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Influence of ohmic heating/osmotic dehydration treatments on polyphenoloxidase inactivation, physical properties and microbial stability of apples (cv. Granny Smith)

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ABSTRACT

The combined effect of ohmic heating (OH) and osmotic dehydration (OD) with vacuum impregnation (VI), on the polyphenoloxidase (PPO) inactivation, physical properties and microbial stability of apples stored at 5 °C or 10 °C was analyzed. The treatments were performed using a 65% (w/w) sucrose solution and with ohmic heating at 13 V/cm at 30 °C, 40 °C or 50 °C for 90 min. Examination of the dehydrated samples showed that the water loss and the solid gain were greater with the OD/OH and VI/OH treatments at 50 °C. PPO was completely inactivated by the OD/OH and VI/OH treatments at 50 °C. There was a correlation between the PPO activity, the color change and the browning index of the treated and stored samples; the values for these parameters were stable when PPO was inactivated. The lowest loss of firmness and color was obtained with the VI/OH treatment at 50 °C. The shelf-life of the apples treated with VI/OH at 50 °C and stored at 5 °C was extended to more than 4 weeks. Therefore, the VI/OH treatment at 50 °C was determined to be the best process for dehydrating apples.

Industrial relevance: The aim of this research was 1 to study the combined effect of ohmic heating (OH) and osmotic dehydration (OD) with vacuum impregnation (VI) on the polyphenoloxidase inactivation and microbial stability of osmotically dehydrated apples stored at either 5 °C or 10 °C. Two technologies, OH and OD were performed at 30, 40 or 50 °C with an electric field intensity of 13 V/cm and conventional heating for 90 min. The results showed a correlation between the PPO activity, the color change and the browning index of the treated and stored samples; the values were stable when PPO was inactivated. PPO was completely inactivated by the OD/OH and VI/OH treatments at 50 °C. The shelf-life of the apples treated was extended to more than 4 weeks. Under the investigated conditions, VI/OH treatment at 50 °C and stored at 5 °C may be considered the better minimal processing that preserves the fresh-like properties.

1. Introduction

Ohmic heating (OH), a thermal process that uses electrical energy to heat foods as a method of preservation, can be used for microbial inactivation or other processes such as blanching, pasteurization, sterilization, evaporation and dehydration. Conventional heat treatments involve high temperatures that can reduce the nutritional and sensorial quality of the foods. In OH processing, food components become the elements of an electric circuit through which an alternating current (AC) flows, generating heat in the foods based on their intrinsic properties of electrical resistance (Sarang, Sastry, & Knipe, 2008; Zell, Lyng, Cronin, & Morgan, 2009). Ohmic heating provides rapid and uniform heating, which reduces the treatment time and results in less thermal damage to vitamins, pigments and other elements (Machado, Pereira, Martins, Teixeira, & Vicente, 2010). A study of vitamin C in acerola pulp during ohmic and conventional heating treatment showed that ohmic heating performed with low voltage gradients degraded both ascorbic acid and total vitamin C in a manner similar to that of conventional heating. However, high voltage gradients induced greater ascorbic acid degradation due to electrochemical reactions (Mercali, Jaeschke, Tessaro, & Ferreira, 2012).

The effects of different cooking methods on the textural properties of cylindrical pieces of root vegetables, such as carrot, red beet and golden carrot, were analyzed; OH resulted in greater softening rates, and the final hardness of the samples treated with OH was significantly lower than those of the samples treated by microwave or conventional heating (Farahnaky, Azizi, & Gavahian, 2012). Simulation and optimization of OH of highly viscous foods demonstrated the importance of the treatment chamber geometry because the chamber geometry influences both the current and fluid flow patterns. Thus, uniform heating obtained by modifying the insert forms significantly improved the temperature distribution within OH systems with sidewise parallel electrodes (Shynhary & Sastry, 2012).

