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Vacuum impregnation and drying of calcium-fortified pineapple snacks

Marla Mateus de Lima [a], Giustino Tribuzi [a], José Antonio Ribeiro de Souza [a], Ivan Gonçalves de Souza [b], João Borges Laurindo [a], Bruno Augusto Mattar Carciofi [a, *]

[a] *Department of Chemical and Food Engineering, Federal University of Santa Catarina, EQA/CTC/UFSC, 88040-900, Florianópolis, SC, Brazil*
[b] *Department of Chemistry, Federal University of Santa Catarina, QMC/CFM/UFSC, 88040-900, Florianópolis, SC, Brazil*

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ABSTRACT

Impregnation methods combined with drying (convective- or freeze-) were used for producing calcium-fortified pineapples snacks. Three impregnation alternative were evaluated: I) at atmospheric pressure for 20 min; II) applying 10 min of vacuum (13.33 kPa) to a container with pineapple samples immersed into the impregnating solution followed by 10 min of impregnation at atmospheric pressure; and III) applying vacuum impregnation followed by vacuum pulses (6.70 kPa) after removing the samples from the impregnating solution. The impregnating solution concentration was 1 g Ca^{2+} 100 ml^{-1} prepared with $CaCl_2$. The influence of the impregnation method on the kinetics of convective-drying and on porosity, shrinkage, glass transition temperature, water sorption isotherms, texture and microstructure of convective-dried and freeze-dried pineapple samples were determined. After drying, vacuum-impregnated products presented 91% higher concentration of Ca^{2+} than pineapples impregnated at atmospheric pressure (equal total processing time). Calcium chloride impregnation increased the drying rates and positively influenced the physical properties of the convective-dried product. The combination of vacuum impregnation and drying is a suitable way for the production of calcium-fortified pineapples, which are porous-and-crunchy, with high glass transition temperature favouring its preservation during storage.

1. Introduction

Pineapple is a fruit widely diffused worldwide. In terms of production, it represents the third most important tropical fruit, after bananas and mangoes (FAOSTAT, 2013). As well as many other fruits, it has a relatively short shelf life, limiting the commercialization of fresh fruits and increasing postharvest losses. The research of alternatives that can reduce these losses is very important. The most frequent preservation strategies applied to pineapple are dehydration and thermal processing (canning or juice pasteurizing) (ISHS, 2012).

Furthermore, this fruit can be used for the development of fortified foods, when enriched with specific nutrients, such as essential minerals. In particular, calcium fortification represents an interesting strategy to add value to dried fruits. Calcium is one of the most important minerals for the human health, which functions are principally related to growth, bone health and reproduction (Barrera, Betoret, Corell, & Fito, 2009). Unfortunately, there are few excellent dietary sources of calcium, so worst if milk and dairy products are not regularly present in the diet (IBGE, 2011; Singh et al., 2006). The gap between consumed and recommended calcium dietary intake has been increasing the demand for enriched or fortified products.

Many authors confirmed that calcium impregnation improves the nutritional value of processed fruits (increasing calcium concentration and bioavailability), which can represent a new source of this mineral (Anino, Salvatori, & Alzamora, 2006; Xie & Zhao, 2004). Furthermore, as well known, Ca^{2+} at the fruit cell wall can prevents softening during processing, by the formation of calcium bridges between uronic acid carboxyl function that integrate the pectin chain superstructure (Vicente, Saladié, Rose, & Labavitch, 2007). This interaction provides rigidity to the cell, contributing to the firmness and texture of processed products (Jackman & Stanley, 1995).

Vacuum impregnation represents a useful procedure to

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* Corresponding author.
E-mail address: bruno.carciofi@ufsc.br (B.A.M. Carciofi).

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introduce solutes directly into the porous structure of the foodstuff (hydrodynamic instead of diffusional transport), increasing considerably the mass transfer rate, depending on the processing parameters and the product characteristics (Carciofi, Teleken, Bertelli, Prat, & Laurindo, 2015; Fito, 1994). During the vacuum application (first step), entrapped air is drained from the intracellular spaces of the tissue immersed in an impregnation solution; when the atmospheric pressure is restored (second step), the solution penetrates into the pores as a consequence of pressure gradients (Carciofi, Prat, & Laurindo, 2011; Fito, 1994; Laurindo, Stringari, Paes, & Carciofi, 2007).

Calcium impregnation in fruits has been widely studied, in particular when combined with osmotic dehydration (Barrera et al., 2009; Ferrari, Carmello-Guerreiro, Bolini, & Hubinger, 2010; Moranga, Moraga, Fito, & Martínez-Navarrete, 2009; Moreno et al., 2012; Pereira, Ferrari, Mastrantonio, Rodrigues, & Hubinger, 2006; Silva, Fernandes, & Mauro, 2014) and as pre-treatment of air drying processes (Ahrne, Prothon, & Funebo, 2003; González-Fésler, Salvatori, Gómez, & Alzamora, 2008). Many studies related to pineapple osmotic dehydration and air-drying are reported by the literature (Cortellino, Pani, & Torreggiani, 2011; Lombard, Oliveira, Fito, & Andrés, 2008; Silva et al., 2014, among others). These papers reported the influence of vacuum impregnation or of drying conditions on the physicochemical properties of processed pineapple. However, few studies have reported the combined influence of calcium impregnation and dehydration on the properties of processed pineapple. Silva et al. (2014) studied the effect of the concentration of calcium lactate on color, water activity, texture and composition of osmotic dehydrated pineapple. As expected, higher solution concentrations resulted in higher calcium concentration in the processed product, leading to products with higher firmness.

