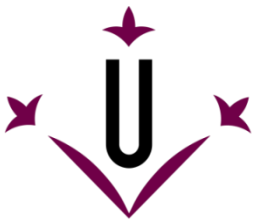

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Combined effect of pulsed light, edible coating and malic acid dipping to improve fresh-cut mango safety and quality

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ABSTRACT

The impact of pulsed light (PL), alginate coating (ALC) and malic acid dipping (MA) treatments on quality and safety aspects of fresh-cut mango was studied. Fresh-cut mangoes were inoculated with *L.innocua* and then subjected to PL (20 pulses at fluence of 0.4 J•cm^{-2}/ pulse), ALC (2 %) or MA (2 %) treatments. Moreover, different combinations of PL, ALC and MA were assayed to evaluate possible synergisms among treatments. Microbial stability and quality parameters (colour, pH, soluble solids and firmness) of fresh-cut mango were examined throughout 14 days of storage at 4 °C.

Results show that MA-PL and PL-ALC-MA treatments additively reduced *L.innocua* counts by 4.5 and 3.9 logs, respectively. Microbial population in fresh-cut mango remained below 6 log CFU/g over 14 days. Differences between firmness values of untreated and treated fresh-cut mangoes were evident throughout storage. Namely, firmness of alginate-coated slices sharply increased and progressively decreased over storage. Colour parameters and total soluble solids content decreased in all treated mango slices throughout 14 days, while pH was kept similar to that of the fresh tissue. An optimal combination of different treatments enables to ensure safety of fresh-cut mango with minimal quality deterioration throughout storage.

Key words: Fresh-cut mango; combined treatments, *L.innocua*, pulsed light, edible coatings.

1. INTRODUCTION

The growing demand for ready-to-eat fruits and vegetables has led to an increasing interest in the study of methods that enhance their safety while preserving freshness. Although fruits do not generally pose a safety hazard, peeling and cutting operations make fresh-cut fruits more susceptible to microbial attack. *Listeria sp* can be a hazardous contaminant of fresh-cut fruits as it is able to survive in a wide range of pH and temperature conditions. In fruits of low acidity, in which mango is included, *Listeria sp* may also find the conditions to survive and multiply (Penteado, de Castro, & Rezende, 2014). Among fresh-cut melon, apple and pineapple are the most commonly consumed and studied; however the demand for other fruits such as mango is continuously growing (Siddiq, Sogi, & Dolan, 2013). Mango (*Mangifera indica L.*) is one of the most harvested tropical fruits (FAO, 2012). It is widely demanded for its yellow colour, fleshy texture and unique flavour. Freshness and appearance are the primary criteria determining consumer satisfaction. Produce safety is also critical to maintain consumer confidence. Therefore, developing adequate treatments to obtain fresh-cut mango could help to promote its consumption and enable industry to satisfy the market trends.

Recent research in preservation methods for fresh-cut fruits has focused on assuring safety and maintaining original characteristics of fruit, while avoiding the undesired effects caused by handling and processing (Caminiti et al., 2011; Moody, Marx, Swanson, & Bermúdez-Aguirre, 2014; Proctor, 2010). Pulsed light (PL) treatments are being studied as a feasible alternative to conventional preservative processes (Oms-Oliu, Martín-Belloso, & Soliva-Fortuny, 2008). This technology involves the application of very short high-intensity pulses of broad spectrum light: (180 - 1100 nm). The composition of the spectrum and the energy density has been shown to play an important role in microbial cell death by PL (Keklik, Demirci, Puri, & Heinemann, 2012; Ramos-Villarroel, Martín-Belloso, & Soliva-Fortuny,

2011). Different studies have proposed the use of PL treatments for the decontamination of fresh-cut fruits; however, applications for fresh-cut tropical fruits are scarce. As far as we know, literature offers only a prospective study regarding the application of PL for the decontamination of fresh-cut mango (Charles, Vidal, Olive, Filgueiras, & Sallanon, 2013). On the other hand, edible coatings based on polysaccharides such as sodium alginate have been proposed for extending the shelf-life of fresh-cut fruits (Rojas-Graü, Tapia, Rodríguez, Carmona, & Martin-Belloso, 2007). These coatings are commonly formed as a thin layer on the cut surface of fruits, acting as a barrier against gas exchange and transpiration. Edible coatings enable to retard the physiological response to mechanical stress and other physical disorders leading to moisture and solutes migration, gas exchange, respiration and increased oxidative phenomena that have a deleterious impact on the product quality (Oms-Oliu et al., 2010; Raybaudi-Massilia, Mosqueda-Melgar, & Tapia, 2010). However, their effects in preventing microbial inactivation are scarce (Raybaudi-Massilia, Mosqueda-Melgar, & Martín-Belloso, 2008). The use of organic acids is another strategy which could be used to ensure safety of fresh-cut fruits. Malic acid dips have been shown to enable a decrease in microbial loads, thus ensuring safety and extending quality of fresh-cut produce over storage (Gómez et al., 2012; Raso & Barbosa-Cánovas, 2003; Rojas-Graü, Raybaudi-Massilia, et al., 2007; Tapia et al., 2007; Valencia-Chamorro, Palou, Del Río, & Pérez-Gago, 2011). Their antimicrobial activity could be attributed to the reduction of the medium pH, decrease of the intracellular pH by ionization of undissociated acid molecules.

As these strategies do not individually succeed in guaranteeing safety and quality maintenance of fresh-cut fruits, a combined methods approach stands as a good alternative to achieve this goal. Hence, the aim of the present work was to assess the effectiveness of combining PL, alginate coating and malic acid on the reduction of *Listeria innocua*

population as well as to evaluate microbial growth and physicochemical parameters (pH, soluble solids, colour and firmness) of mango slices over refrigerated storage.