Osmotic dehydration (OD) preserves attributes such as color, firmness and flavor and reduces the water activity, providing products with

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a high moisture content (a_w = 0.92–0.97) and an extended shelf-life (Wiley, 1994). OD is a process that may be used to increase the shelf-life of raw fruit while minimally decreasing its quality. OD of fruits has become an important relevant technique to decrease the water activity, thus increasing the product's stability (Moreno et al., 2012).

The application of a pulsed vacuum for a short duration at the beginning of the osmotic dehydration process has beneficial effects on the process kinetics and quality for many fruits (Fito & Chiralt, 2000). Vacuum impregnation (VI) increases the rate of water-related weight loss and solid gain by introducing controlled quantities of a solution into the porous structures of fruits and vegetables (Barat, Talens, Barrera, Chiralt, & Fito, 2002; Deng & Zhao, 2008; Moreno, Bugueño, Velasco, Petzold, & Tabilo-Munizaga, 2004).

Polyphenoloxidase (PPO) is an oxidoreductase enzyme that, in the presence of oxygen, catalyzes the oxidation of *o*-phenolic compounds to *o*-quinones, which are subsequently polymerized to dark-colored pigments (Van Loey, Verachtert, & Hendrickx, 2002). The enzymatic browning caused by polyphenoloxidase activity in fruits and vegetables is a great problem for the food industry and is one of the main causes of spoilage during processing and storage. Inhibiting browning is important to maintain the sensory attribute of color in apples (Burdurlu & Karadeniz, 2003). Enzymatic browning can be inhibited by chemicals such as ascorbic acid or sulfites or by heat treatment (Kim, Kim, & Park, 2005). Studies of native enzymes in cloudy apple juice demonstrated enhanced inactivation of PPO with the increasing temperature, pressure and time of continuous high pressure carbon dioxide (HPCD) treatment (Xu et al., 2011). Applying electrical fields via ohmic heating inactivated PPO and lipoxygenase more rapidly than did conventional heating. Ohmic heating has been shown to be a useful alternative method for pasteurizing or sterilizing food products that may also enhance the rate of PPO inactivation in food materials (Jakób et al., 2010).

VI and OH pretreatment, with and without the addition of citric acid, cause profound changes in apples, and the water loss and solid gain during OD are significantly increased when the apple tissues were pretreated with citric acid (Allali, Marchal, & Vorobiev, 2010). The combination of osmotic dehydration at atmospheric pressure and ohmic heating treatments favors mass transfer as the working temperature increases; VI and VI–OH treatments at 50 °C represent the best processing conditions for dehydrating pear pieces in a sucrose solution at 65°Brix (Moreno et al., 2011). The shelf-life of strawberries treated with VI–OH at 13 V/cm and 30 °C and stored at 5 °C was extended from 12 days (control samples) to 25 days (Moreno et al., 2012).

The aim of this work was to investigate the combined effect of ohmic heating and osmotic dehydration with vacuum impregnation on the polyphenoloxidase inactivation, physical properties and microbial stability of osmotically dehydrated apples (cv. Granny Smith) stored at either 5 °C or 10 °C.

2. Materials and methods

2.1. Sample preparation

Fresh apples (cv. Granny Smith) from Chile were obtained from commercial sources and stored in a refrigerator at 4 °C. The apples were peeled and cut into 1 cm^3 cubes. The samples were dipped in a solution of 1% ascorbic acid and 2% citric acid for 3 min to prevent enzymatic browning. A 65°Brix sucrose solution was used as the hyperosmotic solution. This solution contained 1.13 g/l of calcium chloride ($CaCl_2$) and 2 mg/l of potassium sorbate ($C_6H_7KO_2$) to increase conductivity and retain firmness.

