



Universitat de Lleida

Document downloaded from:

<http://hdl.handle.net/10459.1/84208>

The final publication is available at:

<https://doi.org/10.1016/j.fm.2020.103631>

Copyright

cc-by-nc-nd, (c) Elsevier, 2021



Està subjecte a una llicència de [Reconeixement-NoComercial-SenseObraDerivada 4.0 de Creative Commons](https://creativecommons.org/licenses/by-nc-nd/4.0/)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

Application of an innovative water-assisted ultraviolet C light
technology for the inactivation of microorganisms in tomato
processing industries

Maribel Abadias^{a*}, Pilar Colás-Medà^a, Immaculada Viñas^b, Gloria Bobo^a, Ingrid Aguiló-
Aguayo^a

^a IRTA, Postharvest Programme, Parc Científic i Tecnològic Agroalimentari de Lleida,
Parc de Gardeny, Edifici Fruitcentre. 25003-Lleida, Catalonia, Spain.

^b Food Technology Department, University of Lleida, Agrotecnio Center, Lleida, Spain

***Corresponding author:** M. Abadias (isabel.abadias@irta.cat)

22 **Abstract**

23 We aimed to study the efficacy of a water-assisted UVC light device (WUVC) as
24 an innovative clean technology for the disinfection of fresh sound tomatoes and
25 processing wash water and water turbidity was evaluated as a critical parameter. First,
26 wash waters with different turbidities (from 0.4 to 828 NTU) were inoculated with
27 *Listeria innocua* and treated in the WUVC device at different dosages. Secondly, fresh
28 tomatoes, inoculated with *L. innocua* and non-inoculated ones, were treated using the
29 WUVC device containing wash water of different turbidities for different times. The
30 reduction of *L. innocua* populations on wash water and on the surface of tomato was
31 influenced by turbidity; lower reduction values were observed at higher turbidities.
32 Washing tomatoes with tap water with UVC lamps off (control treatment, TW) decreased
33 *L. innocua* population on the surface of tomatoes but did not eliminate those bacteria
34 that went into the water. Contrarily, when UVC lights were on, *L. innocua* population in
35 wash water after treatment significantly decreased, those in clean water being the lowest
36 populations. Reductions of native microbiota on the clean water treated with the highest
37 UV-C radiation dose were lower than those obtained when tomatoes were artificially
38 inoculated. We demonstrated that high reductions of *L. innocua* population on fresh
39 tomatoes could be achieved using the WUVC system but some drawbacks related to the
40 increase of turbidity should be solved for its implementation in real conditions.

41

42 **Keywords:** water assisted UVC, *Listeria innocua*, microbial load reduction, wash water
43 quality, water turbidity

44

45 1. Introduction

46 Tomato (*Lycopersicon esculentum* Miller) and its derived products have a very
47 interesting nutritional value in addition to prominent antioxidant, anti-inflammatory, and
48 anticancer properties (Salehi et al., 2019) and they are widely consumed as a raw, frozen
49 or minimally processed product. In 2017, Spain produced 4,768,595 tn of tomatoes,
50 which represented 20.6% of the total produced in the EU, being the third highest EU
51 producer (FAOSTAT, 2019). About 54% of the tomato production was destined for
52 processing (Lahoz-García et al., 2019). The consumption in Spain is estimated as 12.84
53 kg/person/year (MAPA, 2018).

54 Fresh and processed tomatoes have been implicated in several outbreaks
55 worldwide. In the EU, there has been one *Salmonella* outbreak and one Norovirus
56 outbreak associated with tomato consumption in 2007 and 2011 respectively (EFSA
57 BIOHAZ Panel, 2014). The outbreak associated with tomatoes contaminated with
58 *Salmonella* Strathcona was reported to have 43 human cases in Denmark and 28 cases
59 in Germany, Italy, Austria and Belgium (Müller et al., 2016). From 1998 to 2017, in the
60 US, there were 170 outbreaks attributed to tomatoes or tomato products, causing 8379
61 illnesses, 853 hospitalizations and 9 deaths (NORS, 2019), the main causative agent
62 being *Salmonella* spp. In 2018, another outbreak involving the consumption of tomatoes
63 contaminated with *Salmonella* affected 69 people in Kansas, without deaths reported
64 (Foodborne Illnesses Outbreak Database, 2019). Contaminated water used in
65 postharvest processing has been implicated in some of these tomato-associated
66 outbreaks. Such contamination can occur when operations fail to recondition wash water
67 effectively and maintain sufficient levels of sanitizers (Zhou et al., 2014). Recently, in
68 August to October 2019, another outbreak of *Salmonella* infection linked to small
69 tomatoes was reported in Sweden, with 82 people involved (Colombe et al., 2019).

70 Chlorine in its various available forms is the most common sanitizer used in dump
71 tanks and flume water in fruit and vegetable processing industries. However, some

72 disadvantages related to its use include the formation of potentially hazardous
73 disinfection by-products (Food and Agriculture Organization & World Health
74 Organization, 2009), strong pH dependence for optimal antimicrobial function, the
75 potential of gas emission that may affect worker comfort and health, and its
76 environmental effects have increased the search for alternative systems. Another
77 important point to take into account during commercial washing processes is that due to
78 operational costs and environmental constraints on water usage, the water used in
79 industries is reused throughout the daily operation. This causes a rapid deterioration of
80 wash water quality manifested by an increase in COD (Chemical Oxygen Demand) and
81 turbidity due to the entrance of waxes, soil, dust, pesticide residues, leaf debris and
82 organic exudates from damaged fruits that deplete hypochlorous acid and promote the
83 formation of toxic chlorinated by-products (Luo et al., 2011).

84 Among the alternative sanitation methods, ultraviolet light (UV) has emerged as a
85 physical non-thermal technology for its advantages: efficacy against a broad range of
86 spoilage and pathogenic microorganisms, a non-toxic and 'residue-free' status, a
87 minimal negative effect on organoleptic and nutritional properties, and relative low costs
88 and low energy usage compared to thermal decontamination technologies (Artés et al.
89 2009, Gayán et al., 2014). UV light includes wavelengths in the range of 200-400 nm of
90 which short-wave UV (UV-C, 200-280 nm) has the most effective germicidal effects
91 (Bintsis et al. 2000). The antimicrobial effect of UV-C light is primarily based on the
92 formation of pyrimidine dimers in the DNA, which inhibit transcription and eventually lead
93 to mutagenesis and cell death (Witkin, 1976). This technology has been used for the
94 decontamination of drinking water and packages. It has also been investigated for
95 inactivation of microorganisms in fresh-cut vegetable washing waters (Lehto et al., 2017;
96 Mahoney et al., 2018). There are many studies on the application of UVC to reduce
97 microorganisms on the surface of fruits, such as apples (Graça et al., 2013), melon
98 (Manzocco et al., 2011), watermelon (Artés-Hernández et al., 2010), strawberries

99 (Birmpa et al., 2013) and tomatoes (Lim and Harrison, 2016; Mukhopadhyay et al.,
100 2014). Most of these studies involved the use of cabinets or devices in which UV light is
101 disseminated by air. However, one of the main drawbacks of UV light in air is that it is
102 limited due to its shallow penetration ability, the shadowing effect and the potential
103 overheating of the product, which can affect its quality (Liu et al., 2015). The innovation
104 of the water-assisted UVC light (WUVC) technology studied is that the lamps are
105 immersed in water. This enables fresh produce to move and rotate randomly to achieve
106 full exposure of all surfaces of fresh produce to UVC. Water could also help remove
107 pathogens from food surfaces, which could be more easily killed in wash water (Collazo
108 et al., 2018; Guo et al., 2017). Another benefit of this system is that it prevents the heating
109 and drying of fresh produce by direct UV exposure without the presence of water (Huang
110 et al., 2018). However, increasing turbidity of wash water would impair the penetration
111 ability of UVC light. Huang et al. (2018), Guo et al. (2017), Liu et al. (2015) and Huang
112 and Chen (2019) have explored this technology using a UVC light chamber in which
113 produce was immersed and agitated in a washer while exposed to UV lamps situated on
114 the top of the chambers. Our WUVC prototype is quite different as UVC lamps are
115 immersed in the water (Collazo et al., 2018, 2019) as well as the produce. Previous
116 results demonstrated reductions around 2.5-log units of *L. innocua* in broccoli florets after
117 2 min treatment in the WUVC prototype evaluated in the present study whereas control
118 water treatment obtained reductions of about 0.5-log units (Collazo et al., 2019).