2. MATERIALS AND METHODS

2.1. Mango slices preparation

'Tommy Atkins' mangoes were purchased from a local market (Lleida, Spain) at commercial maturity. Mango pH (3.46 ± 0.01) (Crison 2001 pH-meter; Crison Instruments S.A; Barcelona, Spain), total soluble solids (13.9 ± 0.2 °Brix) (Atago RX-1000 refractometer, Atago Company Ltd; Japan) and firmness (5.74 ± 0.7 N·s) (Texture Analyzer TA-XT2 Stable Micro Systems Ltd., Surrey, England, UK) of the fruit flesh were determined before processing. Whole mangoes were washed with an aqueous solution of sodium hypochlorite (300μL/L) and then peeled and cut to obtain 5 mm-thick slices. Sliced mangoes were inoculated and/or subjected to the different treatments, as described in the following sections. Once treated, slices (35±1g) were placed into transparent polypropylene trays and stored (4 ± 1 ºC) until analysis at days 0, 3, 7, 10 and 14.

2.2. *Listeria innocua* culture and inoculation

L. innocua IPL 1.17 (Institute Pasteur de Lille; Lille, France), as a surrogate of the pathogenic *Listeria monocytogenes*, were provided from the culture collections of the Department of Food Technology (University of Lleida, Spain). Stock culture of *L.innocua* was grown in tryptone soy broth (TSB) with 0.6 % yeast extract (Bioakar Diagnostic; Beauvais, France) and incubated at 35 °C with continuous agitation at 200 rpm for 15 h to obtain cells in stationary growth phase (10^8 - 10^9 CFU/mL). Mango slices (35 g) were inoculated by spreading 100 μL

of *L.innocua* stock cultures over the entire upper surface with a sterile micropipette before treatment and packaging (Ramos-Villarroel et al., 2011).

2.3. Pulsed light treatment

Pulsed light (PL) treatments were carried out with a XeMaticA-2L System (SteriBeam Systems GmbH, Germany). The experiments were performed at a charging voltage of 2.5 kV. The system is equipped with a lamp situated 8.5 cm above the sample holder. The lamp delivered pulses of 0.3 ms with an overall radiant fluence of 0.4 $J \cdot cm^{-2}$ at the sample level. The total light energy was measured according to the calibration of the equipment with a standard light source estimated by photodiode readings and manufacturer's directions. The emitted spectrum ranged from 180 - 1100 nm. To evaluate the effect of the wavelength of PL on the inactivation of *L.innocua*, two types of UV filters were used: a 2 mm-thick Pyrex glass filter that cuts off wavelengths below 305 nm hence allowing to pass some UVB, all UVA, visible light (V) and infrared (IR) wavelengths (89 % of the emitted energy); and Makrolon polycarbonate plastic filter that cuts all light below 400 nm, thus allowing only V and IR light to pass through (83 % of the emitted energy). In addition, treatments with increasing number of pulses (0, 10, 15, 20, 25, and 30) were assayed in order to evaluate the inactivation of *L.innocua* as affected by PL.

2.4. Alginate coating

Film-forming solutions were prepared by dissolving 20 g of alginate coating (ALC) (FMC Biopolymer Ladybum Works, USA) into 1000 mL of distilled water and homogenised with an Ultra Turrax T25 (IKA WERKE, Germany). Calcium chloride (20 g) was dissolved into 1000 mL of distilled water to be used as a crosslinking agent (Sigma-Aldrich Chemic.

Steinhein, Germany). Mango slices were dipped into the sodium alginate solution (2 % w/v) during 2 minutes and the excess was removed thereafter. A second dipping in calcium chloride (2 % w/v) solution was performed for ALC-coated mango slices.

2.5. Malic acid solution

DL-Malic acid (20 g) (MA) (Fluka; Steinhein, Germany) was dissolved by stirring into 1000 mL of distilled water. Mango slices were dipped into MA solution during 2 minutes. It must be noted that MA was incorporated to the calcium chloride solution when combined with the edible coating.

2.6. Combined treatments

Different combinations of PL (20 pulses of broad-spectrum light), ALC (2 % w/v) and MA (2 %) were evaluated to elucidate possible synergistic, additive or antagonist effects. The evaluated treatments were: ALC followed by PL (ALC-PL), MA followed by PL (MA-PL), ALC followed by MA (ALC-MA), PL followed by ALC and MA (PL-ALC-MA) and ALC followed by MA and PL (ALC-MA-PL). Untreated mango slices dipped in distilled water were considered as a control reference treatment (C).

2.7. Microbiological analyses

Sliced mangoes (10 g) were placed into sterile plastic bags with 90 mL of saline peptone water (Bioakar Diagnostic; Beauvais, France) and homogenized for 1 min in a stomacher blender (IUL Instruments, Barcelona, Spain) for microbial analyses. Serial dilutions were made and 100 μL were placed in Palcam agar plates (Bioakar Diagnostic; Beauvais, France) and spread with a Drigalsky handle. The evaluation was made by duplicate for each dilution

and the plates were incubated for 48 h at 37 ºC. Microbial population was evaluated and the results expressed as $\log_{10}$ CFU/g.

Enumeration of psychrophilic microorganisms on sliced mango was carried out by agar plate counting (PCA) (Biokar Diagnostic; Beauvais, France), after incubation at 4 ± 1 °C for 10 days, following the ISO 17410 (2001) method. Mould and yeast counts were determined by the ISO 7954 (1987) method using chloramphenicol glucose agar (CGA) (Biokar Diagnostic; Beauvais, France) and incubating for 4 days at 25 ± 1 °C. Counts were expressed as $\log_{10}$ CFU/ g.

2.8. Physicochemical determinations

2.8.1. pH and total soluble solids

The pH (pH-meter Crison Instruments S.A. Barcelona, Spain) and total soluble solids (TSS) (refractometer, Haake RS 80) were determined in a homogenate obtained from crushed mango slices (20 g). Triplicate analyses were carried out and results were expressed as mean and standard deviation.

