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Influence of ohmic heating and vacuum impregnation on the osmotic dehydration kinetics and microstructure of pears (cv. Packham's Triumph)

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ABSTRACT

The effect of ohmic heating (OH) and vacuum impregnation (VI) on the osmotic dehydration kinetics and microstructure of pears was studied. Three different dehydration levels (30, 40 and 50 °C) were used, by applying VI or not (OD) and OH (100 V). Dehydrated samples showed that the application of OH during the osmotic treatments had significant effects on the kinetics of water loss and sugar gain as well as on the microstructure of samples. The greatest water loss was observed with the OD–OH. The largest amount of solute gain and the smallest firmness loss were obtained in the VI–OH. In some treatments, the process time was reduced by as much as 40%. The SEM observations showed that cell deformation and cell rupture were significant in the OD–OH than on the VI–OH samples. The increases in the permeability of cell by OH explain the acceleration of mass transference and process time reduction.

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1. Introduction

Osmotic dehydration (OD) at mild temperatures, which is considered minimal processing, preserves fresh-like characteristics of fruits and can be used to obtain various pear products or ingredients for many food products. OD preserves attributes such as color, texture and aroma, and it reduces water activity, giving high-moisture products extended shelf life.

The use of vacuum impregnation (VI) allows an increase in the rate of water-related weight loss and solid gain, and it introduces controlled quantities of a solution into the porous structure of fruits and vegetables (Barat et al., 2002; Moreno et al., 2004; Deng and Zhao, 2008). Mass transfer during osmotic dehydration occurs through the semipermeable cell membranes. The dominant resistance in the mass transfer in the biological materials changes from partial to total permeability, leading to significant changes in tissue architecture (Aguilera and Lillford, 2000; Rastogi et al., 2000; Quiles et al., 2004).

Two resistances oppose mass transfer during the osmotic dehydration of fruits: internal and external. The fluid dynamics of the solid–fluid interface governs the external resistance whereas the internal, and much more complex, resistance is influenced by cell tissue structure, cellular membrane permeability, deformation of vegetable/fruit pieces and the interaction between the different mass fluxes (Fito, 1994; Fito and Chiralt, 1997).

Ohmic heating (OH) is a thermal process in which heat is internally generated by the passage of an alternating electrical current (AC) through a body, such as a food system that serves as an electrical resistance. A food product, thanks to its numerous ionic compounds, is a conductor of electricity. In the ohmic heating processes, the food components become the parts of the electric circuit through which the alternating current flows, generating heat in the foods based on their intrinsic properties of electrical resistance (Salengke and Sastry, 2007; Sarang et al., 2008; Zell et al., 2009).

The interest in OH technology is due the fact that products are of a superior quality to those processed by conventional technologies (Castro et al., 2003). The main advantages claimed for this technology are uniformity of heating and improvements in quality with minimal structural, nutritional or organoleptic changes. Possible applications include most of the heat treatments such as blanching, evaporation dehydration, and fermentation as well as pasteurization and sterilization.

For a food item consisting of a liquid–particulate mixture, heat can be generated using OH at rates that are the same or comparable in both the liquid and particulate phases if the electrical conductivities of the two phases are equal. OH thus provides a technology for processing particulate foods at the rate of an high temperature short time (HTST) process but without the limitations of heat transfer to particulates found in conventional HTST processes (Sarang et al., 2008). Temperature can increase rapidly in OH, making the technology efficient HTST treatment that preserve product quality. Homogeneity of the process depends on the

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homogeneity of electrical conductivity in the chamber, electrode geometry and the resistance time of solid–liquid mixture in the heather (Eliot-Godéreaux et al., 2001).

Wang and Sastry (1997) evaluated the effects of an ohmic pretreatment to vegetables and found no significant changes in the moisture content of the final product. Eliot et al. (1999) studied the influence of precooking by OH on the firmness of cauliflower and concluded that OH combined with low-temperature precooking in saline solutions offers viable solution to HTST sterilization of cauliflower florets. In a study by Castro et al. (2003), the suitability of several strawberry-based products to be processed by OH was tested.

The phenomenon of cell membrane electropermeabilization has been known for several decades and has recently received increasing attention because of its applicability to the manipulation of cells and tissues (Weaver and Chizmadzhev, 1996). Strictly speaking, our knowledge is phenomenological, as it is based on measurements of electrical currents through planar bilayer membranes (BLM) under the influence of strong electric fields and on the molecular transportation of molecules into (or out of) cells subjected to electric field pulses (Kulshrestha and Sastry, 2006).

In a previous study osmotically dehydrated raspberries (*Rubus idaeus*) treated with ohmic heating at a variable voltage (to maintain a temperature between 40 and 50 °C) and an electric field intensity <100 V/cm showed that processing time was significantly reduced by the ohmic heating. In some cases, this reduction in time even reached 50% (Simpson et al., 2007). Vacuum impregnation (VI) and ohmic heating (OH) pre-treatment with and without addition of citric acid were used to enhance the mass transfer kinetics during osmotic dehydration (OD) of apple cubes. The water loss and sugar gain during osmotic dehydration were significantly increased when the apple tissue was pre-treated with addition of citric acid. The pre-treatments led profound changes in apple fruit structure, evaluated measurements of fruit firmness and electrical conductivity (Allali et al., 2009).

