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FEASIBILITY OF ULTRASONIC WAVES TO IMPROVE MASS TRANSFER RATE DURING OSMOTIC DEHYDRATION OF SEEDLESS GUAVA (*Psidium guajava* L.)

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ABSTRACT

Osmotic dehydration is a viable process for the partial removal of water in which cellular materials are placed in a concentrated solution of soluble solute. The initial results showed that the values of mass transfer terms (0.2 (*g/g*) water loss and 0.03 (*g/g*) solid gain) at the studied range of process variables including temperature of 33 ºC, sucrose concentration of 30% w/w and 180 min of immersion time were not in accordance with an efficient osmotic dehydration process which 40–60% water loss and <10% solid gain are mostly aimed. Thus, feasibility of ultrasonic wave in order to improve the rate of mass transfer was investigated. Ultrasonic treatment was carried out with 20 kHz frequency in the amplitude range of 25-75% for different lengths of sonication time (10-30 min). The highest amounts of water loss (0.42 (*g/g*)) and solid gain (0.073 (*g/g*)) were obtained by application of ultrasonic treatment. These increases can be attributed to increased cell wall permeability, facilitating transport of water and solute, as evidenced by the excess conductivity of ultrasonically treated samples as compared with a control condition. The results revealed that ultrasonic technology can be carried out to improve rate of mass transfer during osmotic dehydration.

Keywords: Osmotic dehydration, Mass transfer, Seedless guava, Ultrasound wave.

INTRODUCTION

Guava, *Psidium guajava* L., is native to the Caribbean and common throughout all warm areas which has great amount of vitamins C (>3 times as much Vitamin C as an orange), A and B. Guava fruit, as other tropical fruits, is highly perishable which needs preservation methods to increase its shelf-life [1]. Drying is the most popular and well-known postharvest technology to increase shelf-life of tropical fruits which is perishable and deteriorates rapidly after harvesting [2]. Hot air drying method has several drawbacks such as quality deterioration of the final product, energy intensive and consequently cost intensive because it is a simultaneous heat and mass transfer process accompanied by phase change [3]. Therefore, scientists and innovative food centres try to develop new drying technologies with the aim to introduce new, safer, fresher and better quality foods with longer life for local and export markets. In recent years, osmotic dehydration has received increasing attention in field of fruits and vegetables preservation due to its potential to keep sensory and nutritional properties similar to the fresh fruits as well as low temperature and energy requirements [4]. Generally, osmotic dehydration is a low efficiency and slow process due to the fact that osmotic pressure is a sole driving force for mass transfer during the dehydration process [5]. Several studies have shown that the structure/composition of the material [6], the nature of the solutes [7] and the pretreatments such as freezing/thawing [8] are main factors which could affect mass transfer rate during osmotic dehydration process. Non-thermal processes combined with osmotic dehydration have been applied in order to improve processing efficiency and final product quality due to the undesired physico-chemical and nutritional changes during traditional thermal pretreatments. It was claimed that the high intensity of ultrasonic waves can generate cavitation inside liquids which can affect mass transfer due to the asymmetric implosions of the cavitation bubbles close to a solid surface [9]. In a solid medium, the sound waves cause other series of effects include heating of the medium [10], structural effects such as the ‘‘sponge effect’’ [11], acoustic streaming or micro-streaming [9] or the generation of micro-channels [12] that can affect mass transfer. Due to the very different results obtained for different fruits, more studies on the effect of power ultrasound on dehydration is still needed to evaluate for which type of fruits and vegetables this technology is viable. The aim of this study was to investigate the feasibility of ultrasound waves to improve the mass transfer rate during osmotic dehydration of seedless guava.

