat treatment and analysed at T₁ and T₃₀. The SE units were either submitted to heat
160 treatment (SEt) or used as negative controls (SEc). Types of ricotta salata samples, analysis
161 performed and sampling times are summarized in Table 2. Temperatures obtained during treatments
162 were monitored using datalogger (KT 20T, Kimo, Montpon Ménéstérol, France) positioned on the
163 surface of an additional ricotta salata sample. Loggers were button shaped stainless steel recorder
164 with a diameter of ca. 17 mm and height < 6 mm which were inserted with their lower side 0.5 cm
165 deep in the paste and their upper side in the interface between ricotta rind and packaging bag.

166

167 *Microbiological analysis*

168 Ricotta salata rind was aseptically collected cutting the wedges surfaces up to 2 cm in depth.
169 Detection and enumeration of *L. monocytogenes* (ISO 11290-1:1996/Amd 1:2004; ISO 11290-
170 2:1998/Amd 1:2004) and enumeration of aerobic mesophilic bacteria (ISO 4833:2003) were
171 conducted in accordance with standard methods. The potential presence of sublethally injured cells
172 that may survive the heat treatment but may not be cultured on selective media was investigated

173 using the Thin Agar Layer (TAL) method (Kang & Fung, 1999; Wu & Fung, 2001). This method
174 combines the ability of nonselective agar media to growth injured cells and of selective media to
175 differentiate microorganism. Preliminary identification of *L. monocytogenes* was confirmed by
176 picking 5 suspected colonies from each positive sample which were submitted to phenotypic and
177 molecular identification (Doumith and others 2004; De Santis and others 2007). To confirm that
178 strains recovered at T₃₀ were the same as the ones used in the inoculum, a selection (up to 5 strains
179 from each temperature time combination) was submitted to pulsed-field gel electrophoresis (PFGE),
180 according to the protocol proposed by Graves and Swaminathan (2001). The PCR serogroups were
181 used as preliminary screening criteria of isolates to be submitted to PFGE. Comparison of
182 restriction profiles allowed to differentiate between inoculated strains and strains originating by
183 natural contamination.

184

185 *Centesimal composition and intrinsic factors*

186 Ricotta salata centesimal composition (fat, moisture, protein, total solids and sodium chloride) and
187 intrinsic factors (pH and a_w) were determined to account for possible interaction with *L.*
188 *monocytogenes* survival and growth. Compositional data were obtained by near infrared
189 transmittance (NIT) using a compositional analyzer (FOSS, Eden Prairie, MN, USA), while pH and
190 a_w were measured using pH meter GLP22 (Crison Instruments SA, Barcelona, Spain) and water
191 activity meter Aqualab 4TE (Decagon, Pullman, WA, USA), respectively. Comparison of
192 centesimal composition and intrinsic factors ($\bar{x} \pm SD$) of ricotta salata wedges submitted to heat
193 treatment with the nine different temperature-time combinations and over time (T₁ and T₃₀) was
194 conducted using the Fisher's least significant difference (LSD) test, performed with Statgraphics
195 Centurion XVI software (StatPoint Technologies, Warrenton, VA, USA).

196

197 *Sensory analysis*

198 The "Difference from control test" allowed to determine if a significant difference between the
199 treated (SEt) samples and the negative control (SEc) exist and to estimate the size of this difference
200 (Meilgaard and others 1999). In order to quantify the experimental noise (*placebo* effect), the
201 control sample (SEc) must be served during each session both as reference and as blind sample.
202 This cause a sensory fatigue especially if all of nine time-temperature combinations samples have to
203 be taken into account, for this reason the sensory analysis was restricted to only five heat treatments
204 corresponding to the lowest and highest time-temperature combinations (75°C and 90°C, 10 min
205 and 30 min) and the central point (85°C treated for 20 min). All of these heat treatments were
206 performed and evaluated in triplicate. Thirty assessors equally distributed between females and
207 males, aged from 25 to 50 years were selected after attending a course of 60 hours in sensory
208 analysis (ISO 8586-1: 1993) applied to dairy products. Assessors were asked to determine the
209 difference between the control sample (SEc) and the blind coded test sample (SEt) on a numerical
210 ten points scale (0 = no difference and 9 = very large difference). The Ricotta salata wedges were
211 portioned into parallelepiped pieces (5 x 1.5 x 1.5 cm) and served in a randomized and balanced
212 order (Macfie and others 1989), in odorless plastic containers marked with a random three-digit
213 number (Meilgaard and others 1999) at room temperature. Assessors were also provided with an
214 unsalted cracker and a glass of water in order to rinse their mouth after each evaluation. Raw data
215 (n=540) were analyzed by the two-way ANOVA ($P \leq 0.05$) using the Statgraphics Centurion XVI
216 software (StatPoint Technologies, Warrenton, VA, USA).

