FOOD ENGINEERING

Combination of technologies for the dehydration of pineapple

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Abstract

Three technologies were studied as pretreatments to improve mass transfer during osmotic dehydration of pineapple. Effects of vacuum impregnation, high power ultrasound, and microwave heating on water loss, solids gain, and rehydration capacity of the pineapple samples were quantified. Each pretreatment technology was evaluated at three operating conditions. Additionally, energy consumption was quantified as an indicator of the impact of each pretreatment on the final product cost. Microwave processing conditions of 1000 W during 1 min (MD1 procedure) and 500 W during 2 min (MD2 procedure), showed promising effects to be used as osmotic dehydration pretreatments, due to their positive influence on both solid and water transfer rates and due to low energy consumption in terms of kJ / g of removed water. On the other hand, under the experimental conditions of this work, ultrasound treatments were identified as not environmentally friendly from the energy use standpoint, because their energy consumption was found to be from 3 to 6 times larger than that observed for the MD1 procedure. Lastly, it was found that vacuum impregnation experiments increased solids transport, but decreased water loss.

Keywords: Drying, Osmotic dehydration, Microwave heating, Ultrasound, Vacuum impregnation, Tropical fruits.

INGENIERÍA DE ALIMENTOS

Combinación de tecnologías para la deshidratación de piña

Resumen

Se estudiaron tres tecnologías como pretratamientos para incrementar la transferencia de masa durante la deshidratación osmótica de piña. Se cuantificaron los efectos de impregnación con pulsos de vacío, ondas de ultrasonido de alta potencia y calentamiento por microondas sobre la pérdida de agua, la ganancia de sólidos y la capacidad de rehidratación de las muestras de piña. Cada tecnología de pretratamiento se evaluó bajo tres condiciones de operación diferentes. Adicionalmente, el consumo de energía se cuantificó como un indicador del impacto de cada pretratmiento sobre el costo final del producto. Las condiciones de procesamiento con microondas de 1000 W durante 1 min (procedimiento MD1) y 500 W durante 2 min (procedimiento MD2), mostraron efectos promisorios para ser utilizadas como pretratamientos para deshidratación osmótica, debido a su influencia positiva en la transferencia de agua y sólidos y a su bajo consumo de energía en términos de kJ / g de agua retirada. Por otro lado, bajo las condiciones experimentales utilizadas en este trabajo, los tratamientos con ultrasonido se identificaron como no amigables con el medio ambiente desde el punto de vista de uso de la energía porque su consumo energético se encontró que es de 3 a 6 veces mayor que el observado para el procedimiento MD1. Finalmente, la impregnación con pulsos de vacío aumentó la transferencia de sólidos pero disminuyó la transferencia de agua.

Palabras clave: Deshidratación osmótica, Calentamiento por microondas, Ultrasonido, Impregnación en vacío, Frutas tropicales.

1. Introducción

Osmotic dehydration (OD) is well known as a drying pretreatment for food materials because it can reduce energy costs and also improve quality of the final products (Torreggiani & Bertolo, 2004; Chiralt et al., 2005; Ortega-Rivas, 2007; Andrés et al., 2007; Lombard et al., 2008). OD is usually carried out by immersion of the samples in a highly concentrated solution of sugar or salt. It has been applied successfully to a variety of fruits by reducing up to 30 % of their initial moisture content. The chemical potential that exists between the solution and the food sample leads to mass transfer fluxes such that water flows out of the sample and solutes enter into the tissue. However, since osmotic pressure is the only driving force for mass transfer, OD is a slow process. Other processes such as vacuum infusion, ultrasound, high pressure, high-intensity electric field pulses, and blanching and freezing have been investigated earlier in order to improve diffusion coefficients during OD (Rastogi et al., 2002; Ayala-Aponte et al., 2003; Taiwo et al., 2003; Deng & Zhao, 2008; Dhingra et al., 2008).

Vacuum impregnation (VI) is a processing method by means of which air and native suspension are removed from porous spaces within a food and replaced by an external solution. The sample immersed in a solution is exposed to a low pressure in order to ensure that air trapped in food is removed. Atmospheric pressure is then re-established and external solution penetrates the food sample (Fito et al., 1996). This phenomenon implies both a fast change in food composition and modification of physical conditions that control mass transfer after the VI process (Martinez-Monzo et al., 1998; Barat et al., 2001).

