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Convective drying of cape gooseberry fruits: Effect of pretreatments on kinetics and quality parameters

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A B S T R A C T

The effect of physical (fast freezing with liquid nitrogen and slow freezing followed by thawing) and chemical (alkaline solution of ethyl oleate) pretreatments on the kinetics and quality parameters of cape gooseberry (*Physalis peruviana*) during convective drying (60 °C, 2 m/s) was studied. The influence of the pretreatments on the drying kinetics, shrinkage, rehydration capacity, ascorbic acid retention, water activity, textural profile, and color were evaluated. Five thin-layer equations were evaluated for their ability to predict the drying kinetics, of which the Wang & Singh equation performed best. All of the pretreatments reduced the drying time by reducing the resistance of the waxy skin of the gooseberry to mass transfer. The chemical pretreatment promoted the shortest drying time and the highest ascorbic acid retention, rehydration capacity, the best maintenance of texture, as well as the least shrinkage.

1. Introduction

The cape gooseberry (*Physalis peruviana*) is a climacteric fruit native to the Andean region. The fruit is characterized by significant levels of ascorbic acid, vitamin A, minerals, tocopherols, and carotenoids (Bravo & Osorio, 2016; Narváez-Cuenca, Mateus-Gómez, & Restrepo-Sánchez, 2014; Ramadan, 2011). However, *P. peruviana* is perishable with fast deterioration and therefore requires preservation techniques.

Cape gooseberry fruits are covered with an external waxy skin that limits the permeability of moisture. The plant wax is made of a heterogeneous mixture of lipids deposited on the cuticle surface. Physical and chemical pretreatments have been suggested for improving mass transfer through the skin during drying (Bingol, Roberts, Balaban, & Devres, 2012; Doymaz & Özdemir, 2014).

Physical and chemical pretreatments have been applied to fruits with waxy a layer (either whole or sliced), including grapes (Adiletta, Russo, Senadeera, & Di Matteo, 2016), blueberries (Zielinska, Sadowski, & Błaszczak, 2015), tomatoes (Corrêa, Justus, Oliveira, & Alves, 2015), and plums (Hedayatizadeh & Chaji, 2016). All of these studies have reported an increase in moisture diffusion, a reduction in total drying time, and improved maintenance of quality parameters in pretreated samples compared with untreated samples.

Cape gooseberry fruits were blanched and chemically treated with sunflower oil/K_2CO_3, olive oil/K_2CO_3 or olive oil/NaOH by Vásquez-Parra, Ochoa-Martínez, and Bustos-Parra (2013), who concluded that an olive oil/K_2CO_3 pretreatment produces better final quality properties than the other tested treatments. To our knowledge, freezing and chemical pretreatments with ethyl oleate/Na_2CO_3 have not previously been reported for this fruit.

The present work aimed to evaluate the effect of two freezing rates (fast freezing in liquid nitrogen and slow freezing in a domestic freezer) and chemical (alkaline solution of ethyl oleate) pretreatments for improving the convective drying rates of cape gooseberry. The experimental data were fitted to five empirical equations (Newton, Page, logarithmic, Wang & Singh, and Henderson & Pabis) and the quality characteristics (shrinkage, rehydration capacity, acid ascorbic retention, water activity, texture profile, and color) were evaluated.

2. Material and methods

2.1. Material

The cape gooseberry fruits were obtained from Lavras, Minas

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Gerais, Brazil. The fruits, at the ripe condition, were chosen visually by uniform size, weight, and color. The fresh fruit was stored at 7 ± 1 °C prior to the experiments. Before each pretreatment, the calix of the fruits was manually removed. The initial moisture content (3.11 ± 0.01 kg H_2O/kg dry basis [d.b.]) was determined using a vacuum oven at 70 °C, as described in AOAC method 931.04 (AOAC, 2010). Analyses of the total soluble solids (Tecnal, AR-200 model, São Paulo, Brazil) and water activity (a_w) (Aqualab, 3-TE model, Decagon Devices, Inc., Pullman, WA, USA) were performed to characterize the fresh fruits. The total soluble solids were 12.89 ± 0.66 kg solute/100 kg fruit, and the a_w was 0.932 ± 0.006 for the fresh fruit.

2.2. Experimental conditions

The convective drying experiments in the tunnel dryer were performed with fresh (untreated) and treated samples. The conditions of the pretreatments and drying are listed below.

2.2.1. Pretreatments

Pretreatments of the waxy skin before drying were: (i) fast freezing by the immersion in liquid nitrogen (−196 °C for 10 s) followed by thawing at 25 °C (Ketata, Desjardins, & Ratti, 2013); (ii) slow freezing in a domestic freezer (Electrolux, DC51 model, Brazil) at −18 ± 2 °C, followed by thawing at 25 °C for 2 h (Zielinska & Michalska, 2016); and (iii) fruits dipped in an aqueous solution of ethyl oleate at 2% (v/v) and Na_2CO_3 at 2.5% (w/v) at 40 °C for 3 min (Adiletta et al., 2016).

