Published in Food and Bioprocess Technology
4 (2011) 610-615
Repository version

Food Bioprocess Technol (2011) 4:610–615
DOI 10.1007/s11947-010-0351-3

Dehydration of Malay apple (*Syzygium malaccense* L.) using ultrasound as pre-treatment

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Abstract

This work examined the influence of the ultrasonic pre-treatment prior to air-drying on dehydration of jambo (Syzygium malaccense L.) also known as Malay apple. This study allowed estimate water loss and sugar gain during the pre-treatment and the effective water diffusivity in the air-drying process for jambo subjected to ultrasonic pre-treatment. Results showed that during the ultrasonic treatment, in distilled water, the Malay apples lost sugar, so such a pre-treatment stage can be a practical process to produce dried fruits with lower sugar content. The water effective diffusivity increased by 28.1% (best result) after application of ultrasound, which caused a reduction of about 27.3% in the total drying time.

Keywords: *Syzygium malaccense L.; Jambo; Drying; Ultrasound; Optimization.*

Introduction

Conventional air-drying is a simultaneous heat and mass transfer process, accompanied by phase change being a high cost process. Usually, some form of pre-treatment, such as ultrasound pre-treatment, osmotic dehydration, mechanical dewatering, is used to reduce the initial water content or to modify the fruit tissue structure to reduce the total drying processing time (Delgado et al., 2009; Fernandes et al., 2010; Uribe et al., 2010). In this work the use of ultrasound as a pre-treatment to air-drying was investigated.

Ultrasonic waves can cause a very rapid series of alternative compressions and expansions, in a similar way to a sponge when it is squeezed and released repeatedly (the so-called sponge effect). Ultrasound produces cavitations that can be beneficial for the removal of moisture that is strongly attached to the solid. Deformation of porous solid materials, such as fruits, caused by ultrasonic waves is responsible for the creation of microscopic channels that reduces the diffusion boundary layer and increases the convective mass transfer in the fruit (Tarleton & Wakeman, 1998; Fuente-Blanco et al., 2006).

Malay apple (*Syzygium malaccense* L.), also known as red jambu and mountain apple, is native to Malaysia. Malay apples became widespread throughout some tropical regions of the world, especially in Africa and South America. The fruit, oblong or bell-shaped, 5 to 10 cm long, 2.5 to 7.5 cm wide at the apex, has thin, smooth, waxy skin, red, crisp or spongy, juicy flesh of very mild, sweetish flavour (Figure 1). There may be a single nearly round seed or 2 hemispherical seeds, 1.6 to 2.0 cm in width. The fruits of some trees are entirely seedless. The fruits are rich in phosphorus (14.7 ± 3.2 mg), iron (0.50 ± 0.30 mg) and calcium (5.7 ± 0.2 mg) (Morton, 1987).

Figure 1. *Malay apple. (a) side view; (b) upper view; (c) sectional cut.*

In this work the influence of time in ultrasound on water loss, sugar gain and water diffusivity of Malay apple was evaluated. The integrated process (ultrasound and air-drying) was optimized searching for the operating condition that minimizes total processing time.

Materials and methods

Preparation of samples

Malay apples (*Syzygium malaccense* L.) were bought from the local market (Fortaleza, Brazil). Only fruits with a maturity stage described by dark red skin were used and soft fruits were discarded. Malay apple samples were cut in halves obtaining two domes and then were cut in four equal parts to obtain slices of similar dimensions. The moisture content of the fruit was determined by heating in a drying oven (Marconi model MA-185, Piracicaba, Brazil) at 60ºC for 24h according to AOAC method 934.06 (AOAC, 1990). The initial soluble solids content of the fruit (ºBrix) was determined by refractometry.

Ultrasound pre-treatment

An experimental set of 4 Malay apple samples was immersed in distilled water and subjected to ultrasonic waves during 10, 20, 30, 45 and 60 min. The water to fruit ratio was set at 4:1 (weight basis). This ratio was used because previous works (Fernandes et al., 2006a; Fernandes et al., 2006b; Teles et al, 2006; Oliveira et al, 2006) have shown that at this liquid medium to fruit ratio the dilution of the osmotic solution is negligible.