119 The aim of this study was to evaluate the efficacy of an innovative WUVC technology
120 for the sanitation of fresh sound tomatoes and processing water and to study the effect
121 of turbidity. WUVC technology was evaluated on tomatoes artificially inoculated with
122 *L. innocua* and on natural epiphytic microbiota.

123

124

125 **2. Material and methods**

126 2.1. *Plant material*

127 Plum tomatoes (*Lycopersicon esculentum*) were obtained from a local provider
128 in the Central Market of Lleida (Catalonia, Spain) the day before the experiment. They
129 were sorted and stored at 5 ± 1 °C. Tomatoes with visible defects or damaged were
130 rejected.

131

132 2.2. *Bacterial strain and inoculum preparation*

133 *L. innocua* strain CECT-940 (*Colección Española de Cultivos Tipo*, Burjassot,
134 Spain) was used in this study for safety reasons as the equipment was located in a
135 laboratory without biosafety containment measures. *L. innocua* was grown for 24 h in
136 50 mL of TSB (Trypto-caseine Soy Broth, Biokar Diagnostics, Beauvois, France)
137 supplemented with 6 g/L of yeast extract (Biokar Diagnostics, Beauvois, France)
138 (TSBYE) at 37 ± 1 °C in a rotatory shaker set at 150 rpm. Afterwards, the culture was
139 centrifuged at $9,800 \times g$, at 10 °C, for 10 min. The pellet was suspended in saline peptone
140 (PS, 8.5 g NaCl (VWR Chemicals, Leuven, Belgium) and 1 g peptic digest of meat USP,
141 (Biokar Diagnostics)) to obtain a concentrated suspension, which was approximately
142 10^{10} cfu/mL. *L. innocua* population of the suspension, and was checked by plating in
143 TSAYE (TSA supplemented with 6 g/L of yeast extract, 2.5 g/L glucose (PanReac
144 Applichem, Barcelona, Spain and Darmstadt, Germany) and 2.5 g/L K_2HPO_4 (PanReac
145 Applichem)) and Palcam (Biokar Diagnostics) followed by incubation at 37 ± 1 °C for 48 ± 2
146 h.

147

148 2.3. *WUVC equipment*

149 Water-assisted UVC (WUVC) laboratory scale equipment (LAB-UVC-Gama, UV-
150 Consulting Peschl España, Castellón, Spain) was used for the experiments. It consisted
151 of a water tank (15 L) equipped with 4 UV lamps (17.2 W, 254 nm, GPH 303T5L/4,166
152 Heraeus Noblelight, Hanau, Germany) enclosed by a quartz tube (25 mm of outer

153 diameter) to prevent the lamp's contact with the wash water and product (Fig.1). The
154 tank has a water recirculating system motioned by a water pump that pressurises water
155 through multiple sprinkles on the top. Compared to conventional UV-C chambers, the
156 recirculating system allows the rotation of the product and improves the accessibility of
157 UV-C light to all sides of the product and facilitate the inactivation of microorganisms that
158 are removed from the surface to the wash water. Before and after treatments, the
159 temperature was measured using an infrared thermometer DualTemp Pro (Labprocess
160 Distribuciones, Barcelona, Spain). Irradiance (W/m^2) was measured through an orifice
161 located in the lid of the equipment using a UV-Sensor EasyH1 (Peschl Ultraviolet, Mainz,
162 Germany). The average UV-C radiation with the empty tank was $11.2 W/m^2$ ($11.0-11.4$
163 W/m^2).

164

165 2.4. *Effect of WUVC on the survival of L. innocua in water*

166 The effect of WUVC for the reduction of *L. innocua* in water was determined at
167 different turbidity levels (organic load). In order to prepare different wash waters, 0, 1,
168 2.5, 5 and 10% commercial canned chopped tomato pulp was added to wash water in
169 the WUVC system, according to values provided by a frozen vegetable industry.
170 Turbidity, conductivity, pH and oxido-reduction potential (ORP) were determined for each
171 wash water. Turbidity was measured using a portable turbidimeter (TN-100, Eutech,
172 Singapore) measuring in Nephelometric Turbidity Units (NTU). Conductivity was
173 determined using a conductivity measurement instrument (Testo model 240, Cabrils,
174 Barcelona, Spain). ORP and pH were measured in a pH-meter (GLP22, Crison, Alella,
175 Barcelona, Spain) equipped with a pH probe (ref. 52-03, Crison) or ORP probe (ref.62-
176 51 Hach, Vézenaz, Geneva), respectively.

177 UVC lamps were switched on for 15 min and the UV-C radiation was checked to
178 verify that it was in the desired range ($11.0-11.4 W/m^2$). Afterwards, the WUVC tank was
179 filled with 12 L of cold (7 ± 2 °C) water and the UVC lights were switched on for 12-15 min.
180 The tomato pulp was added and the recirculation was turned on. Afterwards, the required

181 amount of *L. innocua* inoculum was added to have an initial concentration of about
182 10^7 cfu/mL (7 log cfu/mL). Triplicate 10-mL samples were taken initially and after 1, 3, 5
183 and 7 min (UV-C radiation doses of 0.7, 2.0, 3.4 and 4.7 KJ/m², respectively) depending
184 on the water turbidity. *L. innocua* was determined by plating duplicate 10-fold dilutions
185 onto selective medium (Palcam) followed by incubation at 37 ± 1 °C for 48 h. The
186 experiment was repeated twice.

187

188 2.5. Effect of WUVC on survival of *L. innocua* on the surface of tomato

189 The day before the experiment, plum tomatoes were washed with tap water, dried
190 and put in plastic cavity tray liners inside plastic boxes. A circle of about 2.5 cm in
191 diameter was drawn on the surface of each tomato using an indelible marker. Afterwards,
192 50 µL of the prepared suspension of *L. innocua* (10^{10} cfu/mL) were inoculated on the
193 tomato peel by pipetting small droplets inside the marked surface of each tomato to
194 simulate contamination from a point source such as contact with soil or workers' hands
195 (Beuchat et al. 2001). They were stored at room temperature overnight to facilitate
196 microorganism settlement.

197 On the day of the experiment, the equipment was set up as indicated previously.
198 In order to evaluate the effect of organic matter (turbidity) on the efficacy of WUVC, 0, 3
199 and 10% of tomato pulp was added in different trials. Turbidity, conductivity, pH and ORP
200 of water were measured. Twelve inoculated tomatoes were treated for 1, 3 and 5 min
201 (UV-C radiation doses of 0.7, 2.0 and 3.4 KJ/m², respectively). The population of
202 *L. innocua* in wash water after treatment was also determined in duplicate samples as
203 indicated previously. Moreover, duplicate 1-mL of wash water after treatment was also
204 added to 9-mL of Dey-Engley Neutralizing Broth (Sigma-Aldrich, St. Louis, MO, USA) to
205 determine the presence or absence of *L. innocua* in case the counts were below
206 detection limit (5 ufc/mL, 0.70 log cfu/mL). Dey-Engley tubes were incubated at 37 °C for
207 24-48 h.

