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Effect of different sanitizers on microbial and sensory quality of fresh-cut potato strips stored under modified atmosphere or vacuum packaging

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Abstract

Chemicals containing SH-groups as sulfites and chlorine-based agents are commonly employed in the fresh-cut process of vegetables such as potatoes to prevent browning and to sanitize produce. However, there is a concern over the application of these compounds in fresh-cut commodities as they might affect human and environmental safety and this has created the need to investigate alternatives. In the present work, the effectiveness of different traditional and non-traditional sanitizers on the sensory and microbial quality of fresh-cut potatoes stored under passive modified atmosphere packaging (MAP) and vacuum packaging was investigated. Six different washing treatments consisting of water, sodium sulfite, sodium hypochlorite, Tsunami, ozone and the combination of ozone–Tsunami were evaluated. Browning and growth of aerobic mesophilic bacteria, psychrotrophic bacteria, coliforms, lactic acid bacteria (LAB), anaerobic bacteria, moulds and yeasts were studied. In general, vacuum packaging preserved the appearance better than MAP. Under MAP only sodium sulfite prevented browning although it conferred off-odors. After 14 days of storage, there was no evidence of browning in fresh-cut potatoes dipped in ozonated water or ozone–Tsunami and stored under vacuum and these treatments maintained initial texture and aroma. However, the use of ozonated water alone was not effective in reducing total microbial populations. Ozone–Tsunami resulted in the most effective treatment to control microbial growth achieving 3.3, 3.0 and 1.2 log-reductions for LAB, coliforms and anaerobic bacteria, respectively. Therefore, although microbial growth was not slowed down by ozone alone, the combination of ozone–Tsunami resulted an efficient and promising treatment for controlling microbial growth and maintaining sensory quality of potato strips under vacuum.

Keywords: Browning; Hypochlorite; Ozone; Packaging; Peroxyacetic acid; *Solanum tuberosum* L.

1. Introduction

Demand for fresh-cut fruit and vegetables has been increasing in recent years, mainly because consumers look for freshness and convenience when they purchase

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these commodities. However, fresh-cut processing includes unit operations such as peeling, trimming or cutting that alter the integrity of the commodity's tissues and can induce wounding stress (Saltveit, 2003). One of the most important consequences of this stress in fresh-cut potatoes is the development of enzymatic browning which can lead to changes in color and loss of nutritional value (Tudela et al., 2002a,b). Moreover, microbial development from natural flora is promoted due to the destruction of tissues and subsequent release of nutrients. Pathogens may form part of this microflora, leading to a potential safety problem (Beuchat, 1995; Francis et al., 1999).

Several studies have been done to determine the efficacy of washing, sanitizing and modified atmosphere packaging (MAP) conditions in order to inhibit browning and spoilage in fresh-cut fruit and vegetables (Sapers and Miller, 1998; Lanciotti et al., 1999; Bai et al., 2001; Emmambux and Minnaar, 2003). Chemicals containing SH-groups including sulfites are commonly employed to prevent browning in vegetables such as potatoes. However, the application of these compounds in fresh-cut commodities can cause bronchial asthma (Peroni and Boner, 1995) and undesirable flavors in addition to a significant reduction in the nutritional value in potatoes (Chalom et al., 1995). Agents that are chlorine-based have been often used to sanitize produce and surfaces, as well as reduce microbial populations in water applied during cleaning and packing operations (Delaquis et al., 2004). However, the production of chlorinated organic compounds, such as trihalomethanes, which are potential carcinogens (Fawell, 2000), has created the need to investigate the efficiency of non-traditional sanitizers and other alternative technologies. Therefore, preservation methods for fresh-cut fruit and vegetables are still under study. The concept of using multiple intervention methods where various preservation technologies, healthier for consumers, are employed is increasing their importance (Parish and Davidson, 1993; Soliva-Fortuny and Martín-Belloso, 2003).

Research on the efficacy of peroxyacetic acid to inactivate microorganisms has produced varying results. One group of researchers has demonstrated the effectiveness of peroxyacetic acid (Tsunami Ecolab, Mendota Heights, MN, USA) reducing *Escherichia coli* O157:H7 populations on the surface of cantaloupe melons but this treatment was not effective on asparagus spears (Park and Beuchat, 1999).