217

218 *Validation of heat treatment*

219 The effectiveness of each of the nine heat treatment combinations was evaluated computing the
220 minimum difference between *L. monocytogenes* concentration (\log_{10} cfu g⁻¹) before the treatment
221 (T₀) and after the treatment (T₁ and T₃₀) and expressed as performance criterion or performance

222 standard (Δ). The Δ was computed independently for each of the three production batches and for
223 each value was obtained from triplicate samples.

224

225 *Statistical analysis*

226 Comparison of Mean mesophilic bacteria counts (\log_{10} cfu g^{-1}), intrinsic properties ($\bar{x}\pm SD$) and
227 centesimal composition ($\%\pm SD$) between temperature-time combinations at T_1 and T_{30} was
228 conducted using Fisher's least significant difference (LSD) test. All statistical analyses were
229 performed with Statgraphics Centurion XVI software (StatPoint Technologies, Warrenton, VA,
230 USA).

231

232 **Results**

233 *L. monocytogenes* contamination and background microflora

234 In all BLs natural contamination with *L. monocytogenes* was never observed. In artificially
235 contaminated ricotta salata wedges (PCs) *L. monocytogenes* mean count expressed as \log_{10} cfu g^{-1}
236 ($\bar{x}\pm SD$) was 5.24 ± 0.11 , 5.4 ± 0.05 and 5.03 ± 0.4 in the first, second and third batch, respectively.
237 Aerobic mesophilic bacteria enumeration ($\bar{x}\pm SD \log_{10}$ cfu g^{-1}) in BLs was 4.86 ± 0.31 , 6.44 ± 0.46 ,
238 6.53 ± 0.41 while in PCs was 5.67 ± 0.19 , 7.12 ± 0.26 and 6.35 ± 0.62 in the first, second and third
239 batch respectively. At T_0 the reduction in mean \log_{10} cfu g^{-1} total bacterial counts changed
240 according to temperature, ranging between ca. 1.5 and 3.0 for ricotta treated at $75^\circ C$ and up to 5.0
241 for treatment at $85^\circ C$ and $90^\circ C$, while bacterial counts at T_{30} was a function of the time of heat
242 treatment, with an average increase of 2.5-3.0 observed only in ricotta samples treated for 10 min.
243 Pair-wise comparison of aerobic mesophilic bacteria counts between temperature-time
244 combinations at T_1 and T_{30} is reported in table 3.

245

246 *Post lethality treatment*

247 The fate of *L. monocytogenes* (inactivation, survival or growth) was assessed for each temperature-
248 time combination at T₁ and T₃₀. Despite treatment applied for 10 min showed a certain degree of
249 reduction of *L. monocytogenes* concentration at T₀ (between ca. 1 log at 75°C and 5 log at 90°C), in
250 the successive 30 days of refrigerated storage *L. monocytogenes* concentration increased to levels as
251 high as the initial contamination or even higher. After the water bath treatment applied for 30 min
252 with all three different temperatures, *L. monocytogenes* was not recovered with the detection
253 method, suggesting a full efficacy of treatments (figure 1). The treatments for 20 min were not
254 effective only for the lowest temperature tested. The performance standard or Δ of each of the nine
255 treatment combinations is reported in table 4.

256

257 *L. monocytogenes* strains characterization

258 Overall, 217 strains were confirmed as *L. monocytogenes* by molecular identification, 45 from PCs
259 and 172 from EUs, respectively. Of the strains recovered from PCs, 11 belonged to serogroup 1/2a,
260 12 to serogroup 1/2b, 3 to serogroup 1/2c and 19 to serogroup 4b. Of the strains recovered from
261 EUs 68 (39.5%) were serogroup 1/2a, 48 (27.9%) serogroup 1/2b, 32 (18.6%) serogroup 1/2c and
262 24 (13.9%) serogroup 4b. Comparison of PFGE profiles of the 48 *L. monocytogenes* strains selected
263 from EUs at T₃₀ showed identical profiles with strains used to contaminate the ricotta salata wedges.
264 None of the strains showed similar profile with the reference strain ATCC 19111.

265

266 *Temperature monitoring*

267 The temperature recorded on ricotta salata rind before hot water bath treatment was 3.7±0.5°C. The
268 graph in figure 2 shows the evolution of the temperature on ricotta salata rind over time for each of
269 the three water temperature used during treatments.

