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Short Communication: Osmotic Dehydration of Physalis—Influence of Ultrasound Pretreatment

Cláudia Leites Luchese · Poliana Deyse Gurak · Ligia Damasceno Ferreira Marczak

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Abstract *Physalis peruviana* Linnaeus belongs to the family Solanaceae, and its potential cultivation is currently being explored due to its high productivity, sensory aspects and presence of several bioactive compounds. The shelf life of fresh physalis after harvesting is short, and its water content is high; therefore, osmotic dehydration, an alternative technology, could reduce the postharvest loss of this fruit. However, one factor that has hindered the application of this technology is the waxy skin of the fruit; in this context, the aim of the present work was to evaluate the effect of the pretreatment using an ultrasound probe (frequency, 20 kHz; amplitude, 80 %; for 30 min) on mass transfer during osmotic dehydration (ODU) and compare the results of the osmotic dehydration process without ultrasound (OD). The results showed that after 10 h, the loss of moisture was 47.6 ± 3.8 % and 46.1 ± 0.9 % for OD and ODU, respectively. The results for total sugar (normalized) showed a gain of 2.01 ± 0.22 and 2.05 ± 0.26 (g glucose g^{-1} of fruit) for OD and ODU, respectively. The carotenoid values were not observed to be influenced significantly by pretreatment; the ratios between the initial and final values of carotenoids were 0.74 ± 0.04 and 0.78 ± 0.06 for OD and ODU, respectively. The effective mass diffusivity of water calculated was 3.24 ± 0.49 × 10^{-10} m^2 s^{-1} for OD and 3.34 ± 0.11 × 10^{-10} m^2 s^{-1} for ODU, and the values founded were statistically equal (Tukey; $p > 0.05$). Additionally, the water activity and total color difference were measured for both the OD and ODU processes after 10 h, and statistically equal results were observed. Thus, for the conditions analyzed in this work, osmotic dehydration without and with an ultrasound probe as pretreatment showed no influence on the parameters studied. However, the food industry is constantly investigating new preservation technologies to improve and/or to replace of traditional food preservation techniques, and the treatment using ultrasonic waves has been used in conservation of fruits because it modifies the structure of the fruit increasing the water loss in the processing.

Keywords *Physalis peruviana* Linnaeus · Sonification process · Ultrasound probe · Effective mass diffusivity · Water activity · Colorimetric analysis and carotenoids

Introduction

Fresh physalis has a short postharvest shelf life, high water content and large amounts of bioactive compounds; therefore, alternative technologies such as osmotic dehydration could potentially reduce the postharvest loss of this fruit. Although the bioactive compounds of physalis and their antioxidant activity in vitro and in vivo have been characterized [1–4], there is a lack of studies that evaluate technologies for processing and preserving physalis.

Currently, osmotic dehydration is widely used in the processing of fruit and involves the direct immersion of the fruit in a hypertonic medium. The main driving force for the removal of water during osmotic dehydration is the osmotic pressure differential between the fruit and the hypertonic solution, where the complex cellular structure of the fruit serves as a semipermeable membrane [5–7]. However, Puente et al. [8] and Ramadan [9] claim that the surface of the *Physalis peruviana* L. has low permeability

C. L. Luchese (✉) · P. D. Gurak · L. D. F. Marczak
Chemical Engineering Program, Federal University of Rio Grande do Sul (UFRGS), Rua Engenheiro Luiz Englert, s/n. Campus Central, Porto Alegre, RS CEP: 90040-040, Brazil
e-mail: claudialuchese@yahoo.com.br

to fluid exchange; this is due to microstructural complexity, which hinders the use of techniques such as osmotic dehydration process and hot air drying. The fruit surface is covered by a waxy film composed mainly of resin terpenes, which represents a barrier against diffusion. In order to modify the surface of the physalis and to enhance the removal of water from this fruit, the application of the pretreatment prior to the osmotic dehydration process using an ultrasound probe is proposed. According to Esclapez et al. [10], the use ultrasound with high frequency and low intensity is important to improve quality of products or processes because the enhancement of the mass transfer brought about by acoustic-induced cavitation in a liquid medium is one of the beneficial effects of ultrasound. As discussed by Cárcel et al. [11], in the process affected by the application of ultrasound, the occurrence of intense effects at interfaces can affect the phenomena of mass transfer, reducing the thickness of the boundary layer, promoting improvements in the kinetics of water loss during the dehydration and drying processes.