Ozone has been extensively applied for sanitation of drinking water with efficacy against bacteria, molds, viruses and protozoa (Korich et al., 1990; Restaino et al., 1995). Furthermore, ozonated water has reduced microbial populations and extended the shelf life of some fresh-cut fruit and vegetables (Beuchat, 1998; Kim et al., 1999). The decrease in pathogens including *Salmonella typhimurium*, *Yersinia enterocolitica*, *Staphylococcus aureus*, *Listeria monocytogenes* and *E. coli* O157:H7 has also been described (Restaino et al., 1995; Singh et al., 2002). Therefore, the use of ozonated water has been suggested as an interesting alternative to traditional sanitizers due to its efficacy at low concentrations and short contact times as well as the breakdown to non-toxic products (Graham, 1997; Rice, 1999).

The objective of this study was to provide information on how different traditional (sodium hypochlorite and sodium sulfite) and non-traditional (peroxyacetic acid and ozone) sanitizers alone or in combination, affect the microbial and sensory quality of fresh-cut potato strips stored under different packaging conditions (MAP and vacuum).

2. Materials and methods

2.1. Potato strip processing

Potatoes (*Solanum tuberosum* cv Monalisa) were purchased from a local supplier in Murcia, Spain, and transported by car to the laboratory (5 km) where those with defects (cuttings and bruisings) were discarded. Sound tubers were kept at 4 °C and 70% relative humidity (RH) in darkness prior to processing. Potatoes were hand-peeled and washed with sterile deionized water (electrical conductivity = 0.28 μS cm^{-1}) at 8 °C. After peeling, the tubers were sorted for absence of visual defects and uniform color. Potatoes were cut in 8 mm × 8 mm strips with a manual potato cutter (Sammic CF-4, Azpeitia, Spain). Immediately after cutting, the strips were again washed with sterile deionized water to remove excess starch and other cellular constituents and then strained on a draining board to reduce the water content on the potato strip surface. Uniform strips were selected and broken pieces were discarded.

The whole process was conducted at 8 °C under sanitary conditions.

2.2. Wash solutions preparation

Potato strips were washed with six different solutions at 8 °C: (A) sterile deionized water (pH 5.81), (B) 2 g L^{-1} sodium sulfite (Sigma–Aldrich, St. Louis, MO, USA; pH 4.35) as it is usually used in the fresh-cut potato industry and (C) 80 mg L^{-1} total chlorine adjusted to pH 6.50 with citric acid prepared from sodium hypochlorite (10%, w/v; Panreac, Montcada i Reixac, Barcelona, Spain). Total chlorine concentration was determined following the method reported by the American Society for Testing and Materials (ASTM, 2003). The following treatments were also tested: (D) solution of 300 mg L^{-1} Tsunami™ (pH 3.79; Henckel Ecolab Ibérica S.A., San Joan Despí, Barcelona, Spain) containing peroxyacetic acid, (E) 20 mg L^{-1} min total ozone dose (pH 7.50) and (F) 20 mg L^{-1} min total ozone dose and 300 mg L^{-1} Tsunami. This last washing treatment was applied by rinsing fresh-cut potatoes in ozonated water, and immediately after that dipping them in the Tsunami solution. All washing times were 3 min, except for ozonated water where the time treatment was sufficient to achieve the required concentration and was always less than 5 min.