The experiments were carried out under ambient water temperature (25ºC) in an ultrasonic bath (Unique model USC 25 kHz, São Paulo, Brazil) without mechanical agitation. The ultrasound frequency was 25 kHz and the intensity was 60 W or the equivalent to 1785 W/m^2, which was determined by the calorimetric method. The experiments were carried out in triplicate. At the end of the ultrasonic pre-treatment a sample of the liquid medium was taken to determine its soluble solids content by refractometry. This procedure was carried out to quantify the amount of soluble solids that the fruit loses to the water.

Ultrasound assisted osmotic dehydration

The ultrasound assisted osmotic dehydration was carried out in similar way to the described previously in the ultrasound pre-treatment sub-section, but using an osmotic solution as liquid media. The osmotic solution used in each experiment was prepared by mixing food grade sucrose with distilled water to give a concentration of 25 and 50ºBrix. The experiments were carried out in triplicate.

After removal from the solution, the weight and moisture content were measured individually. The concentration of the solution was monitored during the runs determining the osmotic solution soluble solids content (ºBrix) using a refractometer.

Weight and moisture content of the samples were used to calculate the response variables of the experimental planning: water loss (WL) and solid gain (SG), according to the following equations:

$$WL(\%) = \frac{(w_i \cdot Xi - w_f \cdot X_f)}{w_i} \cdot 100 \tag{1}$$

$$SG(\%) = \frac{[w_f \cdot (1 - X_f) - w_i \cdot (1 - X_i)]}{w_i \cdot (1 - X_i)} \cdot 100 \tag{2}$$

Air Drying

At the end of the pre-treatment the dehydrated samples were drained, blotted with absorbent paper to remove the excess solution and transferred to a forced circulating air-drying oven (Marconi model MA-085, Piracicaba, Brazil) set at 60ºC. This temperature was set because it is the highest temperature in which there is low degradation of the quality of fruits. Air was injected at the sides of the dryer at 0.12 m^3/s. The air moisture content was 16% and was determined by psychrometry (dry and wet bulb temperature).

The air-drying process was modeled assuming diffusion-controlled mass transfer with the liquid flow within the fruit conforming to Fick's second law of diffusion. Only the falling-rate period (diffusion-controlled mass transfer period) was considered because during the experiments the constant-rate period (heat transfer-controlled mass transfer period) was not observed. The equation used to model the falling-rate period was a simplification of Fick's second law considering long drying times.

$$\frac{dH}{dt} = -\frac{2\pi}{\delta^2} \cdot D \cdot (H - H_{eq}) \tag{3}$$

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Results and discussion

The analysis of the fresh fruit showed that Malay apples had an initial moisture content of 0.87 ± 0.03 g water/g fresh fruit and a soluble solids content of 12.7 ± 0.5 ºBrix. At the end of the ultrasonic pre-treatment in distilled water the fruit has incorporated water from the liquid medium (Table 1).

Table 1. *Soluble solids gain and water loss of malay apples subjected to different pre-treatments for 60 min, and water diffusivity of malay apples in air-drying process after application of the pre-treatment.*

Operating condition	Soluble Solids Gain [%]	Water Loss [%]	Water Diffusivity* [m^2/s]
With ultrasound application			
in distilled water	- 33.40 ± 1.67	- 12.02 ± 0.60	$4.46\times10^{10} \pm 0.23\times10^{10}$
in osmotic solution (25ºBrix)	62.83 ± 3.14	- 9.43 ± 0.47	$5.75\times10^{10} \pm 0.29\times10^{10}$
in osmotic solution (50ºBrix)	101.04 ± 5.05	6.20 ± 0.31	$3.74\times10^{10} \pm 0.19\times10^{10}$
Without ultrasound application			
in distilled water	- 13.74 ± 0.69	- 13.20 ± 0.66	$4.33\times10^{10} \pm 0.21\times10^{10}$
in osmotic solution (25ºBrix)	20.27 ± 1.01	- 2.00 ± 0.10	$4.67\times10^{10} \pm 0.23\times10^{10}$
in osmotic solution (50ºBrix)	124.97 ± 6.25	6.15 ± 0.30	$3.54\times10^{10} \pm 0.19\times10^{10}$

** all regressions R^2 were above 0.98*

Similar result was found with ultrasonic-assisted osmotic dehydration with an osmotic solution of 25ºBrix, where the fruit also has incorporated water. This result is unusual in osmotic dehydration and is rarely observed. Water loss was observed only when the fruit was immersed in an osmotic solution of 50ºBrix (Figure 2).