Ultrasonic waves can cause rapid alternating compression and expansion in the fruit (sponge effect). The tension resulting from these waves may be higher than the surface tension that keeps the water inside the capillary tubes in the fruit, thus creating microscopic channels that can facilitate the removal of water. According to revision realized for Esclapez et al. [10], in solid/liquid systems, such as osmotic dehydration processes of fruits (solids) in osmotic solution (liquid), the enhancement of the mass transfer brought about by acoustic-induced cavitation in a liquid medium is one of the beneficial effects. When mechanical waves are transmitted through a fluid, the average distance within molecules is modified, oscillating around their equilibrium position. During the compression cycle, the intermolecular distance shortens and lengthens again in the rarefaction cycle. When the pressure decrease in the rarefaction cycle is enough to exceed the critical distance between molecules, cavities can appear in the bulk liquid. Those incipient bubbles keep on growing until the system reaches its minimal pressure and the subsequent compression cycle starts. Then, the cavities can start another rarefaction cycle or collapse adiabatically resulting in a violent implosion at the end of a compression cycle. Cavitation bubbles exist for few acoustic cycles before collapsing, giving rise to smaller bubbles that could act as new cavitation nuclei or simply get dissolved. Moreover, ultrasound promotes the phenomenon of cavitation, which can be useful for the removal of strongly bonded water. The application of ultrasonic waves can promote the formation of microchannels on the surface of a solid, causing changes in the microstructure of the solid and thus increasing the permeability of the fruit and enhancing the mass transfer process [12]. Therefore, the aim of this study was to evaluate the osmotic dehydration of physalis with (ODU) and without (OD) a 30-min pretreatment using an ultrasound probe (power, 750 Watts; frequency, 20 kHz; amplitude, 80 %).

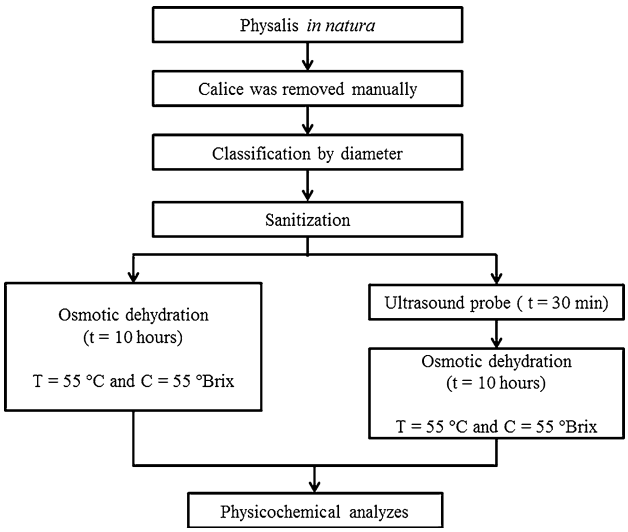

Fig. 1 Flowchart of osmotic dehydration processes applied to physalis without and with ultrasound pretreatment

Materials and Methods

Osmotic Dehydration with and Without Ultrasound Pretreatment

Physalis peruviana L. was purchased from a local market, imported from Colombia; all fruit came from the same grower. Those with certain quality attributes were selected for use in the study: uniform diameter (1.5–2.5 cm), degree of maturation (9–12 °Brix) and no defects. Sanitization of samples was made with solution of sodium hypochlorite 250 ppm for 10 min. Osmotic dehydration was carried out for time periods ranging from 0 to 10 h in an acrylic tank with a coil connected to a thermostatic bath to maintain a constant temperature. A sample:solution ratio of 1:20 was used to guarantee a constant concentration of the osmotic medium. The osmotic medium was agitated vigorously and continuously with a mechanical agitator (model 713, FISATOM, São Paulo, SP, Brazil), and the pretreatment using approximately 800 g of physalis immersed in 2 L of solution of osmotic solution (55 g sucrose per 100 g solution) was realized with ultrasound probe (Sonics Vibracell model VC750, diameter 1.2 cm e power de 750 Watts, Newtown, USA). The OD and ODU treatments (duration, 30 min; frequency, 20 kHz; amplitude, 80 %; intensity, 632 W cm^{-2}; sample:solution ratio, 1:3) were carried out as shown in the flowchart presented in Fig. 1.

Each condition experimental was realized in triplicate. During osmotic dehydration, the temperature and the concentration of the osmotic sucrose solution were maintained at 55 °C and 55° Brix, respectively. The pretreatment time was determined from the literature (Nowacka et al. [13] and Fernandes et al. [14]), and the sample:solution ratio was limited and determined by the size of the equipment available for the experiments.

Moisture Content

The moisture content of the samples was determined by a gravimetric method, according to AOAC 930.04 [15]. The analysis of moisture content was conducted in triplicate in all experimental conditions at predetermined times (0, 1, 2, 3, 4, 6, 8 and 10 h).

