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Use of vacuum impregnation for the production of high quality fresh-like apple products

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ABSTRACT

The application of vacuum impregnation (VI) for the production of high quality fresh like apple products has been investigated. Preliminary tests were carried out to select the optimal VI treatment conditions (P: 857–50 mbar; VI time: 10–1000 s). The use of isotonic sorbitol, glucose, fructose, sucrose, trehalose and maltose solutions was then studied to keep quality and improve stability of the VI treated apples. VI at 738 mbar for 10 s allowed the penetration of the impregnation agent (water) with minimal effects on fruit composition and quality. VI isotonic solutions determined a limited solute increase while affected mechanical properties positively; firmness of apples processed with sorbitol solution was higher than that of the fresh fruit. Moreover, they contributed to preserve apples from browning. After 7 days, h° values significantly higher than the untreated samples were obtained with trehalose > sorbitol > glucose > sucrose > maltose. Sensory analysis confirmed the positive effect of isotonic VI solution on apples quality.

1. Introduction

The production and consumption of fresh-cut fruits is parallel to the growth of the demand of fresh, convenient and nutritious foods (Luo et al., 2011). The food industry has been responding with skilful marketing initiatives and the development of new products and processes that use innovative technologies (FAO, 2010).

In fruit processing, this aim is achieved by developing actions and processes that allow the enrichment of vegetable products with desirable compounds. Within this context, vacuum impregnation (VI) has been largely used to obtain a rapid penetration of solvated compounds in plant tissues together with a homogeneous concentration profile of the solutes in the final products (Moreno et al., 2011; Allali et al., 2010; Atarés et al., 2008). VI has proved to be an useful method to enrich fruit and vegetable tissue with desirable solutes (e.g. firming and antioxidant agents, flavours, cryoprotectans, vitamins, minerals, probiotics) able to stabilize and/or improve the sensory and/or the functional properties of food products (Radziejewska-Kubzdela et al., 2014; De Rossi et al., 2011; Betoret et al., 2003; Gras et al., 2003; Hironaka et al., 2011; Jeon and Zhao, 2005; Martinez-Monzo et al., 1998; Schulze et al., 2012; Guillem et al., 2008; Xie and Zhao, 2003; Comandini et al., 2010).

During VI, the vegetable porous fraction composed by the intercellular spaces, is filled by an external solution to a degree that depends on various factors including the applied process conditions (sub-atmospheric pressure level, process duration and temperature), the osmotic pressure and viscosity of the impregnation fluid (Guillemin et al., 2008), the size and shape of the samples, its effective porosity (pore size and distribution) which affect the capillary pressure of fluids within the vegetable tissue and its response to mechanical stress (Schulze et al., 2012; Andres et al., 2001; Fito et al., 1996; Mujica-Paz et al., 2003a, 2003b).

The VI implies two main steps. The former is the “vacuum step”, characterized by the immersion of the food (generally cut in pieces having homogeneous shape and size) in a solution and its exposure to sub-atmospheric pressure, thus promoting the expansion and outflow of internal gas, together with pore native liquid, from the food porous space (Zhao and Xie, 2004). In the latter one, the “impregnation step”, the atmospheric pressure is re-established and the external solution penetrates the food porous space compressing the residual gas until the pressure equilibrium is reached.

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A mechanistic description of the VI treatment in solid porous food systems has been proposed by Fito et al. (1996) by coupling the hydrodynamic mechanism (HDM) and the deformation-relaxation phenomena (DRP) models.

The literature focused on the modelling of the VI process variables and on its use in the production of vegetable products, reports conditions in terms of vacuum pressure and/or treatment times that induce dramatic changes on the composition of vegetables and on their physical and sensory characteristics. In such experimental conditions, simultaneously with the enrichment of external solutes, the hydrodynamics and the deformation-relaxation phenomena that occur in VI process can determine mechanical damages on the vegetable tissue together with the loss of native compounds as water, organic acids, sugars, salts and other important bioactive compounds.

These phenomena can negatively affect the texture, colour, pH and the global likeness and attractiveness of the processed products. Therefore, in addition to the choice of the raw material, it is of utmost importance to calibrate the process parameters depending on the product target to be achieved and its characteristics in terms of quality and stability.

Aim of this study was, thus, to evaluate the feasibility of the use of a non-conventional vacuum impregnation treatment characterized by mild processing conditions for the production of high quality fresh-like apple product.

For this purpose, a preliminary modulation of the VI process parameters (pressure and time) was carried out in order to identify the operative conditions that allow to minimise the process impact on the overall quality and stability of apples. In these experiments, water has been used as an impregnant agent to evaluate the change in the composition and the mechanical damages induced on the tissue by different processes by the solvent itself and the related undesirable changes in quality attributes.