270

271 *Ricotta salata composition*

272 Intrinsic properties values ($\bar{x}\pm\text{SD}$) determined on the 18 BLs were 6.40 ± 0.16 for pH and
273 0.977 ± 0.01 for a_w , while composition values ($\%\pm\text{SD}$) were respectively of 53.92 ± 3.29 for moisture,
274 21.50 ± 3.75 for fat, 16.50 ± 1.52 for proteins and 3.42 ± 0.28 for NaCl. Composition analysis was also
275 conducted on 162 treated samples (CUs) and differences in intrinsic properties and composition
276 between the 9 treatment combinations at T_1 and T_{30} are reported in table 5. Ricotta salata wedges
277 pH and a_w showed no significant difference with respect to the heat treatment ($P>0.05$) and were
278 always above the lower limits for *L. monocytogenes* growth.

279

280 *Sensory features*

281 Difference from the control test performed by ANOVA showed no significant difference ($P=0.45$)
282 (treatment effect) between the control sample (SEc) and the test sample (SEt) (table 6). Mean and
283 standard deviation of the control, provided as blind samples (blind control), are statistically
284 comparable with the means and the standards deviation of the heat treated samples, indicating that
285 the heat treatment do not produce an effect greater than the experimental noise. Since all of the five
286 heat treated samples, the lowest and highest time-temperature combinations (75°C and 90°C , 10
287 min and 30 min) and the central point (85°C treated for 20 min), are not significant different, it is
288 reasonable to extend the same result on the four time-temperature combinations included in this
289 field and not evaluated by the sensory analysis: (85°C for 10 min and 30 min, 75°C and 90°C for 20
290 min). Moreover the ANOVA shows that also the factor “replicate” is not significant ($P=0.84$) (table
291 6) validating both the heat treatments and the sensory analysis.

292

293 **Discussion**

294 Contamination of ricotta salata with *L. monocytogenes* is mainly a post process contamination
295 originating from the processing environment and is generally limited to the rind (Pilo and others
296 2007). This represents a serious concern since ricotta salata wedges are consumed as such and the

297 rind is edible. Ricotta salata production includes pressing of the curd which could favour deepening
298 of the microorganism in the first centimeters of the paste. In addition the risk of cross contamination
299 in ricotta salata wedges is increased by transfer of the microorganism through blades during
300 mechanical cutting. Despite the contamination of ricotta salata with *L. monocytogenes* is not a rare
301 finding, the observed prevalence could range from 0.0% to as high as 20.0-30% (Spanu and others
302 2015b), in the present study was never detected from blank samples. The processing environment
303 represents the main contamination route. Therefore, the reason for this wide variability of
304 contamination between premises is largely due to difference in the implementation of good hygienic
305 and good manufacturing practices by the processor. A cheesemaking plant of proven history in
306 implementing and maintaining hygienic procedures provided ricotta salata samples used in the
307 present study. In addition, in order to avoid as much as possible the occurrence of natural
308 contamination, the production of ricotta salata batches intended to be used in the present study
309 where monitored, to guarantee that all the necessary measure where put in place to limit
310 contamination of the product. However, in many circumstances the prevention of environmental
311 contamination is almost impossible to avoid by the mere use of hygienic measures. Therefore, it is
312 essential for food business operator to implement strategies to control the contamination in order to
313 comply with microbiological limits for *L. monocytogenes* in RTE foods. A number of post-lethality
314 treatments have been proposed, among which hot water bath of vacuum packed ricotta salata
315 demonstrated to be effective (Spanu and others 2013; Spanu and others 2015a). The present study
316 evaluated the listericidal effect of nine different water bath temperature-time combinations in
317 vacuum packed ricotta salata wedges. The performance criterion of the treatment was to reduce *L.*
318 *monocytogenes* concentration of 5 log cfu g⁻¹ from ricotta salata surface. In order to account for the
319 potential presence of sublethally injured cells, which during this period may recover their ability to
320 growth, the fate of *L. monocytogenes* was evaluated also after 30 days of refrigerated storage.
321 Efficacy of treatments was conditioned by exposition time rather than temperature. None of the