2.2. Osmotic dehydration

Osmotic treatments with atmospheric pressure (OD) and vacuum impregnation (VI), were performed with conventional and ohmic heating (OH) at 30, 40 and 50 °C. The processing time was 90 min for the osmotic treatments (OD, VI, OD/OH and VI/OH). The ratio of solution to fruit was 3:1 (w/w) to avoid excessive dilution of the solution. For the vacuum impregnation treatments, a 50 mb vacuum was applied for 5 min and then atmospheric pressure was restored. For the OH treatments, the samples were immersed in concentric cylindrical tanks (3.7 cm and 19 cm in diameter) made of stainless steel with a plastic bottom connected to a generator by two electrodes (Moreno et al., 2011). The osmotic solution was subjected to an alternating current at 60 Hz and 100 V, generating an electric field of 13 V/cm. The temperature was measured with a Teflon-coated thermocouple device (CPSS-116-24-PFA). An OM-420 data logger (Omega Engineering, Stamford, USA) was employed to simultaneously measure the temperature, voltage and current. The temperature was controlled during the osmotic treatments (OD, VI, OD/OH and VI/OH) with a water bath. To standardize the temperature, orbital shaking at 100 rpm (Barnstead/Lab-Line MaxQ 2000, Iowa, USA) was employed (Moreno et al., 2012).

2.3. Analysis of sample composition

The water activity was measured with a dew point hygrometer (Aqua Lab Model 4TE, Pullman, USA). The moisture content was determined by the technique defined by the Association of Official Analytical Chemists (AOAC) (Association of Official Analytical Chemists, 2000). The soluble solid contents were determined using a digital refractometer (Leica Mark II, Buffalo, NY, USA). All of the measurements were performed in triplicate and the mean values are reported.

The changes in the water and soluble solid contents (ΔM^w_t and ΔM^s_t, respectively) were calculated using the following equations:

$$\Delta M_t^w = \left[\frac{M_t^o \cdot X_t^w - M_0^o \cdot X_0^w}{M_0^o}\right];\quad \Delta M_t^s = \left[\frac{M_t^o \cdot X_t^s - M_0^o \cdot X_0^s}{M_0^o}\right]$$

where M^o_t and M^o_o represent the sample weight at times t and 0, respectively, and X^w_t, X^s_t, X^w_o and X^s_o are the water (w) and soluble solid (s) mass fractions of the sample at times t and 0, respectively.

2.4. Polyphenoloxidase activity (PPO)

The PPO activity was determined using a spectrophotometric method (Rocha & Morais, 2001) with some modifications. Ten grams of the fruit samples, in triplicate, was homogenized in an ice bath with 30 ml of 0.2 M phosphate buffer (pH 6.5) and 0.6 g of polyvinylpyrrolidone (PVPP, Sigma P6755-Germany) for a total of 3 min with a 1 min interval after each minute using an Ultra-Turrax homogenizer (IKA Labortecknik, T25 Basic, Germany). Two drops of Triton X-100 solution (Fluka Biochemika, Switzerland) was added. The mixture was centrifuged at 6000 rpm for 30 min at 4 °C in a refrigerated benchtop centrifuge (Hettich Zentrifugen Universal, Tuttlingen, Germany) and the supernatant was filtered. An aliquot (0.40 ml) of the supernatant was added to 3.0 ml of the substrate solution (catechol 0.15 M) and the absorbance at 420 nm was obtained using a spectrophotometer (PG Instruments Ltda., T 70, and Vietnam). The residual activity of the PPO was estimated with the following equation:

$$\text{Residual activity} = \frac{\text{PPO specific activity after osmotic dehydration}}{\text{PPO specific activity in the fresh sample}} \times 100.$$

2.5. Analysis of the optical parameters

The color analysis of the apple samples was performed with a Minolta Chroma Meter CR-200 (Minolta Corp., Osaka, Japan). The CIE Lab coordinates were obtained using a D_{65} illuminant and a 2° observer as a reference system. The instrument was calibrated with a standard white plate (L = 97.59; a = −0.07; and b = 1.59). A glass Petri dish containing a sample was placed above the white