Sucrose Content

The extraction of sugar from the fruit was performed by immersing the fruit in a 100 °C water bath for 45 min, followed by centrifugation (30 min, 6,000 rpm), after which the volume was increased to 25 mL by addition of water. The solution was filtered through a 0.22-μm membrane filter before injection The sugar content was determined by high-performance liquid chromatography (HPLC) (Series 200, PerkinElmer Corp., Norwalk, CT, USA) according to Zuleta and Sambucetti [16]. The column used was a Rezex RHM Monosaccharides, and the precolumn was a Holder KJO-4282, both from Phenomenex (Macclesfield, Cheshire, UK). 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 (Series 200, PerkinElmer Corp., Norwalk, CT, USA) was used for quantification. Identification of sugars was based on the retention time, and quantification was carried out using external calibration with glucose as the standard. The analysis was conducted in triplicate at predetermined times (0, 1, 2, 3, 4, 6, 8 and 10 h).

Total Carotenoid Content

The analysis of the carotenoids in the physalis samples was performed only at the initial time (fresh physalis) and final time (after 10 h) in triplicate. The carotenoids were exhaustively extracted with cold acetone, partitioned into petroleum ether and washed with distilled water [17]. The quantification of total carotenoids was carried out using a spectrophotometer (Model 1800 UV–Visible, Shimadzu®, Stanford, CT, USA) with a wavelength of 450 nm. The results are expressed as all-*trans*-β-carotene using an absorptive coefficient of 2,592 because all-*trans*-β-carotene is the predominant carotenoid in physalis [18].

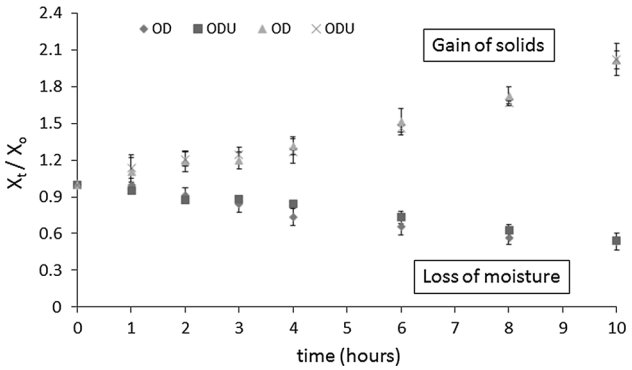

Fig. 2 Dimensionless values of water loss and sucrose incorporation in physalis during the process of osmotic dehydration without (OD) and with (ODU) ultrasound pretreatment

Determination of Water Activity

Experimental values of water activity were obtained by direct reading on an electronic hygrometer (Aqualab 3TE, Decagon, Pullman, WA, USA), which had been calibrated with saturated salt solutions according to the AOAC method no 978.18 [15]. Duplicate measurements were taken for fresh samples and for samples after 10 h of osmotic dehydration.

Colorimetric Analysis

Color measurements were performed for fresh samples and for samples triturated after 10 h of osmotic dehydration with and without pretreatment using ultrasound probe. The analysis was carried out in triplicate using a colorimeter (Minolta, Model CR 400, Konica Minolta Sensing, Japan) and the CIELAB color space, with D_{65} as an illuminant and an observer angle of 10° according to CIE [19]. The total color difference (ΔE^*) was calculated as the Euclidean distance between two points in the three-dimensional space defined by L^*, a^* and b^*, according to Heredia et al. [20].

Statistical Analysis

Statistical analyses were carried out using STATISTICA 8.0 (Statsoft Inc., Tulsa, OK, USA) and the t test from Excel for Windows, version 7.0 with a 95 % significance level ($p < 0.05$).

Results and Discussion

Water Loss and Sucrose Incorporation

The moisture content and the normalized sucrose content (x_t/x_o) were determined at different immersion times and

are plotted in Fig. 2. The experimental results were normalized with respect to the initial content to enable a better comparison. The initial temperature of the samples was approximately 25 ± 2 °C, and after pretreatment was approximately 48 ± 2 °C; this increase in temperature occurred because the ultrasound probe promotes the agitation of internal molecules, and this kinetic energy is transformed into thermal energy, heating the sample.

Physalis showed initial moisture content of approximately 83 % (wet basis). After pretreatment with ultrasound, the moisture content was approximately 82 % (wet basis), demonstrating that dehydration did not occur during pretreatment. In contrast, Fernandes et al. [14] found that for melon cubes (*Cucumis melo* L.) with 2 cm edge, after having been exposed to 30 min of treatment with ultrasonic waves (frequency, 25 kHz; intensity, 4,870 W m^{-2}; temperature, 30 °C; medium, distilled water), the water content of the samples increased by approximately 10 % relative to the initial value. In another study, Nowacka et al. [13] evaluated the use of an ultrasonic bath (frequency, 35 kHz; duration, 10, 20 and 30 min) as a pretreatment to the process of osmotic dehydration (sucrose solution, 61.5 %) of kiwifruit slices (thickness, 10 mm) and observed the formation of microchannels (by Magnetic Nuclear Resonance) in the samples and an increase in moisture loss due to use of the ultrasound pretreatment.