2.8.2. Colour parameters

Colour was expressed as L*, a* and b*, which indicate luminosity, chromaticity on a green (-) to red (+) axis, and chromaticity on a blue (-) to yellow (+) axis, respectively. Lightness (L*) was determined with a tri-stimulus Minolta CR-400 colorimeter (Konica Minolta Sensing, INC, Osaka, Japan) using a D65 illuminant and an observation angle of 10º. For reference, a standard white tile (Y=94.00, x=0.3158, y=0.3322) was used. Based on the CIE L*, a* and b* values Hue angle (h°) was calculated (eq. 1). Colour parameters were obtained as the mean of three determinations.

$h° = \tan^{-1} (b^*/a^*)$ eq.1

2.8.3. Firmness

Firmness of sliced mangoes was analysed with a TA-XT2 Texture Analyser (Stable Micro Systems Ltd., England, UK) by considering the impulse required to penetrate the fruit flesh with a 4 mm diameter steel rod. To this purpose the area beneath the force-time curve was recorded. The test speed was 4 mm/s and the distance of penetration was 4 mm. Results were the mean of six measurements per sample and given as the delta firmness in N·s.

2.9. Data analysis

The treatments were conducted in duplicate; hence data were representative of two independent experimental runs. Statistical analyses were performed using the Statgraphics v.5.1 software (Manugistics, Inc. Rockville, MA, USA). The results were compared by analysis of variance (ANOVA) followed by Tukey's multiple comparison test to determine differences among means with a significance level of 5 %.

3. RESULTS AND DISCUSSION

3.1. Inactivation of *L. innocua* on mango slices

3.1.1. Effect of PL

The effect of PL spectral range and pulse number on the *L. innocua* population on mango slices is shown in Fig. 1. Inactivation was higher as pulse number increased. However, no additional inactivation was observed for treatments above 20 full spectrum pulses. Under those conditions, corresponding to an energy of 8 $J \cdot cm^{-2}$, 3.15 log reductions of *L. innocua* population were achieved. Similarly, Ramos-Villarroel, Martín-Belloso, & Soliva-Fortuny, (2011) and Ramos-Villarroel, Aron-Maftei, Martín-Belloso, & Soliva-Fortuny (2014) reported 2.61 and 2.97 log reductions of *L. innocua* population on fresh-cut avocado after treatments of 15 and 30 pulses, respectively. In addition, microbial inactivation rates decreased for intense treatments, probably due to the "shadow" effects caused by the formation of biofilms, the product geometry and the internalization of microorganisms in the fruit tissue. Furthermore, significant differences ($p < 0.05$) were observed between treatments using full spectrum PL and spectral ranges in which the UV component was removed, either partially (λ= 305 - 1100 nm) or completely (λ= 400 - 1100 nm). This is in line with other studies describing a higher bactericidal effect for light wavelengths in the range of 250 - 270 nm than for those above 305 nm. Higher inactivation levels achieved when UV light was used are related to the induction of DNA strand breaks and formation of pyrimidine dimers (Guerrero-Beltrán, 2004; Keyser, Műller, Cilliers, Nel, & Gouws, 2008). However, inactivation was yet significant for wavelengths above 400 nm, denoting a weak effect of light on *L. innocua*. Although high-energy pulse light treatments present several drawbacks due to the generation of heating on the product surface, no thermal effect was attributed to the

219 decrease of *L. innocua* population. Thus, inactivation was related with the amount of energy
220 received at the sample surface, wavelength and the microorganism type.
221
222 3.1.2. **Effect of combined methods**
223 The reduction of *L. innocua* counts on treated mango slices as affected by the combination of
224 PL, ALC and MA treatments is shown in Fig. 2. The assayed treatments led to a significant
225 ($p< 0.05$) reduction of the *L. innocua* survival fraction compared to those of untreated mango
226 slices. The three preservation factors applied individually led to a substantial reduction of the
227 initial counts. MA treatment was more effective than PL and ALC, in this order, leading to
228 2.9, 2.5 and 1.9 log reductions, respectively. Beyond the already discussed photochemical
229 effect of PL (Ross, Griffiths, Mittal, & Deeth, 2003), the antimicrobial effects of malic acid
230 have been reported to decrease the intracellular pH by ionization of un-dissociated molecules
231 (Ramos-Villarroel et al., 2014; Rathnayaka, 2013). Our results are in line with those reported
232 by Raybaudi-Massilia, Mosqueda-Melgar, Sobrino-López, Soliva-Fortuny, & Martín-Belloso,
233 (2009), who achieved 4 log reductions of *Listeria monocytogenes* counts in fresh-cut apples
234 dipped with MA. On the other hand, although sodium alginate has not been reported to
235 possess any antimicrobial effect, ALC treatments could remove part of microbial load or even
236 limit their ability to grow on the product surface.
237 Regarding the combined treatments, no synergistic effects were observed. However, the effect
238 of the combination of MA and PL was additive, leading to a maximum reduction of 4.49 log
239 cycles. It is noteworthy that the combination of the three preservation factors provided lower
240 inactivation levels, which at the same time depended on the order of the treatments
241 application. Hence, PL-ALC-MA and ALC-MA-PL treatments led to 3.92 and 3.03 log
242 reductions of the *L. innocua* populations, respectively. This fact was attributed to the

243 antagonistic action of the ALC factor, which may limit the effectiveness of the PL and MA
244 factors (Raybaudi-Massilia et al., 2010). Moreira, Tomadoni, Martín-Belloso, & Soliva-
245 Fortuny, (2015) observed that a gellan gum-based coating hindered the effectiveness of PL
246 applied to fresh-cut apples due to the blockage of a significant part of the UV-C radiation,
247 thus reducing the extent of photochemical inactivation. In this sense, our results are consistent
248 and suggest that PL treatments should be applied before alginate coating and malic acid
249 treatments. Although the feasibility of applying a combined methods strategy for reducing the
250 *L. innocua* populations growing on mango slices was demonstrated, a further experiment was
251 carried out to evaluate the impact of the assayed treatments on quality aspects throughout
252 refrigerated storage.
253