Thereafter, series of experiments were carried out by using the optimised VI process conditions and different carbohydrate solutions (sorbitol, glucose, sucrose, trehalose and maltose) as impregnating agents in order to improve and/or stabilize the quality characteristics of the fresh cut apples. These solutes were chosen due to their ability i) to protect some cell components by preserving the fluidic state of the membranes (Hincha and Crowe, 1998; Sola Penna and Meyer-Fernandes, 1998), ii) to affect the structural properties of the cell walls by the increase of pectin–pectin interactions (Sato and Miyawaki, 2008), iii) to inhibit enzymatic reactions by reducing the system viscosity and water activity and/or by non-competitive biochemical inhibition (Nicoli et al., 1991a; 1991b; Neri et al., 2010, 2014). Due to these unique properties, low molecular weight carbohydrates have been extensively used as impregnating agents in both fresh and processed fruit products in order to preserve cell structures, improve texture, limit colour changes induced by enzymatic-browning and pigment degradation, limit ascorbic acid degradation and improve aroma (Torreggiani, 1995; Mastrocola et al., 1997, 1998; Torreggiani et al., 1999; Ferrando and Spiess, 2001; Pittia et al., 2004; Mastrocola et al., 2005; Comandini et al., 2010).

2. Material and methods

2.1. Raw material

Apples (cv. Golden delicious) were purchased in a local market. Variability of the raw material was reduced by the choice of commercially available apples of ‘extra’ category produced in a Northern Italian region with highly standardised quality parameters in terms of colour, size and weight according to the EU regulation. Before the VI treatment, apples were washed, peeled and cut in 1 cm^3-cubes.

Experiments were carried out using batches of fruit with similar ripening degree. In particular, in the first step of the experimental design, apples with an average moisture of 15 ± 0.1 g 100 g^{-1} and a soluble solids content expressed as °Brix of 12.4 ± 0.3 were selected whilst in the second step of the experimental design, apples with an average moisture content of 13 ± 0.1 g 100 g^{-1} and a soluble solids content of 12.5 ± 0.3 °Brix were used. In both batches the starch conversion index was equal to about 5 on a scale 0–10.

All chemicals were obtained from Sigma (Steinheim, DE).

2.2. Experimental design

The first step of this study was aimed to identify the VI process conditions, in terms of a combination of pressure and time, that determine minimal changes on the apple composition and its physical properties. Sub-atmospheric pressures ranging from 857 to 50 mbar were investigated using a constant treatment time (10 s). Vacuum times of 100 and 1000 s were further tested by applying 857, 738 and 619 mbar pressure conditions. Deionized water was used as an impregnation agent. Fresh non-vacuum treated apples were also analysed and taken as reference samples.

In the second step, the optimized VI conditions were applied to evaluate the effect of different solutes on quality and stability of the fresh cut apples. Isotonic (13% w/w) sorbitol, glucose, sucrose, trehalose and maltose aqueous solutions were investigated. Samples VI treated in water (control) and non-vacuum treated (fresh) were also analysed as reference samples.

2.3. Vacuum impregnation (VI)

The VI treatment was carried out by using a vacuum laboratory equipment composed of a glass cylindrical chamber (10 L volume) that includes a stainless steel holed holder connected to a vacuum pump (SC 920, KNF ITALIA, Milan, Italy) and an external water flow chamber for the process temperature control connected to a thermostated water bath set at 20 °C ± 1 °C.

Each experiment was performed at least in duplicate on 300 g of apple cubes and freshly-made solution. Apple cubes were added to the VI solution in a 1:4 (w/w) fruit/solution ratio. After VI, the atmospheric pressure was restored and apples were left in contact with the VI solution for 1 min in order to equilibrate. Thereafter samples were drained and excess liquid was removed by lightly dabbing fruit surfaces with absorbent paper. When necessary, samples were packed in BOPP bags (film thickness: 30 μm) in air and stored at 4 °C.

2.4. Moisture and mass transfer parameters

Moisture content was determined according to the AOAC gravimetrical method Ref. 925.10 (AOAC, 1990). To determine the total mass change due to VI, the weight of the fruit was measured before and after the VI treatment. Total mass changes at time *t* (ΔM^{0}_{t}), water mass changes at time *t* (ΔM^{W}_{t}) and soluble solids changes at time *t* (ΔM^{SS}_{t}) were then calculated as described by Sacchetti et al. (2001).

2.5. Carbohydrates determination

Sorbitol, glucose, sucrose, trehalose and maltose were determined by a Dionex (San Donato Milanese, Italy) ICS 3000 Ionic Chromatograph equipped with ICS 3000 S P pump and ICS 3000 ED detector. Extraction and analysis were carried according to Neri et al. (2011). Each sample (25 g) was combined with 100 ml of distilled water and ground with an Ultra-Turrax T 18 basic