322 treatments applied for 10 min resulted effective, while all temperatures inactivated *L.*
323 *monocytogenes* when the treatment was prolonged up to 30 minutes. Intermediate situation was
324 observed for the 20 minutes treatments which were effective at 85°C and 90°C. Although *L.*
325 *monocytogenes* was inactivated to some extent (ca. 4 log) by treatments at 85°C and 90°C for 10
326 minutes, the cells surviving to the heat treatment increased in the subsequent storage to levels as
327 high as 5 log. Temperatures registered by dataloggers on ricotta salata surface explain the effect on
328 *L. monocytogenes* inactivation. Treatments conducted at 75°C only when applied for 30 min
329 allowed to obtain temperature on the product > 70°C which were maintained for 10 min, while after
330 the 10 min and 20 min treatments the maximum temperature registered were respectively 65.5°C
331 and 70°C. Although the treatment at 85°C for 10 min reached 72.6°C, it stayed above 70°C on
332 ricotta surface only for 2 min, justifying the survival of *L. monocytogenes*. Treatments at 85°C for
333 20 min and 30 min guaranteed on ricotta surface temperature above 70°C for 12 min and 23 min,
334 respectively. Similar behavior was observed for treatment at 90°C for 10 min which reached 76.3°C
335 on the product surface but temperature above 70°C were maintained only for 4 min. The 90°C for
336 20 min and 30 min hesitated in maximum temperature of 84.6°C and 88.1°C on ricotta rind which
337 were above 70°C for 14 min and 24 min respectively. Strains capable to survive and growth after
338 heat treatment belonged to the wild type, suggesting that they are characterized by a greater
339 resistance or a better adaptation to the substrate as compared with reference strains. However it
340 should be considered that the actual temperature recorded by dataloggers is the balance between hot
341 water bath temperature at the interface product-packaging and cold product temperature on the
342 lower face of the datalogger. Despite differences in treatment efficacy, the sensory analysis reveals
343 that the heat treated samples (SEt) are not significant different from the untreated control samples
344 (SEc), indicating that any heat treatments between 75°C for 10 min and 90°C for 30 min does not
345 affect the sensory properties of ricotta salata wedges.

346

347 **Conclusion**

348 Superficial contamination of ricotta salata rind with *L. monocytogenes* is difficult to avoid even
349 with strict production hygiene procedures. Compliance with microbiological limits could be
350 obtained with the application of control strategies aimed to reduce the contaminations originating in
351 the post-processing environment. Post-lethality treatments such as hot water bath applied on
352 packaged ricotta salata are effective and feasible treatment to kill *L. monocytogenes* from ricotta
353 salata surface. Eligible treatments in ricotta salata wedges are 75°C for 30 min, 85°C for 20 and 30
354 min and 90°C for 10, 20 and 30 min. These treatments should not be intended as an alternative
355 measure to good manufacturing and good hygiene practices but rather an additional tool to obtain
356 compliance with microbiological criteria.

357

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364

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366 contribution for the study designing, data analysis and interpretation of the results. Carlo Pala,
367 Daniele Casti, Sonia Lamon, Francesca Cossu and Michela Ibba collected the samples and
368 performed the experiments. Riccardo Di Salvo, Carlo Piga, Antonio Ullu performed the sensory
369 analyses. Enrico Pietro Luigi De Santis coordinated the research group. All the authors participated
370 to the manuscript drafting and revising.

371

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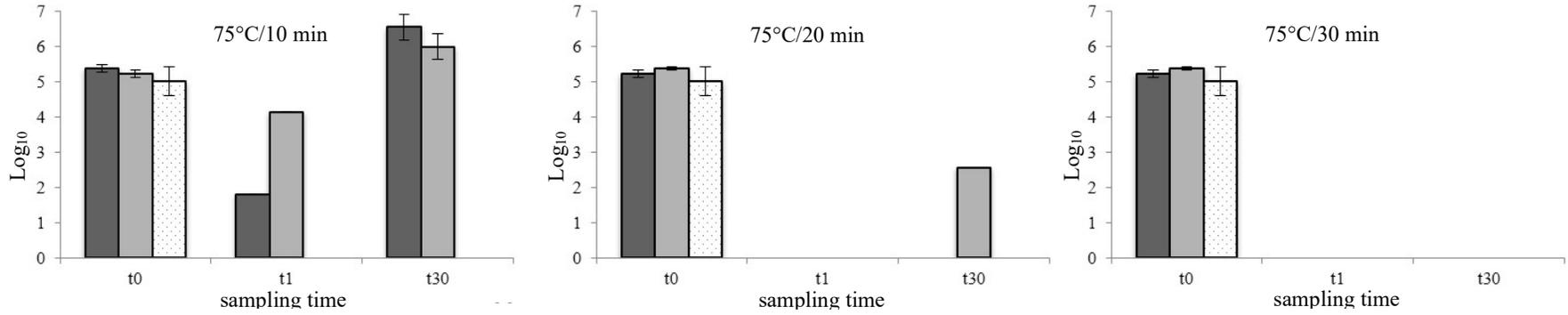
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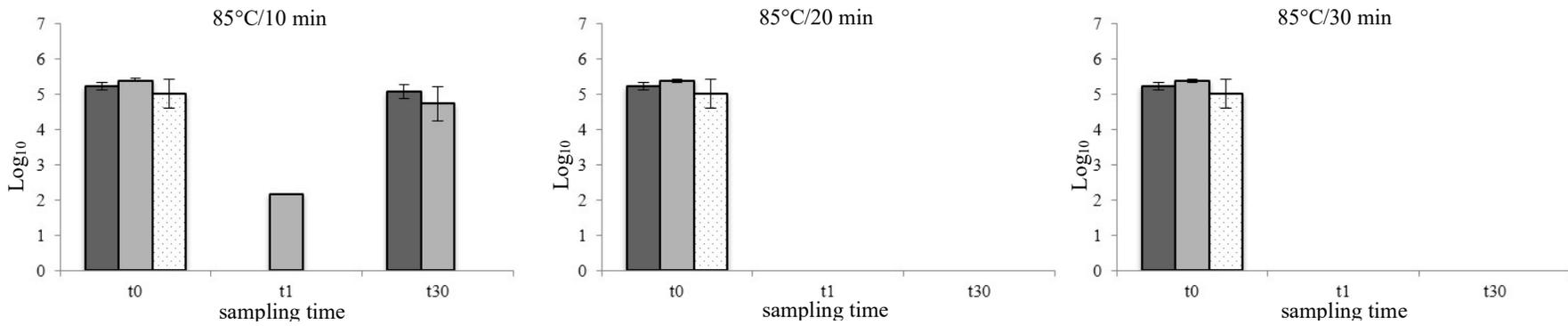
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496 Figure 1. Inactivation of *L. monocytogenes* (\log_{10} cfu g^{-1}) in artificially contaminated ricotta salata wedges analyzed 24 h (T_1) and 30 days (T_{30}) after
497 water bath heat treatment with 9 temperature time combinations.

