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Osmotic dehydration of physalis (*Physalis peruviana* L.): Evaluation of water loss and sucrose incorporation and the quantification of carotenoids

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ABSTRACT

The rapid growth in demand for physalis production is associated with its nutraceutical and medicinal characteristics. However, one aspect that hampers its commercialization is the high perishability. In present work it is proposed to submit *Physalis peruviana* L. for osmotic dehydration, to evaluate the effects of temperature (40–70 °C) and osmotic sucrose solution concentration (40–70 g 100 g^{-1} solution). Moisture content and total sugar content analysis were performed along the osmotic dehydration process and the total content of carotenoids was analyzed for the fresh fruit and after 10 h of processing. Water mass diffusivity ranging between 1.4–2.9 × 10^{-10} m^2 s^{-1} and the effective mass diffusivity of sucrose ranged from 0.7 to 1.1 × 10^{-10} m^2 s^{-1}. Among all conditions studied in the experimental design, the osmotic dehydration was more efficient when performed at a temperature of 70 °C and an osmotic solution concentration of 70 g 100 g^{-1} of solution. In these conditions, there was the highest water loss and a statistically significant reduction in the water activity of this fruit. However, the greatest loss of total carotenoids (approximately 50%) was observed. Under this experimental condition, the tissue matrix of physalis suffered structural changes, as proven through scanning electron microscopy analysis.

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1. Introduction

The physalis genus includes approximately 100 species, and the main species are *Physalis angulata* Linnaeus, *Physalis pubescens* L., *Physalis alkekengi* L. and *Physalis peruviana* L.; the last species is the most well-known and studied. *Physalis peruviana* L. originates from the region of the South American Andes and belongs to the family Solanaceae; it grows in different soil types and has low requirements for fertilization (Cedeño & Montenegro, 2004; Puente, Pinto-Muñoz, Castro, & Cortés, 2011; Ramadan, 2011). The physalis fruit is characterized as a spherical berry, with a diameter between 1.25 and 2.50 cm and a mass between 4 and 10 g. The physalis is protected by the calyx, which completely covers the fruit during its development and ripening (Mayorga, Knapp, Winterhalter, & Duque, 2001; Tapia & Fries, 2007). *Physalis peruviana* L. has been known for centuries, but its potential for intensive cultivation has only recently begun to be explored, mainly due to the presence of bioactive compounds, such as ascorbic acid, phenolic compounds, phytosterols and carotenoids. Other compounds are also present in physalis, and its medicinally active components have been studied, including withanolides (Chandrasekaran, Dayakar, Veronica, Sundar, & Maurya, 2013; Fang, Liu, & Li, 2012), withaesteroides (Pérez-Castorena, Luna, Martínez, & Maldonado, 2012) and physalins (Hsu et al., 2012; Soares et al., 2006). These compounds presented important pharmacological properties, including antimicrobial, antibacterial, antitumor, antinflammatory, hepatoprotective, immunomodulatory and immunosuppressive properties – in addition to demonstrating effectiveness for the inhibition of unwanted responses in autoimmune diseases and allergies as well as the transplantation of organs.

Colombia is the world's leading producer of the fruit of physalis. However, since 2009, Brazil and Chile have appeared as active competitors, mainly due to promising results regarding the

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cultivation, production and marketing of this fruit. Despite increased production, a factor that hampers international marketing is its high perishability. According to the Colombian Institute for Technical Standards and Certification (1999), commercialization of the fruit is recommended within 12 h after harvest; otherwise, it must be stored at a temperature of 4 °C and a relative humidity of 90%. Currently, osmotic dehydration is widely used for fruit processing by the direct immersion of the product in a hypertonic medium. This process can also be used as a pretreatment for a number of conventional processes, such as drying using hot air, to improve the final quality, reduce the energy costs or develop new products. The main driving force for water removal in osmotic dehydration processes is the osmotic pressure difference between the fruit and the hypertonic solution, and the complex cellular structure of the fruit serves as a semipermeable membrane (Azoubel & Murr, 2004; Porciuncula, Zotarelli, Carciofi, & Laurindo, 2013; Rastogi & Raghavarao, 1997; Rodrigues & Fernandes, 2007). However, the osmotic dehydration process presents some disadvantages related with the management and destination of osmotic solutions after use, a long time of the process and the high water activity of the final product (Moraga, Moraga, & Martínez-Navarrete, 2011).

Because of the short shelf life of fresh physalis after harvesting, the presence of large amounts of bioactive compounds and its high water content, osmotic dehydration is an alternative technology to reduce the post-harvest of this fruit. In addition, several studies (Chandrasekaran et al., 2013; Fang et al., 2012; Hsu et al., 2012; Li et al., 2013), were found in the literature regarding the characterization of the bioactive compounds of physalis and their antioxidant activity *in vitro* and *in vivo* however, there was a lack of studies evaluating technologies for physalis' processing and preservation. Thus, the aim of this study was to estimate the water loss and the gain of solids in order to evaluate the effective diffusivity of water and sucrose at different temperatures and concentrations of an osmotic solution from the analytical solution of Fick's second law in spherical coordinates for the osmotic dehydration of physalis. In addition, this study aimed to evaluate a number of quality parameters before and after 10 h of the osmotic dehydration process, such as the total carotenoid content, the overall color difference, browning index and the water activity.