MATERIALS AND METHODS

Raw Material

Fresh seedless guava (*Psidium guajava* L.) fruits were obtained from a local market (Serdang, Malaysia) on daily basis prior to each set of experiments. Fruits were chosen at commercial maturity according to their similarity of color, size, absence of surface defects and ripening grade (around 8 ºBrix). Before each experiment fruits were washed, peeled and cut into 20±2 mm cubes manually using very sharp stainless steel knife, and gently blotted with tissue paper to remove the excess of surface humidity. Care was exercised to select only cubes that have same size to minimize the effect of sample size on the experimental data. The dimensions of fruit cubes were measured by Mitutoyo digital caliper (±0.02 mm) (Mitutoyo, Waterbury, CT, USA).

Ultrasound-assisted Osmotic Dehydration

The seedless guava cubes were treated in a 500 mL beaker filled with the sucrose solution (30% w/w) by a 500 W ultrasonic equipment (Sonics & Materials Inc., Model VC505, Danbury, CT, USA) equipped with a titanium ultrasonic probe (13 mm diameter) which fixed vertically at 1-2 cm from the samples. There was no direct contact between the fruit and the sonotrode. The nominal frequency was 20 kHz. In order to change ultrasonic intensities the power level was controlled by the variation of the amplitude of the piezo crystals. Applied amplitudes were 25%, 50% and 75% of the maximal equipment power (500 W), corresponding to 125, 250 and 375 W. The corresponding ultrasound intensities were 94, 189 and 284 W/cm^2. The immersed samples in the osmotic solution were subjected to ultrasonic waves during a period of 10 to 30 min. The temperature of the osmotic solution was maintained at 33 ºC throughout all treatments, and no significant increase in temperature (less than 2 ºC) was observed during treatment due to circulation of water in water bath (Memmert, WNE14. Memmert GmbH Co. KG, Germany). The ratio of fruit to osmotic solution was set at 1:10 (w/w). After the treatments, the samples were removed from the syrup, rinsed in distilled water (below 30 s) eliminate the excess solution adhered to the surface, and carefully blotted with tissue paper to remove the excess surface water. Sampling was performed in time intervals of 15, 30, 45, 60, 120 and 180 min of osmotic dehydration. The experimental set-up was shown in Fig 1. All experiments were performed in triplicate.

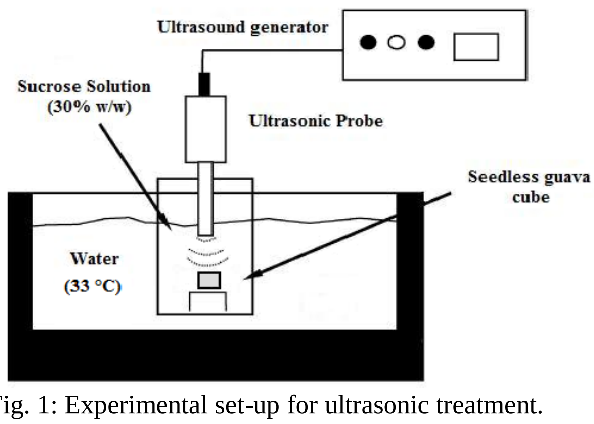

Fig. 1: Experimental set-up for ultrasonic treatment.

Determination of Water Loss (WL) and Solid Gain (SG)

The fresh and dehydrated seedless guava cubes after each contact time were placed in oven (Heraeus Vacutherm VT6025, Germany) at 105 °C until constant weight (48 h) in order to measure the moisture and solids content according to Association of Official Analytical Chemists (AOAC) method 931.04 (AOAC, 1990).

In order to determine mass change, all samples were weighed before and after treatment using an analytical balance (Mettler AJ 150, Switzerland) with accuracy of ±0.0001 g. From these data, water loss (WL) and solid gain (SG) were determined in all the cases at different times, t, in agreement with the following expressions [13].

$$WL(g/g) = \frac{(M_0 - m_0) - (M - m)}{M_0}, \quad (1) \qquad SG(g/g) = \frac{m - m_0}{M_0} \quad (2)$$

where M_0 is the initial mass of fresh sample (g), M is the mass of sample after time (t) of osmotic dehydration (g), m is the dry mass of sample (g) after time (t) of osmotic dehydration, m_0 is the initial dry mass of sample (g).

