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Application of citric acid and mild heat shock to minimally processed sliced radish: Color evaluation

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ABSTRACT

The aim of this research was to study the effects of two hurdle technologies, citric acid application (CA) at 0.3%, 0.6% and 0.9% and thermal treatments (IT) for 1, 2 and 3 min at 50 °C, on the color of radish slices over 10 d of refrigerated storage. Contribution of the hurdles and their interactions were evaluated by examining the treatment effects on the following parameters: chromatic coordinates (L^*, a^* and b^*) and the indices: chroma (ΔC^*), total color difference (ΔE) and Color Index (CI^*).

The chromatic parameters for fresh radish (control samples) were $L_0 = 69.43 \pm 0.62$, $a_0 = -0.46 \pm 0.05$ and $b_0 = 5.37 \pm 0.37$, while the calculated color indices were chroma = 5.39 ± 0.36, $\Delta E = 0$ and $CI^* = -1.19 \pm 0.17$. Regarding control samples, the b^* values showed an increasing trend during storage, which was associated with browning of the slices. Both ΔE and ΔC^* values presented similar trends as reported for b^*. Based on statistical analysis of the parameters and indices tested, the single hurdle application of low citric acid concentration (0.3%) or intermediate immersion time (2 min) at 50 °C minimized the radish slices color changes during storage. However, better results were obtained when two hurdles in series were applied. According to analysis, the treatment T7 (1 min IT, 0.3% CA) was selected as the best treatment to improve the retention of typical natural color of the minimally processed sliced radishes.

1. Introduction

The market for ready-to-use and ready-to-eat vegetables has increased in recent years in response to the increasing demand for fresh, healthy and convenient food (Manolopoulou and Varzakas, 2011; Geeroms et al., 2008).

Minimal processing of vegetables involves a combination of procedures, such as selection, washing, peeling, slicing and shredding, among others. Cells and membranes are damaged by processing, especially at the cut edges, leading to metabolic alterations (due to increased respiration and biochemical changes) and microbial spoilage with detrimental effects on food quality (Plaza et al., 2011; Gonzalez-Aguilar et al., 2001). Therefore, ready-to-use products usually have a shorter shelf life than whole product.

Several alternatives have been proposed to extend the shelf life of these products. Among them, controlling the temperature during distribution and storage is by far the simplest way to delay deterioration (by decreasing metabolic reaction rates) and to retain fresh product appearance (Nunes et al., 2009). However, even greater shelf life extension may be achieved by the combined application of different treatments (hurdle technology). Application of combined hurdles, at lower intensities than when they are applied individually, can improve the microbiological quality of food and reduce their impact on sensorial and nutritional quality (Ross et al., 2003; Leistner, 2000).

Enzymatic browning in fresh-cut vegetables is one of the most important phenomena that reduce shelf life extension by strongly affecting the consumer's purchase decision (Oms-Oliu et al., 2010). The disruption of cellular compartments caused by peeling and cutting allows the enzymes (such as polyphenoloxidase) and substrates (such as polyphenols) to mix and hence, to produce browning reactions (Limbo and Piergiovanni, 2007). Different treatments have been evaluated to reduce browning in fresh-cut products. The most common is to dip or immerse them in anti-browning agent solutions. For example, citric acid is

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Table 1
Applied treatments performed as simple and double hurdle technologies.

Citric acid (%)	Heat treatment time at 50 °C (min)			
	0	1	2	3
0	CO	T1	T2	T3
0.3	T4	T7	T10	T13
0.6	T5	T8	T11	T14
0.9	T6	T9	T12	T15

used, which lowers pH and chelates copper in the active site of the polyphenoloxidase enzyme (Limbo and Piergiovanni, 2006). In addition to chemicals, other physical treatments, like heat shock, have been successfully applied to prevent browning reactions and to extend postharvest storage of fresh-cut vegetables (Ansorena et al., 2011; Martín-Diana et al., 2006). Heat shock represses the induction of phenylalanine ammonia lyase (PAL) activity and phenolic accumulation during storage preventing tissue browning (Roura et al., 2008). Additionally, this treatment may assist in the decontamination of vegetable surfaces with higher efficiency when compared to chlorinated-water treatments (Alegria et al., 2010).

Many vegetable crops are minimally processed in Argentina. Among them, radish is gaining importance. It is used as an ingredient in mixed salads and is also considered to be an important source of medicinal and nutritional components (Lu et al., 2008). However, scarce information is found in the literature about the application of hurdle technologies to preserve minimally processed radishes during refrigerated storage.

The aim of this investigation was to determine the application effects of mild heat shock and immersion in citric acid (single and combined hurdles) on minimally processed radish to minimize color change during refrigerated storage.