2.3. Ozonated water

Extra-dry compressed air (0.7 Pa) was passed through a water-cooled corona discharge generator (model 1A, Steriline, Ozono Electrónica Ibérica, Granada, Spain) to produce ozone. Gaseous ozone production (3 g h^{-1}) was measured with an ozone gas analyzer (model H1-SPT, IN USA Inc., Needham, MA, USA). A flow of ozone of 150 NL h^{-1} was dissolved in deionized water by an inverse mixer. The excess gas was neutralized by a thermal destroyer (model DOT 1.1, Ozono Electrónica Ibérica) at 550 °C. The dissolution tank had a volume of 100 L. Ozonated water was impelled out by a pump at a flow rate of 1 m^3 h^{-1}, and conducted through a stainless steel plate heat exchanger (model UFX 6-11, Barriquand, Roanne Cedex, France), coupled to a water cooling unit of 1.98 kW capacity (model TAE 015 PO, MTA Srl, Conselve, Italy). Finally, the ozonated water arrived at the 50 L treatment tank and returned to the dissolution tank by a second pump closing the circuit. An amperometric selective probe equipped with a temperature compensation sensor was used to monitor dissolved ozone and connected to a dissolved ozone analyzer (B&C Electronics Srl, Carnate, Milano, Italy), which can measure in two ranges (0–2 and 2–20 mg L^{-1}). The indigo trisulfonate spectrophotometric method (Bader and Hoigné, 1981; APHA, 1989) was used to calibrate the analyzer, and also to check the ozone concentration applied. The decrease in absorbance was measured at 25 ± 0.1 °C in a spectrophotometer (UV-1603 Shimadzu, Tokyo, Japan) equipped with a temperature controller (CPS 240, Shimadzu). The ozone dose applied was controlled with an integration system of concentration by temperature implemented in a programmable automaton (model Siemens S7 + TD200, Ingeniería y Control Remoto S.L., Granada, Spain). All the experiments with ozone were made in the pilot plant of CEBAS-CSIC (Murcia, Spain) attending strict safety and protection rules.

2.4. Packaging

Potato strips were packaged using two different packaging methods: passive modified atmosphere packaging without initial gas injection and vacuum packaging (VAC). The batches of fresh-cut potato undergoing MAP were sealed in low-density polyethylene (LDPE) bags (Plásticas Redelmont S.A., Valencia, Spain) of 16 cm × 8 cm with the following film characteristics: 109 μm thickness and permeance at 4 °C of 2.9×10^{-15} mol s^{-1} m^{-2} Pa^{-1} for O_2 and 5.2×10^{-15} mol s^{-1} m^{-2} Pa^{-1} for CO_2. For VAC, multilayer film bags (BB4L Cryovac, sealed Air S.L., Sant Boi de Llobregat, Spain) were used. The film characteristics were as follows: 59 μm thickness and permeance at 23 °C of 1.4×10^{-13} mol s^{-1} m^{-2} Pa^{-1} for O_2 and 7.1×10^{-13} mol s^{-1} m^{-2} Pa^{-1} for CO_2. Vacuum packaging was carried out by exclusion of air from the bags with a gas exchange device (Zermat, Carburos Metálicos S.A., Madrid, Spain). The gas permeance of LDPE film was indirectly calculated by the equations of Exama et al. (1993), whereas for the multiplayer film used for VAC, permeance values were provided by the manufacturer. These films were selected because both are commonly used in the fresh-cut potato industry. All samples were stored at 4 °C for up to 14 days and sensory and microbial quality was evaluated initially

and after 5, 11 and 14 days. Three replicates of 100 g of fresh-cut potatoes were used for each treatment and sampling date. All sanitizer solutions were combined with the storage under MAP and VAC.

2.5. Gas analysis and sensory evaluation

Changes in O_2 and CO_2 concentrations in MAP-packed bags were measured with a calibrated syringe on the day of evaluation using a gas chromatograph (Shimadzu GC-14, Kyoto, Japan) equipped with a thermal conductivity detector (TCD). The gas was drawn from the bags using a septum attached to the bags.

The organoleptic characteristics including browning, texture and aroma of fresh-cut potatoes were evaluated initially and after 5, 11 and 14 days of storage by a four-member expert panel. Browning of fresh-cut potatoes was scored on a 5–1 scale, where 5 = severe browning, 3 = moderate browning and 1 = no browning. Texture was evaluated when the potato strips were pressed between the thumb and index finger, on a scale 5–1, where 5 = very firm and turgid, 3 = moderately firm and 1 = very soft. Aroma was determined after the panelists broke the potato strips and smelled the aroma using a scale of 5–1, where 5 = full typical aroma or flavor, 3 = moderate and 1 = none.

