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Hot water treatment and peracetic acid to maintain fresh-cut Galia melon quality

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ABSTRACT

The aim of the present study was to investigate if the use of hot water immersion dipping (HWD) alone or combined with other ecofriendly methods, could replace the use of chlorine in fresh-cut fruits such as melon. Melon pieces were subjected to hot (60 °C) or cold (5 °C) water dipping (60, 90, 120 s or 60 s, respectively) followed by immersion in 80 mg L^{-1} peracetic acid (PAA) for 60 s at 5 °C or in water, packed in polypropylene trays under passive modified atmosphere (7.4 kPa O_2 and 7.4 kPa CO_2 at steady state), and stored up to 10 days at 5 °C. Respiration rate, ethylene emission, microbial load, flesh firmness, polyamine content and sensorial quality were determined. As main conclusions the longer HWD treatment times (90 and 120 s) followed by PAA dip, provided the lowest metabolic activity and helped to control microbial load without affecting the sensorial quality. In addition, both treatments increased the polyamine content helping to maintain the cell membranes integrity.

Industrial relevance: Maintaining quality and microbial safety are the most important concerns of the fresh-cut fruit and vegetables industry. The present study focused on assessing the effect of HWD treatments alone or in combination with PAA, on the respiration rate, ethylene emission, microbial load, flesh firmness, polyamines content and quality retention of fresh-cut Galia melon. According to our results, the use of a heat treatment alone or combined with PAA could replace the use of chlorine, and could be a feasible alternative for fresh-cut industry as a sanitizing method, as or more effective as chlorine.

1. Introduction

Fresh-cut fruit or minimally fresh processed has been a rapidly growing segment of the produce industry and was predicted to exceed U.S. $1 billion by 2008, with fresh-cut melon products being a significant segment of this industry (Clement 2004). However, fresh-cut fruits and vegetables are no longer considered low risk in terms of food safety (Bhagwat 2006). In commercial elaboration processing, the quality maintenance and microbial safety are the most important concerns and an accurate disinfection program should be achieved (Artés, Gómez, Aguayo, Escalona, & Artés-Hernández 2009). The fresh-cut industry has used chlorine as one of the most effective sanitizers to assure the safety of their product. However, there is a trend in substituting chlorine from the disinfection process because of concerns about its efficacy, and the environmental and health risks associated with the formation of carcinogenic halogenated disinfection by-products (Ölmez & Kretzschmar 2009). In this sense, the implementation of heat treatments, alone or in combination with other sanitizing methods, could be a viable alternative to preserve the sensory and microbial quality of the products without leaving chlorine residual.

Heat can be applied to fruit and vegetables, including melon, as hot water dips (HWD), vapor heat, or hot dry air. Moreover, hot water treatments are less costly and easily applied at commercial scale, particularly in treatments of short duration (Hofman, Stubbings, Adkins, Meiburg, & Woolf 2002).

Heat causes changes in fruit ripening, such as inhibition of C_2H_4 synthesis and action of cell wall degrading enzymes, due to changes in gene expression and protein synthesis (Paull & Chen 2000). Heat treatments have been shown to effectively reduce human pathogens and native microflora on whole cantaloupe melon (Annous, Burke, & Sites 2004; Solomon, Huang, Sites, & Annous 2006), and have been used successfully in fresh-cut fruit and vegetables like Amarillo melon (Aguayo, Escalona, & Artés 2008), watermelon (Aguayo, Escalona, Gómez, Rodríguez-Hidalgo, & Artés 2008), mangoes (Djioua et al. 2009), rocket leaves (Koukounaras, Siomos, & Sfakiotakisa 2009) and shredded carrot (Alegría et al. 2010). In all these fresh-cut products heat treatments maintained the microbial and sensory quality.

One of the effects of heat treatment related to stress conditions is the increase in polyamine concentrations like putrescine (Put);

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spermidine, (Spd) and spermine (Spm) as reported by Bouchereau, Aziz, Larher, and Martin-Tanguy (1999). Specifically, accumulation of Put was found in chilling-injured pepper, cucumber, orange, lime and lemon (Martínez-Romero, Serrano, & Valero 2003; Serrano, Pretel, Martínez-Madrid, Romojaro, & Riquelme 1998; Serrano et al. 1996).

As it is well known, current sanitizing methods, mainly the use of chlorine, are not completely effective for reducing microbial load of fresh-cut fruit and vegetable products. For this reason, the combination of different physical and chemical sanitizing methods has been required to successfully maintain microbiological safety. For example, Ukuku, Pilizota, and Sapers (2004) demonstrated that immersion of inoculated cantaloupe in hot water (70 °C for 1 min) combined with 5% H_2O_2 resulted in up to 3.8 log colony forming units per g of sample (cfu g^{-1}) reduction in *Salmonella*. In addition, generally recognized as safe (GRAS) compounds have been applied in hot water to improve the efficiency of their antifungal action (Klaiber, Baur, Wolf, Hammes, & Carle 2005).

Temperatures used for HWD on different fresh-cut products range from 40 to 60 °C, while dipping times range from 1 to 5 min in most published works (Gómez et al. 2008; Paull & Chen 2000).

Peracetic acid (PAA) is a sanitizing agent that does not react with proteins to produce toxic or carcinogenic compounds (Holah, Higgs, Robins, Worthington, & Spencely 1990) as chlorine does. The efficiency of PAA has been studied in several fresh-cut commodities like potatoes, celery and cabbage (Hilgren & Salverda 2000) and Galia melon (Silveira, Aguayo, & Artés 2010; Silveira, Conesa, Aguayo, & Artés 2008). Combining PAA with hot water immersion dipping (HWD) may further enhance its antimicrobial effects.