208 Tomatoes were left to dry at ambient temperature (about 2 h). The population of
209 *L. innocua* before and after treatments was evaluated as follows: The inoculated surface
210 of 3 tomatoes per treatment and time were cut using a cork borer of 2.2 cm of diameter
211 (3.80 cm²) and only the peel (1-2 mm) was cut using a scalpel. The entire circle was put
212 in a 80 mL-filtered bag (BagPage®, Interscience BagSystem, Saint Nom, France) and
213 20 mL of buffered peptone water (BPW, Biokar Diagnostics) were added and
214 homogenized in a blender (Minimix® 100, Interscience, France) for 120 s at 12 strokes/s.
215 Duplicate ten-fold dilutions of the homogenates were made in saline peptone (SP, 8.5
216 g/l NaCl) and plated in selective medium Palcam as described above. Results were
217 expressed in log cfu/cm². Detection limit was 1.42 log cfu/cm² (26 cfu/cm²). When the
218 counts were below the detection limit, an arbitrary value of ½ detection limit (13 cfu/cm²,
219 1.1 log cfu/cm²) was attributed for calculation. The experiment was repeated 3 times.

220

221 2.6. *Effect of WUVC on survival of native/epiphytic microbiota on the surface of* 222 *tomato*

223 In order to test the efficacy of WUVC on the survival of native microbiota, the
224 experiment was conducted as explained before using non-inoculated unwashed
225 tomatoes. The effect of turbidity (0, 3 and 10% tomato pulp) and time (3 and 5 min,
226 corresponding to UV-C radiation doses of 2.0 and 3.4 KJ/m², respectively) were also
227 determined. Twelve tomatoes were treated in each batch. Moreover, a control treatment,
228 which consisted of washing tomatoes with tap water in the same device with the UVC
229 lights off (TW), was included. The experiment was carried out three times.

230 The populations of total aerobic mesophilic microorganisms (TAM) and moulds and
231 yeasts (M&Y) were determined on the surface of tomato and in wash water after
232 treatment. In tomatoes, the populations were determined in triplicate (three tomatoes).
233 In each tomato, 4 circles of 2.2 cm diameter (3.8 cm², total surface 15.2 cm²) were made
234 using a cork borer. The peel was taken off using a scalpel and introduced in a filtered
235 stomacher bag with 20 mL of BPW and homogenized as described before. Duplicate

236 ten-fold dilutions were made for each sample and 100 mL plated in PCA and DRBC
237 medium for TAM and M&Y determination, respectively. Plates were incubated at 30 °C
238 for 3 days for TAM and at 25 °C for 5 days for M&Y. Results were expressed in log
239 cfu/cm². Detection limit was 0.82 log cfu/cm² (6.6 cfu/cm²). When the counts were below
240 the detection limit, an arbitrary value of ½ detection limit (3.3 cfu/cm², 0.52 log cfu/cm²)
241 was attributed for calculation. The populations of TAM and M&Y in wash water after
242 treatment were also determined in duplicate samples by plating 100 µl onto PCA and
243 DRBC plates respectively. In order to determine the presence of microorganisms in wash
244 water samples when counts were below detection limit, duplicate 1-mL of wash water
245 after treatment were also added to 9-mL Dey-Engley Neutralizing Broth followed by
246 incubation at 30 and 25 °C, respectively.

247

248 2.7. *Statistical analysis*

249 All experiments were performed at least two times and included three biological
250 replicates per treatment and sampling time. Microbial counts (cfu/cm² or cfu/mL) were
251 transformed to log₁₀. Reduction was calculated by subtracting the initial log cfu/mL or
252 cm² from the log cfu/mL or cm² after the treatment. Data were analysed using the
253 statistical software JMP (version 11 SAS Institute Inc., NC, USA). Means were compared
254 by analysis of variances (ANOVA) and separated by Tukey's test (P < 0.05).

255

256 3. Results

257

258 3.1. *Effect of WUVC on the survival of L. innocua in water*

259 The properties of wash waters changed according to the tomato pulp added
260 (Table 1). Increasing the tomato pulp in wash water increased turbidity, conductivity and
261 ORP but decreased pH. Turbidity values ranged from 0.42 to 828 NTU.

262 The initial population of all experiments and tested conditions was 7.03 ± 0.39 log
263 cfu/mL (data not shown). The reduction of *L. innocua* in wash water depended on both
264 UV-C radiation doses and water turbidity (Fig.2). For each UV-C radiation dose, an
265 increase in turbidity reduced WUVC efficacy. After 1 min treatment (0.7 KJ/m^2 of UV-C
266 radiation dose), reductions ranged from 3.5 log cfu/mL to 1.0 log cfu/mL for turbidities
267 ranging from 0.42 to 300 NTU. After 5 min treatment (3.4 KJ/m^2 of UV-C radiation dose),
268 wash water turbidities in the range of 0.42 and 148 NTU gave similar reduction values
269 (around 5 log cfu/mL). When the turbidity increased up to 828 NTU, the reduction of
270 *L. innocua* was above 1.0 and 1.7 log cfu/mL units showed non-significant differences
271 after 5 and 7 min of treatment (3.4 and 4.7 KJ/m^2 of UV-C radiation doses), respectively.

272

273 3.2. Effect of WUVC on survival of *L. innocua* on the surface of tomato

274 Properties of wash water in the experiments with tomatoes (inoculated with
275 *L. innocua* or uninoculated) are shown in Table 2. As seen before, increasing the amount
276 of tomato pulp in wash water increased turbidity, conductivity and ORP but decreased
277 pH. Turbidity values range from 0.88 to 664 NTU.

278 The initial population of *L. innocua* on the tomato surface was 6.43 ± 0.34 log
279 cfu/cm² (data not shown). Reduction of *L. innocua* on the surface of tomatoes (Fig. 3)
280 did not depend on UV-C radiation dose, only WUVC treatment for 1 min (0.7 KJ/m^2) with
281 wash water of 166 NTU turbidity (TW 3%) with 3.7-log reductions was significantly lower
282 than other UV-C radiation dose (5.2 to 5.4-log reductions obtained after 3 and 5 min).
283 The effect of turbidity was observed after 3 and 5 min of treatment (UV-C radiation doses
284 of 2.0 and 3.4 KJ/m^2 , respectively), when reduction values at the highest turbidity tested
285 (664 NTU, TW 10%) were about 1.2 log units lower than those observed at 0.88 (TW 0%)
286 and 166 NTU (TW 3%). Results demonstrated that control washing with water without
287 UVC light (TW) greatly decreased *L. innocua* population on the surface of tomatoes, with
288 reductions of 4.40 and 5.18 log cfu/cm² regardless of UV-C radiation dose. However, TW
289 with no UVC light did not eliminate those bacteria that went into the water, with microbial

290 counts above 2 log cfu/mL (Fig. 4). Contrarily, when UVC lights were on, *L. innocua*
291 population in wash water after treatment significantly decreased, being the lowest
292 populations when water was clean (TW 0%). In the case of using high-turbidity wash
293 water (TW 10%) more than 3 min (UV-C radiation dose of 2.0 KJ/m²) were required to
294 reduce microbial contamination below 1 log cfu/mL.

295

296 3.3. Effect of WUVC on the indigenous microbiota of tomato surface

297 According to the results obtained in inoculated experiments, only 3 and 5 min
298 treatments (corresponding to UV-C radiation doses of 2.0 and 3.4 KJ/m²) were tested.
299 Properties of wash water in non-inoculated experiments (Table 3) were similar to those
300 obtained in *L. innocua* inoculated experiments.

301 Initial population of TAM on the tomato surface was 2.26 log cfu/cm² (Fig. 5) and
302 the reductions observed were lower than those obtained when tomatoes were artificially
303 inoculated (≤ 0.8 log). Organic load did not significantly affect the reduction of epiphytic
304 microbiota after 3 and 5 min washing. The increase of UV-C radiation dose was only
305 significant when wash water had no organic matter (WUVC 0%).

306 However, the population of TAM in the wash water after washing was significantly
307 influenced by the organic load (Fig. 6); the reductions observed were significantly higher
308 (lower population) when turbidity values were lower. High populations ($>10^3$ cfu/mL)
309 remained in wash water in control (no UVC lights) washing while in WUVC 0% tomato
310 pulp (0.91 NTU) counts were below 10 cfu/mL. For each treatment, no significant
311 differences were observed according to UV-C radiation dose. Molds and Yeast results
312 are not shown as they were below the detection limit in most cases.