2. Materials and methods

2.1. Plant material and sample preparation

Radishes (*Raphanus sativus* L.) were purchased from a local market in Mar del Plata, Argentina. They were kept at 5 ± 1 °C in darkness prior to processing. Radish roots were separated from leaves and washed in tap water to eliminate any surface contamination. Then, they were cut with a manual cutter into slices of about 3–4 mm and washed again in tap water using a ratio of sliced radish to water of 1:10 (w:w).

2.2. Treatments application

The samples were divided into 16 lots for the application of the different treatments: immersion in citric acid solutions and thermal treatments as single and double hurdle technologies. Citric acid treatments were carried out by immersion of radish slices in citric acid solutions of 0.3, 0.6 and 0.9% (w/w) (Merck, Argentina) for 1 min. The ratio between solids and the soaking solution was 1:10 (w:w). Thermal treatments were carried out in a thermostatically controlled water bath with recirculation (Lauda E300, Germany). The samples were placed in sterile containers and immersed in water at 50 °C for 1, 2 and 3 min. Thereafter, samples were removed from the bath and cooled immediately in cold water at 0–4 °C for 3 min. For the application of combined treatments (hurdle technology), heat treatment was carried out followed by immersion in citric acid solution. Table 1 summarizes the different treatments applied as single and double hurdle technologies.

2.3. Storage conditions

After treatments, 50 g of radish slices were packed in polyethylene bags (25 cm × 30 cm) of 25.4 μm thickness (with O_2, CO_2 and water vapor transmission rates of 3.08×10^{-4}, 2.05×10^{-3} and 2.05×10^{-6} mmol^3 m^{-2} s^{-1}, respectively, at P = 101,325 Pa, T = 25 °C).

Bags were sealed using manual equipment (HL, FS-300, Argentina). Samples were stored at 5 ± 1 °C in a refrigerated chamber (GAZA, Argentina). Two bags for each treatment were analyzed at 2, 4, 7 and 10 d of storage.

2.4. Color measurements

Surface color was measured with a colorimeter (Lovibond, RT Series, England). The colorimeter was standardized against a white tile (L^* = 97.63, a^* = 0.3133, b^* = 0.3192). Measurements were done in triplicate over each surface sample. Color was recorded using the CIE – $L^*a^*b^*$ uniform color space ($L^*a^*b^*$), where L^* indicates lightness (whiteness or brightness/darkness), a^* indicates chromaticity on a green (−) to red (+) axis, and b^* indicates chromaticity on a blue (−) to yellow (+) axis (CIE, 1978). Numerical values L^*, a^*, b^* were used to estimate total color difference (ΔE) (Eq. (1)), chroma (C^*) (Eq. (2)), and Color Index (CI^*) (Eq. (3)) according to:

$$\Delta E = \sqrt{(a* - a_o)^2 + (b* - b_o)^2 + (L* - L_o)^2} \quad (1)$$

$$C* = \sqrt{a*^2 + b*^2} \quad (2)$$

$$CI* = \frac{a^* \cdot 1000}{L^* \cdot b^*} \quad (3)$$

Total color difference (ΔE) is generally used to acknowledge the difference between two colors according to the following scale: Trace level difference ΔE^* = 0–0.5, slight difference ΔE^* = 0.5–1.5, noticeable difference ΔE^* = 1.5–3.0, appreciable difference ΔE^* = 3.0–6.0, large difference ΔE^* = 6.0–12.0, very obvious difference $\Delta E^* > 12.0$ (Chen and Mujumdar, 2008). Chroma (C^*) is a measure of color intensity or saturation, which varies from dull (low value) to vivid (high value). Regarding Color Index, CI^* values between −40 and −20 are related to blue-violet to dark green colors; between −20 and −2 to dark green and yellowish green colors; between +2 and +20 to pale yellow and deep orange colors; and between +20 and +40 to deep orange and deep red colors (Vignoni et al., 2006).

Additionally, chroma was reported as a difference (ΔC^*) with respect to chroma value of fresh radish at zero time.

2.5. Statistical analysis

Results reported in this research are LS mean values (least square mean, means estimators by the method of least squares) together with their standard deviations. Experimental data were analyzed using SAS, software version 9.0 (SAS, 1999). The General Linear Model procedure (PROC GLM) was used to carry out the Analysis of Variance (ANOVA), with confidence limits of 95%.

A statistical model was used to evaluate the effects of storage time on color indices of radish slices without any treatment (control samples, CO). For this model, the independent variable of the ANOVA was Storage Time (ST: 0, 2, 4, 7 and l0 d).

A second statistical model was used to evaluate the effects of mild heat shock treatment, as single hurdle, on color immediately after treatment as well as during storage. Thus, a two-way ANOVA was applied using the following factors as variation sources: Immersion Time (IT: 0, 1, 2 and 3 min), Storage Time (ST: 0, 2, 4, 7 and l0 d) and the interaction between them (IT * ST). Data used