Consequently, the aim of this work was to determine the effect of the HWD treatment combined with PAA on metabolic activity, microbial and sensory quality changes of fresh-cut Galia melon.

2. Material and methods

2.1. Minimally fresh processed melon

Galia melons (*Cucumis melo* var. *cantalupensis* Naud) of the commercial cv. Cyro, grown in open-air irrigated plantations under the Mediterranean climate of the Campo de Cartagena (Murcia, Spain), were hand harvested in a state of maturity defined using the scale color of Difrusa Export, SA for Galia melon (scale 1 to 9) and according to soluble solids content (SST), expressed as °Brix. The maturity stage corresponded to 6 on color scale and 11 °Brix. This soluble solids content level is considered as corresponding to the optimal commercial ripening stage for allowing the usual time lapse for distribution and retail sale (Artés, Escriche, Martínez, & Marín 1993). Melons were selected in a packinghouse according to their size (almost spherical, of about 1 kg weight) and external skin color, discarding damaged fruit. Sound melons of uniform appearance were transported about 30 km to the Pilot Plant of the Postharvest and Refrigeration Group at the Technical University of Cartagena, where they were stored at 10 °C. The next morning, in a disinfected cold room at 10 °C, minimal processing began by washing the fruits with tap water, draining, and then drying with blotting paper. Melons were hand cut into eight slices, parallel to the longitudinal axis, and blossom and stem-ends discarded. For reaching a good visual appearance of melon pieces, the placenta must be properly separated from the pulp and discarded, avoiding browning. Additionally, the stress produced during processing must be minimized. Consequently, the use of sharp knives for cutting and separating fresh-cut melon pulp from seeds and placenta has been strongly recommended (Aguayo, Escalona, & Artés 2004). Subsequently, the pulp was hand cut into trapezoidal shaped sections (3.4 ± 0.4 cm wide, 4.4 ± 0.5 cm length). Knives were disinfected with chlorinated (0.1 g L^{-1}) water for 30 min before use.

2.2. Hot water dipping and packaging

After cutting, melon pieces were treated by HWD at 60 °C for 60, 90 or 120 s followed by an immersion in 80 mg L^{-1} PAA (Sigma-Aldrich, Germany) at 5 °C for 60 s. Two control treatments were used, the first used melon pieces dipped in water at 5 °C during 60 s followed by immersion in 80 mg L^{-1} PAA at 5 °C for 60 s. In the second control, melon pieces were treated by HWD at 60 °C for 60 s followed by immersion in tap water at 5 °C for 60 s.

For HWD, a special bath designed and constructed by the Postharvest and Refrigeration Group was used. The bath consisted of a plastic box of 190 L capacity equipped with an electrical resistance element (Selecta, Barcelona, Spain) to heat the water, and a recirculation water mechanism connected to a 50 L deposit which maintained the water temperature homogenized using a pump and thermostat. When the water achieved the selected temperature (60 °C), the melon pieces were put in a wire mesh (previously disinfected), and the corresponding HWD treatment was applied. To confirm the temperature maintenance in melon, a thermometer was inserted in the centre of a piece of melon. The thermal difference in the center of the melon pieces before and after the HWD was no higher than 2 °C.

For all treatments, after washing, melon pieces were drained in a colander, and samples of 145–150 g were packaged into polypropylene (PP) trays of 0.250 L. Trays were heat-sealed (Barket, Befor Model, Chassieu, France) with an oriented polypropylene film (OPP) of 35 μm thickness to generate a passive modified atmosphere packaging (MAP) by the interaction between the respiration of the product and the permeability of the selected film. Permeability of this film at 23 °C and 75% RH was 5.5 L m^{-2} d^{-1} atm^{-1} for O_2 and 10 L m^{-2} d^{-1} atm^{-1} for CO_2 (data provided by Plásticos del Segura, Murcia, Spain). These trays were stored up to 10 d at 5 °C. The final gaseous concentration found inside the MAP trays was 7.4 kPa O_2 plus 7.4 kPa CO_2. Three repetitions (trays) were evaluated for each treatment on day 0, 3, 7 and 10 of chilling storage.

2.3. Respiration rate and ethylene emission

Samples of 150 g cut melon from each treatment were placed into 1 L glass jars at 5 °C. Jars were connected to a gas flow panel (Postharvest and Refrigeration Group, Cartagena, Spain) with an air flow of 0.1 to 0.2 L h^{-1}, humidified to 95% RH. The jars were closed for 2 h and then the increase in CO_2 was measured by taking a 0.5 mL gas sample from the headspace through a silicone septum using a plastic syringe. This sample was injected into a gas chromatograph (Thermo Finningan Trace, Thermo-Quest, Milan, Italy) equipped with a thermal conductivity detector. The measurements were done every 1 or 2 days during 10 days at 5 °C. Between measurements, jars were flushed with humidified air in order to avoid CO_2 accumulation higher than 0.3 kPa (Artés et al. 1993).

2.4. Microbial analysis

From each replicate, 3 random samples of 30 g of fresh-cut melon were collected from trays and homogenized for 2 min in 270 mL of sterile peptone buffered water (Scharlau, Barcelona, Spain) in a sterile stomacher bag with a Colorworth Stomacher 400 (Steward Laboratory, London UK). Serial dilutions were prepared in the same peptone solution. Mesophilic, psychrotrophic aerobic bacteria and *Enterobacteriaceae* were quantified on days 0, 3, 7 and 10. Plate count agar was used for enumeration of mesophilic and psychrotrophic aerobic bacteria, incubated for 48 h at 30 °C or 7 days at 7 °C, respectively. Violet-red bile dextrose agar, overlaid with the same medium and incubated at 37 °C for 24 h was used for *Enterobacteriaceae*. Microbial counts were expressed as $\log_{10}$ cfu g^{-1}. Microbial quality of the product was evaluated by following the Spanish microbial legislation for minimally fresh processed vegetables (RD 3484/2000 2001). According to this, the maximum microbial loads tolerated are 7 log cfu g^{-1} for aerobic bacteria.