Determination of Membrane Damage or Conductivity

Conductivity of the solution after the desired osmotic dehydration intervals measured using a conductometer (model 30/10FT, Yellow Spring Instrument Co., Inc., USA) at 25 ºC. Measurements were done in triplicate and average values were reported.

RESULTS AND DISCUSSIONS

Effect of Ultrasonic Treatment on Water Loss and Solid Gain during Osmotic Dehydration

The experimental results obtained for WL and SG after osmotic dehydration with/without ultrasound treatment were illustrated in Figs 2 and 3, respectively. As expected, the treated samples showed higher SG and WL than non-treated fruit. The statistical analysis showed that there is no significant difference between 30 and 40 min of sonication time ($p > 0.05$) for all terms of mass transfer (data not shown). Thus, ultrasound should apply for 10-30 min. This finding is consistent with those obtained by Fernandes and Rodrigues [14] and Azoubel et al. [15].

Fig 2 plotted SG as a function of ultrasonic wave’s intensities and lengths of sonication time during osmotic dehydration. In the graph, as ultrasonic wave’s intensities and duration of ultrasonic treatment increase, SG by seedless guava samples also increased. According to Table 1, the highest amount of solid content for ultrasound-assisted osmotic dehydration was equal to 0.073 (g/g) ±0.009 while it was 0.040 (g/g) ±0.010 in absence of ultrasonic treatment. These findings are consistent with that of Fernandes and Rodrigues[14] who found that solid uptake increased up to 27.9%, 34.1% and 10% for papaya, pineapple and sapota by ultrasound treatment, respectively. This probably occurred due to the cellular tissue modification (intracellular adhesion) as a result of ultrasonic treatment which leads to collapse of cellular structure and flow of the solute to the fruit tissue. In addition, formation of micro-channels facilitates the transfer of solids through the tissue by decreasing resistance of the tissue to the flow of large molecules, such as sucrose molecules.

Fig 3 clearly shows the WL during the osmotic dehydration process with/without ultrasound at different ultrasonic wave’s intensities and sonication times. The variation of WL as well as SG in ultrasonic experiments significantly ($p<0.05$) depended on the intensity of ultrasound wave and duration of ultrasonic treatment. Seedless guava lost 0.19 (g/g) ±0.020 of water during osmotic dehydration in absence of ultrasound while the WL of ultrasonically treated seedless guava at ultrasound intensities of 94 and 284 W/cm^2 for 30 min of sonication time were 0.37 (g/g) ±0.010 and 0.42 (g/g) ±0.008, respectively (Table 1). Thus, the highest applied ultrasound intensity produced an intensive dehydration due to an alteration in the structure of seedless guavas tissue, allowing more water movement from the tissue to the sucrose solution. Similar findings further supported by Fernandes and Rodrigues[14] which reported 3.2%, 14.1% and 13.2% of WL during ultrasound-assisted osmotic dehydration of papaya, pineapple and sapota, respectively.

The WL/SG is an adequate index to assess the efficiency of osmotic process allowing prediction of the water and solute transfers’ relationship inside the food. The final WL/SG values were evaluated at each experimental condition and reflected in Table 1. It is obvious that with increase of ultrasound wave’s intensity the WL/SG ratio increase indicating a high efficiency of water removal with minimal solid uptake. Furthermore, increase the length of sonication treatment decrease the efficiency of the process which indicates the deep structural changes in product tissue. It is worthy of note that lost of membrane selectivity signifies more pronounced solid intake by the product which is often undesirable.