2. Material and methods

2.1. Osmotic dehydration

Physalis peruviana L., imported from Colombia, were purchased from a local market, always from the same producer. They were selected according to their quality attributes: uniform diameter (1.5–2.5 cm), degree of maturation (9–12 °Brix) and freedom from defects. The fruits showed initial moisture content of approximately 82% (wet basis) or 4.7 g water g^{-1} initial dry solids. Osmotic solutions were prepared with distilled water and commercial sucrose to a final concentration of 40 ± 2; 55 ± 3 and 70 ± 2 g sucrose 100 g^{-1} solution (Andrade, Neto, Nóbrega, Azoubel, & Guerra, 2007), according to a 2^2 experimental design, with three replicates at the center point. Osmotic dehydration was carried out in an acrylic tank connected to a thermostatic bath to maintain a constant temperature (40 ± 1 °C; 55 ± 2 °C and 70 ± 2 °C; Khoyi & Hesari, 2007). A sample-to-solution ratio of 1:20 was used to guarantee that the concentration of the osmotic media could always be considered constant. The osmotic medium was agitated vigorously and continuously with a mechanical agitator (FISATOM, model 713, São Paulo, SP, Brazil) at 1800 rpm to ensure the specified concentration on the surface of the food. The osmotic dehydration process was performed for a period of 0–10 h under constant conditions.

2.2. Analytical determinations

2.2.1. Moisture content

The moisture content was determined by a gravimetric method in triplicate, according to AOAC 930.04 (AOAC, 1990a, 1990b). The water loss (*WL*) was calculated using Eq. (1) according to Souraki, Ghavami, and Tondro (2014).

$$WL = \frac{W_o - W_t}{m_o} \quad \left(\text{g water g}^{-1} \text{ initial mass of fruit}\right) \tag{1}$$

where W_o represents the initial moisture mass in fresh physalis, W_t represents the moisture mass for processed samples at any time t and m_o represents the initial mass of fruit in nature.

2.2.2. Sucrose content

The sugars extraction was performed by immersion of samples (2.5 g) in a water bath heated to 100 °C for 45 min, followed by centrifuging (30 min–6000 rpm), after the solution was filtered through a 0.22 μm membrane filter before injection (Zuleta & Sambucetti, 2001). The sugar content was determined by HPLC (High-Performance Liquid Chromatography, PerkinElmer Corp., Series 200, Norwalk, CT, USA). The column used was a Rezex RHM Monosaccharides, and the precolumn was a Holder KJO-4282, both from Phenomenex (Macclesfield, Cheshire, U.K.). The sample was eluted using a mobile phase of Milli-Q purified water at a flow rate of 0.5 mL min^{-1} and a column temperature of 80 °C. A refractive index detector (PerkinElmer Corp., Series 200, Norwalk, CT, USA) was used for quantification. Identification of sugars was based on the retention time (glucose and fructose standards were 12.3 and 13.2 min, respectively), and quantitation was carried out using external calibration using glucose standard. The analysis of sugar content was conducted in triplicate at predetermined times (0, 1, 2, 3, 4, 6, 8 and 10 h). The solid gain (*SG*) was calculated using Eq. (2) according to Souraki et al. (2014).

$$SG = \frac{S_t - S_o}{m_o} \quad \left(\text{g sugar g}^{-1} \text{ initial mass of fruit}\right) \tag{2}$$

where (S_t) represents the sugar content for processed samples at any time t; (S_o) represents the sugar content initially present in samples and (m_o) represents the initial mass of physalis in nature.

2.2.3. Mathematical modeling

According to Crank (1975), the solution of Fick's Second Law for unsteady-state diffusion in terms of spherical coordinates, assuming the diffusion to be radial, is given by Eq. (3):

$$\frac{WL_t - WL_\infty}{WL_o - WL_\infty} = \frac{SG_t - SG_\infty}{SG_o - SG_\infty} = 1 - \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-n^2\pi^2 Fo\right) \tag{3}$$

where *WL* represents the water loss (g water g^{-1} initial mass of fruit) and SG represents the solute gain (g sugar g^{-1} initial mass of fruit); the sub-indices t, o and ∞ represent the values at dehydration time t, time equal zero (physalis in nature) and at equilibrium, respectively. n represents the number of terms in the sum; r is the average radius of samples (m); t represents the processing time (s); and D_{ef} is the water or solid effective mass diffusivity ($m^2\ s^{-1}$). *Fo* is the Fourier Number for diffusion, according Eq. (4):

$$Fo = \frac{D_{ef}\ t}{r^2} \tag{4}$$

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