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Influence of dual-stage sugar substitution pretreatment on drying kinetics and quality parameters of mango

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ABSTRACT

The aim of this work was to evaluate the use of the dual-stage (D3S) technique as a pretreatment on mango drying kinetics and on product quality. This pretreatment consisted in two stages, in which high-calorie sugars are partially removed from fruit samples in the first stage and, in the second stage, low-calorie sugar (*Stevia*-derived) is incorporated to the fruit to maintain its sweetness. The drying process was conducted in a fixed bed dryer at 60 °C and air velocity of 2 m/s. Experimental data were fitted successfully using the two-term exponential model. The dried pretreated samples presented faster drying rates. Evaluation of the final product was performed by means of total phenolic content, total carotenoid content, water activity, texture, color and sensorial test. Samples subjected D3S process had lower phenolic and carotenoid contents, reduced water activity, their texture was softer, and color difference was smaller compared to untreated samples. Sensory evaluation showed pretreated sample with good acceptance.

1. Introduction

Fresh fruits are highly perishable, and processing is an alternative to extend their shelf-life. Among the available processes, dehydration, mainly convective drying, is a common procedure to obtain products with reduced moisture content which are easy to store and transport. Other advantages are linked to the diversification of dried products than can be offered to consumers, since they can be eaten directly or used as food ingredients, such as in breakfast cereals, bakery, desserts and confectionary products (Gamboa-Santos et al., 2014). However, the quality of dried products decreases due to the heat sensitivity of the nutrients and adverse changes in physicochemical properties of most fruits and vegetables (Abonyi et al., 2002).

During recent years, emergent technologies have been proposed to reduce the limitations related to conventional drying techniques. As a non-thermal strategy in drying of fruits and vegetables, the application of high power ultrasound (US) represents a promising alternative (Cárcel, García-Pérez, Benedito, & Mulet, 2012). Ultrasound has been used to enhance mass transfer in solid/liquid food systems (Azoubel, Baima, Amorim, & Oliveira, 2010). Ultrasonic waves can cause rapid series of alternative compressions and expansions, in a similar way to a sponge when it is squeezed and released repeatedly (sponge effect). In addition, ultrasound produces cavitation, which may be helpful to remove strongly attached moisture. The sponge effect caused by ultrasound application may be responsible for the creation of microscopic channels in porous materials, such as fruits, that reduce the diffusion boundary layer, thus increasing the convective mass transfer in the fruit (Fuente-Blanco, Sarabia, Acosta-Aparicio, Blanco-Blanco, & Gallego-Juárez, 2006).

As consumers have become more aware of different diets and their impact on health, food companies and marketers have begun to dedicate more time and effort to develop healthier and more nutritive products. A new pretreatment technique using ultrasound called dual-stage sugar substitution (D3S) has been proposed prior to drying to produce low calorie dried fruits. The process removes high-calorie sugars from the fruit and replaces it with a natural

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low-calorie sugar restoring the sweetness of the fruit (Garcia-Noguera, Weller, Oliveira, Rodrigues, & Fernandes, 2010).

The drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behavior, and for optimizing the drying parameters. Thin layer drying equations describe the drying phenomena in a unified way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalize drying curves. In the development of thin layer drying models for agricultural products, generally the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature condition is measured and correlated to the drying parameters (Midilli, Kucuk, & Yapar, 2002).

The objective of this work was to evaluate the use of the D3S technique as a pretreatment on the convective drying of mango. Thin-layer drying characteristics of mango and the quality of the dried fruit in terms of total phenolic and total carotenoids contents, water activity, color, texture and sensorial analysis were evaluated.

2. Material and methods

2.1. Raw material

Market-ripe ‘Tommy Atkins’ mangoes with green–purple peel, firm texture and yellow flesh (Sogi, Siddiq, & Dolan, 2015) were obtained from a local market (Recife, PE, Brazil). The average initial moisture content was 0.864 ± 0.002 kg water/kg fresh fruit. The fruits were hand peeled and cut into slices (3.0 × 5.0 × 0.5 cm) using cutters designed for this purpose.

2.2. D3S process

The D3S process was based on Garcia-Nogueira et al. (2010) and on a previous work with mango (unpublished).