The fruit subjected to the ultrasonic pre-treatment, in distilled water, lost soluble solids to the liquid medium. The amount of soluble solids transferred to the liquid medium during the process increased from 28.2% after 10 minutes in ultrasonic bath to 33.4% after 60 minutes. This was an interesting result since the ultrasound pre-treatment showed to be a process that lowers the amount of soluble solids of the fruit, especially sugars (97% - determined by the DNS method, Miller (1959)). Low sugar content fruit could be used in several foodstuffs directed to consumers' interested products with low sugar content.

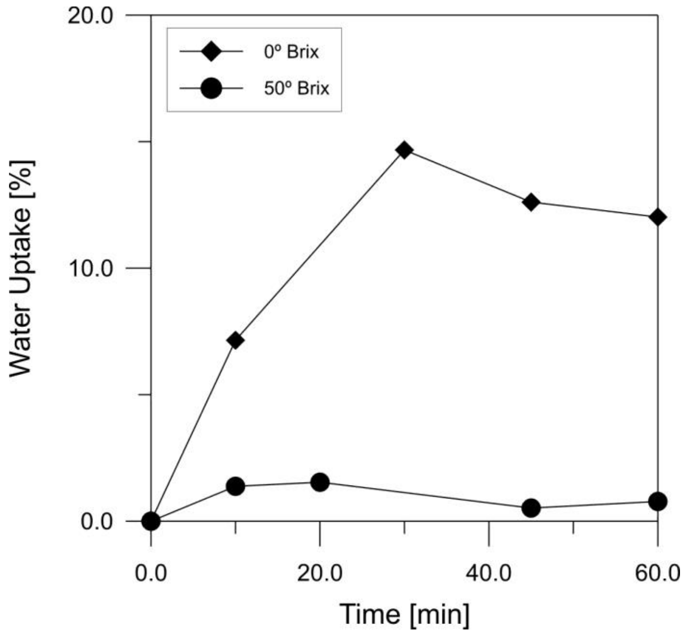


Figure 2. *Water loss in Malay apples during ultrasound pre-treatment.*

The amount of soluble solids lost to the liquid medium was higher when ultrasound was applied than without application of ultrasound (Table 1), showing that ultrasound application has affected the process. After 60 minutes, ultrasound increased the loss of soluble solids by 144% compared to the control experiment carried out without ultrasound application. The soluble solids loss observed for Malay apples was slightly lower than the soluble solids loss observed for other fruits such as banana and pineapples, which have lost respectively 21.3 and 23.2% after 30 minutes, while Malay apples lost 17.0% under the same conditions (Fernandes & Rodrigues, 2007; Fernandes et al., 2008b).

The fruit subjected to ultrasound in an osmotic solution of 25ºBrix incorporated a large amount of sugar (62.8% after 60 minutes), which increased further in an osmotic solution of 50ºBrix (101% after 60 minutes). Low osmotic pressure, as when an osmotic solution of 25ºBrix is employed, combined with ultrasound application may create microscopic channels in the fruit, which facilitates the incorporation of sugar by the fruit. High osmotic pressure, as when an osmotic solution of 50ºBrix is employed, increases the rate of cell breakdown (Fernandes et al., 2008a; Fernandes et al., 2009; Rodrigues et al., 2009a; Rodrigues et al., 2009b), which combined to the sponge effect of ultrasound may ease mass transfer from the osmotic solution towards the fruit increasing the incorporation of sugar by the fruit.