2.6. Microbiological analysis

Growth of the most important groups of microorganisms associated with the spoilage of fresh-cut potato was followed during the experiment. Ten grams of fresh potato strips was homogenized with a stomacher (IUL Instrument, Barcelona, Spain) for 90 s in sterile 400 Lab stomacher bags (Seeward Medical, London, UK) in a 1:10 dilution with sterile 1% peptone buffered water (AES Laboratoire, Combourg, France). All culture media used in this study were purchased from Scharlau Chemie S.A. (Barcelona, Spain). Total aerobic mesophilics were enumerated by the standard plate count method using plate count agar (PCA) and by incubating plates at $30 \pm 1\,^{\circ}C$ for 48 h. Total psychrotrophic bacteria were enumerated by a standard plate count method using PCA and by incubating plates at $4 \pm 1\,^{\circ}C$ for 7 days. Mould and yeast counts were performed in oxytetracycline glucose yeast extract agar by incubation at 25 °C for 5–7 days. Coliforms and lactic acid bacteria were isolated using Endo agar and Man, Rogosa and Sharpe (MRS) agar, respectively, and by incubating plates at $37 \pm 0.5\,^{\circ}C$ for 24 h and $30 \pm 1\,^{\circ}C$ for 48 h, respectively. Total anaerobic bacteria counts were carried out using sulfit-polymyxin-sulfadiazin-A (SPS) agar and the plates were incubated at $35 \pm 0.5\,^{\circ}C$ for 24–36 h in anaerobic jars with an atmosphere generation system (Oxoid, Basingstoke, Hampshire, UK). Microbial analyses were achieved immediately after cutting and after 5, 11 and 14 days of storage. All samples were analyzed in duplicate and each microbial count is the mean of three packages. Microbial counts were expressed as log CFU g^{-1} of tissue.

2.7. Statistical analysis

There were three replications per treatment and evaluation period. All data represent the mean of three replicates. Analysis of variance (ANOVA), followed by Duncan's Multiple Range Test with a significant level of $P \leq 0.05$, was performed on the data using SPSS (Windows 2000, Statistical Analysis).

3. Results and discussion

3.1. Gas composition

After 5 days of storage, the steady state within packages had been reached with O_2 and CO_2 levels of about 0.3–1.4 and 6.3–8.3 kPa, respectively (Fig. 1). The atmospheres created in the packages were in the range recommended for fresh-cut potatoes with O_2 and CO_2 levels 1–3 and 6–9 kPa, respectively (Gorny, 2003). In this case, the rate of O_2 depletion was six–eight times higher than that of CO_2 accumulation due to the permeability of the film used (Fig. 1).

No significant differences were observed in the package atmospheres between washing treatments throughout the storage period (Fig. 1). Therefore, the respiratory activity of the potato strips in response to the different sanitizers was similar for all treatments. These results are in agreement with those reported for green pepper slices exposed to sequential washes, which had similar O_2 and CO_2 levels during the storage (Toivonen and Stan, 2004). Potato strips washed with ozonated water did not increase their respiration, as the atmospheric modification was similar to that of

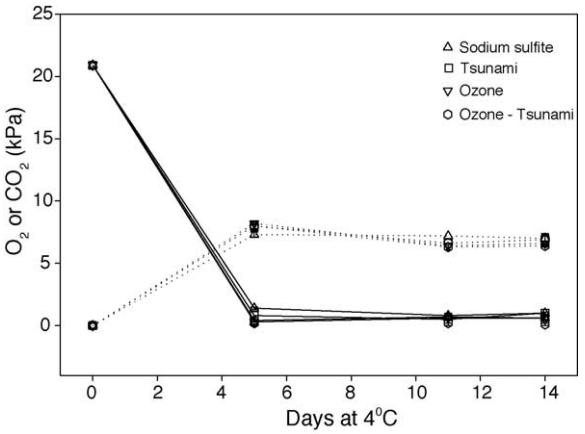

Fig. 1. Package headspace levels of oxygen (—) and carbon dioxide (- - -) over 14 days of storage at 4 °C for fresh-cut 'Monalisa' potato in LDPE film that was subjected to four wash treatments prior to packaging. Each value represents the mean of three 100 g packages and the vertical bars correspond to S.D.