254 **3.2. Effects of combined treatments during storage on quality parameters of fresh-cut**
255 **mango**

256 **3.2.1. Microbial stability**

257 Among the naturally-occurring microbiota of untreated fresh-cut mangoes, moulds and yeasts
258 were initially predominant (Figure 3). However, after cutting, mould and yeast counts
259 remained almost stable, whereas psychrophilic bacteria abruptly increased. After the
260 application of the different treatments, both fungi and psychrophilic bacteria were reduced.
261 On the one hand, mould and yeast counts on the freshly cut untreated mango slices were
262 significantly ($p < 0.05$) reduced after the application of any of the individual or combined
263 treatments (fig. 3a). The lowest mould and yeast loads just after processing were observed for
264 mango slices subjected to PL or PL-ALC-MA, with reductions of 2.07 and 2.09 log cycles,
265 respectively. Mould and yeast inactivation achieved with the other treatments ranged from 1
266 to 1.5 log cycles. On the other hand, psychrophilic bacteria were less affected by the

treatments (fig. 3b). The highest inactivation of psychrophilic bacteria was obtained with the PL treatment (1.37 log cycles), followed by the PL-ALC-MA treatment (1.09 logs cfu/g). Mould and yeast counts observed after each treatment were maintained without substantial change during the first week of storage. This lag period coincided with an increase in the psychrophilic bacteria counts (Figure 3b) and might be directly attributed to the environmental changes promoted by minimal processing. In general, psychrophilic bacteria counts increased during the days thereafter processing but then they did not significantly change during the storage. In contrast, an increase in the moulds and yeasts populations was observed subsequently regardless the treatment applied. Microbial quality of mango slices was best maintained after the application of the PL-ALC-MA treatment. Hence, those samples exhibited the lowest counts for moulds and yeasts as well as for psychrophilic bacteria at the end of the studied period.

In accordance with the results obtained for *L. innocua* inactivation, microbial growth was influenced by the order of treatments combination. In this sense, PL application before coating enabled light to more efficiently decontaminate mango surface from microorganisms. Consistently, ALC, ALC-MA and ALC-PL treatments presented the highest microbial growth over storage. However, when applied in the adequate order, alginate coatings could help to maintain the integrity of damaged fruit tissues, thus limiting the presence of exudates and the consequent proliferation of microorganisms, as in the case of mango slices subjected to the PL-ALC-MA treatment.

3.2.2. Physicochemical parameters

3.2.2.1. Total soluble solids (TSS) and pH

Regarding TSS, significantly lower values, compared with the untreated, were observed just after the processing with the exception of mango samples subjected to the PL treatment (Table 1). These differences may be attributed to sugars lixiviation from the fruit slices when immersed into the dipping solutions used in the ALC and MA treatments (Chiumarelli, Ferrari, Sarantópoulos, & Hubinger, 2011; Hodges & Toivonen, 2008). Initial TSS values were kept almost constant over storage although a slight decrease, probably caused by microbial spoilage, was observed specially in untreated mango slices over the second week of storage.

Concerning pH values, these were significantly affected by the type of treatment applied. Malic acid dips resulted into a reduction of the natural pH of mango. However, this reduction was not considered to play a significant role on quality stability, as the greatest pH change, as much as 0.36 units, occurred after the PL-ALC-MA treatment. The decrease in pH may be explained by the acidification of the cytoplasm which can be promoted by the production of CO_2. As it is produced, this gas is partially dissolved in the water of the cellular tissues with the consequent decrease of pH medium (A. Y. Ramos-Villarroel et al., 2011). PL applied individually was not found to cause any pH modification. In contrast, alginate coated mango slices exhibited increased pH values in comparison with those obtained for untreated sliced mango. This may be attributed to the pH of the sodium alginate solution (pH = 4.3), which is higher than that of untreated mango (pH = 3.5).

3.2.2.2. Colour

Lightness (L*) and hue angle (h°), of mango slices as affected by combined treatments are displayed in Table 2. L* is an indicative parameter associated with the enzymatic browning of fruit and vegetables. ALC treatments, either individually applied or in combination led to decreased L* values compared to the colour of untreated mango slices (73.42 ± 2.53) or with

other combined treatments. L* values of mango slices stored 14 days were similar to those of the just processed although untreated mango slices increased L* values up to 77.3 ± 3.5. On the other hand, mango slices had similar h° value between untreated (93.3 ± 1.1) and treated mango slices at day 0. From then on, differences on h° values between treated and untreated mango slices were not observed or were really scarce.

According to Chiumarelli et al., (2011) and Ramos-Villarroel et al. (2011) a decrease of L* and h° parameter in fresh-cut mango and avocado respectively was observed due to PL treatment. Moreover, other authors suggested that mango cubes could develop undesirable colour as a consequence of the exposure to visible light due to a decompartmentalization process allowing colour substances such as phenolic compounds and carotenoids to come in contact with oxidative enzymes (Charles et al., 2013; Gómez et al., 2012). Despite of this, the present results indicated no signs of browning in treated mango slices. In this regard, the chlorine wash may reduce the browning effect as reported by Chen, Zhu, Zhang, Niu, & Du (2010) for fresh-cut lettuce. In addition, mango slices containing ALC preserved natural pigments of mango, such as carotenoids, confined in the cells, thus, the oxidation was avoided throughout the storage.