The use of ultrasound within food industry has been a subject of research during the past 15 years. Both low energy high frequency and high energy low frequency technologies have been studied (Mason et al., 1996; Knorr et al., 2004; Dolatowski et al., 2007). However, the use of low frequency high power ultrasound (US) is becoming increasingly appreciated in the food processing area because of its effects on living cells, enzymes, and mass transfer during processing (Patist & Bates, 2008; Cameron, et al., 2008). The use of US as pretreatment of other drying processes has been found to improve mass transfer and therefore opens up the possibility of using temperatures lower than the traditional ones (Mason et al., 1996; Fernandes et al., 2008). Fernandes & Rodrigues (2007) found that water diffusivity of banana pieces exposed to ultrasonic waves during 20 min was increased 14.4 % and their air-drying times reduced by 11 %. Furthermore, Jambrak et al. (2007) observed that drying times of different vegetables were shortened when using US as pretreatment of various drying methods. Additionally, they found that rehydration properties for ultrasound treated samples where better than those for untreated samples. De la Fuente-Blanco et al. (2006) found similar results as those obtained by Jambrak et al. (2007), by using a novel ultrasonic drying equipment that employed direct contact of the vibrator with the samples. On the other hand, a negative effect on pepper firmness after ultrasonic treatment was found by Gabaldón-Leyva et al. (2007). Increased mass transfer rates have been found when OD is combined with ultrasonic treatments (Deng & Zhao, 2008; Simal et al., 1998); however, structure collapse and firmness loss were observed in apple cubes when ultrasound and OD were used as combined drying method (Deng & Zhao, 2008). This mass transfer enhancement has been explained by three mechanisms: cavitation, acoustic streaming, and compression-rarefaction (Mason et al., 1996; Knorr et al., 2004).

Despite some drawbacks such as uneven heating and possible textural damage observed after microwave heating (MW), it has been recognized over the last decades that MD can lead to economical benefits during drying of food materials (Andrés et al., 2007; Dev et al., 2008). As microwaves can penetrate the sample's tissue, the centre can easily reach temperatures near the boiling point of water. Therefore, during microwave drying, mass transfer is influenced by the pressure gradient, which is the main driving force. Too rapid mass transport may cause quality damage or undesirable changes in the food texture by '*puffing*' (Nijhuis et al., 1998). However, this may or may not be a limitation depending on the desired quality attributes of the final product. For example, the rapid evaporation caused by MW could yield cell-wall damage which increase mass transfer when combined with other drying methods such as air drying or osmotic dehydration, but, on the other hand, it can induce sample shrinkage and nutrient loss (Zhang et al., 2006).

Selection of the proper drying technology or combination of technologies affects final product quality and cost. Therefore, the aim of this work was to study the influence of different technologies on mass transfer kinetics during OD, on energy costs, and on rehydration capacity of pineapple pieces.

2. Materials and methods

Prior to dehydration treatments, pineapples (Var. Golden) were peeled and cut into triangle-alike pieces (10 mm base x 30 mm sides x 5 mm width). All samples were processed during 75 min by using various technologies such as microwaves and high power ultrasound. Details on the experimental work are summarized in Table 1 and in the following paragraphs.

Table 1. Description of the combined processing methods used in this work.

Procedure code	Description of the procedure
US2	Ultrasound: 15 min. Osmotic dehydration: 1 hour.
US5	Ultrasound: 30 min. Osmotic dehydration: 45 min.
US6	Ultrasound: 45 min. Osmotic dehydration: 30 min.
MD1	Microwave: 1 min at 1000 W. Osmotic dehydration: 74 min.
MD2	Microwave: 2 min at 500 W. Osmotic dehydration: 73 min.
MD3	Microwave: 30 min at 100 W. Osmotic dehydration: 45 min.
V1	Vacuum pulse: one, 15 min at the beginning of the osmotic treatment. Osmotic dehydration: 60 min at atmospheric pressure.
V4	Vacuum pulses: 4 pulses, 5 min each and 5 min atmospheric pressure in between for the first 35 min of the osmotic treatment. Osmotic dehydration: 40 min at atmospheric pressure.
V8	Eight vacuum pulses: 5 min each and 5 min atmospheric pressure in between for 75 min of the osmotic treatment.