313

314 4. Discussion

315 In this work, we studied the effect of a water-assisted UVC system, a novel UVC-
316 based technology to the decontamination of fresh sound tomatoes and tomato

317 processing wash water, in which UVC lamps are immersed in water. Studies were carried
318 out in artificially inoculated tomatoes, using *L. innocua*, and in non-inoculated tomatoes,
319 for the evaluation of its effect on natural epiphytic microorganisms. The effect of the
320 turbidity of wash water was determined, as the efficacy of UVC treatment could be
321 affected. Turbidity values were selected in a range provided by a frozen tomato company
322 in Spain.

323 Results demonstrated that turbidity and time greatly affected the efficacy of the
324 WUVC for the elimination of *L. innocua* artificially inoculated in wash water. For the same
325 UV-C radiation dose, reduction values were lower at higher turbidities and higher UV-C
326 radiation dose were needed at higher turbidities to obtain similar results. UV dose is the
327 product of UV intensity and time of exposure, so longer treatment time should provide
328 more damage to bacterial cell and, on the contrary, the presence of organic matter
329 (increased turbidity) in the wash water would prevent the penetration ability of UVC light.

330 A frozen tomato processing plant provided turbidity values used in this study and
331 they were considerably higher than others used in different studies (Liu et al., 2015, Guo
332 et al., 2017). Our results demonstrated that to obtain *L. innocua* reductions ≥ 4 log cfu/mL,
333 wash water should have turbidity values < 148 NTU and treatment times should be higher
334 than 3 min (UV-C radiation dose > 2.0 KJ/m²). Similarly, Liu et al. (2015) reported that
335 UV inactivation of *Microcystis viridis* decreased when water turbidity increased from 1 to
336 30 NTU. Guo et al. (2017) also found an adverse effect of organic load and soil on water
337 assisted UV inactivation, with increasing *Salmonella* survivors in wash waters of
338 increased turbidity. In that study, wash waters from tomato (61.9 NTU), lettuce (96.7
339 NTU), baby-cut carrot (160 NTU) and baby spinach (232 NTU) were tested. However, in
340 the case of tomato, they found that the single water-assisted UV treatment completely
341 eliminated the cocktail of mutant *Salmonella* strains in wash water, regardless of water
342 quality. For lettuce, spinach and carrots, the single water-assisted UV treatment did not
343 completely eliminate *Salmonella* in wash water regardless of water quality, indicating the
344 need for the combination with chemicals. Letho et al. (2016) found that the inactivation

345 of *E. coli* and *Candida lambica* with UV-C with an interfering carrot juice (1%) decreased
346 the inactivation and lengthened its application and suggested a water filtration to
347 enhance the disinfection efficacy.

348 In the case of tomato surface, *L. innocua* populations were reduced by 3.27-5.36 log
349 cfu/cm² (Fig.5) and turbidity and UV-C radiation dose had no such influence as that
350 observed for wash water. Results demonstrated that using a water wash without UVC
351 light (TW) greatly decreased *L. innocua* population on the surface of tomatoes, with
352 reductions of 4.40 and 5.18 log cfu/cm² regardless of treatment time (radiation dose).
353 This could be attributed to the mechanical removal of bacterial cells from the peel to the
354 wash water caused by the agitation and waterjet through the sprinklers. However, when
355 using water alone, about 2.5 log cfu *L. innocua*/mL were present in wash water. Liu et
356 al. (2015) observed *E. coli* O157:H7 higher microbial reductions using longer wet UV
357 treatments on skin-spot inoculated blueberries; the reductions achieved were 3.4, 3.9,
358 5.2 log cfu/g for 2, 5 and 10 min. In these conditions, they achieved undetectable levels
359 in wash water. In a similar study, Huang et al. (2018) found that there were not significant
360 differences on the reduction of *Salmonella* on the surfaces of grape tomatoes,
361 blueberries and baby spinach when compared to WUV and tap water wash, with
362 reductions between 0.88 and > 3.64 log cfu/g depending on the produce item. However,
363 there were significant differences in the residual *Salmonella* population in turbid wash
364 water, being significantly higher when no UV light was used. Similarly, Pangloli and Hung
365 (2013) found that tap water reduced the number of *E. coli* O157:H7 on the surfaces of
366 blueberries by 1.9–2.7 log cfu/g through physical or mechanical washing without killing
367 the pathogen with pathogen populations of 3.6–3.8 log cfu/mL in wash solution.
368 Therefore, even washing with tap water could be effective in reducing microbial
369 contamination of produce although it might not prevent the possibility of cross-
370 contamination as most of the microorganisms that went to water were not eliminated. In
371 order to diminish the negative effects of organic matter in wash water, Alharbi et al.
372 (2017) investigated a combination of electrocoagulation combined with UV light to reduce

373 the organic content and enhance the microbiological quality of wash water derived from
374 shredded lettuce processing.

375 In non-inoculated tomatoes, the efficacy of WUVC treatment was lower than that
376 obtained in *L. innocua* inoculated samples, with values ≤ 0.8 log cfu/cm² of TAM after 3
377 min washing. Similarly, wash water turbidity did not affect the survival population on the
378 tomato surface but it had a significant influence on the reduction of microorganisms on
379 wash water. Increasing turbidity from 0.91 to 169 NTU increased the microbial counts in
380 wash water from <1 -log to 2.4 log cfu/mL. Similar to what happened in inoculated
381 samples, TW was as efficient as WUVC in reducing the microorganisms on the surface
382 of tomato, but residual population in wash water after washing was very high ($>10^3$
383 cfu/mL) compared to WUVC with 0% of tomato pulp. It was likely that the higher reduction
384 of *L. innocua* on artificially spot inoculated samples was due to the loose attachment to
385 the smooth surface of tomato while indigenous microbiota were strongly attached or
386 internalized in cracks, (micro)wounds or bruises and/or protected by biofilms. It is known
387 that biofilm could protect microorganisms from environmental changes and microbial
388 treatments (Simões et al., 2010). According to this, Guo et al. (2017) found the highest
389 *Salmonella* reduction using water assisted UV on grape tomatoes followed by iceberg
390 lettuce and baby spinach, while the lowest *Salmonella* reduction was achieved on baby-
391 cut carrots and this was attributed to the surface structure. Mukhopadhyay et al. (2014)
392 found that inoculation site also influenced dry UVC treatment; better results of
393 inactivation were found when *Salmonella* and *E. coli* were inoculated on tomato surface
394 than on tomato scar. Moreover, low efficacy of WUVC on epiphytic microorganisms may
395 also be due to a higher resistance of some of them. However, in an irregular and rough
396 surface such as broccoli florets, Collazo et al. (2018) found higher reductions of
397 mesophilic aerobic microorganisms (around 2-log reduction) after washing 2 min in the
398 same equipment. Esua et al. (2018) combined UVC light treatment with ultrasound for
399 the reduction of native microbiota on the surface of tomatoes and found higher reduction
400 values (2-log) than those found in our studies. This could be due explained by the higher

401 dosage level used (6.46 KJ/m²), which was almost double than ours (3.36 KJ/m²) and
402 the combination with ultrasound. In this study, we have demonstrated that high
403 reductions of *L. innocua* population on fresh tomatoes could be achieved using a novel
404 WUVC system as it decreases microbial load on both tomatoes and wash water. Current
405 insights show that the main expected effect of sanitizing treatments during produce
406 washing is to reduce and control the microbial load of the water rather than produce
407 decontamination (Van Haute et al., 2015). Constant wash water quality changes should
408 be taken into account. Consequently, by maintaining the water quality throughout
409 produce processing, the potential for cross-contamination during washing can be
410 diminished (Gil et al., 2009; Parish et al., 2003; Van Haute et al., 2015). Finally, this
411 WUVC system could be easily implemented in the existing washing lines, as UVC lights
412 could be installed in the washing tanks and shields should be installed to protect workers
413 from UVC exposure. However, more studies should be carried out in order to increase
414 its efficacy in case of washing lines with high organic matter, for example, with a
415 combination of a low risk or no residue chemical, including a prewashing step before
416 WUVC and/or a filtration system to maintain low turbidity in the UVC washing tank.