The soluble solids gain by the fruit was rapid and more than 60% of soluble solids gain was observed in the first 10 minutes of pre-treatment (Figure 3). Rapid soluble solids gain usually indicates that the gained sugar remains mainly in the surface of the sample, leading to high concentration of sugar in the surface of the fruit (Rodrigues and Fernandes, 2007; Salvatori et al., 1998; Salvatori et al., 1999; Chiralt and Talens, 2005). This high sugar concentration creates an extra resistance for water transfer from the fruit to the osmotic solution. This fact may explain the low water loss (about 5%) when the fruit is immersed in a 50ºBrix osmotic solution. The low water transfer at 50ºBrix indicates that the sugar concentration at the surface of the sample is slightly lower than 50ºBrix. This high concentration of sugar at the surface of the sample explains the water incorporation when the fruit is immersed in a 25ºBrix. Since the surface of the sample has as higher sugar concentration than the osmotic solution, water will flow toward the fruit resulting in the observed water incorporation.

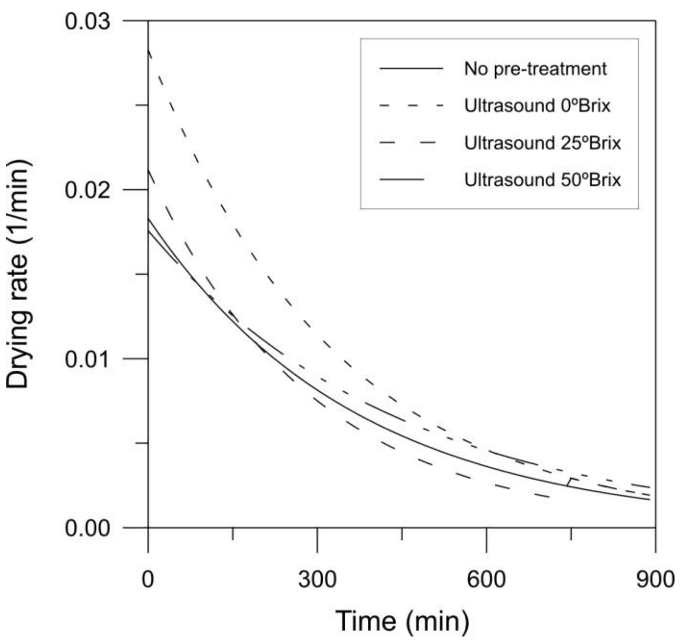
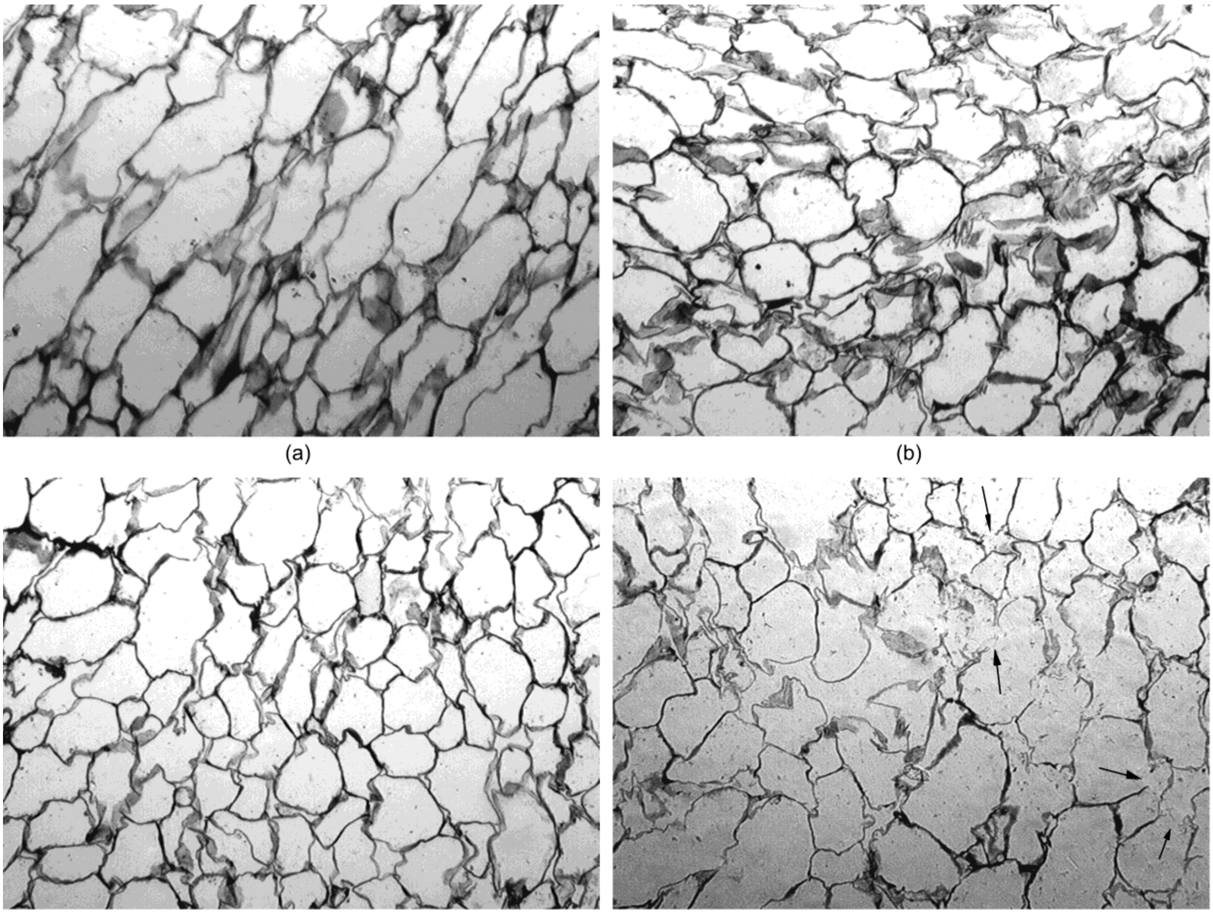