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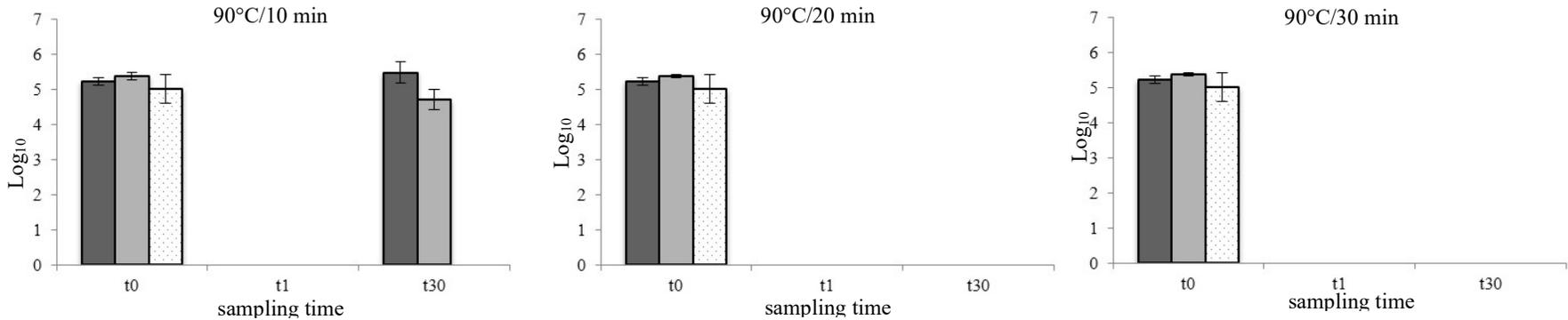


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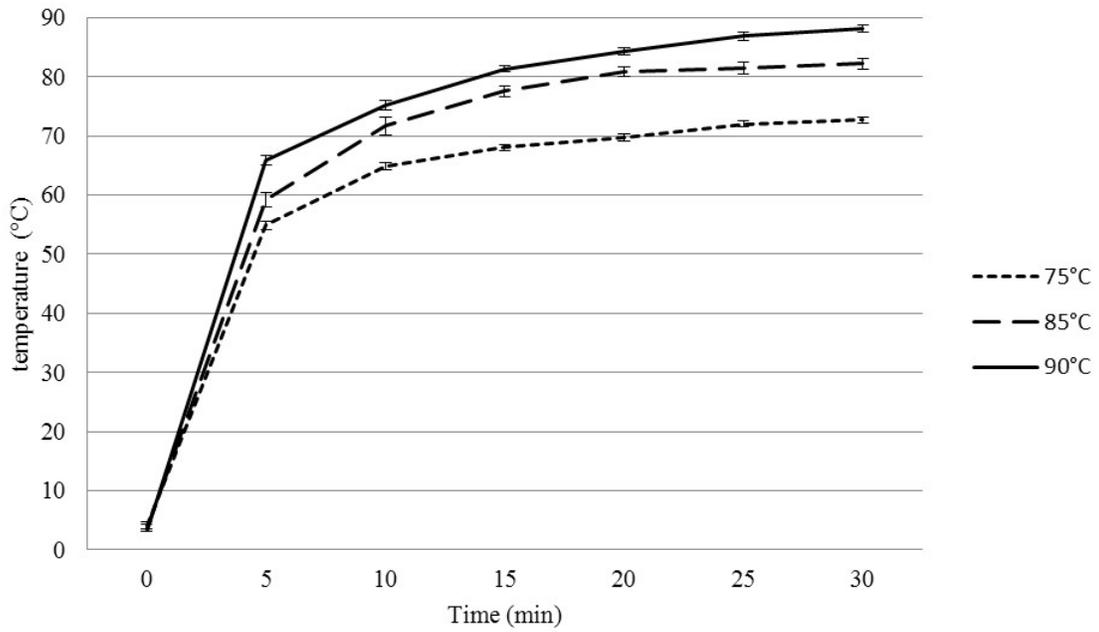
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505 ■ = replicate a; ■ = replicate b; ■ = replicate c; Sample size: t0 n = 3 for each replicate; t1 and t30 n = 3 for each replicate and
506 temperature/time combination.