The objective of this study is to determine the influence of vacuum impregnation and drying method on drying kinetics and on the properties (porosity, shrinkage, glass transition temperature, water sorption isotherms, texture and microstructure) of calcium-fortified pineapples.

2. Material and methods

2.1. Pineapple samples and impregnation solution

Pineapples (*Ananas comosus* (L.) Merrill) were purchased in the local market (Florianópolis, Brazil) and selected according to their soluble solids content. The whole fruits were washed, manually peeled, and cut (discarding their extremities) in slices with thickness of 5 mm and diameter of about 85–90 mm. Afterwards, each slice was cut into eight identical triangles with base of about 30–35 mm.

The impregnation solution was prepared by adding 3.675 g of $CaCl_2 \cdot 2H_2O$ to each 100 mL of distilled water, resulting in a Ca^{2+} concentration of 1.00 g 100 ml^{-1}.

2.2. Experimental device

Impregnation experiments were performed with the device illustrated by Fig. 1. It consisted of a jacketed vessel (50 L) in which the temperature was controlled by water from a thermostatic bath (Quimis, Q214M2, Diadema, Brazil) and monitored by T-type thermocouples (IOPE, TX-TF-TF-R-30AWG, Brazil) connected to a data acquisition system (Agilent, 34970A, Malaysia). A vacuum pump (DVP, LC.305, Italy) was used to reduce the pressure inside the chamber. This pump was connected to a proportional solenoid valve (Asco, E290-PD, Barueri, Brazil) coupled to a pressure transducer (Warme, WTP 4010, Itu, Brazil) and to a dedicated software that performed valve control and data acquisition (Altem, Florianópolis, Brazil). A sanitary centrifugal pump (nominal maximum flow rate of 5000 L h^{-1}, Bombinox, BL5, São José, Brazil), connected at the bottom of the vessel, was able to recirculate the solution and stir continuously the impregnation solution inside the vessel. Vapour produced during vacuum application was condensed in a vessel filled with silica gel.

2.3. Impregnation procedure

Pineapple samples were submitted to atmospheric impregnation, vacuum impregnation and vacuum impregnation followed by drainage vacuum pulses, performed in triplicate. For all these procedures, samples were weighed, placed inside a nylon mesh bag and immersed in the impregnation solution in the jacketed vessel, kept at 25 °C. The pineapple:solution mass ratio of 1:20 was used to avoid changes of the solution concentration during impregnation.

The impregnation step was performed by three different procedures, as described in the following.

I) Atmospheric pressure impregnation (AI) was carried out by immersing pineapple samples in the impregnation solution under atmospheric pressure for 20 min.

II) Vacuum impregnation (VI) was carried out by applying vacuum of 88 kPa (absolute pressure of 13.33 kPa) for 10 min in the container with pineapple samples immersed into the impregnating solution, followed by 10 min immersion under restored atmospheric pressure.

III) Vacuum impregnation followed by drainage pulses (VI-P) was performed by applying vacuum impregnation to the samples, followed by a drainage step. It was done by applying vacuum pulses (absolute pressure of 6.7 kPa) to the vessel, after removing the samples from the impregnating solution. The required time intervals to reach the final pulse pressure were 3.3 ± 0.3 min (VI-P1 samples) and 6.0 ± 0.7 min (VI-P2 samples).

After processing, water adhered to the surface of samples was blotted with filter paper for 5 s and the total mass variation (*MV*) during impregnation was determined according to Equation (1).

$$MV = \frac{m_i - m_0}{m_0} \cdot 100 \quad (1)$$

in which m_0 and m_i are the sample mass before and after impregnation procedure.

2.4. Drying procedure

Impregnated samples (AI, VI, VI-P1, and VI-P2) and non-impregnated samples (N) were dehydrated by convective-drying (CD) and freeze-drying (FD). All the experiments described in the following were performed in triplicate.

CD was performed in a convective oven (Tecnal, TE 394/2, Piracicaba, Brazil) at 60 °C, air relative humidity of 25% and air velocity of 1 m s^{-1}. Moisture content and water activity of pineapple samples were determined throughout the convective-drying by removing three samples from the oven every 15 min during the first hour, every 30 min in the second hour, and every hour for the next 12 h.

Freeze-drying was performed in laboratory scale equipment (Liotop, L101, São Carlos, Brazil). Samples were distributed on stainless steel plates, frozen at −60 °C for 4 h, and freeze-dried in a chamber under 20 ± 5 Pa for 24 h.