3.2.2.3. Firmness

Figure 4 shows the changes in firmness of mango slices as affected by combined treatments and storage time. Treated mango slices, except those subjected to PL, ALC-MA and ALC-MA-PL treatments, had higher firmness after processing than untreated mango slices. Fruits are likely to soften mainly due to hydrolysis of the pectic acids found in cell walls. Nevertheless, a protective effect of alginate and PL treatments against texture loss in mango slices was observed during storage. This fact was attributed to the action of calcium ions, which enable the crosslinking effect between the alginate polymer and calcium. Also, PL

338 could lead to the increase of polyamines, which could be related with a limitation of the
339 accessibility to the cell wall of the deleterious enzymes that promote softening (Charles et al.,
340 2013). Furthermore, an additive effect was observed when PL and alginate were combined. In
341 this sense, coating applied after PL treatment may have more influence on mango surface
342 texture than alone since pulsed light may have already increased the permeabilization of the
343 cell wall. Similarly, Gómez et al., (2012) observed, by light microscopy, that apple discs
344 treated by PL and dipping solution of ascorbic acid and calcium chloride increased the
345 resistance to rupture compared with untreated apple disc. This is in line with different studies
346 that described PL as a feasible treatment for firmness enhancement in fresh-cut fruits
347 (Gonzalez-Aguilar, Wang, Buta, & Krizek, 2001; Manzocco, Da Pieve, & Maifreni, 2011;
348 Ramos-Villarroel et al., 2011).
349

CONCLUSIONS

A PL treatment of 20 pulses of broad-spectrum light (λ= 180 - 1100 nm) with an overall energy 8 $J \cdot cm^{-2}$ was most suitable for controlling the growth of *L. innocua* on fresh-cut mango. The reduction could still be improved when MA-PL and PL-ALC-MA treatments were used.

Moulds and yeasts and pshychrophilic bacteria counts of mango slices were below 1 x 10^6 CFU/g after 14 days. In addition, the results suggested an additive effect on microbial load reduction by treatments combination. In that sense, low microbial counts were obtained in mango slices treated by those combined treatments where PL was applied first. PL, ALC, MA and their combinations contributed to maintain the colour parameters of sliced mango for 14 days. Mango slices had high resistance to rupture when PL treatment was individually applied or combined with both ALC and MA. Beyond confirming that PL plays an important role on fresh-cut mango preservation, the present study indicated better quality parameters and microbial stability in PL-ALC-MA treated mango slices.

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Table 1: Changes in mango slices total soluble solids (TSS) and pH during 14 days of storage (4 °C) after treatments PL: pulsed light (20 pulses at λ = 180-1100 nm and 0.4 J·cm^{-2}/ pulse); ALC: alginate coating (2 %); MA: malic acid (2 %) and C: untreated. Data shown are the mean of two replicate measurements ± standard deviation. Values within a column followed by the same lowercase letter are not significantly different ($p < 0.05$). Values within the same line followed by the same uppercase letter are not significantly different ($p < 0.05$).

	TSS									pH								
	0	3	7	10	14	0	3	7	10	14
CONTROL	12.9 ± 0.6^{Aa}	12.1 ± 0.3^{Aa}	11.9 ± 0.1^{ABa}	11.5 ± 0.1^{Ba}	11.1 ± 0.1^{Ba}	3.46 ± 0.01^{Aa}	3.48 ± 0.04^{Aa}	3.6 ± 0.0^{Ba}	3.46 ± 0.01^{Aa}	3.33 ± 0.01^{Ca}
PL	12.6 ± 0.9^{Aa}	12.6 ± 0.8^{Aa}	12.4 ± 0.1^{Ab}	13.1 ± 0.5^{Bb}	13.6 ± 0.1^{Ab}	3.37 ± 0.05^{Aa}	3.45 ± 0.09^{Ba}	3.5 ± 0.0^{Ba}	3.33 ± 0.01^{Ab}	3.56 ± 0.01^{Bb}
ALC	11.3 ± 0.9^{Abb}	11.3 ± 0.7^{Aab}	10.6 ± 0.2^{Ab}	10.9^{A} ± 0.1^{Ac}	10.1 ± 0.1^{Aa}	3.48 ± 0.03^{Aa}	3.48 ± 0.1^{Aa}	3.57 ± 0.02^{Ba}	3.39 ± 0.01^{Cb}	3.54 ± 0.01^{Bb}
MA	11.3 ± 0.2^{Abb}	10.9 ± 0.1^{Bb}	11.0 ± 0.1^{Ba}	10.4 ± 0.1^{Bc}	10.5 ± 0.1^{Ba}	3.28 ± 0.03^{Ab}	3.13 ± 0.1^{Bc}	3.41 ± 0.05^{Cb}	3.36 ± 0.01^{Ab}	3.57 ± 0.01^{Cc}
PL-ALC	12.0 ± 1.1^{Aa}	11.3 ± 0.1^{Bab}	11.4 ± 0.1^{Ba}	11.2 ± 0.4^{Ba}	11.0 ± 0.1^{Aa}	3.6 ± 0.04^{Ac}	3.7 ± 0.1^{Ab}	3.60 ± 0.01^{Aa}	3.45 ± 0.03^{Ba}	3.44 ± 0.01^{Bc}
ALC-PL	10.9 ± 0.2^{Ab}	11.5 ± 0.8^{Aab}	11.1 ± 0.1^{Aa}	10.9 ± 0.5^{Ac}	10.4 ± 0.1^{Bc}	3.69 ± 0.01^{Ac}	3.63 ± 0.06^{Ab}	3.61 ± 0.01^{Aa}	3.51 ± 0.02^{Bc}	3.64 ± 0.01^{Acd}
MA-PL	12.0 ± 0.9^{Aab}	12.0 ± 0.6^{Aa}	11.3 ± 0.1^{Ba}	11.6 ± 0.1^{Ba}	11.5 ± 0.1^{Aab}	3.22 ± 0.03^{Ab}	3.22 ± 0.02^{Ac}	3.3 ± 0.0^{Ac}	3.51 ± 0.01^{Bc}	3.53 ± 0.02^{Cb}
ALC-MA	11.4 ± 0.8^{Ab}	12.4 ± 0.6^{Aa}	11.4 ± 0.1^{Aa}	11.5 ± 0.4^{Aa}	11.9 ± 0.1^{Aac}	3.3 ± 0.1^{Ab}	3.2 ± 0.2^{Ac}	3.41 ± 0.01^{Bb}	3.46 ± 0.02^{Ba}	3.5 ± 0.02^{Bb}
ALC-MA-PL	10.6 ± 0.8^{Ab}	10.6 ± 0.6^{Ab}	11.2 ± 0.2^{Aa}	10.3 ± 0.2^{Ac}	10.0 ± 0.1^{Aa}	3.27 ± 0.05^{Ab}	3.21 ± 0.15^{Ac}	3.3 ± 0.01^{Ac}	3.32 ± 0.03^{Ab}	3.40 ± 0.01^{Bc}
PL-ALC-MA	11.3 ± 0.5^{Aab}	11.3 ± 0.3^{Aab}	11.1 ± 0.1^{Aa}	10.8 ± 0.1^{Ac}	11.2 ± 0.3^{Aa}	3.10 ± 0.01^{Ab}	3.2 ± 0.08^{Ac}	3.3 ± 0.01^{Ac}	3.65 ± 0.01^{Bcd}	3.45 ± 0.01^{Bc}

