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Influence of sodium replacement and vacuum pulse on the osmotic dehydration of eggplant slices

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ABSTRACT

Partial replacement of sodium chloride by potassium and calcium chlorides has been proposed as a strategy for reducing the sodium content of osmodehydrated eggplant. The influence of sodium substitutes and vacuum application (VA) on mass transfer parameters and chemical, mechanical and optical properties were investigated. Kinetics of water loss, solid gain and water activity were performed and fitted by the model of Barbosa Junior et al. This model was satisfactorily adjusted, mainly for the osmotic dehydration at atmosphere pressure. VA and the calcium increased the ascorbic acid retention in 29.33 and 85.06%, respectively. VA increased water loss up to 53% and ions incorporation, especially that of potassium (648%). The VA caused a higher total color difference, maximum stress and elasticity as compared to the osmotic dehydration at atmospheric pressure.

Industrial relevance: The present paper evaluates the osmotic process with atmospheric and reduced pressures and the production of osmodehydrated eggplant slices with reduced sodium content by the partial replacement of sodium chloride by potassium chloride and calcium chloride. Vacuum can accelerate the osmotic process and enhance the diffusion of water and solutes within the products. The coupling of sodium substitution with reduced pressure could offer an interesting array of different processes and healthier products. This project is a feasibility study of the partial replacement of NaCl by KCl and $CaCl_2$ and the application of vacuum with regard to effects on mass transfer parameters and the chemical, optical and mechanical properties of osmodehydrated eggplant slices.

1. Introduction

Eggplant (*Solanum melongena* L.) is an important crop of subtropical and tropical regions. This fruit presents low caloric value and is a good source of minerals, vitamins and anthocyanins. Eggplant has also received great attention due to its high antioxidant activity and medicinal properties, and its consumption is recommended for diabetic patients (Hussain, Omeera, Suradkar, & Dar, 2014; Zaro, Ortiz, Keunchkarian, & Chaves, 2016). The eggplant consists mostly of water, which limits its shelf life. Therefore, techniques that enhance its stability are required (Bahmani, Jafari, Shahidi, & Dehnad, 2015).

Osmotic dehydration (OD) is a water removal treatment that preserves physical, chemical, nutritional, sensorial and functional properties of food with limited changes to the food's integrity. This technique involves the immersion of the product in a hypertonic aqueous solution leading to a loss of water through the cell membranes of the product and subsequent flow along the inter-cellular space before diffusing into the solution. It also allows the diffusion of solutes from the osmotic solution into the food tissue (Junqueira, Corrêa, & de Mendonça, 2016; Kaushal & Sharma, 2016; de Mendonça, Corrêa, de Jesus Junqueira, Pereira, & Vilela, 2016; Torreggiani, 1993).

OD is usually employed as a pretreatment before drying. A reduction of the total drying time was observed by Aydogdu, Sumnu, and Sahin (2015) and Osidacz and Ambrosio-Ugri (2013) when using sodium chloride as an osmotic agent during the pretreatment prior to further drying processes. Ganjloo and Bimakr (2015) evaluated the OD of eggplant using sucrose at different concentrations as an osmotic agent and found that the best condition for mass transfer was 30% (w/w) sucrose.

An increase in mass transfer rates can be achieved by the application of vacuum in the first minutes of the osmotic dehydration in a process called pulsed vacuum osmotic dehydration (PVOD). The reduction in pressure causes an expansion of the internal gases in the pores of the fruit and vegetables, expelling them via hydrodynamic mechanisms (HDM) enhanced by the pressure difference, increasing the surface area available for mass transfer (Fito, 1994; Junqueira, Corrêa, & Ernesto, 2016; de Oliveira, Corrêa, de Angelis Pereira, Ramos, & Vilela, 2016; Viana, Corrêa, & Justus, 2014).

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The osmotic agents employed during OD are responsible for the sensory properties and nutritional value of osmodehydrated vegetables. Sodium chloride (NaCl) is an osmotic agent that presents higher osmotic pressure than sugars because of its ionic characteristics. Consequently, transfers between the solution and the food are favored, and the water activity of the product is significantly reduced (Hamdan, Sharif, Derwish, Al-Aibi, & Altaee, 2015; Tarefe et al., 2016).

Since OD is a counter-current diffusional process, the incorporation of sodium can be considered a disadvantage, due to its effects on sensory quality and undesirable health impacts. Excessive sodium intake is linked to hypertension and cardiovascular diseases (Rodrigues, Souza, Mendes, Nunes, & Pinheiro, 2016; Tamm, Bolumar, Bajovic, & Toepfl, 2016).

Therefore, the substitution of NaCl by other chloride salts in processed foods could offer diverse and healthier products and improve consumer acceptance. The most common sodium chloride substitutes in processed food are potassium chloride (KCl), calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$). These salts present promising perspectives since their addition did not significantly affect the physicochemical and sensorial characteristics of the final products compared to NaCl (Bautista-Gallego, Rantsiou, Garrido-Fernandez, Cocolin, & Arroyo-López, 2013).

A diet based in low sodium content and high potassium and calcium uptake is suggested to reduce high blood pressure problems and prevent against osteoporosis (Bautista-Gallego et al., 2013).

In processed food, the partial substitution of NaCl by other cationic ions, is usually related for fishery (Faralizadeh, Zakipour, & Khanipour, 2016), meat (Fellendorf, O'Sullivan, & Kerry, 2016), dairy (Khetra, Kanawjia, & Puri, 2016) and bakery (Sayar, Erdoğdu, Eydemir, & Nayman, 2016) products. However, no studies regarding the combination of different salts as sodium substitutes during the osmotic dehydration of fruits and vegetables were published. Moreover, studies about the effects of the combination of different salts as osmotic agents coupled with vacuum application were not found.