Figure 3. *Soluble solids gain in Malay apples during ultrasound pre-treatment.*

The morphology of the fruit tissue, before and after ultrasound application is presented in Figure 4. The cells of Malay apples are small and irregular in shape (Figure 4a). Figure 4b and 4c present respectively the cells of Malay apples after application of ultrasound for 30 min in distilled water and in an osmotic solution of 25ºBrix. The cells did not present many differences when compared with untreated Malay apples cells. The cells were irregular in shape and very few microscopic channels were observed in the samples. The microscopic channels observed in Malay apples tissue are short and were formed by detachment of contiguous cells. No breakdown of cells was observed when the fruit was immersed in an osmotic solution of 25ºBrix. The presence of few microscopic channels contributes to the low loss of water observed during ultrasound application.

Figure 4d shows the tissue morphology of the fruit immersed in an osmotic solution of 50ºBrix. The figure shows that under this processing condition the cells present several breakdown points and the intercellular spaces are much broader than when the fruit is immersed in distilled water and in osmotic solution of 25ºBrix. Changes in tissue morphology were not significant after 30 min of ultrasonic processing time.



(a) (b) (c) (d)

Figure 4. *Photomicrograph of Malay apples samples. (a) without pre-treatment; (b) after 30 minutes of ultrasound pre-treatment immersed in distilled water; (c) after 30 minutes of ultrasound pre-treatment immersed in 25oBrix osmotic solution; (d) after 30 minutes of ultrasound pre-treatment immersed in 50oBrix osmotic solution. Magnification of 380x.*

Water effective diffusivity during the air-drying process was found to be higher when the Malay apples were pre-treated for 30 minutes under ultrasonic waves in an osmotic solution of 25ºBrix (5.84×10^{-10} $m^2.s^{-1}$) (Figure 5). Pre-treating the Malay apples using distilled water resulted in a maximum water effective diffusivity of 5.66×10^{-10} $m^2.s^{-1}$, which was close to the value obtained with the osmotic solution of 25ºBrix. Both diffusivities were higher than the effective diffusivity obtained for the fresh fruit (4.56×10^{-10} $m^2.s^{-1}$) during air-drying. As a consequence, the fruit submitted ultrasound pre-treatment dried faster during the air-drying stage if compared to the fresh fruit with no pre-treatment.