507 **Figure 2.** Temperatures recorded during water bath heat treatment on the interface ricotta salata
508 rind packaging bag surface.



509 Each data point is the mean of temperatures recorder in the three replicates (batch A, B and C).
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523 Table 1. Types of treatment and ricotta salata wedges samples used in the hot water bath validation study.

Temperature-time condition		Ricotta salata samples					Total
Temperature	Minutes	BL ¹	PC ²	EUs ³	CUs ⁴	SEs ⁵	
No treatment	-	18	9	-	-	42	69
75°C	10	-	-	18	18	12	48
	20	-	-	18	18	3	39
	30	-	-	18	18	12	48
85°C	10	-	-	18	18	3	39
	20	-	-	18	18	12	48
	30	-	-	18	18	3	39
90°C	10	-	-	18	18	12	48
	20	-	-	18	18	3	39
	30	-	-	18	18	12	48
Total		18	9	162	162	114	465

524 ¹BLs (Blank Samples): not inoculated units; ²PCs (Positive Controls): samples inoculated with *L.*
525 *monocytogenes*; ³EUs (Experimental Units): samples inoculated with *L. monocytogenes* and successively
526 heat treated; ⁴CUs (Composition Units): heat treated units for physico-chemical analysis; ⁵SEs (Sensory
527 Units): samples used to assess the effect of heat treatment on sensory properties.

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536 Table 2. Types of ricotta salata samples, analysis and testing times.

Analysis	Test units	Sampling time			Total
		T ₀ ^a	T ₁ ^b	T ₃₀ ^c	
Detection and enumeration of <i>L. monocytogenes</i> and aerobic mesophilic bacteria	BLs ¹	18	-	-	18
	PCs ²	9	-	-	9
	EUs ³	-	81	81	162
	CUs ⁴	-	81	81	162
Intrinsic properties and composition	BLs ¹	18	-	-	-
	CUs ⁴	-	81	81	162
Sensory analysis	SEs ⁵				38

537 Superscript letters are referred to the time between inoculation and analysis: ^a = day of inoculum and heat
 538 treatment; ^b = 24 hours after heat treatment; ^c = 30 days after heat treatment. Superscript numbers are referred
 539 to test units: ¹BLs (Blank Samples): not inoculated units; ²PCs (Positive Controls): samples inoculated with
 540 *L. monocytogenes*; ³EUs (Experimental Units): samples inoculated with *L. monocytogenes* and successively
 541 heat treated; ⁴CUs (Composition Units): heat treated units for physico-chemical analysis; ⁵SEs (Sensory
 542 Units): samples used to assess the effect of heat treatment on sensory properties.

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552 Table 3. Comparison of aerobic mesophilic bacteria counts (\log_{10} cfu g^{-1} ; $\bar{x} \pm \text{SD}$) of heat treated ricotta
 553 salata wedges with 9 different temperature-time combinations analyzed 24 h after the treatment (T_1) and after
 554 storage at refrigeration temperature for 30 days (T_{30}).

Treatment		Aerobic mesophilic bacteria			
Temperature	Minutes	+ve/n	T_1	+ve/n	T_{30}
75°C	10	8/9	3.89± 0.90 ^A	9/9	6.64±0.27 ^A
	20	5/9	3.14± 1.08 ^A	7/9	3.01±0.38 ^C
	30	2/9	3.41± 0.58 ^{AB}	1/9	1.48±0.0 ^C
85°C	10	6/9	3.04± 1.14 ^{ABC}	9/9	5.51±1.18 ^B
	20	3/9	1.10± 0.17 ^D	5/9	1.91±0.75 ^C
	30	2/9	1.15± 0.21 ^D	2/9	1.67±0.95 ^C
90°C	10	7/9	1.98± 0.93 ^{BCD}	8/9	5.08±1.55 ^C
	20	1/9	1.00± 0.0 ^{CD}	1/9	1.48±0.0 ^C
	30	1/9	1.00± 0.0 ^{CD}	1/9	1.00±0.0 ^C

555 Means in the same column on the same testing time (T_1 or T_{30}) with different superscript letter are
 556 significantly different ($P \leq 0.05$). +ve/n are the number of samples where aerobic mesophilic bacteria could
 557 be enumerated.