2.5. Firmness analysis

A puncture test was used to evaluate the melon pieces' firmness, based on the resistance of each piece to pressure applied by a Lloyd instrument (LR10K, Fareham, Hants, United Kingdom). During the puncture test, a 4.5 mm diameter flat-head stainless steel cylindrical probe penetrated the middle of the longitudinal axis of the pieces (5 mm depth) at a speed of 50 mm/s (as described in Aguayo et al. 2004). At each sampling day, the firmness of 10 pieces from each treatment was measured.

2.6. Polyamine analysis

Free polyamines were analyzed according to the method of Zapata, Serrano, Pretel, Amorós, and Botella (2003). A total of 2 g of frozen tissue was homogenized in a chilled mortar with 3 mL of 0.2 N percloric acid. The homogenate was then centrifuged at 12 000 ×*g* for 20 min at 4 °C. Free polyamines in the supernatant were benzoylated as previously described (Zapata et al. 2003). The organic phase was dried under a stream of N_2 at 70 °C, the residue resuspended in 200 mL of acetonitrile (HPLC grade) and filtered through a HV-4 filter (Millipore, pore size 0.45 mm) for HPLC analysis. Polyamines were determined using an Agilent 1200 Series HPLC (Agilent Berks, UK). The elution system consisted of MeOH/H_2O (64:36) solvent, running isocratically with a flow rate of 0.8 mL min^{-1}. The benzoyl-polyamines were eluted through a reversed-phase column (LiChroCart 250 mm, 4.5 μm Merck, Darmstadt, Germany) and detected by absorbance at 254 nm. A relative calibration procedure was used to determine the polyamines in samples, using standard curves of Put, Spd and Spm from Sigma (Poole, Dorset, England). The results are expressed as nmols per gram of fresh weight (nmol g^{-1}).

2.7. Sensory evaluations

A panel of five people carried out the sensory evaluations in a room at 15 °C. The members of the panel (3 men and 2 women; aged 25 to 60) were trained to recognize and to score the quality attributes of melon pieces using fresh and stored samples. The sensory quality of fresh-cut melon flesh was assessed at the processing day (0 d), and after 3, 7 and 10 days of storage. Appearance was assessed using a 9-point scale to record perceptions of visual appearance where; 1 = inedible, 3 = poor, 5 = fair, 7 = good, and 9 = excellent. Taste and texture were scored on a similar scale, where 1 = completely lacking or soft, 3 = lack or soft, 5 = moderate, 7 = good, and 9 = full characteristic or fresh, respectively. In both scales, the limit of marketability was 5. The term 'acceptability' refers to the overall appreciation of a sample measured on the same scale. The samples were coded with a random 3-digit number to mask the treatment identity, in order to minimize subjectivity and to ensure test accuracy, and compared with a fresh sample (cut before each evaluation) as described in Aguayo, Requejo, Stanley, and Woolf (2010).

2.8. Statistical analyses

The experiment followed a completely randomized design (n = 3). The mean standard error was calculated using Statgraphic Plus version 2.1 (Manugistic, Inc., Rockville, Md., U.S.A) and analysis of variance (ANOVA) and least significant difference test ($P \leq 0.05$) to compare means within each sampling date.

3. Results and discussion

3.1. Respiration rate and ethylene emission

Respiration rate evolution is shown in Fig. 1. After 2 days, respiratory activity, irrespective of treatment, decreased from initial values of 4 to 6 mg CO_2 kg^{-1} h^{-1}, with no differences among treatments. This trend is usually related to the initial stress generated during the cutting process as reported by Aguayo et al. (2004) and Silveira et al. (2010, 2008). In most treatments, the respiration rate started to increase slightly from day 5 until the end of the storage. Melon pieces treated with HWD and PAA, in particular, HWD of 90 and 120 s, had lower respiration rates than the control treatments, with differences most apparent after 5 days of storage. Respiration rates increased in all treatments after day 9, probably related to microbial growth and general tissue deterioration (senescence).

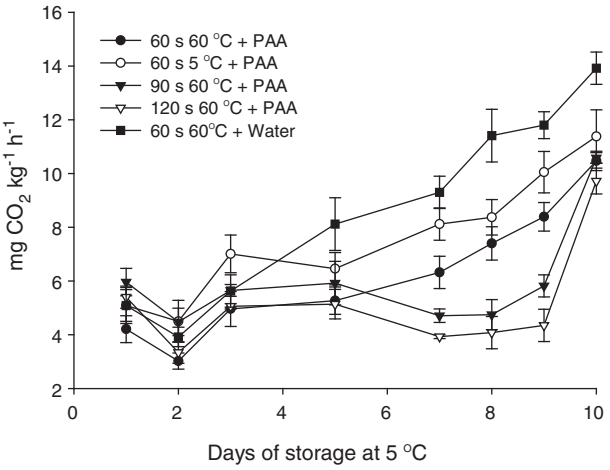

Fig. 1. Respiration rate of fresh cut 'Galia' melon stored under modified atmosphere packaging at 5 °C during 10 d. Vertical bars indicate the standard error of the means (n = 3).