417

418 **Acknowledgements**

419 The authors are grateful to TECALZIM Research Project (Mitigation Strategies
420 to Reduce the Microbial Risks and Improve the Quality and Safety of Frozen and
421 Ready-to-Eat Strawberries) which was funded by the Spanish Ministry of Economy,
422 Industry, and Competitiveness (RTC-2016-5498-2) and CERCA Programme
423 (Generalitat de Catalunya) for its financial support. I. Aguiló-Aguayo thanks the
424 Spanish Ministry of Economy, Industry and Competitiveness and the European Social
425 Fund for the Postdoctoral Senior Grant Ramon y Cajal (RYC-2016-19949). Thanks are
426 also given to Marina Anguera for her technical assistance.

427

428 **REFERENCES**

- 429 Alharbi, K.K.D., Lau, V., Liang, C., Zytner, R.G., Shi, J., Warriner, K., 2017. Treatment
430 of spent wash water derived from shredded lettuce processing using a combination
431 of electrocoagulation and germicidal ultraviolet light. *Food Qual. Saf.* 1, 147-152.
432 doi:10.1093/fqs/fyx012.
- 433 Artés, F., Gómez, P., Aguayo, E., Escalona, V., Artés-Hernández, F., 2009. Sustainable
434 sanitation techniques for keeping quality and safety of fresh-cut plant commodities.
435 *Postharvest Biol. Technol.* 51, 287-296. doi:10.1016/j.postharvbio.2008.10.003.
- 436 Artés-Hernández, F., Robles, P.A., Gómez, P.A., Tomás-Callejas, A., Artés, F., 2010.
437 Low UV-C illumination for keeping overall quality of fresh-cut watermelon. *Postharvest*
438 *Biol. Technol.* 55, 114-120. doi:10.1016/j.postharvbio.2009.09.002.
- 439 Beuchat, L.R., Farber, J.M., Garret, E.H., Harris, L.J., Parish, M.E, Suslow, T.V., Busta,
440 F.F., 2001. Standardization of a method to determine the efficacy of sanitizers in
441 inactivating human pathogenic microorganisms on raw fruits and vegetables. *J. Food*
442 *Protec.* 64, 1079-1084. doi:10.4315/0362-028X-64.7.1079.
- 443 Bintsis, T., Litopoulou-Tzanetaki, E., Robinson, R.K., 2000. Existing potential
444 applications of ultraviolet light in the food industry – a critical review. *J. Sci. Food Agr.*
445 80, 637-645. doi:10.1002/(SICI)1097-0010(20000501)80:6<637::AID-
446 JSFA603>3.0.CO;2-1
- 447 Birmpa, A., Sfika, V., Vantarakis, A., 2013. Ultraviolet light and ultrasound as non-thermal
448 treatments for the inactivation of microorganisms in fresh ready-to-eat foods. *Int. J.*
449 *Food Microbiol.* 167, 96-102. doi:10.1016/j.ijfoodmicro.2013.06.005.
- 450 Collazo, C., Charles, F., Aguiló-Aguayo, I., Marín-Sáez, J., Lafarga, T., Abadías, M.,
451 Viñas, I., 2019. Decontamination of *Listeria innocua* from fresh-cut broccoli using UV-
452 C applied in water or peroxyacetic acid, and dry-pulsed light. *Innov. Food Sci. Emerg.*
453 *Technol.* 52, 438-449. doi: 10.1016/j.ifset.2019.02.004
- 454 Collazo, C., Lafarga, T., Aguiló-Aguayo, I., Marín-Sáez, J., Abadías, M., Viñas, I., 2018.
455 Decontamination of fresh-cut broccoli with a water-assisted UV-C technology and its

456 combination with peroxyacetic acid. Food Control 93, 92-100. doi:
457 10.1016/j.ifset.2019.02.004.

458 Colombe, S., Jernberg, C., Löf, E., Angervall, A., Mellström-Dahlgren, H., Dotevall, L.,
459 Bengnér, M., Hall, I., Sundqvist, L., Kuhlmann-Berenzon, S., Galanis, I., Lindblad, M.,
460 Hansen, A., Rehn, M., 2019. Outbreak of unusual H₂S-negative monophasic
461 *Salmonella* Typhimurium strain likely associated with small tomatoes, Sweden,
462 August to October 2019. Eurosurveillance. 24. doi: 10.2807/1560-
463 7917.ES.2019.24.47.1900643. doi: 10.2807/1560-7917.ES.2019.24.47.1900643.

464 EFSA BIOHAZ Panel (EFSA Panel on Biological Hazards), 2014. Scientific opinion on
465 the risk posed by pathogens in food of non-animal origin. Part 2 (*Salmonella* and
466 Norovirus in tomatoes). EFSA Journal, 12(10), 3832, 75 pp.
467 doi:10.2903/j.efsa.2014.3832.

468 Esua, O. J., Chin, N. L., Yusof, Y. A., & Sukor, R., 2019. Effects of simultaneous UV-C
469 radiation and ultrasonic energy postharvest treatment on bioactive compounds and
470 antioxidant activity of tomatoes during storage. Food Chem. 270, 113-122. doi:
471 10.1016/j.foodchem.2018.07.031.

472 FAOSTAT, 2019. <http://www.fao.org/faostat/en/#data/QC>. Accessed 11 February 2020.

473 Food and Agriculture Organization & World Health Organization, 2009. Benefits and risks
474 of the use of chlorine-containing disinfectants in food production and food processing:
475 report of a joint FAO/WHO expert Meeting, Ann Arbor, MI, USA, 27-30 May 2008.
476 ISBN 9789241598941. <http://www.who.int/iris/handle/10665/44250>.

477 Foodborne Illness Outbreak Database, 2019. 2018 Outbreak of *Salmonella* Newport at
478 Church Supper, Highland, Kansas. Available at:
479 <http://www.outbreakdatabase.com/search/?vehicle=tomato>. Accessed: 14 May 2019.

480 Gayán, E., Condón, S., Álvarez, I., 2014. Biological aspects in food preservation by
481 ultraviolet light: A review. Food Bioprocess. Tech. 7, 1-20. doi:10.1007/s11947-013-
482 1168-7.

483 Gil, M. I., Selma, M. V., López-Gálvez, F., Allende, A., 2009. Fresh-cut product sanitation
484 and wash water disinfection: Problems and solutions. *Int. J. Food Microbiol.* 134(1-2),
485 37-45. doi:10.1016/j.ijfoodmicro.2009.05.021.

486 Graça, A., Salazar, M., Quintas, C., Nunes, C., 2013. Low dose UV-C illumination as an
487 eco-innovative disinfection system on minimally processed apples. *Postharvest Biol.*
488 *Technol.* 85, 1-7. doi:10.1007/s11947-013-1168-7.

489 Guo, S., Huang, R., Chen, H., 2017. Application of water-assisted ultraviolet light in
490 combination of chlorine and hydrogen peroxide to inactivate *Salmonella* on fresh
491 produce. *Int. J. Food Microbiol.* 257, 101-109. doi:10.1016/j.ijfoodmicro.2017.06.017.

492 Huang, R., Chen, H., 2019. Comparison of water-assisted decontamination systems of
493 pulsed light and ultraviolet for *Salmonella* inactivation on blueberry, tomato, and
494 lettuce. *J. Food Sci.* 84, 1145-1150. doi: 10.1111/1750-3841.14510.

495 Huang, R., de Vries, D., Chen, H., 2018. Strategies to enhance fresh produce
496 decontamination using combined treatments of ultraviolet, washing and disinfectants.
497 *Int. J. Food Microbiol.* 283, 37-44. doi:10.1016/j.ijfoodmicro.2018.06.014.