Osmotic dehydration of pineapple pieces was carried out in 60 °Brix sucrose solutions. Recipients were filled with the osmotic solution at 20 °C and 50 g of pineapple pieces, maintaining a product / solution ratio of 1:5 w/w. Osmotic solution was not agitated during the experimental procedures. Blank samples (FFDO) were those processed by using osmotic dehydration without any other method. Vacuum impregnation was carried out by exposing the recipients with the samples to a low pressure (less than 300 mbar). Three different kind of vacuum pulses were carried out as explained in Table 1.

Combined treatments of osmotic dehydration and sonication (US) were carried out in 3.5 L bath (Elma, TI-H 5) equipment. Bags filled with osmotic solution and pineapple pieces were maintained, one at a time, in the sonication bath (35 kHz and 100 W) during periods of 15, 30 and 45 min. Each experiment was performed three times. Samples were maintained in the osmotic solution for 75 min. Afterwards, samples were extracted, rinsed, and blotted with tissue to remove surface water.

Combined treatments of osmotic dehydration and microwave heating (MD) were carried out using a microwave oven (HACEB HM1.1) with a power of 1000 W. A sample of 50 g of pineapple pieces was heated by applying different power levels and heating times (Table 1). Afterwards, pineapple samples were placed in the osmotic solution and removed after 75 min of combined treatment. Lastly, the samples were taken out, rinsed, and blotted with tissue to remove surface water.

Measurements of initial and final moisture content and solid content were carried out according to the AOAC methods 934.06 and 932.12. Water loss (ΔM_w) and solid gain (ΔM_s) were calculated from experimental data by use of the following equations:

$$\Delta M_w = \frac{M_0 X_{w0} - M_t X_{wt}}{M_0} \qquad (1)$$

$$\Delta M_s = \frac{M_t X_{st} - M_0 X_{so}}{M_0} \qquad (2)$$

where M is the weight of the sample, X_w is the water content and X_s is the solid content. The subscript o stands for the initial sample and the subscript t stands for the final sample.

Water holding capacity of the rehydrated samples (RH) was measured according to the procedure described by Bauman et al. (2005) and water holding capacity was expressed as water content of rehydrated sample (d.b).

3. Results and discussion

Experimental results related to mass transfer and energy use are shown in Figures 1, 2 and 3. Additionally, relative effect of each treatment on the observed factors is summarized in Table 2.

Figure 1 summarizes moisture loss and solid gain after various treatments. Additionally, it includes the water loss / solids gain ratio (RT), which is a good way to describe the product characteristics and its potential use. Under the experimental conditions used, the highest water loss was observed in samples processed by using microwaves. Attention should be paid to MD1 and MD2, which doubled the amount of water lost by FFDO.

These results could be related to sudden evaporation caused by the volumetric heating involved in high power microwave processes (Nijhuis et al., 1998). It should be noted that MD1 and MD2 provided between 1 and 2 W / g of sample in a maximum of 2 min. Similar effects to microwaves have been observed by Andrés et al. (2007), who attributed mass transfer enhancement to changes in the structure of the sample (cell-wall damage and '*puffing*' of the tissue). Furthermore, the same results were observed in solid gain measurements where samples processed by using MD1 and MD2 were the ones with higher values, around 3 times higher than those observed in blank samples (FFDO). Lastly, it is important to note that the water loss values observed after MD1 and MD2, with a significance level at 5 %, are statistically different from each other and different from those of other treatments considered in this work. This means that a change in power level around 1 W / g of sample has an observable