Table 2: Changes in mango slices lightness (L*) and hue angle (h°) during 14 days of storage (4 °C) after treatments PL: pulsed light (20 pulses at λ = 180-1100 nm and 0.4 J·cm^{-2}/ pulse); ALC: alginate coating (2 %); MA: malic acid (2 %) and C: untreated. Data shown are the mean of two replicate measurements ± standard deviation. Values within a column followed by the same lowercase letter are not significantly different ($p < 0.05$). Values within the same line followed by the same uppercase letter are not significantly different ($p < 0.05$).

	L*					h°				
	0	3	7	10	14	0	3	7	10	14
CONTROL	73.42 ± 2.53^{Aabc}	71.99 ± 2.58^{Aa}	74.86 ± 3.97^{Aa}	77.2 ± 2.4^{Ba}	77.3 ± 3.5^{Ba}	93.3 ± 1.1^{Ac}	97.15 ± 2.47^{Ba}	93.7 ± 1.1^{Aa}	95.24 ± 1.08^{Ba}	95.8 ± 1.6^{Ba}
PL	76.41 ± 1.96^{Ac}	73.57 ± 0.19^{Ba}	72.04 ± 2.31^{Ba}	78.4 ± 0.3^{Ca}	76.57 ± 2.37^{Aa}	94.2 ± 0.2^{Aab}	94.83 ± 1.20^{Ab}	94.14 ± 2.36^{Aa}	93.86 ± 0.55^{Bb}	92.6 ± 0.8^{Bb}
ALC	73.85 ± 1.05^{Aabc}	67.2 ± 2.9^{Bab}	75.10 ± 0.54^{Cb}	71.7 ± 1.1^{Db}	72.2 ± 2.1^{ADb}	94.81 ± 0.44^{Aab}	97.01 ± 0.23^{Ba}	94.74 ± 0.17^{Aa}	92.94 ± 0.04^{Cb}	95.51 ± 1.67^{Aa}
MA	77.6 ± 2.7^{Aabc}	72.7 ± 1.4^{ABa}	77.20 ± 0.04^{Ac}	75.6 ± 2.0^{Aa}	76.8 ± 4.1^{Aba}	95.3 ± 0.5^{Aa}	97.33 ± 0.55^{Aa}	96.5 ± 0.4^{Bb}	92.84 ± 0.26^{Cb}	95.23 ± 2.16^{Aa}
PL-ALC	72.98 ± 0.08^{Aab}	64.57 ± 1.93^{Bab}	72.40 ± 0.13^{Aa}	70.0 ± 2.5^{Ab}	71.1 ± 1.0^{Ab}	94.03 ± 0.88^{Abc}	96.55 ± 0.04^{Bc}	94.09 ± 0.06^{Aa}	93.85 ± 0.88^{Abc}	96.5 ± 0.1^{Ba}
ALC-PL	69.61 ± 1.68^{Aabc}	66.4 ± 1.2^{Bab}	66.80 ± 1.54^{Ac}	68.2 ± 0.7^{Bc}	67.1 ± 1.8^{A}	95.9 ± 2.3^{Aa}	99.72 ± 1.97^{Bad}	94.95 ± 0.35^{Ca}	95.9 ± 0.5^{Aa}	95.01 ± 0.06^{Aa}
MA-PL	78.01 ± 3.15^{Aabc}	71.26 ± 2.66^{Bab}	71.7 ± 3.9^{Aa}	72.47 ± 0.78$^{A}_{b}$	72.90 ± 2.46^{Ab}	95.20 ± 3.22^{Aa}	97.37 ± 2.78^{Aa}	92.97 ± 0.45^{Bab}	93.03 ± 0.59$^{BCb}_{c}$	94.95 ± 1.10^{Ca}
ALC-MA	72.8 ± 1.2^{Aabc}	65.9 ± 1.9^{Bab}	68.5 ± 1.9^{Bc}	66.89 ± 1.70^{Bc}	72.73 ± 2.32^{Ab}	92.35 ± 1.45^{Ac}	97.01 ± 3.28^{Ba}	92.77 ± 3.10^{Ab}	92.6 ± 1.8^{Ab}	93.39 ± 2.05^{Ab}
ALC-MA-PL	71.33 ± 4.87^{Aa}	65.22 ± 1.29^{Bab}	70.70 ± 3.37^{Aa}	71.8 ± 6.4^{Ab}	69.85 ± 1.31^{Ac}	94.7 ± 1.9^{Abc}	98.25 ± 0.93^{Bad}	95.2 ± 1.5^{Aab}	95.8 ± 3.2^{Ba}	95.65 ± 2.85^{Ba}
PL-ALC-MA	71.6 ± 3.5^{Abc}	67.13 ± 2.64^{Bab}	71.73 ± 4.28^{Ba}	68.6 ± 0.2^{Bc}	70.16 ± 0.06^{Ac}	93.9 ± 1.3^{Aa}	97.26 ± 1.68^{Bad}	94.2 ± 0.8^{Aab}	94.0 ± 1.3^{Aab}	94.5 ± 0.5^{Aa}