498 Lahoz García, I., Santos Arriazu, A., Malumbres Montorio, A., Bozal Yanguas, J.M.,
499 Mauleón Burgos, J., Arechalde Recio, A., Calvillo Ruiz, S., 2019. Tomate de industria.
500 Campaña 2018. *Navarra Agraria*, 232, 11-20.

501 Lehto, M., Kuisma, R., Kymäläinen, H.R., Mäki, M., 2017. Neutral electrolyzed water
502 (NEW), chlorine dioxide, organic acid based product, and ultraviolet-C for inactivation
503 of microbes in fresh-cut vegetable washing waters. *J. Food Process. Preserv.* 42,
504 e13354. doi:10.1111/jfpp.13354.

505 Lim, W., Harrison, M.A., 2016. Effectiveness of UV light as a means to reduce
506 *Salmonella* contamination on tomatoes and food contact surfaces. *Food Control* 66,
507 166-173. doi:10.1016/j.foodcont.2016.01.043.

508 Liu, C., Huang, Y., Chen, H., 2015. Inactivation of *Escherichia coli* O157:H7 and
509 *Salmonella enterica* on blueberries in water using ultraviolet light. *J. Food Sci.* 80(7),
510 M1532-M1537. doi:10.1111/1750-3841.12910.

511 Luo, Y., Nou, X., Yang, Y., Alegre, I., Turner, E., Feng, H., Abadias, M., Conway, W.,
512 2011. Determination of free chlorine concentrations needed to prevent *Escherichia*
513 *coli* O157:H7 cross-contamination during fresh-cut produce wash. *J. Food Prot.* 74,
514 352-358. doi:10.4315/0362-028X.JFP-10-429.

515 Mahoney, L., Younis, B.A., Simmons, C.W., 2018. A novel system for the treatment of
516 wastewater from a tomato processing plant with UV light. *Water Pract. Tech.* 13 (3),
517 662-672. doi:10.2166/WPT.2018.064.

518 Manzocco, L., Da Pieve, S., Maifreni, M., 2011. Impact of UV-C light on safety and quality
519 of fresh-cut melon. *Innov. Food Sci. Emerg. Technol.* 12, 13-17.
520 doi:10.1016/j.ifset.2010.11.006.

521 MAPA (Ministerio de Agricultura, Pesca y Alimentación de España), 2018. Informe del
522 consumo de alimentación en España 2017.
523 [https://www.mapa.gob.es/en/alimentacion/temas/consumo-](https://www.mapa.gob.es/en/alimentacion/temas/consumo-tendencias/informeconsumoalimentacionenespana2017_prefinal_tcm38-456186.pdf)
524 [tendencias/informeconsumoalimentacionenespana2017_prefinal_tcm38-456186.pdf](https://www.mapa.gob.es/en/alimentacion/temas/consumo-tendencias/informeconsumoalimentacionenespana2017_prefinal_tcm38-456186.pdf)

525 Mukhopadhyay, S., Ukuku, D.O., Juneja, V., Fan, X., 2014. Effects of UV-C treatment
526 on inactivation of *Salmonella enterica* and *Escherichia coli* O157:H7 on grape tomato
527 surface and stem scars, microbial loads, and quality. *Food Control* 44, 110-117.
528 doi:10.1016/j.foodcont.2014.03.027.

529 Müller, L., Kjelsø, C., Frank, C., Jensen, T., Torpadahl, M., Søborg, B., Dorleans, F.,
530 Rabsch, W., Prager, R., Gossner, C.M., Ethelberg, S., 2016. Outbreak of *Salmonella*
531 *Strathcona* caused by datterino tomatoes, Denmark, 2011. *Epidemiol. Infect.* 144,
532 2802-2811. doi:10.1017/S0950268816000121.

533 NORS (National Outbreak Reporting System). CDC., 2019.
534 <https://wwwn.cdc.gov/norsdashboard/> Accessed 14 May 2019.

535 Pangloli, P., Hung, Y.C., 2013. Reducing microbiological safety risk on blueberries
536 through innovative washing technologies. *Food Control* 32, 621-625.
537 doi:10.1016/j.foodcont.2013.01.052.

538 Parish, M. E., Beuchat, L. R., Suslow, T. V., Harris, L. J., Garrett, E. H., Farber, J. N.,
539 Busta, F.F., 2003. Methods to reduce/eliminate pathogens from fresh and fresh-cut
540 produce. *Compr. Rev. Food Sci. Food Saf.* 2, 161-173. doi:10.1111/j.1541-
541 4337.2003.tb00033.x.

542 Salehi, B., Sharifi-Rad, R., Sharopov, F., Namiesnik, J., Roointan, A., Kamle, M., Kumar,
543 P., Martins, N., Sharifi-Rad, J., 2019. Beneficial effects and potential risks of tomato
544 consumption for human health: An overview. *Nutrition* 62, 201-208. doi:
545 10.1016/j.nut.2019.01.012.

546 Simões, M., Simões, L.C., Vieira, M.J., 2010. A review of current and emergent biofilm
547 control strategies. *LWT-Food Sci. Technol.* 43, 573-583.
548 doi:10.1016/j.lwt.2009.12.008.

549 Van Haute, S., Sampers, I., Jacxsens, L., Uyttendaele, M., 2015a. Selection criteria for
550 water disinfection techniques in agricultural practices. *Crit. Rev. Food Sci. Nutr.* 55,
551 1529-1551. doi: 10.1080/10408398.2012.705360.

552 Van Haute, S., Tryland, I., Veys, A., Sampers, I., 2015b. Wash water disinfection of a
553 full-scale leafy vegetables washing process with hydrogen peroxide and the use of a
554 commercial metal ion mixture to improve disinfection efficiency. *Food Control* 50, 173-
555 183. doi:10.1016/j.foodcont.2014.08.028.

556 Witkin, EM. 1976. Ultraviolet mutagenesis and inducible DNA repair in *Escherichia coli*.
557 *Bacteriol. Rev.* 40, 869–907.

558 Zhou, B., Luo, Y., Turner, E. R., Wang, Q., Schneider, K. R., 2014. Evaluation of current
559 industry practices for maintaining tomato dump tank water quality during
560 packinghouse operations. *J. Food Process. Preserv.* 38, 2201-2208.
561 doi:10.1111/jfpp.12200.

562

563

564

565

566 **FIGURE LEGENDS**

567 Figure 1. Water-assisted UV (WUVC) light equipment. (A) General overview (B) Detail
568 of the interior of the tank. (1) Water tank equipped with a recirculating water circuit (2)
569 that is put in motion by a water pump (maximum flow 1700 L h⁻¹) (3) which is controlled
570 with a power source (4). Pressurized water is introduced 100 kPa, enters through the
571 bottom of the tank for water bubbling (7). Four equidistant UV lamps (8) (17.2 W)
572 emitting at 254 nm are located in water proofs quartz compartments inside the tank.
573 Radiation is measured on a hole in the lid of the tank (9).

574 Figure 2. Reduction of *L. innocua* (log cfu/mL) on wash water in the WUVC system
575 according to different turbidities and treatment time. *L. innocua* was inoculated at
576 10⁷ cfu/mL. Wash water turbidity was changed by adding different canned chopped
577 tomato amounts (0, 1, 2.5, 5, 10 and 15%). For each time, different letters (A, B, C)
578 indicate significant differences among turbidities according to a Tukey test (P<0.05).
579 For each turbidity, different capital letters (X, Y, Z) indicate significant differences
580 due to treatment time (radiation dose). Vertical bars indicate standard error of the
581 mean. Nd: Not done

582 Figure 3. Reduction of *L. innocua* (log cfu/cm²) on the surface of tomatoes on the
583 WUVC system according to different turbidities and treatment time. *L. innocua* was
584 inoculated by pipetting 50 µL of a 10¹⁰ log cfu/mL suspension. Wash water turbidity
585 was changed by adding different canned chopped tomato amounts (0, 3, and 10%)
586 to tap water (TW). For each time, different capital letters (A, B, C) indicate significant
587 differences among turbidities according to a Tukey test (P<0.05). For each turbidity,
588 different capital letters (X, Y, Z) indicate significant differences due to treatment time
589 (radiation dose). Vertical bars indicate standard error of the mean.