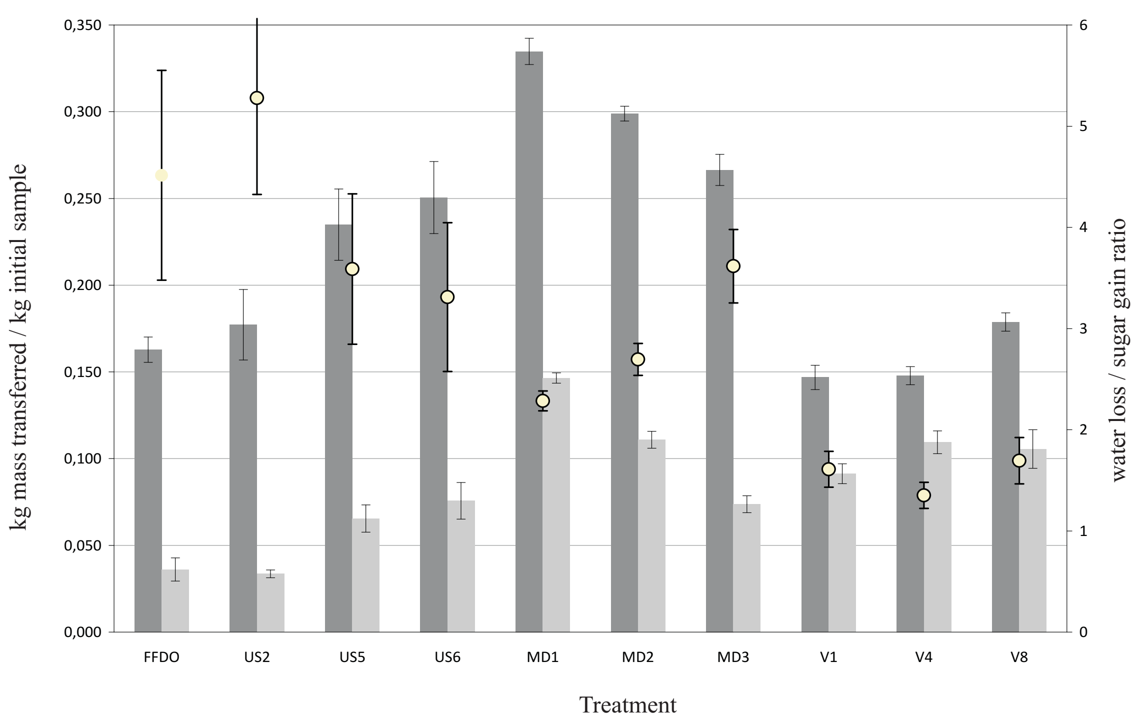

Figure 1. Influence of different combined treatments on mass transfer. Water loss (dark bars) was calculated using Eq. 1 and solids gain (bright bars) was calculated using Eq. 2. Dots represent the ratio (water loss / solids gain), whose values are associated to the secondary Y-axis.

Table 2. Relative effect of different procedures on the product characteristics.

	FFDO	US2	US5	US6	MD1	MD2	MD3	V1	V4	V8
ΔM_w	low	low	inter	inter	high	high	inter	low	low	low
ΔM_s	low	low	low	inter	high	high	inter	inter	high	inter
Rehydration	high	high	high	high	low	low	inter	inter	inter	low
Energy index	low	inter	high	high	low	low	inter	low	low	inter

Three groups of data were identified by dividing the variation range into intervals with the same size. Each interval was named low, intermediate, and high, respectively.

influence on water transfer. In contrast, solids gain values of MD2 were not statistically different from those observed after V1, V4 and V8.

Treatments V1, V4, V8, and US2 are found on the other edge of water loss values (Figure 1 and Table 1) because they showed poor moisture transfer levels. Vacuum impregnation results are in agreement with other results in the literature (Ayala-Aponte et al., 2003; Fito et al., 1996), which explain vacuum as a hydrodynamic effect that increases the solid intake but does not show different results when compared with water loss measurements in osmotic dehydration. Additionally, US2 did not show a great influence on the moisture loss, which is attributed to the short length of treatment (first 15 min of the total processing time). During the first period, mass transfer at solid-liquid interface is not controlling the process, and therefore, the cavitation effect described by others (Simal et al., 1998; Zhang et al., 2006) is not making any difference. The previous statement also explains why under the experimental conditions used in this investigation, ultrasound treatment was the processing method with lower effect on solids transfer from the osmotic solution into the sample. This fact, combined with the middle range effect of US5 and US6 on water loss (Table 1) and on RT values (Figure 1), could give and indication of appropriate processing conditions for obtaining low sugar products as suggested by others (Fernandes & Rodrigues, 2007). RT values for US5 and US6 reported in Figure 1 are similar to those of MD2 and MD2 (no statistical difference between them was detected under a significance level of 5 %), showing that water loss was about three times higher than sugar gain. This effect of US5 and US6 on mass transfer is confirmed by the observations made by Fernandes et al. (2008) on the microstructure of the samples treated with high power ultrasound. They did not observe cell damage; instead, they observed formation of micro-channels, which enhanced mass transfer but in a lower extent than those treatments that broke cell wall.