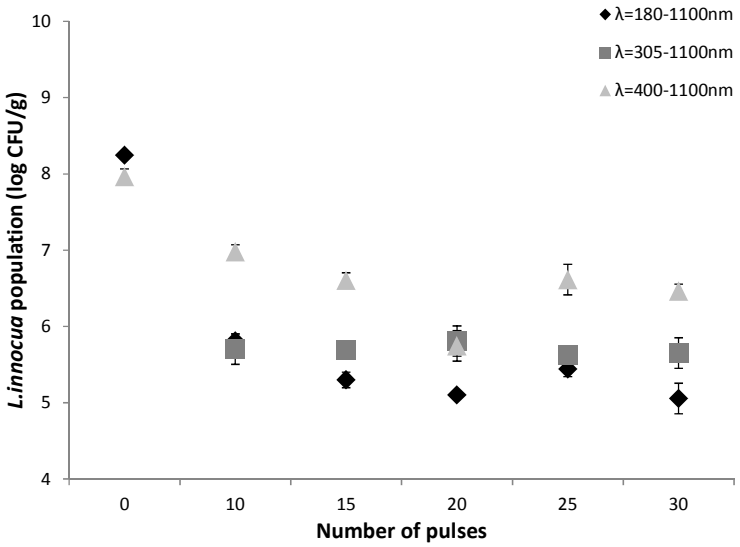

Figure 1: Influence of the spectral range on survival of *L. innocua* inoculated in mango slices treated by pulsed light at different number of pulses. The values are the mean of four determinations ± SD.

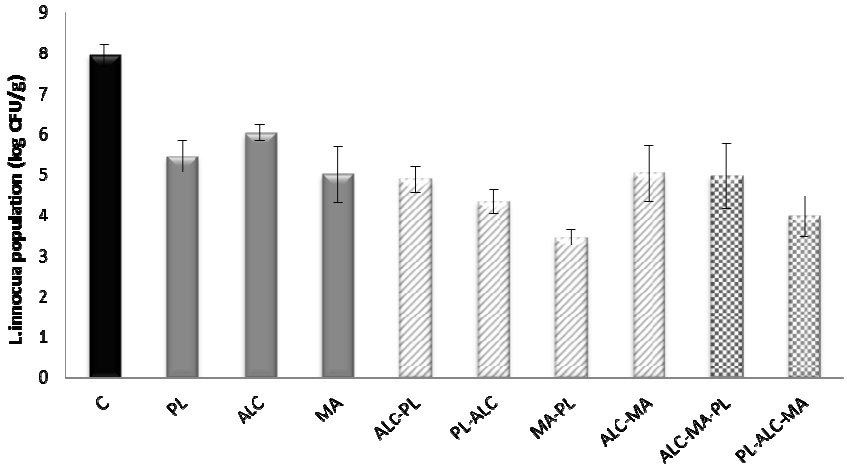

Figure 2: Influence of different individual or combined treatments on survival of *L. innocua* inoculated in mango slices. PL: pulsed light (20 pulses at λ = 180- 1100 and 0.4 J·cm^{-2}/pulse); ALC: alginate coating (2 %); MA: malic acid (2 %) and C: untreated. The values are the mean of four determinations ± SD.