Two mangoes slices were placed in 250 mL Erlenmeyer flasks containing distilled water. The weight ratio between the liquid medium and the fruit ratio was 4:1 (Azoubel et al., 2010). The experiments were carried out with the use of ultrasound for 30 min at 30 °C and were performed at an ultrasonic bath with a thermostat (Unique, model USC-2850A, Brazil), without mechanical agitation. The ultrasound frequency was 25 kHz and the intensity was 4870 W/m^2. The temperature increase during the experiments was lower than 2 °C after 30 min of ultrasound treatment.

After removal from the solution, samples from each group were drained, blotted with absorbent paper to remove excess solution, weighted and then submitted to the second stage.

The second D3S stage, which consisted in the incorporation of *Stevia*-based natural sweetener, was performed for 30 min, solution concentration of 500 g/kg solution and two frequency levels (0 kHz or D3S 1 and 25 kHz or D3S 2). The same weight ratio between the fruit and the liquid medium used in the first stage was applied in this stage.

Stevia powder (Steviafarma, Brazil) was used as the natural sweetener and it consisted of 20 g/kg steviol glycosides and 980 g/kg maltodextrin. The osmotic solution was prepared by dissolving the required quantity of the powder in distilled water.

Experiments were carried out in the same ultrasonic bath and frequency used in the first stage. Erlenmeyers flasks (250 mL) containing samples and osmotic solution were submitted to ultrasonic waves and, after reaching the required process time (30 min), samples were taken out from the osmotic medium, lightly rinsed to remove any excess of solution, drained, weighted and then placed on a pre-weighed drying tray in order to proceed to the drying process. After pretreatment, it was obtained a water loss around 10% (D3S 1) and 12% (D3S 2), and solid gain around 4% (D3S 1) and 3% (D3S 2), resulting in a sample with a moisture content of 861 g water/kg pretreated fruit (D3S 1) and 863 g water/kg pretreated fruit (D3S 2).

2.3. Drying

Drying experiments of untreated and pretreated mangoes were carried out in a continuous flow fixed bed dryer (Sulab, Brazil) at constant air velocity of 2.0 m/s and at air temperature of 60 °C. The dryer system consisted of vertical air flow through trays and was arranged as a closed circuit. To maintain constant air condition only one tray was used with a single layer of sample on it. For the air heating, three electric resistances were used (two of 1600 W and one of 800 W), which could work independently, controlled by a digital thermostat. A thermal-hygrometer (Testo, model 635, Germany) was used to measure the dry bulb temperature and the drying air humidity. The air velocity was monitored using an anemometer (Airflow, model LCS 6000, UK).

For each experiment, nine mangoes slices were placed in the drying tray (for sensorial analysis, twelve slices were dried in each batch). Sample moisture content during the air-drying process was gravimetrically determined from the sample initial moisture content (before air-drying process). Sample weight was measured using a semi-analytical balance. Weighting intervals of 15 min were used until the dynamic equilibrium between the sample moisture content and drying air humidity was reached, when the sample weight became constant. The drying kinetics was studied by observing the drying curves for the considered air temperature.

To select a suitable model for describing the drying process of mango, six different thin-layer drying models were selected to fit the experimental data. The selected thin-layer drying models are presented in Table 1. The models are expressed in the form of moisture content ratio (MR) of samples during drying, and it is expressed as Eq. (1):

$$MR = \frac{X - X_e}{X_o - X_e} \tag{1}$$

where X, X_o and X_e are the moisture content at any given time, the initial moisture content and the equilibrium moisture content, respectively.

The modeling was characterized by the average relative error E (Eq. (2)) calculation and the determination coefficient R^2.

$$E(\%) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{V_e - V_p}{V_e}\right| \cdot 100 \tag{2}$$

where N is the number of experimental data, V_e is the experimental value and V_p is the calculated value. Values of E less than or equal to 10% are considered to fit the experimental data satisfactorily.

Five drying batches for each sample were necessary for the physico–chemical analysis and for sensorial analysis, six batches were needed.

Table 1
Thin layer models used for mathematical of drying of mango.

Model	Equation
Single exponential	$MR = exp(-kt)$
Page	$MR = exp(-kt^v)$
Henderson and Pabis	$MR = a\ exp(-kt)$
Logarithmic	$MR = a\ exp(-kt) + c$
Two-term exponential	$MR = a\ exp(-k_o t) + b\ exp(-k_1 t)$
Wang and Singh	$MR = 1 + at + bt^2$

k, v, a, b, c, k_o, k_1: parameters in thin layer models; MR: moisture content ratio.