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Effect of ultrasound on banana cv Pacovan drying kinetics

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ABSTRACT

The aim of this work was to study and to model the drying kinetics of fresh and ultrasonic pretreated banana cv Pacovan using the diffusional model (Fick's second law) and an empirical two parameters model (Page model). The pretreatment was carried out in an ultrasonic bath at 30 °C. The drying process was carried out in a fixed bed dryer at two different temperatures (50 and 70 °C) and 3.0 m/s air velocity. Page empirical model provided the best simulation of the drying curves. The diffusional model was used to describe the moisture transfer and the effective diffusivities of water were determined and were in the order of 10^{-9} m^2/s. These diffusivities increased with increasing temperature and with the application of ultrasound, while the process time reduced, which can represent an economy of energy, since air drying is cost intensive.

1. Introduction

Banana is the most consumed fruit in several countries (Swasdisevi et al., 2009) and its world production is increasing almost every year, reaching approximately 86 million tones in 2007 (FAO, 2007). Some tropical countries have large plantations, such as Brazil, where the variety Pacovan is the most consumed and produced in the northeast region.

The ripe banana is perishable and deteriorates rapidly after harvesting, hence the need to apply an appropriate post-harvest technology to prolong shelf life. Drying is among the most popular methods for the purpose (Demirel and Thuran, 2003; Karim and Hawlader, 2005; Nguyen and Price, 2007). However, conventional dehydration methods based on hot-air can deteriorate the quality of the final product. Thus, undesired food flavour, colour composition, vitamin degradation and loss of essential aminoacids may be produced (Jayaraman and Das Gupta, 1992; Mujumdar and Menon, 1995). In addition, conventional air drying is energy intensive and consequently cost intensive because it is a simultaneous heat and mass transfer process accompanied by phase change (Barbanti et al., 1994). A pretreatment can be used to reduce the initial water content or to modify the fruit tissue structure in a way that air drying becomes faster (Fernandes and Rodrigues, 2007).

Osmotic dehydration is the most reported pretreatment used prior to air drying (Antonio et al., 2008; Pani et al., 2008; Lombard et al., 2008; Fernandes et al., 2008; Azoubel et al., 2009). However, among emergent new technologies, ultrasonic dehydration is very promising because the process can be carried out at low temperatures, which reduces the probability of food degradation (Mason, 1998) and permits the removal of moisture content from solids without producing a liquid phase change. Its use in food industry is increasing as new uses are studied (Fernandes et al., 2008).

The ultrasonic pretreatment involves the immersion of the fruit in water or in a hypertonic aqueous solution to which ultrasound is applied. 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 and increase the convective mass transfer in the fruit (Tarleton, 1992; Tarleton and Wakeman, 1998; Fuente-Blanco et al., 2006).

The objective of this work was to investigate the use of ultrasound as a pretreatment and its effect on the drying kinetics of banana.

2. Materials and methods

2.1. Materials

Fresh bananas cv Pacovan were obtained in the local market of Juazeiro County, Brazil, in a maturity appropriated for processing

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(yellow with a few brown spots), according to Travaglini et al. (1993). Prior to the start of each experiment, the bananas were sanitized with running potable water, manually peeled and sliced to the thickness of 0.5 cm (3.21 cm average slice diameter). The initial total soluble solids content (determined by refractometry) was 21°Brix.

2.2. Ultrasound pretreatment

An experimental set consisting of four banana samples was immersed in distilled water and submitted to ultrasonic waves for 10, 20 and 30 min. These pretreatment times were chosen after results of kinetics studies carried out beforehand, in which it was observed that after 30 min the changes inferred in the drying process became insignificant. The water to fruit ratio was maintained at 4:1 (weight basis).

The experiments with ultrasound were carried out in separate 250 mL Erlenmeyer flasks to avoid interference between samples and runs, at 30 °C and an ultrasonic bath (Unique, model USC-2850A, Brazil) was used, without mechanical agitation. The ultrasound frequency was 25 kHz.