Paull and Chen (2000) found that heat treatments performed at non-lethal conditions cause a moderate stress when applied to fruit tissues, which provokes a momentary stop of the normal metabolism that is recovered once the fruit is returned to non-stressing temperatures. This fact could explain the reduction on respiration rate observed in HWD melon treatments. Fallik et al. (1999) observed that respiration rate and C_2H_4 emission on bell peppers dipped in hot water (55 °C for 12 s) was significantly lower than untreated ones during 15 days at 7 °C followed by 4 days at 16–18 °C. Salveit (2005) reported a protective effect of heat treatment on tomato membranes, conferring a lower metabolic activity and a higher chilling injuries resistance.

The C_2H_4 emission also showed differences among treatments (Fig. 2). Melon pieces treated with HWD for 90 and 120 s followed by PAA showed significantly lower C_2H_4 emission than all other treatments (< 0.11 μL C_2H_4 kg^{-1} h^{-1}), for up to 7 days. After 8 days of storage, no differences were observed between C_2H_4 emissions of any PAA

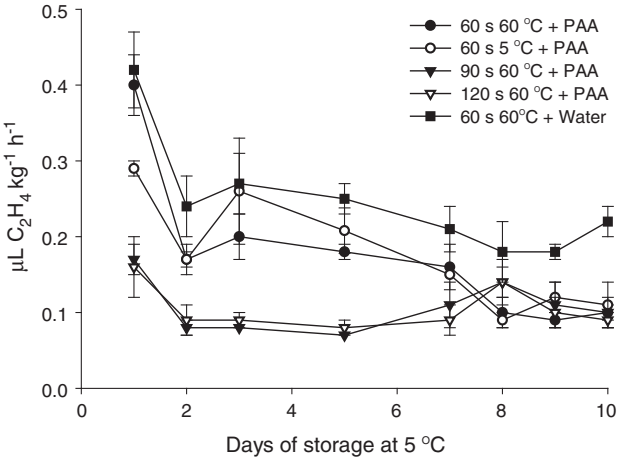

Fig. 2. Ethylene emission of fresh cut 'Galia' melon stored under modified atmosphere packaging at 5 °C during 10 d. Vertical bars indicate the standard error of the means (n = 3).

treatments. HWD treatment followed by water at 5 °C consistently had the highest C_2H_4 emission, until the end of the storage period.

This reduction on C_2H_4 emission has been reported by other authors, for example in whole avocado exposed to hot air (38 °C during 4 h) (Florissen et al. 1996). They explained that this behavior would be a temporary heat effect on the enzyme activities linked with C_2H_4 production, (Lurie 1998; Paull & Chen 2000). In our experiment, the short exposure time would be insufficient to destroy the enzymes, but nevertheless was probably sufficient to cause a reduction in enzyme activity.

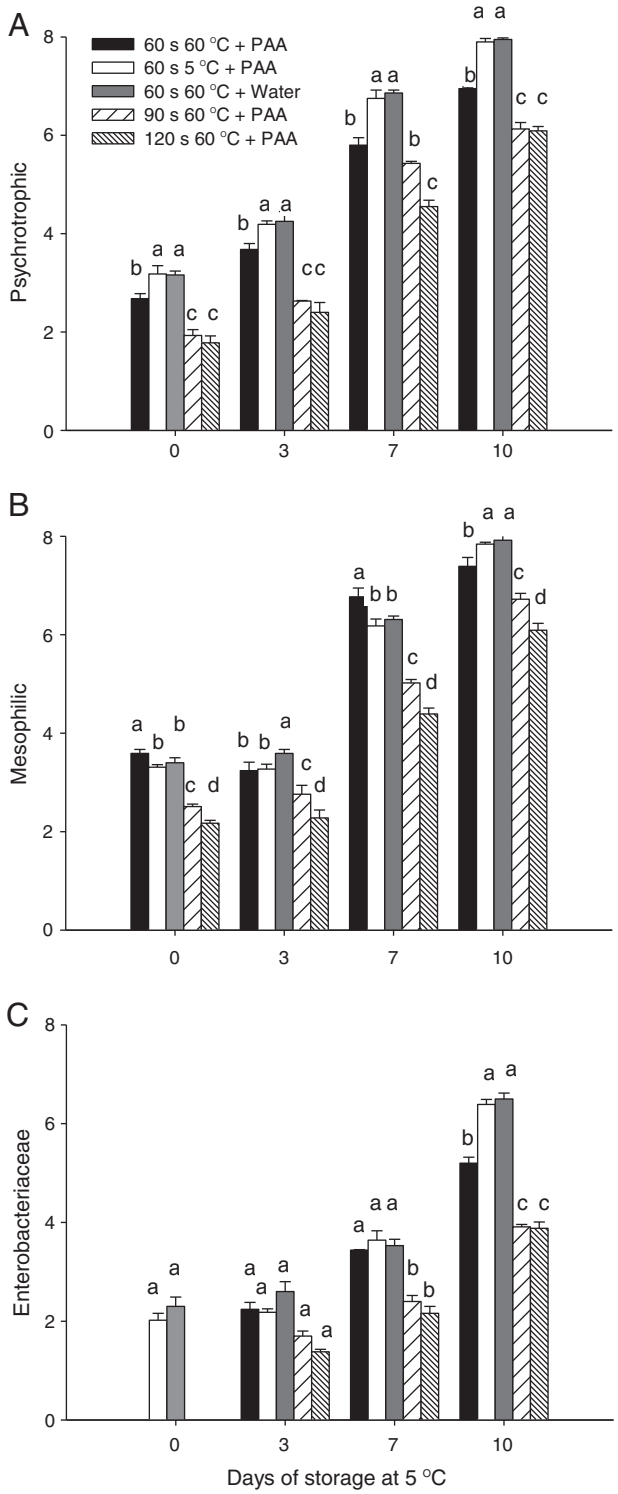

Fig. 3. Microbial growth (log_{10} cfu g^{-1}) from fresh-cut 'Galia' melon stored under modified atmosphere packaging at 5 °C during 10 d. (A) Psychrotrophic (B) mesophilic (C) *Enterobacteriaceae*. Vertical bars represent standard error of the means (n = 3). Letters differentiate statistically significant values within the same sampling time only.