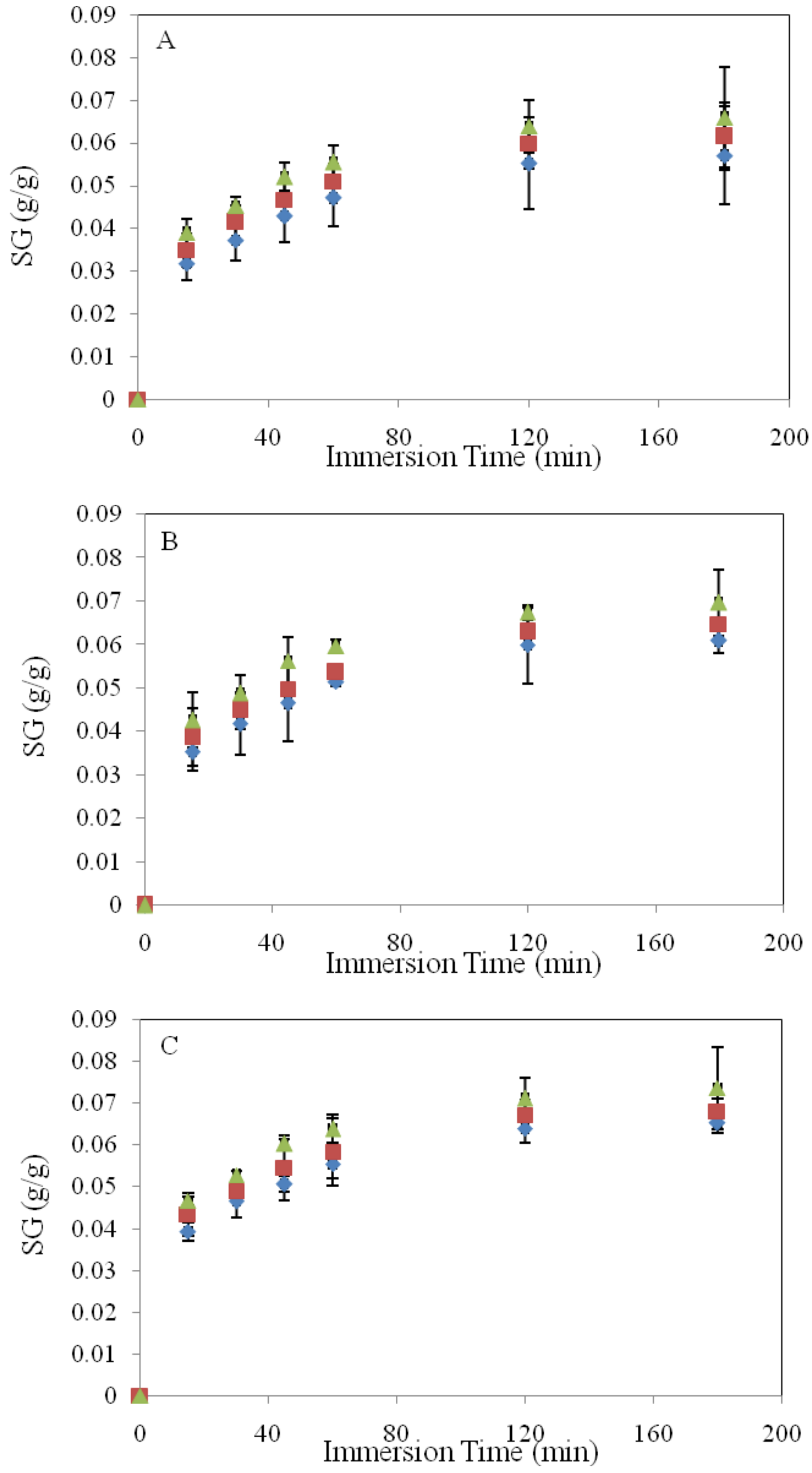

Fig. 2: Effect of ultrasonic wave's intensity on solid gain (A) 94 W/cm^2 (B) 189 W/cm^2 (C) 284 W/cm^2 at different time of exposure (♦) 10 (■) 20 (▲) 30 min.