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570 Table 4. Enumeration, detection and reduction (Δ)a of *Listeria monocytogenes* on the surface of ricotta salata wedges artificially contaminated and heat treated in
 571 hot water bath with different temperature-time combinations.

Treatment			<i>L.monocytogenes</i>							
Temperature	Minutes	Batch	T ₁			T ₃₀				
			Enumeration		Δ	Detection in 25 g	Enumeration		Δ	Detection in 25 g
			+ve/n	log ₁₀ cfu/g	T ₁ -T ₀	+ve /n	+ve/n	log ₁₀ cfu/g	T ₃₀ -T ₀	+ve /n
75 °C	10	A	1/3	4.16±0.00	-0.99	3/3	3/3	6.01±0.37	1.28	3/3
		B	2/3	1.82±1.16	-2.73	3/3	3/3	6.56±0.47	1.73	3/3
		C	0/3	ND	-4.76	3/3	3/3	6.01±0.38	1.63	3/3
	20	A	0/3	ND	-5.15	0/3	3/3	ND	-5.15	0/3
		B	0/3	ND	-5.36	0/3	1/3	2.57±0.00	2.79	1/3
		C	0/3	ND	-4.76	0/3	0/3	ND	-4.76	0/3
	30	A	0/3	ND	-5.15	0/3	0/3	ND	-5.15	0/3
		B	0/3	ND	-5.36	0/3	0/3	ND	-5.36	0/3
		C	0/3	ND	-4.76	0/3	0/3	ND	-4.76	0/3
85 °C	10	A	0/3	ND	-5.15	2/3	2/3	5.09±0.20	0.08	2/3
		B	1/3	2.18±0.00	-3.18	3/3	3/3	4.74±0.49	-0.29	3/3
		C	0/3	ND	-4.76	0/3	0/3	ND	-0.25	0/3
	20	A	0/3	ND	-5.15	0/3	0/3	ND	-5.15	0/3
		B	0/3	ND	-5.36	0/3	0/3	ND	-5.36	0/3
		C	0/3	ND	-4.76	0/3	0/3	ND	-4.76	0/3
	30	A	0/3	ND	-5.15	0/3	0/3	ND	-5.15	0/3
		B	0/3	ND	-5.36	0/3	0/3	ND	-5.36	0/3
		C	0/3	ND	-4.76	0/3	0/3	ND	-4.76	0/3
90 °C	10	A	0/3	ND	-5.15	3/3	3/3	5.48±0.30	0.67	3/3
		B	0/3	ND	-5.36	1/3	2/3	4.72±1.83	0.65	2/3
		C	0/3	ND	-4.76	2/3	3/3	5.58±0.07	0.88	3/3
	20	A	0/3	ND	-5.15	0/3	0/3	ND	-5.15	0/3
		B	0/3	ND	-5.36	0/3	0/3	ND	-5.36	0/3
		C	0/3	ND	-4.76	0/3	0/3	ND	-4.76	0/3
	30	A	0/3	ND	-5.15	0/3	0/3	ND	-5.15	0/3
		B	0/3	ND	-5.36	0/3	0/3	ND	-5.36	0/3
		C	0/3	ND	-4.76	0/3	0/3	ND	-4.76	0/3

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573 ^aValues are the difference between concentration (\log_{10} cfu g^{-1}) the day of artificial inoculation (T_0) and 24 hours (ΔT_1) and 30 days (ΔT_{30}) after treatment. For
574 each batch and for each temperature-time combination values are the minimum difference between the initial contamination level and the maximum count after
575 the treatment in the triplicate samples. +ve/n are the number of samples where *L. monocytogenes* could be enumerated. ND are the samples where *L.*
576 *monocytogenes* was below the detection limit.

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594 Table 5. Intrinsic properties ($\bar{x} \pm SD$) and composition ($\% \pm SD$) of ricotta salata submitted to 9 different heat treatment combinations and analyzed 24 h (T_1) and
 595 30 days (T_{30}) after storage at refrigeration temperature.