2.2.2. Drying experiments

After the skin treatments, the samples were submitted to convective drying in a tunnel dryer (Eco Engenharia Educacional, MD018 model, Brazil) with the parallel flow at 60 °C and 2 m/s (Vásquez-Parra et al., 2013). In each batch, 100 ± 3 g of fresh fruits were dried. The experiments were performed until an average final moisture content of 0.08 ± 0.02 kg H_2O/kg d.b was reached. During the drying, the mass of the samples was monitored using a digital balance (Marte Científica, AD33000 model, Brazil) (accuracy ± 0.01 g) coupled to the sample holder. The moisture content of the dried cape gooseberry was determined in a vacuum oven at 70 °C (AOAC, 2010). All the drying experiments were carried out in triplicates.

2.3. Mathematical modeling

The experimental drying data obtained were fitted using four thin-layer drying equations (Table 1). The moisture ratio (MR) of the samples during drying experiments was calculated using Eq. (1):

$$MR = \frac{X_t - X_{eq}}{X_0 - X_{eq}} \approx \frac{X_t}{X_0} \tag{1}$$

Table 1
Empirical equations applied to the drying curves.

Equation name	Equation	References
Newton	$MR = \exp(-kt)$	Lewis (1921)
Page	$MR = \exp(-kt^n)$	Page (1949)
Logarithmic	$MR = a\exp(-kt) + b$	Akpinar, Bicer, and Yildiz (2003)
Wang & Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)
Henderson & Pabis	$MR = a\exp(-kt)$	Henderson and Pabis (1961)

Where: MR is the moisture ratio, t is the drying time [s] and a, b, n and k are empirical constants and coefficients in drying equations.

where X_t, X_0, and X_{eq} are the moisture content at any time of drying, initial moisture content, and equilibrium moisture content [kg H_2O/kg d.b.] respectively. In the experimental conditions, the X_{eq} is relatively small compared to X_0. Therefore, its value was numerically set to zero (Junqueira, Ernesto, Corrêa, 2017).

2.4. Quality analysis

2.4.1. Volumetric shrinkage

The volume (V) of the samples was calculated based on the mean of three measurements of the fruit diameter in the correspondent coordinate axes with the aid of a calibrated digital caliper (Western, DC-6 model, China). Three samples were evaluated for each treatment during the drying. The volumetric shrinkage was obtained as the ratio of the fruit volume at any drying time (V_t) and the initial fruit volume (V_0). A second-order polynomial was fitted to the experimental volumetric shrinkage and moisture content, as expressed in Eq. (2):

$$\frac{V_t}{V_0} = aX_t^2 + bX_t + c \tag{2}$$

2.4.2. Rehydration capacity

Dried fruits were immersed in distilled water at 25 °C for 14 h to estimate their rehydration capacity (RC) (Vásquez-Parra et al., 2013). After the drying, five dehydrated cape gooseberries were submitted to rehydration. The RC was calculated according to Eq. (3):

$$RC = \frac{Weight\ \ of\ \ rehydrated\ \ samples}{Weight\ \ of\ \ dried\ \ samples} \tag{3}$$

2.4.3. Ascorbic acid content

Ascorbic acid content was determined by the colorimetric method using 2,4-dinitrophenyl hydrazine (Strohecker & Henning, 1967). Ascorbic acid was extracted with 0.5% oxalic acid, filtered, and dosed in the extract, using ascorbic acid as a standard. The data were acquired at 520 nm on a spectrophotometer. The analysis was performed in triplicate, and the results were expressed in mg/100 g. The ascorbic acid retention (AAR) was calculated according to Eq. (4).

$$AAR = \frac{Ascorbic\ \ acid\ in\ \ the\ \ dried\ \ sample}{Ascorbic\ \ acid\ \ in\ \ the\ \ fresh\ \ sample} \times 100 \tag{4}$$

2.4.4. Moisture content and water activity

The moisture content of the fruit was determined in a vacuum drying oven at 70 °C until constant weight (AOAC, 2010). The water activity determination was performed in a hygrometer (Aqualab, 3-TE model, Decagon Devices, Inc., Pullman, WA, USA). The analyses were performed in triplicate.

2.4.5. Texture profile analysis (TPA)

The texture profile analysis (TPA) of the fresh and dried cape gooseberries was performed using a universal texturometer (Stable Micro Systems, TA-X2T, Surrey, England). The test was carried out by two compression cycles between a parallel plate and a cylindrical aluminum probe (36 mm diameter), with 5 s between cycles. The crosshead speed was 3 mm/s (Vega-Gálvez et al., 2015). At least ten samples were evaluated for each treatment. From the resulting