The aim of this work was to evaluate the effect of ohmic heating and vacuum impregnation on the osmotic dehydration kinetics and microstructure of pears (cv. Packham's Triumph).

2. Materials and methods

2.1. Sample preparation

Fresh pears (cv. Packham's Triumph) from Chillan (Chile) were obtained from commercial sources and stored in a refrigerator at 4 °C. The fruits were selected according to their appearance (ripeness, size and color). The pears were peeled and cut into 1-cm^3 cubes. The samples were dipped in a 1.5% ascorbic acid and 3% citric acid solution for 3 min to prevent enzymatic browning. A sucrose solution of 65 °Brix was used as an osmotic solution. The solution contained 2 ppm of potassium sorbate ($C_6H_7KO_2$) as a preservative and calcium chloride ($CaCl_2$) 1.13 [g/L] to retain firmness and increase conductivity.

2.2. Osmotic treatments

The osmotic dehydration was carried out at atmospheric pressure (OD), and the vacuum impregnation (VI) was conducted with conventional and ohmic heating (OH) at 30, 40 and 50 °C. The processing time was 300 min in the osmotic treatments (OD, VI, OD–OH and VI–OH). A vacuum pulse was applied for 5 min at 50 mb at the beginning of the process. After this step, the atmospheric pressure was restored to complete the process time (Moreno et al., 2004). For the OH treatments, the samples were immersed in a concentric cylinder tank (3.7 and 19 cm in diameter) made of stainless steel with a plastic bottom connected to the generator by two electrodes. The osmotic solution was subject to an alternating current at 50/60 Hz and 100 V, generating an electrical field intensity of 13 V/cm, for 5 h. The temperature was measured with CPSS-116-24-PFA Teflon-coated thermocouples. A data-logger OM-320 (Omega Engineering, Stamford, USA) was employed to simultaneously measure the temperature, voltage and current. To standardize the temperature, orbital shaking at 100 rpm (Barnstead/Lab-Line Max^{Q} 2000, Iowa, USA) was employed.

2.3. Analysis of physicochemical properties

The water content (X^w) and soluble solids (X^{ss}) were measured in the fresh and treated samples to determine the compositional changes promoted by osmotic dehydration. The moisture content was determined by the technique defined by the Association of Official Analytical Chemists (AOAC, 2000). The soluble solids were determined by a digital refractometer (Leyca Mark II, Buffalo, NY, USA). All measurements were made in triplicate, and the average values were reported.

Mass transfer parameters and changes in the water and soluble solids ($\Delta M^w{}_t$ and $\Delta M^{ss}t$, respectively) were calculated using Eqs. (1) and (2); $M^o t$ and $M^o 0$ represent the sample weight at time t and 0, respectively, and $X^w{}_t$, $X^{ss}{}_t$, $X^w{}_0$ and $X^{ss}{}_0$ are the water (w) and soluble solid (ss) mass fractions in a sample at time t and 0, respectively.

$$\Delta M_t^w = \left[\frac{M_t^o \cdot X_t^w - M_0^o \cdot X_0^w}{M_0^o}\right] \quad (1)$$

$$\Delta M_t^{ss} = \left[\frac{M_t^o \cdot X_t^{ss} - M_0^o \cdot X_0^{ss}}{M_0^o}\right] \quad (2)$$

The color of the pears was evaluated using a Minolta Chroma Meter CR-200 (Minolta Corp., Osaka, Japan). The instrument was calibrated with a standard white plate ($L = 97.59$, $a = -0.07$, $b = 1.59$). The CIE Lab coordinates used D_{65} illuminant, with a 2° observer as reference system. A glass Petri dish containing a sample was placed above a white plate, and the L, a and b values were recorded. The measurements were made in triplicate and in three different places on each sample, and the mean values were reported. The hue angle (h^*_{ab}) and chroma (C^*_{ab}) were also calculated for Eqs. (3) and (4), respectively. The firmness of the samples was determined using a Texture Analyser TA-XT2 (Stable Microsystems, Haslemere, UK) that had a Kramer shear cell with five blades. The press crosshead speed was set at 2 mm/s. Rectangular pieces of 4 × 3 × 0.3 cm were measured in each mechanical test. The mechanical parameter considered was the maximum peak force (F_{max}), reported as N. Ten replicates were performed for each treatment.

$$H^*_{ab} = arctg\frac{b}{a} \quad (3)$$

$$C^*_{ab} = (a^2 + b^2)^{\frac{1}{2}} \quad (4)$$

2.4. Structural analyses

Structural analyses were carried out using a scanning electron microscope (SEM) and a transmission electron microscope (TEM), that is, a Jeol JSM–6380LV and a Jeol JEM 12000EX-II, respectively, both of OXFORD Instruments, UK. The fresh and treated samples were analyzed from the surface to the center. Sample fixation was done by immersion in glutaraldehyde (2–4%) for 4–24 h in a 0.1-M phosphate buffer (pH 7.2–7.4) at 4 °C. A second fixation was made with a 1% osmium tetraoxide solution for 1–2 h in a

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