Effect of Fruit Size and Processing Time on Vacuum Impregnation Parameters of Cantaloupe and Apple

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ABSTRACT

This study evaluated the effect of two fruit sizes (3.5×2.5×1.0 and 1.2×1.2×0.8 cm^3) and processing time (impregnation and relaxation times; both for 10 and 20 min), on some vacuum impregnation parameters of cantaloupe and apple. Fruit size and processing time significantly affected the mass fraction of fruit occupied by impregnation liquid (X value) and the effective porosity (ε_e) of apples more than cantaloupe. High surface area of fruit and long processing times allowed for significant liquid penetration into the fruit. This study has shown that the effectiveness of vacuum impregnation is a surface-controlled phenomenon.

Keywords: Vacuum impregnation, Impregnation processing time, Fruit size, Cantaloupe, Apple

INTRODUCTION

Vacuum impregnation (VI) is a process that applies reduced pressure to a solid-liquid system, followed by restoration to atmospheric pressure. Vacuum pressure causes the gases inside tissue to expand and flow out of the extracellular spaces. When the pressure is restored, the residual gas is compressed and the external liquid flows into the product pores (Andrés et al., 2001; Krasaekoopt and Suthanwong, 2008). This process can be used to develop novel food products, especially fortified food products. The effects of vacuum impregnation on the properties of porous food materials, including fruits and vegetables, have been studied (Mújica-Paz et al., 2003a; Zhao and Xie, 2004). Some reports investigated using vacuum impregnation with different liquids for mineral fortification in fruits and vegetables (Fito et al., 2001; Gras et al., 2003; Zhao and Xie, 2004).

The quality of the final products after vacuum impregnation treatments was affected by several factors, such as the vacuum and relaxation times of the solid matrix (Derossi et al., 2010), mechanical properties of the materials, transport rate of hydrodynamic mechanism, food structure and size and shape of the sample (Zhao and Xie, 2004). The effect of vacuum impregnation on fruit was reported to be complicated, depending on types of the samples (Mujica-Paz et al., 2003b). However, the effect of fruit size, especially in cubic form, on vacuum impregnation parameters of fruit has not been reported. Although the vacuum impregnation properties of several tropical fruits have been studied, few have looked at cantaloupe.

This present study analyzed the effect of fruit size and processing time (both for impregnation and relaxation times) on some vacuum impregnation parameters of cantaloupe and apple. This understanding might lead to appropriate vacuum impregnation conditions for particular fruits and processes, including fortifying dehydrated fruit.

MATERIALS AND METHODS

Sample preparation for vacuum impregnation treatments

Fresh apple (*Malussylvestris* Mill var. *Granny smith*) and cantaloupe (*Cucumismelo* L. var. *cantalupensis*) were purchased from a local market in Chiang Mai, Thailand. The edible portions of apple and cantaloupe were cut into pieces 1.2×1.2×0.8 and 3.5×2.5×1.2 cm^3. Sucrose solution was used as an impregnation solution and prepared by adding commercial sucrose (MitrPhol Sugar, Thailand) in distilled water until its water activity (a_w) reached the value of the corresponding fruit pieces (Mujica-Paz et al., 2003b). During vacuum impregnation, fruit pieces were submerged in the solution at a ratio of fruit to impregnation liquid of 1:5 (w/w).

Vacuum impregnation treatments

The vacuum impregnation with sucrose solution was performed at 25°C in a vacuum oven (Binder VD23, Germany). The sample was treated under vacuum pressure of 50 mbar for a period of time (vacuum impregnation time), then the pressure was adjusted to atmospheric pressure for a preset time (relaxation time). Samples were then collected for analysis. Both the vacuum impregnation and relaxation times were varied at 10 and 20 min. Each experimental combination was run in triplicate. The amount of liquid incorporated into the fruit slices, expressed as X value, was obtained from Eq. (1) (Mújica-Paz et al., 2003a) and the volumetric deformation of the sample (γ) was calculated from Eq. (2) (Paes et al., 2008).

$$X = \frac{M_f - M_i}{\rho_s V_0} \quad (1)$$

$$\gamma = \frac{V_t - V_0}{V_0} \quad (2)$$

where M_f was the final mass of the fruit (kg), M_i was the initial mass of the fruit (kg), V_0 was the initial volume of the fruit (m^3), V_t was the final volume of samples (m^3) and ρ_s was the density of the sucrose solution (kg/m^3).