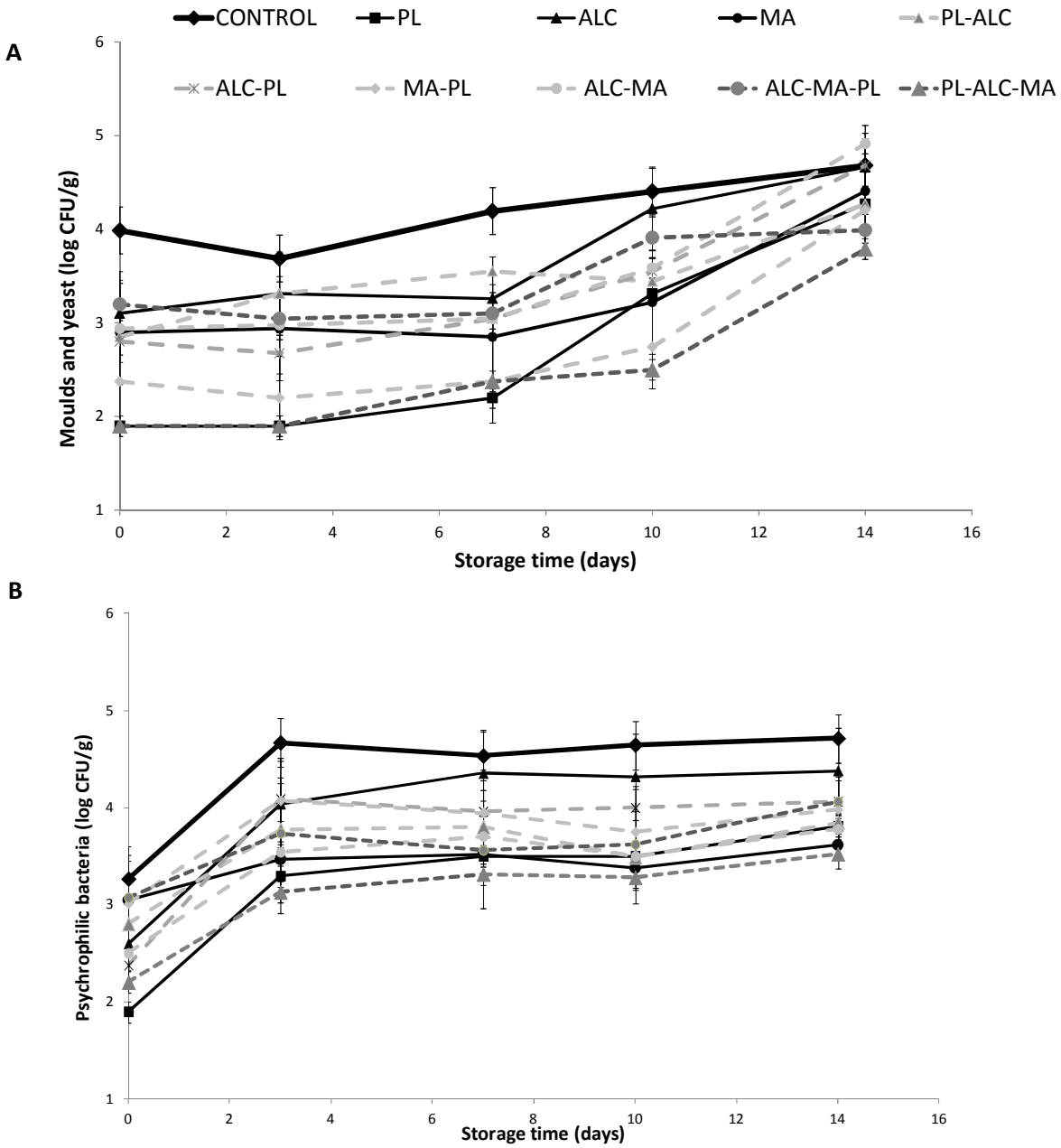

Figure 3: Growth of moulds and yeasts (A) and psychrophilic bacteria (B) on sliced mango submitted to different treatments throughout 14 days of storage at 4 °C. PL: pulsed light (20 pulses at λ = 180- 1100 and 0.4 J·cm^{-2}/pulse); ALC: alginate coating (2 %); MA: malic acid (2 %) and C: untreated. Data shown are the mean of two replicate measurements obtained from two replicate packages ± standard deviation.

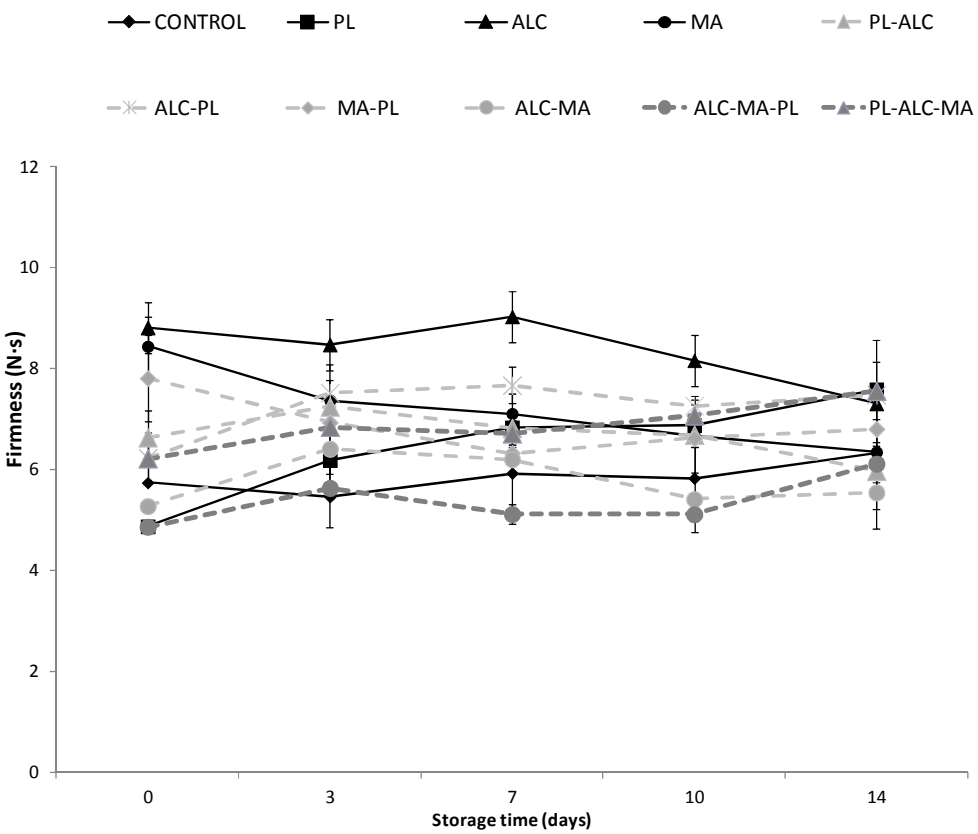

Figure 4: Changes of firmness in stored mango slices after expose them to different treatments. PL: pulsed light (20 pulses at λ = 180- 1100 nm and 0.4 J·cm^{-2}/ pulse); ALC: alginate coating (2 %); MA: malic acid (2 %) and C: untreated. Data shown are the mean of six measurements ± SD.

Highlights

- Broad spectrum pulsed light treatment reduced *Listeria innocua* population in fresh-cut mango.
- Pulsed light combined with edible coating and malic acid had an additive effect on microbial reduction in fresh-cut mango.
- Combined treatments maintained physical attributes of fresh-cut mango throughout storage.
- Pulsed light as a first hurdle in combination with the other treatments enhanced quality of fresh-cut mango for 14 days.