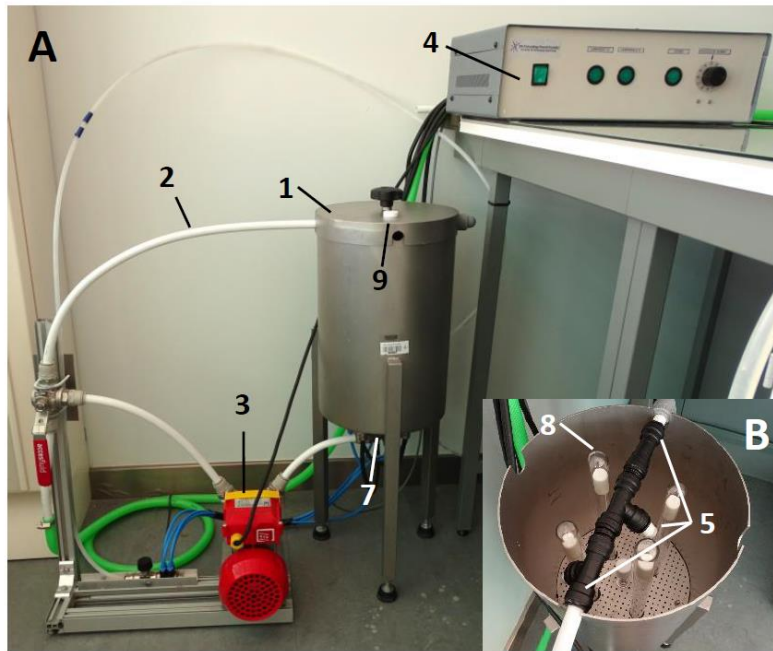
590 Figure 4. Effect of WUVC system on the population of *L. innocua* (log cfu/mL) in the
591 wash water after tomato washing according to different turbidities and treatment
592 times. *L. innocua* was inoculated by pipetting 50 µL of a 10¹⁰ log cfu/mL suspension.
593 Wash water turbidity was changed by adding different canned chopped tomato

594 amounts (0, 3, and 10%). For each time (radiation dose), different capital letters (A,
595 B, C) indicate significant differences among turbidities For each turbidity, different
596 capital letters (X, Y, Z) indicate significant differences due to treatment time.
597 according to a Tukey test ($P < 0.05$). Vertical bars indicate standard error of the mean

598 Figure 5. Effect of WUVC treatment on the population of total aerobic microorganisms
599 (TAM) on the tomato peel ($\log \text{cfu/cm}^2$). Values are mean of at least 6 values and
600 bars indicate standard deviation. For each turbidity tested, different letters indicate
601 significant differences ($P < 0.05$) in TAM population among treatment times,
602 according to a Tukey test. When there were no letters, no significant differences
603 were found. Per each treatment time, no significant differences among turbidities
604 were found. Vertical bars indicate standard error of the mean

605 Figure 6. Effect of WUVC treatment on the population of total aerobic microorganisms
606 (TAM) in the wash water after 3 and 5 min treatments ($\log \text{cfu/mL}$). Values are mean
607 of at least 4 values and bars indicate standard deviation. For each washing time,
608 diferent capital letters indicate significant differences ($P < 0.05$) among treatments,
609 according to a Tukey test. Vertical bars indicate standard error of the mean