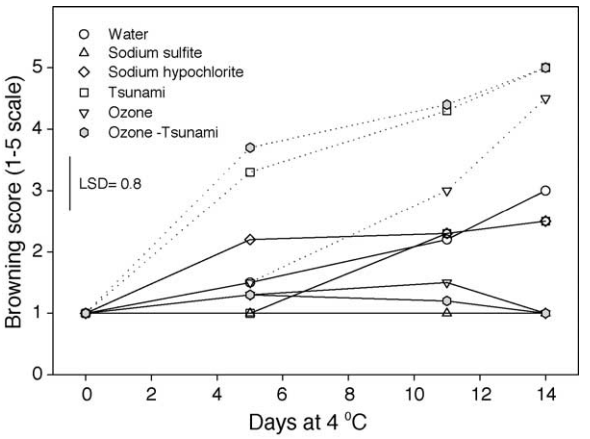

Fig. 2. Effect of wash treatments on browning of fresh-cut 'Monalisa' potato stored under vacuum (—) or modified atmosphere packaging (MAP) (- - -) for 14 days at 4 °C. Values are the mean of four panelist assessments and bars represent LSD at $P \leq 0.05$. Browning scores: 5 = severe, 3 = moderate and 1 = no browning.

the other treatments including water washing. Recently, it has been described that washing reduces respiration since washed tissues have lower respiration than tissues that have not been washed (Toivonen and Stan, 2004).

It was not possible to sample the atmosphere within VAC packages because the film was completely fixed around the potato strips without free headspace.

3.2. Sensory evaluation of washing treatments and packaging

Initially, neither of the washing treatments promoted browning since there were no significant differences in the color of potato strips before and after the washing and when comparing with water washed samples (Fig. 2). When MAP was used, water and sodium hypochlorite dips were not done. The reason was that no effect of controlling browning was observed in preliminary experiments, and therefore both washes in MAP were not considered of commercial interest (data not shown). After 5 days of storage, potato strips washed with Tsunami or ozone–Tsunami and stored under MAP showed a moderate degree of browning (3.3 and 3.7, respectively; Fig. 2). In contrast, strips washed with ozone maintained the initial color and no browning was observed either in MAP or VAC samples at the fifth day. However, when the storage life was prolonged, a significant increase in browning was observed for the ozone treated MAP strips. After 14 days, samples washed with Tsunami, ozone or ozone–Tsunami and stored under MAP showed the highest degree of browning (Fig. 2). When MAP was used, only fresh-cut potatoes dipped in sodium sulfite maintained the initial visual appearance and controlled browning. However, the disadvantage of using a sodium sulfite treatment was that it produced off-odors (data not shown).

Under vacuum, there was no evidence of browning in those fresh-cut potatoes washed with sodium sulfite, ozone and ozone–Tsunami throughout the 14 days of storage at 4 °C (Fig. 2). After 5 days, moderate browning was evident in those strips washed with sodium hypochlorite and storage under vacuum. Therefore, sodium hypochlorite did not control browning on potato strips in contrast to the results found on fresh-cut lettuce and potatoes (Brecht et al., 1993; Baur et al., 2004). After 11 days under VAC, potato strips washed with water and Tsunami reached the same degree of browning as those samples washed with sodium hypochlorite. At the end of the storage, the highest degree of browning for VAC samples was observed in those samples washed with water although there were no significant differences with sodium hypochlorite and Tsunami treatments (Fig. 2). Even when VAC packaging was used, sodium hypochlo-

rite and Tsunami dips were not able to slow down browning development, although in general, vacuum packaging preserved the potato strip appearance better than MAP. When using VAC packaging, ozonated water alone or in combination with Tsunami maintained the visual appearance of potato strips as well as sodium sulfite over 14 days at 4 °C. Apart from the suppression of browning achieved with ozone and ozone–Tsunami, those potato strips maintained the full typical aroma and a very firm and turgid texture.