Rehydration capacity is an important indicator when the product is intended to be used as part of a wet formulation or final product such as morning cereals and yogurts. Even though the product obtained during these experimental trials is not stable and needs further dehydration, we expected to detect significant differences in rehydration properties between treatments at this stage. Therefore, the rehydration index was estimated as water content (d.b.) obtained after a humidifying procedure explained earlier in this paper. These results show (Figure 2) that all samples processed by using ultrasound have the highest rehydration levels. There is evidence that the structure of the sample is not damaged under US processing conditions (Fernandes et al., 2008) and therefore, rehydration capacity was expected to be hold. Furthermore, results are in agreement with those discussed earlier in relation to mass transfer, showing that ultrasound waves had their main effect at solid-liquid interface due to violent collapse of bubbles (cavitation) and on generation of micro-channels which facilitated mass transfer during drying and rehydration. On the other hand, both MD1 and MD2 showed a rehydration index which is half of that corresponding to a blank sample.

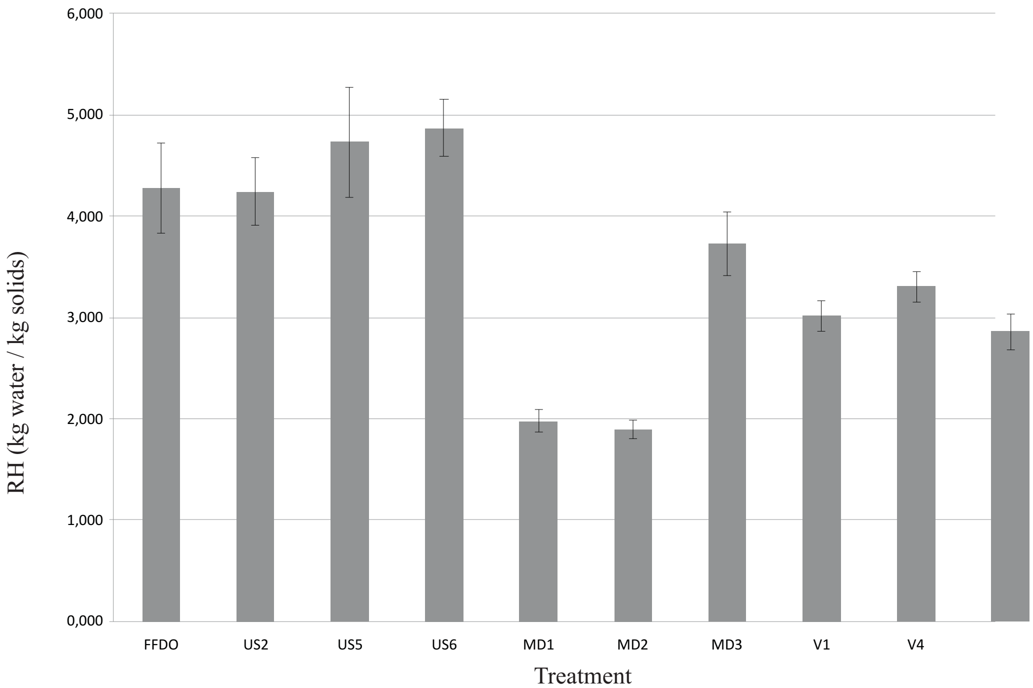

Figure 2. Effect of various combined treatments on the rehydration properties of pineapple samples. RH was estimated as water content (d.b.) obtained after a humidifying procedure explained by Bauman et al. (2005).

This poor performance is related to violent evaporation of water inside samples that caused structure collapse and, at the end, hindered water transport during the humidifying procedure. Same effect of the structure collapse has been reported after vacuum impregnation procedures (Dhingra et al., 2008) and evidence of this can be observed in V8.

It is noteworthy that water content of samples was different after all procedures, and therefore, it is difficult to conclude on the effect of each treatment on the structure collapse. This should be the subject of future studies. However, under the scope of this work, it is possible to conclude that osmotic dehydration, combined with microwaves at high power levels, gives the best results with regard to mass transfer rates during dehydration and in consequence, could yield lower water contents in shorter times. However, rehydration capacity of samples treated with microwaves is poor and therefore, could not be used in products that are intended to be consumed with water contents similar to those of the natural product.

It is clear from Figure 3 and Table 1 that the most expensive procedures in terms of energy consumption are those related to ultrasound – US5 and US6 – , which showed levels of 15,000 and 21,600 kJ / g of removed water. This is in contrast with the energy spent in removing water by using microwaves as a pretreatment: 3,565 and 3,973 kJ / g of removed water for MD1 and MD2, respectively. As discussed earlier, high power-short time microwave processing as in MD1 and MD2, involved mass transfer enhancement and is an example of optimum use of energy for drying purposes. The energy spent after MD3 is in contrast to these results. This treatment used a low power during an extended period; as a result, it warmed the sample but affected the structure in a lower magnitude. Thus, this treatment shows less efficiency from the energy use standpoint. Furthermore, V1 and V4 showed low levels of energy use (4,512 and 6,007 kJ / g of removed water, respectively); however, due to their low levels in water removal (during the 75 min period defined for the experimental trial), these pretreatments are found to be less efficient than microwaves.