Treatment		pH		a_w		Moisture %		Fat %		Proteins %		NaCl %	
Temperature	Min	T_1	T_{30}	T_1	T_{30}	T_1	T_{30}	T_1	T_{30}	T_1	T_{30}	T_1	T_{30}
75°C	10	6.36±0.1 3 ^a	6.30±0.1 2 ^a	0.975±0.0 1 ^a	0.976±0.0 0 ^a	52.94±2.5 8 ^a	52.69±3.3 3 ^a	20.49±2.2 0 ^a	22.88±4.1 6 ^a	18.00±1.7 4 ^a	16.30±1.5 6 ^a	3.30±0.5 2 ^a	3.36±0.26 ab
	20	6.33±0.1 0 ^a	6.27±0.1 4 ^a	0.976±0.0 0 ^a	0.977±0.0 1 ^a	53.50±2.9 1 ^a	54.85±3.1 5 ^a	21.45±4.0 8 ^a	20.67±3.5 8 ^a	17.16±1.3 5 ^a	16.75±1.6 2 ^{ab}	3.23±0.3 6 ^a	3.46±0.22 abc
	30	6.38±0.1 0 ^a	6.23±0.1 7 ^a	0.977±0.0 0 ^{ab}	0.977±0.0 0 ^a	53.04±2.8 4 ^a	54.05±2.6 4 ^a	20.96±2.2 8 ^a	22.23±3.1 6 ^a	18.13±1.5 0 ^a	16.20±1.2 8 ^a	3.25±0.1 5 ^a	3.34±0.26 ab
85°C	10	6.35±0.0 8 ^a	6.24±0.1 3 ^a	0.978±0.0 0 ^{ab}	0.976±0.0 0 ^a	53.21±3.5 7 ^a	54.41±2.8 6 ^a	20.92±2.6 5 ^a	20.62±2.2 3 ^a	17.85±1.7 2 ^a	16.62±1.1 2 ^{ab}	3.31±0.2 6 ^a	3.56±0.38 bc
	20	6.36±0.1 1 ^a	6.27±0.0 7 ^a	0.979±0.0 0 ^{ab}	0.975±0.0 0 ^a	54.67±2.0 7 ^a	53.43±4.1 0 ^a	20.15±2.0 8 ^a	20.61±2.1 1 ^a	17.29±1.5 0 ^a	18.19±2.2 5 ^b	3.31±0.2 3 ^a	3.52±0.22 a
	30	6.39±0.0 9 ^a	6.28±0.0 8 ^a	0.979±0.0 0 ^{ab}	0.980±0.0 1 ^a	54.13±3.6 5 ^a	55.31±3.6 3 ^a	20.42±2.0 5 ^a	20.41±1.9 6 ^a	18.04±2.1 7 ^a	17.15±2.1 9 ^{ab}	3.22±0.2 6 ^a	3.28±0.18 a
90°C	10	6.40±0.1 1 ^a	6.26±0.1 3 ^a	0.981±0.0 1 ^b	0.978±0.0 1 ^a	53.27±3.4 2 ^a	55.02±3.9 8 ^a	22.33±3.8 9 ^a	20.51±3.3 7 ^a	16.99±1.7 7 ^a	16.82±1.4 5 ^{ab}	3.24±0.2 7 ^a	3.43±0.28 abc
	20	6.39±0.1 1 ^a	6.25±0.1 1 ^a	0.981±0.0 1 ^b	0.977±0.0 1 ^a	53.65±4.0 2 ^a	54.02±2.8 0 ^a	21.00±3.0 0 ^a	21.28±2.3 8 ^a	17.91±1.9 7 ^a	17.44±1.7 1 ^{ab}	3.35±0.3 5 ^a	3.61±0.27 c
	30	6.34±0.0 9 ^a	6.24±0.0 8 ^a	0.981±0.0 1 ^b	0.978±0.0 1 ^a	54.92±2.8 4 ^a	54.73±4.0 2 ^a	20.84±2.9 3 ^a	21.53±3.7 4 ^a	16.88±0.9 7 ^a	16.97±1.6 1 ^{ab}	3.41±0.2 7 ^a	3.42±0.20 abc

596 Each data point is the mean of three samples. For each parameter means in the same column on the same testing time (T_1 or T_{30}) with different superscript letter
 597 are significantly different ($P \leq 0.05$).

598

599

600 Table 6. Means and Standard deviation of sensory results

Treatment	Differences from the control
Blind control	3.0 ^a ± 2.1
75°C x 10 min	2.9 ^a ± 2.0
75°C x 30 min	3.3 ^a ± 2.2
85°C x 20 min	3.5 ^a ± 2.3
90°C x 10 min	3.1 ^a ± 2.1
90°C x 30 min	3.1 ^a ± 1.9

601 Mean values with different superscript letters are significantly different among samples.* ($P \leq 0.05$).