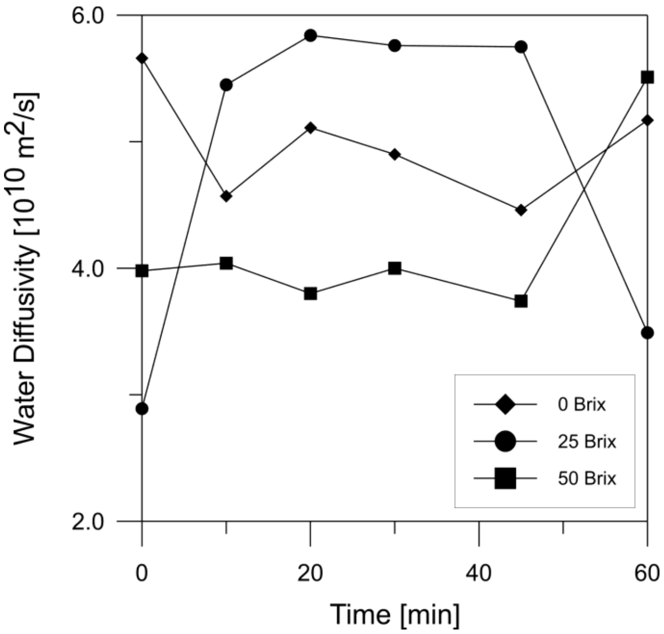


Figure 5. *Water diffusivity in Malay apples during air-drying for different pre-treatment osmotic solution concentrations and time.*

The exception occurred with the pre-treatment using an osmotic solution of 50ºBrix, which reduced the water effective diffusivity to 3.98×10^{-10} $m^2.s^{-1}$ after 10 minutes subjected to ultrasonic treatment. After 60 minutes the water effective diffusivity decreased to 3.74×10^{-10} $m^2.s^{-1}$ under this condition, which was caused by saturation of the surface of the fruit with sucrose creating an extra resistance for mass transfer.

The drying process of fruits considered herein comprehends the pre-treatment process followed by air-drying. Total processing time can be optimized to reduce air-drying to a minimum, reducing costs and increasing overall productivity. The ultrasonic treatment should be carried out while the increase in water diffusivity it provokes leads to a continuous reduction of total processing time. Table 2 shows the optimal total processing time to remove the same amount of water from the fresh fruit, reducing 90% of the initial water content.

Table 2. *Processing time (pre-treatment + air-drying) to remove 90% of the initial water content of the fruit.*

Pre-treatment	Pre-treatment Time [min]	Air-Drying Time [min]	Total Processing Time [min]
No pre-treatment (air-drying only)	---	854	854
ultrasound (distilled water)	10	808	818
ultrasound (25ºBrix)	60	561	621
ultrasound (50ºBrix)	45	977	1022

The optimization showed that the application of the ultrasonic pre-treatment can reduce the total processing time to dry Malay apples, compared to the air-drying process, when distilled water and an osmotic solution of 25ºBrix are employed (Table 2). To reduce the initial moisture content of the fruit by 90%, the total processing time can be reduced by 233 minutes when Malay apples are subjected to ultrasound during 60 minutes in an osmotic solution of 25ºBrix.

Conclusion

The use of ultrasound as a pre-treatment, using distilled water as the liquid medium, caused loss of soluble solids from the fruit to the liquid medium decreasing the amount of soluble solids, especially sugar, of the fruit and producing a dried low sugar fruit.

The use of ultrasound pre-treatment, using distilled water or osmotic solution of 25ºBrix, increased the water effective diffusivity of the fruit leading to faster air-drying of the fruit. The increase in effective water diffusivity was estimated in 28.1% after 30 minutes of ultrasound for the process carried out using an osmotic solution of 25ºBrix.

Acknowledgements

To the Brazilian funding institutes CAPES and CNPq.

Notation

D	effective diffusivity (m^2/min)
H	moisture content of the fruit ($g_{water}/g_{dry\ solids}$)
H_{eq}	equilibrium moisture content of the fruit ($g_{water}/g_{dry\ solids}$)
t	time (h)
WL	water loss (%)
SG	solid gain (%)
X_i	initial fruit moisture on wet basis (g_{water}/g)
X_f	final fruit moisture on wet basis (g_{water}/g)
w_i	initial fruit mass (g)

w_f final fruit mass (g)
δ bed height of the fruit (m)

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