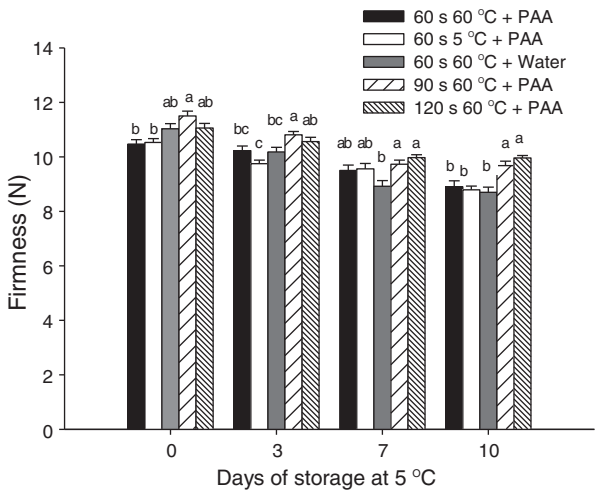

Fig. 4. Flesh firmness of fresh cut 'Galia' melon stored under modified atmosphere packaging at 5 °C during 10 d. Vertical bars indicate the standard error of the means (n = 3). Letters differentiate statistically significant values within the same sampling time only.

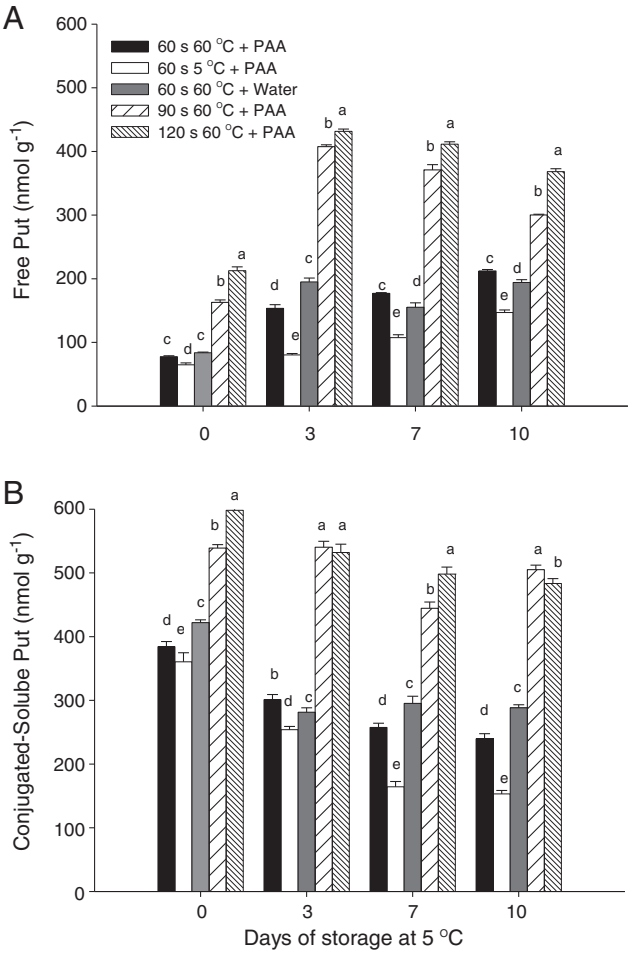

Fig. 5. Putrescine content (nmol g^{-1} FW) of fresh cut 'Galia' melon stored under modified atmosphere packaging at 5 °C during 10 d. (A) Free (B) conjugated-soluble forms. Vertical bars indicate the standard error of the means (n = 3). Letters differentiate statistically significant values within the same sampling time only.

3.2. Microbial growth

The effect of the different treatments on microbial growth is shown in Fig. 3. For psychrotrophic and mesophilic bacteria, HWD of 90 and 120 s with PAA were the only treatments to maintain levels below the maximum permitted by Spanish legislation (RD 3484/2000 2001) of 7 log cfu g^{-1}. These two treatments were consistently significantly lower than all other treatments throughout storage, with reductions between 1 and 2 log units compared to both control treatments, in particular, at the end of the storage period.

Enterobacteriaceae levels never reached legislation limits in any treatments, although HWD of 90 and 120 s were again significantly lower than all other treatments, reducing levels below the limit of detection (2 log cfu g^{-1}) for up to 3 days.

The combination of physical and chemical sanitizer methods is the focus of many researchers, in an effort to obtain safe fresh-cut products for consumers. Examples of this idea include the study of Ukuku, Sapers, and Fett (2003), on the effect of hot water (70 and 100 °C) and H_2O_2 (70 °C) on the reduction of *Salmonella* and *Listeria monocytogenes*. The authors concluded that boiling water or heated H_2O_2 treatments for 1 min can decontaminate melon surface before fresh-cut preparation, with a reduction of 4.5 and 4 log units found on inoculated melon after treatment.

In addition, the synergistic effect of heat treatment with chemical sanitizer was also tested by Klaiber et al. (2005). They found a minor synergistic effect of hot water (50 °C) during 120 s followed by 120 s of immersion in chlorine water (200 mg L^{-1} of free chlorine) on the microbial growth of fresh-cut carrots, showing a reduction of 1.7–2 log units.