3.3. Washing solution effects on microbial stability of potato strips stored under vacuum packaging

The effects of the different sanitizing treatments and wash water on the native mesophilic and psychrotrophic bacteria, yeasts, coliforms, LAB and anaerobic microorganisms of VAC potato strips are shown in Fig. 3. Initially, no significant differences were found between the number of microorganisms in fresh-cut potatoes washed with the sanitizers and those samples washed in water. Only sodium sulfite and hypochlo-

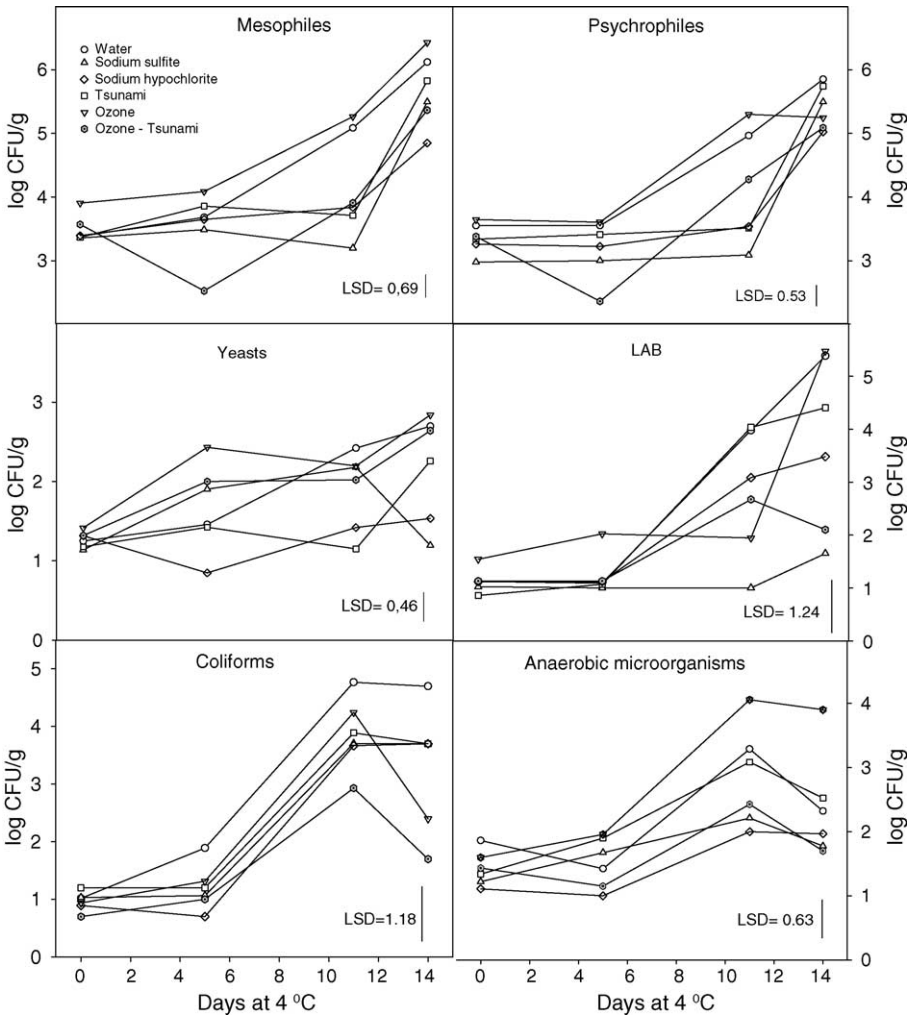

Fig. 3. Effect of wash treatments on growth of mesophilic bacteria, psychrotrophic bacteria, yeasts, lactic acid bacteria, coliforms and anaerobic microorganisms (log CFU g^{-1}) during 14 days storage at 4 °C under vacuum packaging. Values are means of three replicates and bars represent LSD at $P \leq 0.05$.

rite dips achieved 0.6 and 0.7 log-reductions, respectively, on anaerobic microorganisms. Therefore, sanitizers tested were not effective in reducing initial microbial counts except for anaerobic microorganisms. This is in agreement with previous studies in fresh-cut lettuce and potato strips where microbial populations were not controlled by chlorine and hypochlorite dips (Gunnes et al., 1997; Delaquis et al., 2004). This could be a consequence of neutralization of sanitizers by components leaching from cut produce surfaces (Adams et al., 1989).