After removed from the water solution, samples from each group were drained, blotted with absorbent paper to remove excess solution, weighted and submitted to drying. The moisture content of the samples was gravimetrically measured using a vacuum oven at 70 °C for 24 h (Tecnal, TE-395, Brazil). The weight and moisture content data of each sample were used to calculate the water loss (*WL*) and solid gain (*SG*), according to the following equations:

$$WL(\%) = \frac{ww_o - (tw - ws)}{w_o} \times 100 \tag{1}$$

$$SG(\%) = \frac{ws - ws_o}{w_o} \times 100 \tag{2}$$

where *tw* is the total wet weight of the banana slice at the time of the sampling, g; *ws* is the total solids weight, g; ws_o is the initial weight of solids, g; ww_o the initial weight of water, g; and w_o the total initial weight of the sample, g. Each experimental run was performed in triplicate and the reported values are based on average values, the error being less than 0.5%.

2.3. Drying

Drying experiments were carried out in a continuous flow fixed bed dryer (Sulab, Brazil) at constant air velocity of 3.0 m/s and at two air temperatures (50 and 70 °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 (approximately 90 g). 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).

Samples had average initial moisture content (wet basis) of 67.33% (2.06 kg/kg dry basis) for fresh and 68.82% (2.21 kg/kg dry basis), 70.11% (2.34 kg/kg dry basis) and 70.8% (2.43 kg/kg dry basis) for the 10, 20 and 30 min ultrasound pretreated samples, respectively, which was gravimetrically measured using a vacuum oven at 70 °C for 24 h. 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 during the first and the second hour of processing and then 30 min intervals 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.

A plate of thickness 2*L* having the uniform initial moisture X_o, submitted to drying at constant conditions can be described by Fick's unidirectional diffusional equation (Crank, 1975):

$$\frac{\partial X}{\partial t} = D_{eff} \frac{\partial^2 X}{\partial x^2} \tag{3}$$

where *X* is the moisture content, kg H_2O/kg dry matter; *t* is the time, s; D_{eff} is the water effective diffusivity, m^2/s; and *x* is the length, m.

Using the following initial and boundary condition:

uniform initial moisture content: $X(z,0) = X_o$
symmetry of moisture: $\frac{\partial X}{\partial z}\big|_{z=0} = 0$
equilibrium moisture at surface: $X(L,t) = X_e$

And applying:

$$\overline{X} = \frac{1}{L} \int_0^L X(z,t)dz \tag{4}$$

Eq. (3) becomes:

$$\frac{\overline{X} - X_e}{X_o - X_e} = \frac{8}{\pi^2} \sum_{i=0}^{\infty} \frac{1}{(2i+1)^2} \exp\left[-(2i+1)^2 \pi^2 D_{eff} \frac{t}{4L^2}\right] \tag{5}$$

where $\overline{X}$ is the average moisture content at time *t*, kg H_2O/kg dry matter; X_e is the equilibrium moisture content, kg H_2O/kg dry matter; X_o is the initial moisture content, kg H_2O/kg dry matter; *L* is the half of slab thickness, m.

The effective diffusivity (D_{eff}) was obtained by fitting the experimental data to Fick's diffusional model (Eq. (5)), applying the non-linear estimation resources of the Statistica (1995) software. Either the thickness of the fresh banana or the thickness of the ultrasonic pretreated banana was assumed the initial dimension.

One of the most useful empirical models is Page's equation (Page, 1949), which is an empirical modification of the simple exponential model. It was used to fit the experimental drying data and it is written in the form:

$$\frac{\overline{X} - X_e}{X_o - X_e} = \exp(-kt^n) \tag{6}$$

where *k* is the drying constant, *n* is the Page's parameter and *t* is the process time, (s).

The modeling was characterized by the average relative error *E* (Eq. (7)) calculation and the determination coefficient R^2.

$$E(\%) = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{V_e - V_p}{V_e} \right| \times 100 \tag{7}$$

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 (Lomauro et al., 1985).

3. Results and discussion

3.1. Ultrasonic pretreatment

The effect of ultrasonic pretreatment on water loss (*WL*) and solid gain (*SG*) are presented in Table 1. During ultrasound, the fruit gained water and lost solids. Similar results were found by Fernandes and Rodrigues (2007) in the ultrasonic pretreatment of banana