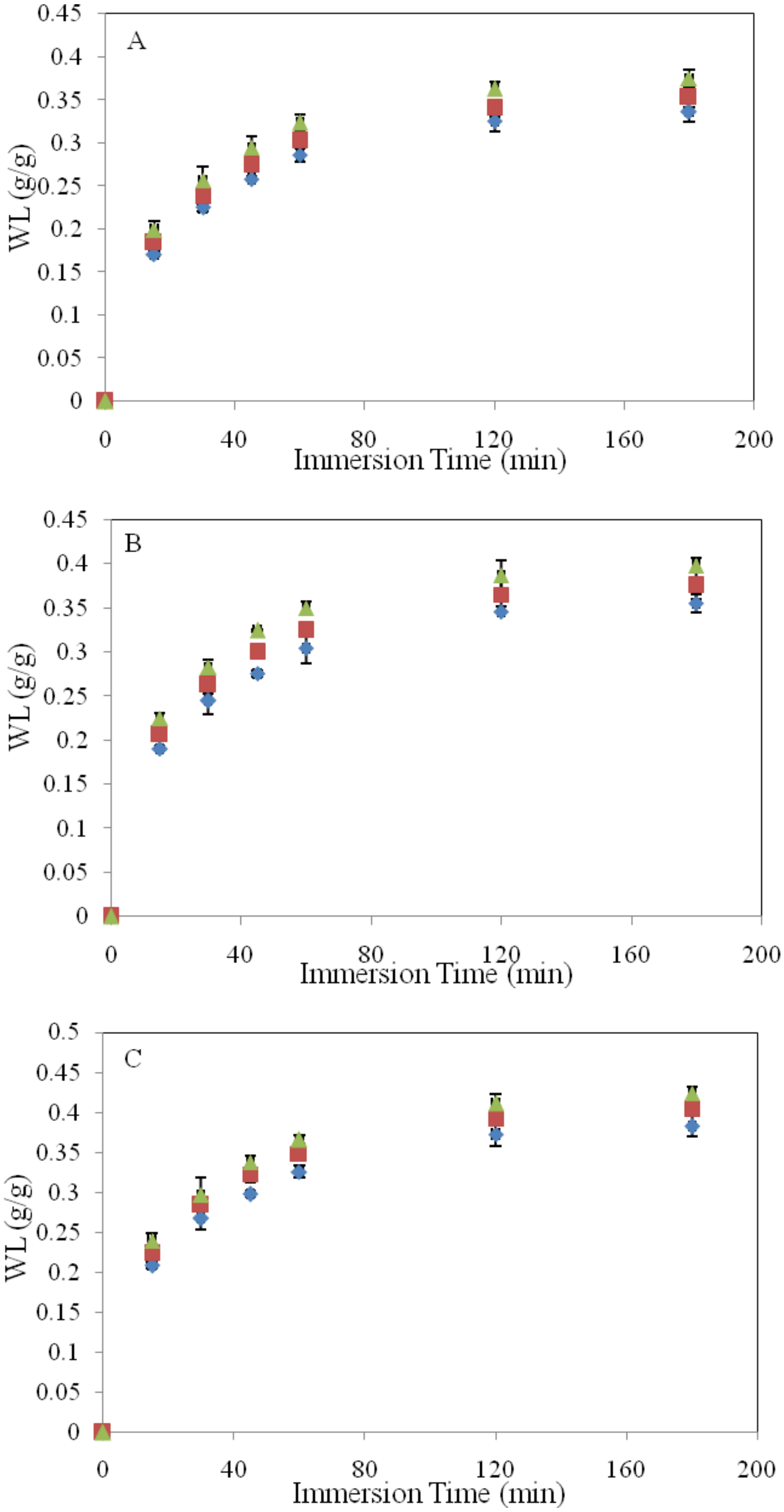

Fig. 3: Effect of ultrasonic wave's intensity on water loss (A) 94 W/cm^2 (B) 189W/cm^2 (C) 284 W/cm^2 at different time of exposure (♦) 10 (■) 20 (▲) 30 min.

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Table 1: Experimental solid gain, water loss and WL/SG values after 180 min of ultrasonic-assisted osmotic dehydration and untreated seedless guava.