According to our results, HWD followed by rinsing in PAA was a successful treatment for controlling bacterial growth, especially at longer HWD treatment times of 90 and 120 s. The positive effect of the PAA on microbial load control has been previously reported by Silveira et al. (2008), who obtained a marketable safe fresh-cut Galia melon after 10 d of storage using PAA (80 mg L^{-1}). Unlike the work of Aguayo, Escalona, Gómez, et al. (2008) where aerobic total bacterial growth on fresh-cut Amarillo melon pieces was reduced by dipping in hot water (60 °C for 1 min), in our case hot water dipping without a PAA dip was not successful at reducing bacterial loads. Lamikanra, Bett-Garber, Ingram, and Watson (2005) also had success with hot water treatment of cantaloupe melon, but used treatment times much longer than those used here (1 h versus 60–120 s).

3.3. Firmness

Firmness changes during the storage of fresh-cut melon are shown in Fig. 4. As expected, flesh firmness decreased during the storage period. The greatest differences among treatments were observed at the end of the storage period. At this moment, the longer HWD times (90 and

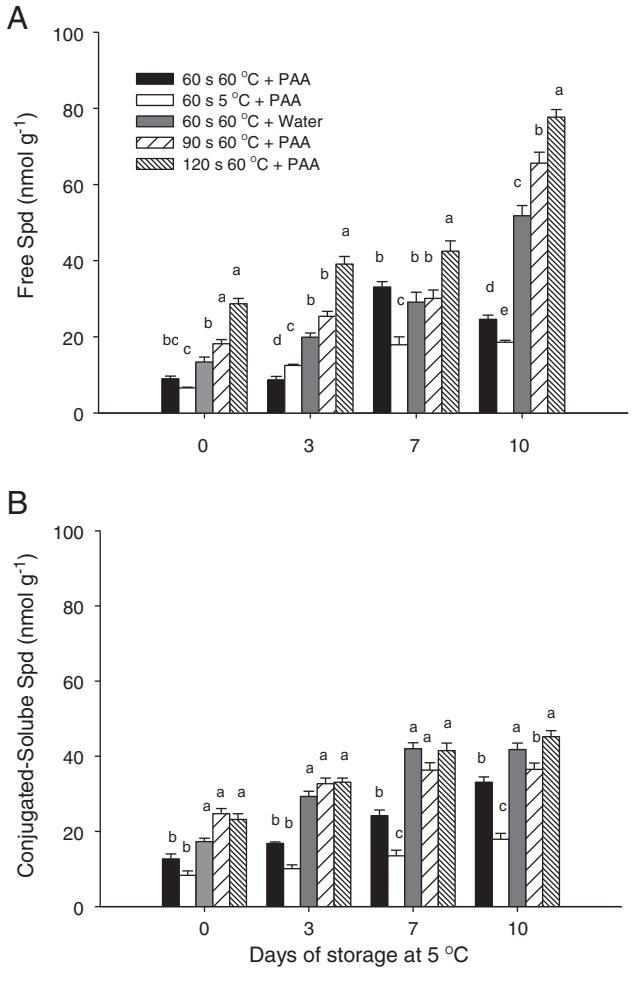

Fig. 6. Spermidine content (nmol g^{-1} FW) of fresh cut 'Galia' melon stored under modified atmosphere packaging at 5 °C during 10 d. (A) Free (B) conjugated-soluble forms. Vertical bars indicate the standard error of the means (n = 5). Letters differentiate statistically significant values within the same sampling time only.

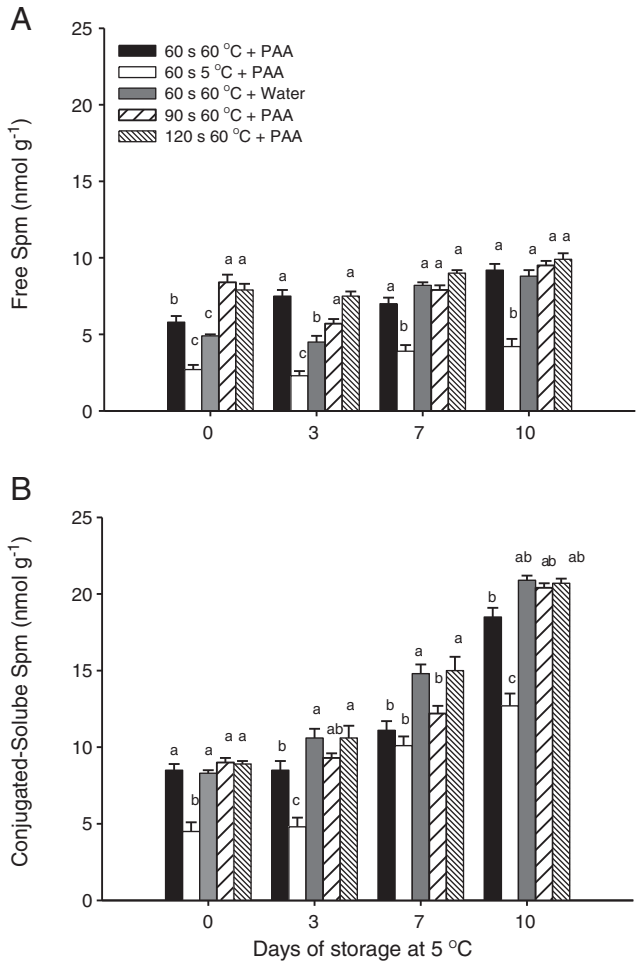

Fig. 7. Spermine content (nmol g^{-1} FW) of fresh cut 'Galia' melon stored under modified atmosphere packaging at 5 °C during 10 d. (A) Free (B) conjugated-soluble forms. Vertical bars indicate the standard error of the means (n = 5). Letters differentiate statistically significant values within the same sampling time only.