After 5 day storage, no growth of mesophilic, psychrotrophic bacteria or LAB was observed for any wash treatment (Fig. 3). Therefore, the lag phases of these different microbial groups at the selected storage conditions were less than 5 days. After 14 days, the lag periods of mesophilic and psychrotrophic bacteria in potato strips washed with water and ozonated water were 5 days before reaching about 10^5–10^6 CFU g^{-1} (Fig. 3). Therefore, although ozonated water could extend the shelf life of potatoes by controlling browning (Fig. 2), it did not result in an effective treatment for reducing the total microbial population. However, the combination ozone–Tsunami reduced initial total plate counts of mesophilic and psychrotrophic bacteria by 1.14 logs over 5 days of storage, but afterwards the natural flora increased for up to 14 days of storage. This could indicate the existence of residual peroxyacetic acid activity during the lag period as a consequence of combined unfavorable conditions including ozone, vacuum and low temperature. This is in agreement with a previous study in fresh-cut salads that demonstrated the existence of residual peroxyacetic activity that inhibited microbial growth during storage (Masson, 1990).

The rate of total microorganism growth was similar for ozone treatments with and without Tsunami. However, the reduction performed in samples treated with ozone–Tsunami throughout the first 5 days reduced final counts by 1 log at the end of the storage. This reduction could be critical since Spanish microbial regulation allows a maximum mesophilic bacteria counts of 10^6 CFU g^{-1} (Real Decreto, 3484/2000) and after 14 days of storage, water and ozone treated samples exceeded this legal limit. Although ozone was not effective in reducing microbial counts, ozone coupled with Tsunami resulted in the most effective treatment controlling both microbial growth and sensory quality of potato strips stored in vacuum. Furthermore, there was a synergistic effect of this combination, since neither ozone nor Tsunami dips reduced initial microbial counts throughout the first 5 days of storage. Tsunami, sodium hypochlorite and sodium sulfite dips increased the lag period of mesophilic and psychrotrophic bacteria up to 11 days (Fig. 3). Therefore, the total number of bacteria after 11 days on potatoes treated with the tested sanitizers including ozone–Tsunami was lower than that of the samples washed with water and ozonated water.

At the end of the storage, ozone–Tsunami and sodium hypochlorite treatments were the most effective in slowing down microbial growth, with mesophilic counts 0.75–1.27 logs lower than in water washed samples, respectively. Although after 14 days, total count reduction was not greater than 1 log for the ozone–Tsunami treatment, it is necessary to take into account its efficiency on all microbial groups analyzed, except for yeasts (Fig. 3). Furthermore, this treatment was especially effective on LAB, coliforms and anaerobic microorganisms obtaining 3.29, 3 and 1.2 log-reductions, respectively, in relation to water wash. Control of these microbial groups is important since they are microorganisms present in fresh-cut vegetables and responsible for the spoilage of fresh produce (Zagory, 1999). Coliforms are used as indicator microorganisms of faecal contamination in water and foods and include potentially pathogen species such as *E. coli*. This microbial group was of special concern in fresh-cut potato strips because it increased tremendously after 11 days of storage, except in ozone–Tsunami treated strips. Anaerobic bacteria include spoilage bacteria able to produce fermentation that contributes to off-flavors (Zagory, 1995) and food-borne pathogens such as *Clostridium botulinum*. This last is one of the greatest concerns in relation to vacuum packaged potatoes since outbreaks related to toxin production could happen in this case if temperature abuse also occurs (Lauridsen and Knochel, 2003).

3.4. Packaging atmosphere on microbial stability of sanitized potato strips

In order to find the best packaging atmosphere for potato strips, VAC and MAP were compared. Growth of mesophilic bacteria, coliforms and anaerobic microorganisms on potato strips was studied after sanitizing the samples (Table 1). For mesophilic bacteria, the sanitiz-

Table 1
Effect of sanitizers and vacuum (VAC) or modified atmosphere packaging (MAP) on the population of mesophilic bacteria, coliforms and anaerobic bacteria (log CFU g^{-1}) of fresh-cut 'Monalisa' potato stored 14 days at 4 °C[a]