Ultrasound intensity (W/cm^2)	Sonication time (min)	SG (*g/g*)	WL (*g/g*)	WL/SG
Untreated		0.040±0.010	0.19±0.020	4.75
94	10	0.057±0.010	0.33±0.010	5.78
	20	0.061±0.007	0.35±0.011	5.73
	30	0.066±0.011	0.37±0.010	5.60
189	10	0.060±0.002	0.35±0.009	5.83
	20	0.064±0.010	0.37±0.014	5.78
	30	0.069±0.007	0.39±0.007	5.65
284	10	0.065±0.002	0.38±0.012	5.84
	20	0.068±0.002	0.40±0.007	5.88
	30	0.073±0.009	0.42±0.008	5.75

Results were expressed as value ± standard deviation(S.D.).

Influence of the Ultrasound Treatment on Membrane Integrity

Leaching of cell constituents into the osmotic solution was determined by measuring conductivity of the medium which will give more information on the cellular integrity. The conductivity of osmotic solution at the end of the process without ultrasound treatment was 2.82±0.15 µs/cm. Fig 5 presents the conductivity of the solution containing treated samples. It is obvious that with higher ultrasonic wave's intensity and duration of sonication the tissue damage becomes more significant, which is indicated by the increase of conductivity of the products (9.2±0.15 µs/cm). Furthermore, a similar trend of the solution conductivity to WL is expected due to the fact that the cell constituents are released during WL. This is confirmed by results shown in Fig 2 and Table 1, which show the highest selectivity of tissue treated with higher ultrasonic wave's intensity and duration of exposure.

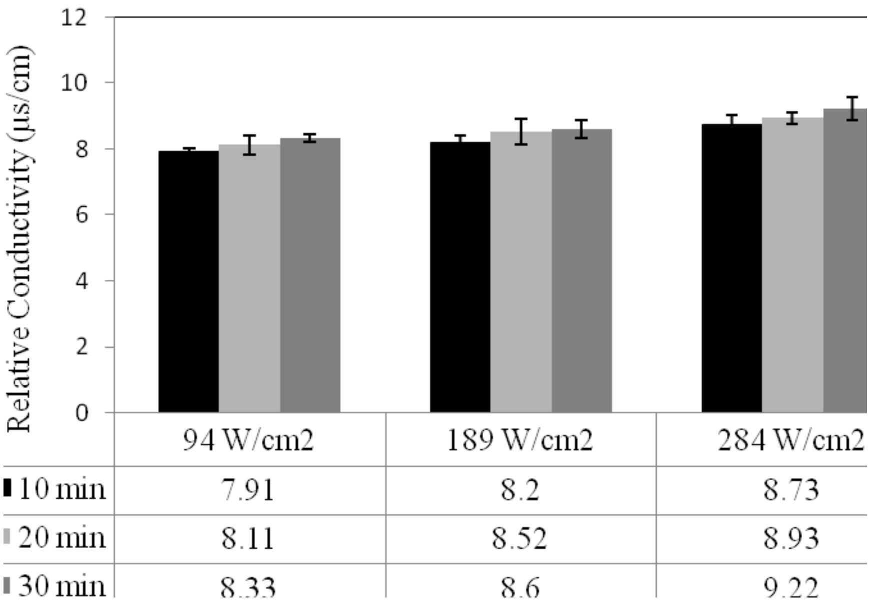

Fig.4: Effect of ultrasonic treatment on relative conductivity.

CONCLUSIONS

In the current study, the influence of ultrasound wave intensity and sonication time on the mass transfer rate during osmotic dehydration was investigated. Results indicated that ultrasonic treatment facilitates the enhancement of mass transfer during osmotic dehydration by increasing SG and WL, as evidenced by conductivity of solution. Due to fixed processing temperature, it can be concluded that this ultrasonic system seems to generate mechanical effects (nonthermal) rather than temperature effects. Applied ultrasonic intensity and length of sonication, however, should be chosen with much care as too high-intensity might result in quality loss. Therefore, further experiments are needed to determine the effects of ultrasound on the sensorial (excessive loss of texture and changes of color and flavor) and nutritional quality (namely vitamin C) attributes.

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