120 s) followed by PAA dip showed the greatest firmness retention, with a softening of only 14 and 10% related to the initial value. The other treatments showed a firmness loss of about 17 and 21%.

The effect of the heat treatment in the firmness maintenance, alone or combined with calcium salts has been reported for several fresh-cut products like melon (Aguayo, Escalona, Gómez, et al. 2008; Lamikanra & Watson 2007) and mangoes (Djioua et al. 2009). In fresh-cut kiwi fruit, the hot water immersion (45 °C during 25 min) maintained fruit firmness during a period of 10 days (Beirão-da-Costa, Steiner, Correia, Empis, & Moldão-Martins 2006). Likewise, Fan, Annous, Beaulieu, and Sites (2008) found a higher firmness retention in cantaloupe melon immersed in hot water (70 °C) during 3 min, compared to melon immersed in cold water (10 °C) for 20 min. Firmness maintenance could be related to cell wall degrading enzyme activity reduction of polygalactoronase (PG) and pectinemethylesterase (PME), glucanase and galactosidase (Lurie 1998; Sozzi, Cascone, & Fraschina 1996). In our work, the duration of hot water treatment was critical, HWD during 60 s did not differ from the cold water immersion; indicating that the immersion time was insufficient to inhibit enzymatic activity.

3.4. Polyamine contents

The predominant polyamine quantified in this experiment, was putrescine (Put), followed by spermidine (Spd) and spermine (Spm). These polyamines appear free or covalently linked to phenolic acids, mainly hydroxycinamic acid (conjugated-soluble polyamines) or linked to dimmers or trimmers of phenolic acid or larger molecules like proteins (conjugated-insoluble polyamines). The conjugated soluble and insoluble forms of the different polyamines prevailed over the free forms.

In general hot water treatment resulted in an increase in polyamine levels over the different analysis times (Figs. 5, 6 and 7).

Initially, free Put levels were highest in 90 and 120 s HWD treatments, with values of 163 and 213 nmol g^{-1}, respectively (Fig. 5A). After 3 days of storage, the free Put concentration increased substantially to 410 and 430 nmol g^{-1}, respectively decreasing to 300 and 368 nmol g^{-1} after 10 days. Free Put levels of unheated melon pieces were the lowest, increasing from 84 at day 0 to 147 nmol g^{-1} at day 10.

A similar trend among treatments was found in conjugated-soluble Put (Fig. 5B). The concentration was highest in 90 and 120 s HWD treatment, increasing from 380 nmol g^{-1} (unheated melon) to 540 or 598 using 90 or 120 s HWD, respectively. At the end of the storage, these levels were of 506 and 483 nmol g^{-1} versus 240 nmol g^{-1} in melon pieces not heated.

Free Spd levels showed a trend similar to Put, although melon treated in HWD water also displayed elevated levels (Fig. 6 A and B). The highest values corresponded to melon pieces treated in HWD for 90 and 120 s with PAA at day 10 with levels of 66 and 78 nmol g^{-1} respectively.

Similar results were registered in conjugated-soluble Spd (Fig. 6B), in both, the lowest values corresponded to the unheated PAA dipped melon which remained relatively unchanged during the experiment, showing a concentration of 7 and 8 nmol g^{-1} of free and conjugated-soluble Spd at the beginning of the experiment and 19 and 18 respectively, after 10 days of storage.