It can be seen in Fig. 2 and in Table 1 that water loss was approximately 47 % after the process of osmotic dehydration both with and without the ultrasound pretreatment. It is also possible to verify that physalis final sucrose content doubled in relation to the initial content, independent of the use of pretreatment. Thus, under the conditions tested, the use of ultrasound sonication did not promote sufficient changes in physalis and did not influence the moisture loss or the sugar incorporation during the process of osmotic dehydration. The effective mass diffusivity of water was calculated from the water loss data through the solution of Fick's Second Law for unsteady-state diffusion in spherical coordinates, and these results are shown in Table 1. The statistical analysis of the effective mass diffusivity of water showed that this parameter was also not statistically influenced by the use of the pretreatment ultrasound probe under the tested conditions. According to Fernandes et al. [14], osmotic dehydration process carried out for <30 min produces a decrease in the water diffusivity due to the highest incorporation of sugar; however, an increase in water diffusivity was observed when the OD process was carried out for more than 1 h, probably, as a consequence of the breakdown of cells lowering the resistance to water diffusion.

Table 1 Results for loss of water, effective mass diffusivity of water, sugar incorporated (normalized data), total carotenoids (normalized data) and overall color difference in physalis subjected to osmotic dehydration with and without ultrasound pretreatment

Process/analysis	OD	ODU	*P* value
Loss of moisture (%)*	47.6 ± 3.8	46.1 ± 0.9	0.53
(D_{ef} of water) × 10^{-10} (m^2 s^{-1})*	3.24 ± 0.49	3.34 ± 0.11	0.38
Gain of sugars (HPLC)*	2.01 ± 0.22	2.05 ± 0.26	0.87
Sugar (t_f)/sugars (t_o)			
Normalized total carotenoids*	0.74 ± 0.04	0.78 ± 0.06	0.34
Carotenoids (t_f)/carotenoids (t_o)			
Total color difference (ΔE^*)*	1.86 ± 0.34	1.84 ± 0.38	0.62

* Average of three replicates ± SD

OD osmotic dehydration, *ODU* osmotic dehydration pretreatment using an ultrasound probe

Total Carotenoid Content

Regarding the analysis of total carotenoids, the normalized results were 0.74 ± 0.04 for OD and 0.78 ± 0.06 for ODU, and the statistical analysis showed that the difference was not statistically significant because the p value was >0.05. Thus, the use of an ultrasound probe did not influence the loss of carotenoids. This finding may be related mainly to the fact that carotenoids are fat-soluble compounds; therefore, they do not easily migrate to the osmotic solution.

Colorimetric Analysis

Results of total color difference (ΔE^*) were presented in Table 1. By statistical analysis is possible to verify that there were no significant statistically differences ($p > 0.05$), therefore, the results of color parameters L^*, a^* and b^* (CIELAB scale) were not presented. Moreover, ΔE^* showed values near 2.0, indicating that even after 10 h of osmotic dehydration with and without ultrasound pretreatment, the samples showed no overall visually detectable difference in color (Melgosa et al. [21]; Lee and Coates [22]).

Water Activity

Concerning the water activity (a_w) after osmotic dehydration without and with the ultrasound pretreatment, the results were 0.962 ± 0.002 for OD and 0.966 ± 0.004 for ODU; there were no statistically significant differences ($p > 0.05$) for this analysis. Stojanovic and Silva [23] analyzed the a_w of blueberries and not found statistically significant differences with or without the use of continuous ultrasound (frequency, 850 kHz) after the osmotic dehydration process (duration, 3 h; temperature, 21 °C; osmotic solution of sucrose, 55° Brix).

One possible explanation for the fact that no statistically significant differences were found in the parameters studied in this present work can be related to the amount of sample subjected to the ultrasound pretreatment. In addition, the high viscosity of the osmotic solution (55 g of sucrose 100 g^{-1} of solution) may have also contributed to minimizing the effect caused by the ultrasound pretreatment in the physalis samples. Fernandes et al. [14] emphasize that the effect of ultrasound probe on food samples seems to be more pronounced when applied in solutions of lower viscosity.

Within the conditions tested in this work, the use of ultrasound probe as pretreatment to osmotic dehydration process in physalis has neither positive effects, such as an improvement on mass transfer, nor negative effects, such as an increasing on carotenoid loss to the osmotic solution. However, as suggestions for further works, it would be interesting to evaluate the effect of a pretreatment process using higher ultrasound powers. Moreover, perform an osmotic dehydration process coupled with the ultrasound probe in order to evaluate the effects of this technology on the increasing of the permeability of the waxy skin of physalis.

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