Sanitizers	Packaging	Mesophilic bacteria			
		0 days	5 days	11 days	14 days
Sodium sulfite	VAC	3.4 bxy	3.5 by	3.2 cx	5.5 dz
	MAP	3.4 bx	3.5 bx	5.3 ay	6.5 bz
Tsunami	VAC	3.4 by	3.9 aby	3.7 bcy	5.8 cz
	MAP	3.4 bx	2.3 cw	4.4 by	6.7 abz
Ozone	VAC	3.9 ax	4.1 ax	5.3 ay	6.4 bz
	MAP	3.9 ax	4.1 ax	5.7 ay	6.5 bz
Ozone–Tsunami	VAC	3.6 aby	2.5 cx	3.9 by	5.4 dz
	MAP	3.6 abx	3.7 bx	5.5 ay	7.0 az
Coliforms					
Sodium sulfite	VAC	1.0 aby	1.1 y	3.7 abz	3.7 az
	MAP	1.0 aby	1.3 y	4.0 az	3.7 az
Tsunami	VAC	1.2 ay	1.2 y	3.9 az	3.7 az
	MAP	1.2 ay	1.2 y	3.6 abz	3.6 az
Ozone	VAC	1.0 abx	1.3 y	4.2 az	2.4 by
	MAP	1.0 abx	1.1 xy	4.0 az	1.7 cy
Ozone–Tsunami	VAC	0.7 bx	1.0 x	2.9 cz	1.7 cy
	MAP	0.7 bx	1.0 NSx	3.1 bcz	2.0 by
Anaerobic bacteria					
Sodium sulfite	VAC	1.2 y	1.7 abyz	2.2 ez	3.7 az
	MAP	1.2 y	1.0 bcy	2.8 cdez	3.7 az
Tsunami	VAC	1.3 w	1.9 ax	3.1 bcdz	3.7 az
	MAP	1.3 x	0.7 cx	3.3 bcz	3.6 az
Ozone	VAC	1.6 y	2.0 ay	4.1 az	2.4 by
	MAP	1.6 y	1.7 aby	3.7 abz	1.7 cy
Ozone–Tsunami	VAC	1.4 yz	1.2 bcy	2.4 dez	1.7 cy
	MAP	1.4 NSx	1.3 abcx	2.2 ey	2.0 by

[a] Values are means of three replicates which were plated in duplicate. NS, not significant. (a–d) Means within columns of the same group of microorganism followed by different letters are significantly different ($P \leq 0.05$). (z–w) Means within rows followed by different letters are significantly different ($P \leq 0.05$).

ing treatments in MAP had a lag phase duration of less than 11 days. In contrast, the sanitizing treatments in VAC increased the lag phase up to 11 days, except with the ozonated water treatment (Table 1). This sanitizer was the only one that the effect on microbial counts was independent of the packaging atmosphere, since there was no significant difference in the mesophilic bacteria in those VAC and MAP packages. Therefore, atmosphere composition was critical for microbial inactivation when the effective sanitizing treatments were used.

The initial counts of coliforms increased after a 5 day lag period for all the tested conditions and no significant differences were observed among them (Table 1). However, after 11 days of storage at 4 °C, the maximum coliform counts decreased in those samples washed with ozone or with ozone–Tsunami for both VAC and MAP. VAC packaging enhanced the anti-microbial effect in the case of coliforms for the combination ozone–Tsunami. In contrast, survival of coliforms in samples washed with sodium sulfite or Tsunami were not influenced by the packaging atmosphere (Table 1).

The populations of anaerobic bacteria remained stable for up to 5 days but subsequently increased up to 11 days of storage. The anaerobic counts continued to increase for up to 14 days in samples treated with sodium sulfite or Tsunami in both VAC and MAP throughout the storage period. On the contrary, anaerobic bacteria in ozone and ozone–Tsunami samples declined after 11 days and the fate of survivors in those treated samples was not influenced by the packaging atmosphere since there was no significant difference between MAP and VAC (Table 1). The combination of vacuum package and ozone or ozone–Tsunami washing was necessary in order to achieve the efficiency of both anti-browning and anti-microbial control, which are especially important in fresh-cut potatoes.

4. Conclusions

The best packaging method to preserve the sensory quality of fresh-cut 'Monalisa' potatoes up to 14 days at 4 °C was vacuum packaging. Under MAP, browning could only be inhibited by the use of sodium sulfite, although after 14 days at 4 °C it promoted off-odors. The use of ozone as a washing treatment alone was not effective to control microbial growth whereas the combination of ozone–Tsunami and vacuum packaging maintained both sensory and microbial quality. For the future, more studies should be carried out to determine the synergistic effects, taking into account the positive effects on the sensory and microbial quality of these combined treatments.

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