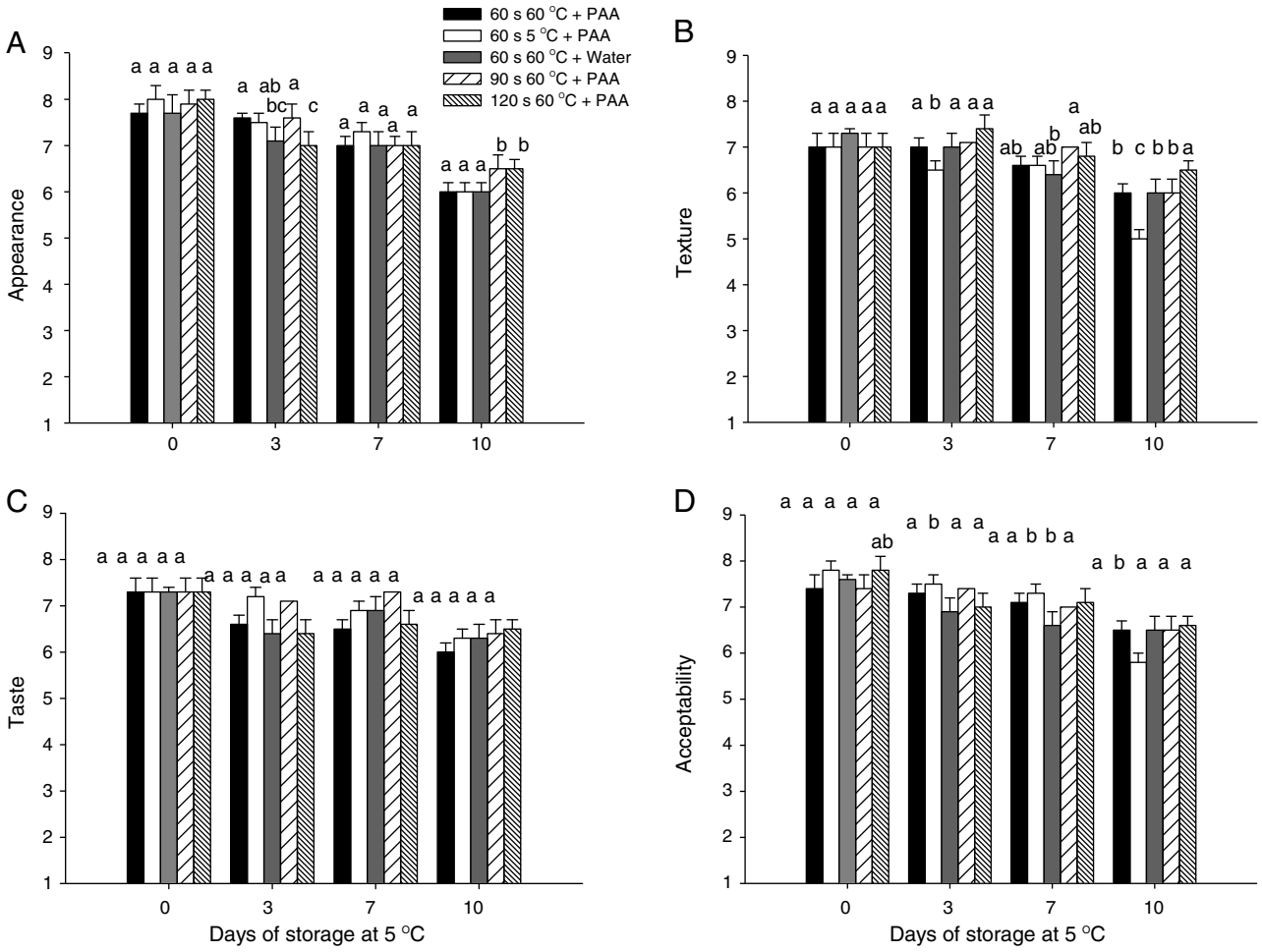

Fig. 8. Sensorial evaluation (1 to 9) of fresh cut 'Galia' melon stored under modified atmosphere packaging at 5 °C during 10 d. (A) External appearance (B) texture (C) taste (D) acceptability. Vertical bars indicate the standard error of the means (n = 7).

The Spm was detected in lower concentration than the others polyamines (Fig. 7A and B). Initially, the treatments of HWD for 90 and 120 s were higher in free Spm contents but at the end of the experimental period no differences were registered among the HWD at 60, 90 or 120 s which all presented levels of around 9 to 10 nmol g^{-1}. As observed in the other polyamines, the lowest value corresponded to the melon pieces immersed in cold water plus PAA. There was no significant difference between HWD treatments at 0 day or 10 day, although HWD for 60 s with PAA was slightly lower than HWD for 90 and 120 s with PAA.

We found HWD melon pieces, in particularly for 90 and 120 s, trended to increase polyamine levels. This can be explained by the stress generated using a hot temperature such as 60 °C. In this sense, many other authors proposed that polyamines increase when the fruit and vegetables suffer biotic or abiotic stress situations (high or low temperatures, nutritional changes, osmotic shock, UV-C radiation, lower O_2 level, pathogens attacks, etc.). These behaviors would be related to complex survival responses developed by the fresh products to maintain their integrity and to keep surviving (Feng & Barker 1993).

In this sense, polyamines work as free radical scavengers, stabilizing membranes by means of ionic interactions to provide protection against environmental stress (Drolet, Dumbroff, Legge, & Thompsom 1986). Feng and Barker (1993) suggested that Put increases as a result of stress provoked by high temperatures and that Put could probably protect tissue from this stress. Furthermore, in several studies, exogenously added polyamines have been shown to protect plant tissue from the detrimental effects of several types of stress (Kramer et al. 1992).

According to our results, the increase in polyamine levels of fresh-cut Galia melon could be related to the stress generated by HWD at 60 °C, even when the immersion time was of only 60 to 120 s.

3.5. Sensory evaluation

Sensory evaluation results are shown in Fig. 8. External appearance scores decreased during storage period. At day 10, melon pieces treated with HWD for 90 and 120 s scored the higher values (6.0 and 6.5, respectively). Nevertheless, all treatments were considered as appearing acceptable for consumption. Texture decreased during the storage period showing a similar trend to appearance values (Fig. 8B). After 10 days, the lowest value corresponded to unheated melon pieces with a value of 5.5. The other treatments scored significantly higher values between 6.0 and 6.5. Melon piece flavor was not affected by HWD (Fig. 8C), however, it decreased in all treatments probably as a consequence of SST and acidity loss (data not shown) as these substrates are needed for the respiratory process. Acceptability showed slight differences among treatments, with the same negative trend (Fig. 8D). At the end of the experiment, the lowest value corresponded to cold water combined with PAA. This treatment was significantly different although after 10 days of storage it was still above the limit of marketability.

As a general conclusion related to melon sensory quality, HWD treatments did not adversely affect the sensorial attributes of fresh-cut Galia melon and longer dipping times (90 and 120 s) induced higher scores in the appearance. Similarly, Klaiber et al. (2005) reported that sensorial quality of carrots washed in warm chlorinated water (50 °C for 120 s) was only slightly reduced compared to the unwashed carrots.

4. Conclusions

Results from this study suggest that the longer HWD treatments times (90 and 120 s) followed by PAA dip, are effective to control the microbial growth, and maintain the overall quality in fresh-cut Galia melon acceptable for consumption after 10 days at 5 °C. Furthermore, these treatments had a positive effect reducing the melon metabolism (respiratory rate and C_2H_4 emission) and helped to maintain the pulp firmness.

Moreover, HWD treatment, especially for 90 and 120 s, resulted in an increase in polyamine levels, especially Put, which may explain the retention of quality since polyamines act as free radical scavengers and play an essential role in maintaining stability of cell membranes.

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