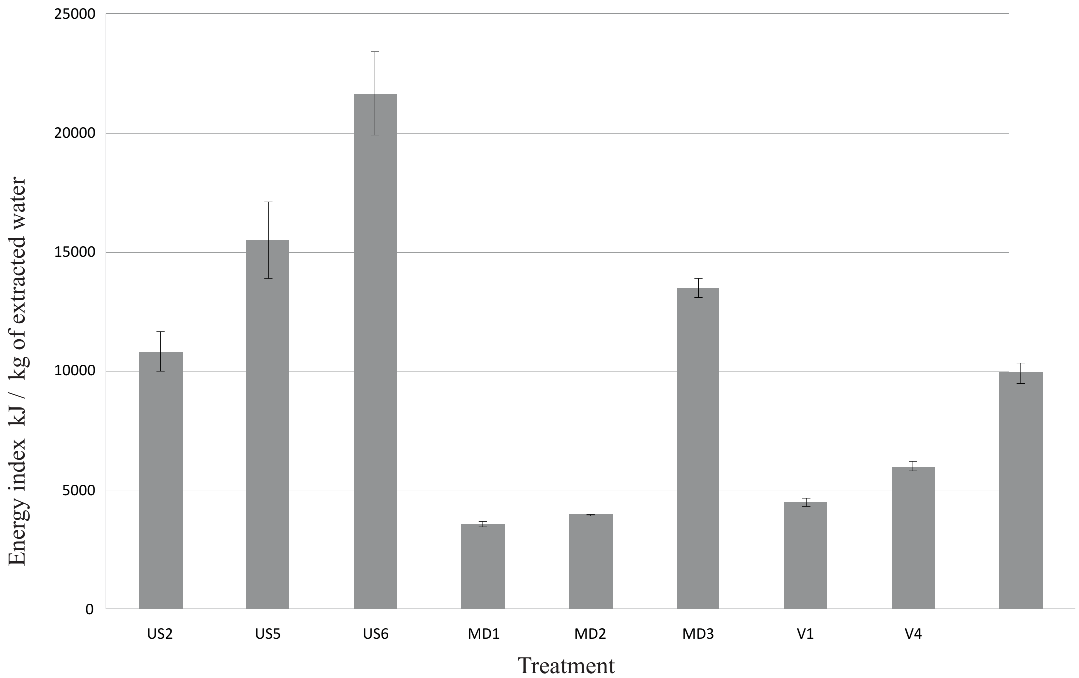

Figure 3. Energy consumed by various combined treatments.

4. Conclusions

Under the experimental conditions used in this work, microwave pretreatments (MD1 and MD2), showed promising effects as osmotic dehydration pretreatments. They have the highest positive influence on both solid and water transfer rates. This is probably due to the effect of high power energy transfer on cell wall disruption. Furthermore, MD1 and MD2 used the lowest amount of energy: 3,565 and 3,972 kJ / g of removed water, respectively. Lastly, rehydration levels after these treatments were low (around 46 % of that corresponding to a blank sample); therefore, products obtained will not be suitable for wet formulations.

Ultrasound treatments facilitate mass transfer during OD, mainly due to the cavitation effect (that reduces boundary layer resistance) and the formation of micro-channels in the intercellular structure. However, their effect on mass transfer during dehydration is low when compared with the effect that could have caused cell-wall disruption (MD1 and MD3). Additionally, US treatments are not environmentally friendly from the energy use standpoint. They showed energy levels that are from 3 to 6 times higher than those of MD1.

Vacuum impregnation experiments showed an important influence on solids transport rates; however, water losses were not high. These results were expected due to the hydrodynamic phenomena caused by the vacuum pulses. Although the energy index was not high for V1 and V4, these treatments were not as efficient as MD1 because the water losses were 66 % lower than those corresponding to the aforementioned microwave treatment. Lastly, due to the collapse caused by the evacuation of air from the sample's tissue during the vacuum pulses, the rehydration index was not high for this kind of combined treatments.

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