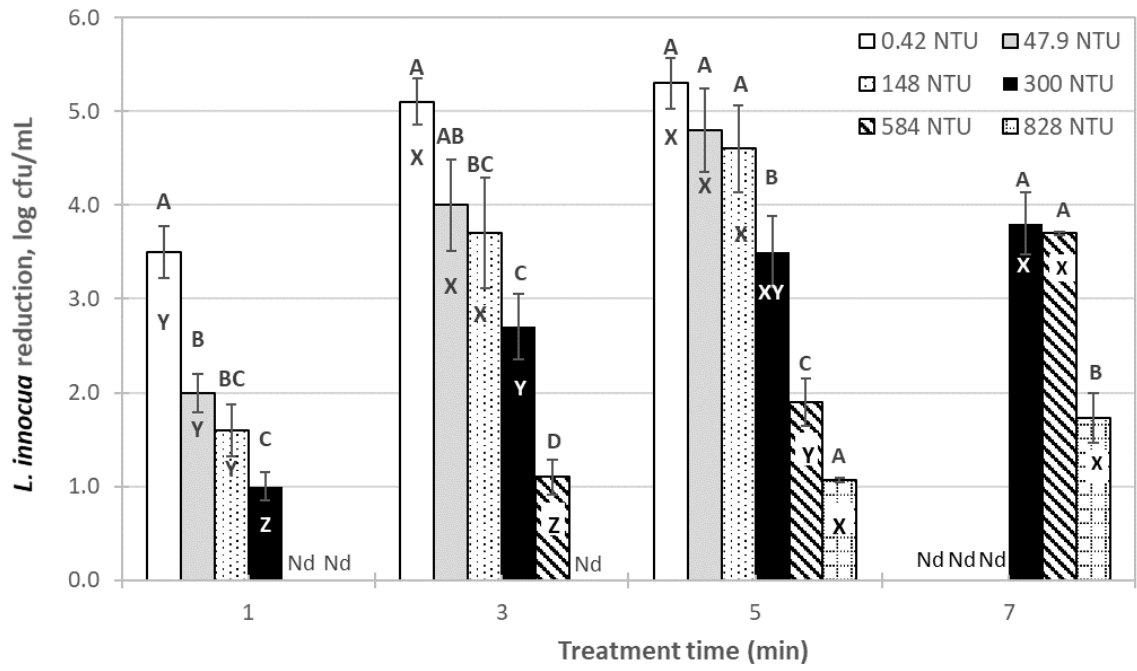
610



611

Figure 1

612

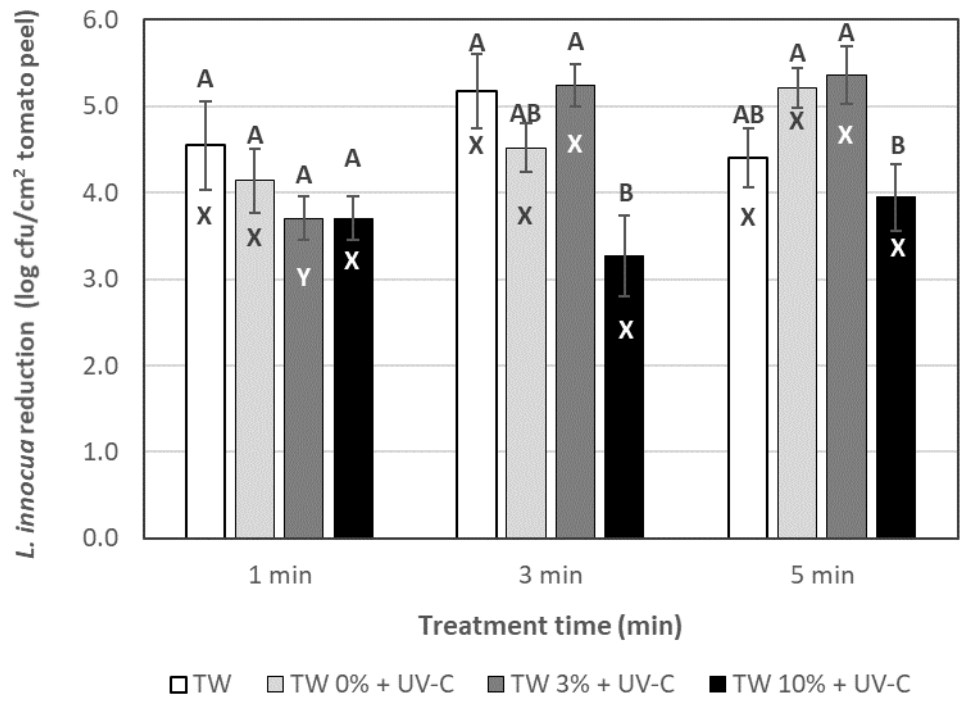


613

614

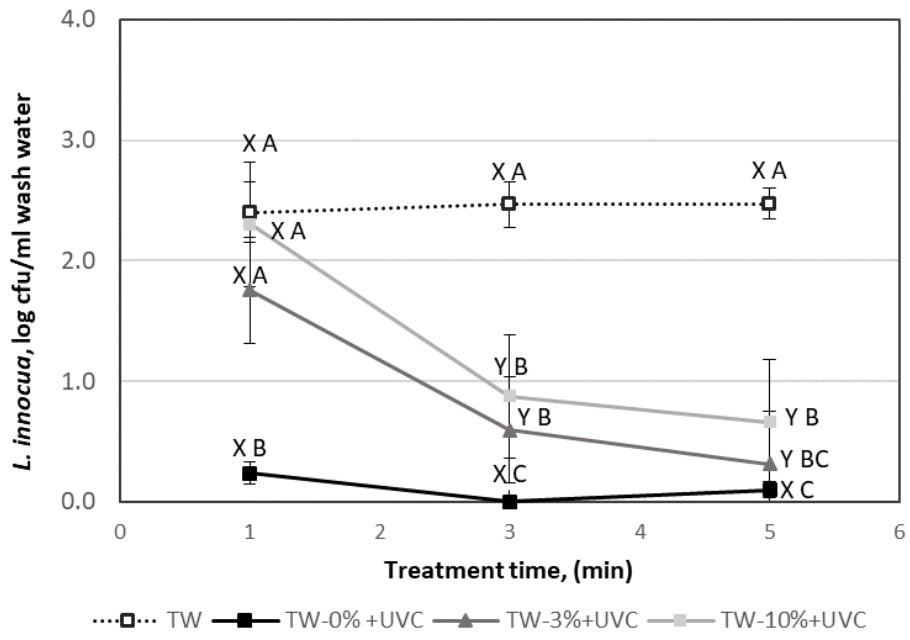
615 **Figure 2**

616



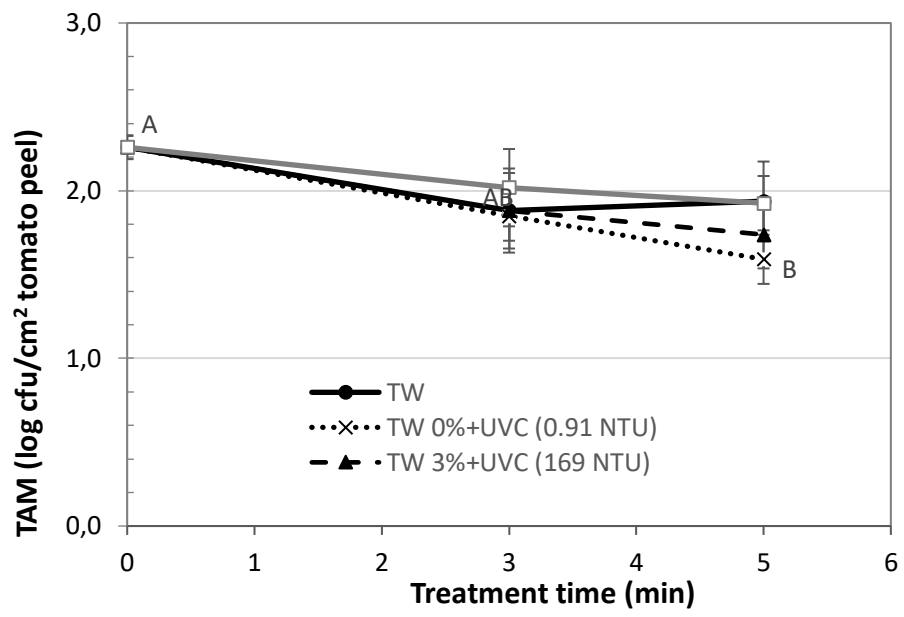
617
 618
 619
 620

Figure 3



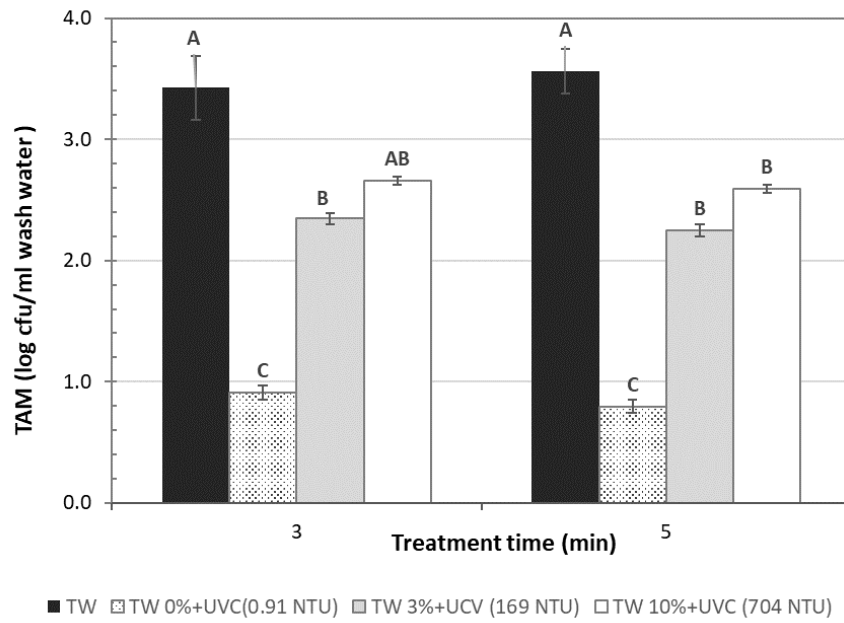
621
622
623
624

Figure 4



625
 626
 627
 628

Figure 5



629
 630
 631
 632

Figure 6

633 Table 1. Properties of wash water in the experiments of *L. innocua* inactivation in water
 634

Tomato pulp concentration (%)	Turbidity (NTU)		Conductivity (μ S/cm)		pH		ORP (mV)	
	Mean	Desvest	Mean	Desvest	Mean	Desvest	Mean	Desvest
0 %	0.42	0.15	322	14	7.94	0.06	242	18
1 %	47.9	7.5	426	55	7.20	0.48	242	8
2.5 %	148	14	747	7	6.58	0.67	249	4
5 %	300	26	1219	7	5.53	0.68	284	25
10 %	584	31	2085	21	4.68	0.15	310	29
15 %	828	21	2825	120	4.49	0.10	306	28

635

636 Table 2. Properties of wash water in tomato trials, with or without *L. innocua* inoculation.

637

Tomato pulp concentration (%)	Turbidity (NTU)		Conductivity (μ S/cm)		pH		ORP (mV)	
	Mean	Desvest	Mean	Desvest	Mean	Desvest	Mean	Desvest
0 %	0.88	0.40	322	14	7.94	0.06	243	5
3 %	166	24.7	747	7	6.58	0.67	262	30
10 %	664	36	2155	89	4.52	0.09	277	22

638

639 Table 3. Properties of wash water. Natural microbiota experiments

640

Tomato pulp concentration (%)	Turbidity (NTU)		Conductivity (μ S/cm)		pH		ORP (mV)	
	Mean	Desvest	Mean	Desvest	Mean	Desvest	Mean	Desvest
0 %	0.91	0.45	325	5	7.96	0.12	215	21
3 %	169	34	713	68	5.72	0.32	251	19
10 %	704	69	2070	373	4.45	0.07	270	2

641