The aim of this work was to evaluate the influence of sodium chloride replacers as osmotic solutes (potassium and calcium chlorides) and the vacuum application on mass transfer parameters (water loss, solid gain and water activity reduction), chemical (minerals), mechanical (maximum stress and elasticity), optical (color changes and browning index) and functional (ascorbic acid) properties of osmodehydrated eggplant slices.

2. Material and methods

2.1. Materials

The eggplant fruits (*Solanum melongena* L.) used in the osmotic processes were purchased in the local market (Lavras, MG, Brazil) and stored in a refrigerator at 8 ± 1 °C for 48 h prior to the experiments. The fruits were selected based on their size, peel color, appearance and firmness. Fresh eggplant was characterized with respect to the chemical composition (moisture content, crude fat, protein, ash, crude fiber and carbohydrate) according to the methodology proposed by the AOAC (2007) and is presented (on wet basis) as follows: moisture content 92.24 ± 0.08 kg 100 kg^{-1}; crude fat 0.13 ± 0.01 kg 100 kg^{-1}; protein 1.19 ± 0.02 kg 100 kg^{-1}; ash 0.56 ± 0.01 kg 100 kg^{-1}; crude fiber 1.00 ± 0.01 kg 100 kg^{-1} and carbohydrate 4.86 ± 0.04 kg 100 kg^{-1}. All analyses were performed in triplicate.

Analyses of water activity (Aqualab, 3-TE model, Decagon Devices Inc., Pullman, WA, USA), total soluble solids (Tecnal, AR-200 model, São Paulo, Brazil), pH (Digimed, DMpH-2 model, São Paulo, Brazil) and color parameters of the peel and internal parenchyma (Minolta colorimeter, CR 400 model, Japan) were also performed to characterize the fresh material. The fresh eggplant presented an a_w of 0.992 ± 0.001. The total soluble solids were 3.14 ± 0.46 kg solute 100 kg^{-1} fruit, and the pH was 5.09 ± 0.02. The color parameters observed for peel were $L^* = 28.495 \pm 1.643$; $a^* = 4.290 \pm 0.564$ and $b^* = -2.090 \pm 0.336$, and those for internal parenchyma were $L^* = 86.674 \pm 0.914$; $a^* = -5.821 \pm 0.677$ and $b^* = 21.340 \pm 2.409$.

2.2. Sample preparation and treatments

The fruits were washed in tap water and cut into disk-shaped samples (0.40 ± 0.03 cm thickness and 5.00 ± 0.50 cm diameter). The peel was maintained during the sample preparation in order to avoid the radial diffusion of water and solutes during the osmotic process. The slices were immersed for 3 min in a solution of 1% (w/w) ascorbic acid and 2% (w/w) citric acid to reduce enzymatic browning (Moreno et al., 2013).

The osmotic solutions were prepared with distilled water and the osmotic agents. The concentration of all osmotic solutions was 0.1 kg of solid kg^{-1} solution. The formulation and the a_w of each solution are presented in Table 1.

2.3. Osmotic dehydration processes

Osmotic experiments were performed at atmospheric pressure (OD) and under vacuum (PVOD). The experiments were conducted in a temperature-controlled oven (Solab SL104/40, Piracicaba, Brazil) coupled with a vacuum pump. For the PVOD treatments, a vacuum pressure of 145 mbar was applied to the system during the first 10 min of process, after which the local atmospheric pressure of 755 mbar (Lavras, MG, Brazil) was restored.

The temperature was set at 30.0 ± 1 °C, and the ratio of solution to fruit was 1:10 (w/w) to prevent dilution of the osmotic solution during the experiments (Corrêa, Dev, Gariepy, & Raghavan, 2011). At preset times (10, 20, 30, 40, 60, 90, 120, 180, 240, 300 and 360 min), the samples were removed from solution. Each removed sample was then immersed in a bath of cold distilled water for 10 s to stop the osmotic process, and the surface of the sample was gently wiped with absorbent paper to remove excess solution. The sample was weighed and submitted to moisture content determination according to AOAC method 934.06 (AOAC, 2007) (Junqueira, Corrêa, & de Mendonça, 2016). All the experiments were performed in four replicates.

The Eqs. (1) and (2) were used for obtaining the water loss (WL) and the solid gain (SG), respectively.

$$\mathrm{WL}\ \ (\%) = \frac{(M_0 X_{w0}) - (M_t X_{wt})}{M_0} \times 100 \tag{1}$$

$$\mathrm{SG}\ \ (\%) = \frac{(M_t X_{st} - M_0\,(1 - X_{w0}))}{M_0} \times 100 \tag{2}$$

where M_0 is the weight of the sample at time $t = 0$ s [kg], X_{w0} is the initial water content [kg water 100 kg^{-1} sample], M_t is the weight of the sample at time t [kg], X_{wt} is the water content [kg water 100 kg^{-1} sample] at time t and X_{st} is the soluble solid content [kg solid 100 kg^{-1} sample] at time t.

Table 1
Composition and water activity of the osmotic solutions in osmotic dehydration (OD) and pulsed vacuum osmotic dehydration (PVOD).

	Treatments	NaCl (%)	KCl (%)	$CaCl_2$ (%)	$a_w \pm$ SD
OD	1	10.0	–	–	0.945 ± 0.001
OD	2	7.5	2.5	–	0.949 ± 0.001
OD	3	7.0	2.5	0.5	0.949 ± 0.002
OD	4	5.0	4.0	1.0	0.953 ± 0.002
PVOD	5	10.0	–	–	0.945 ± 0.001
PVOD	6	7.5	2.5	–	0.949 ± 0.001
PVOD	7	7.0	2.5	0.5	0.949 ± 0.002
PVOD	8	5.0	4.0	1.0	0.953 ± 0.002