Effective porosity (ε_e) of the sample was determined using Eq. (3).

$$\varepsilon_e = \frac{(X-\gamma)r+\gamma}{r-1} \tag{3}$$

where *r* was a compression ratio (atmospheric/vacuum pressure) (Andrés et al., 2001).

The water loss (WL) and solid gain (SG) of the samples were calculated using Eq. 4 and 5 of Paes et al. (2008), respectively.

$$WL = \frac{W_{wo} - W_w}{W_o} \times 100 \tag{4}$$

$$SG = \frac{W_s - W_{so}}{W_o} \times 100 \tag{5}$$

where w_{wo} was the initial weight of water in the sample (kg), w_w was the weight of water in the sample at the end of the treatment (kg), w_o was the initial weight of the sample (kg), w_s was the weight of dry solids at the end of the treatment (kg) and w_{so} was the initial weight of dry solids in the sample (kg).

Statistical analysis

The experiment was set up using a Complete Randomized Design. Analysis of variance (one way ANOVA) was performed on the experimental results to determine the effect of treatments on the vacuum impregnation parameters. Mean differences were determined by Duncan's New Multiple Range. All statistical analysis was performed using SPSS Statistic Base version 17.0 for Windows, serial number 5068035 (SPSS Inc., Chicago, USA).

RESULTS

The volumetric fraction of fruit occupied by impregnation liquid was affected by fruit type. The incorporated liquid in apple was much higher than that of cantaloupe. The impregnation times also played a role, especially in apple (Figure 1). Smaller sample sizes and longer processing times resulted in higher volumes of incorporated liquid.

Corresponding to the X value, the effect of the studied parameters on ε_e was clearly seen in apple (Figure 2). Long processing time provided higher space for liquid penetration. The fruit size also affected the ε_e in the same trend as the processing time.

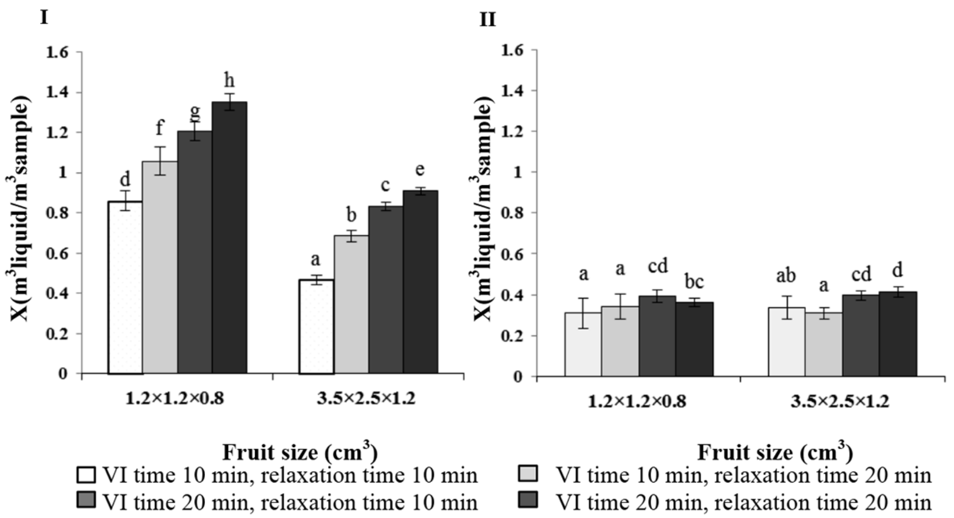

Figure 1. Effect of fruit size and impregnation time on mass fraction of fruits occupied by impregnation liquid (X value) of apple (left) and cantaloupe (right) after vacuum impregnation.

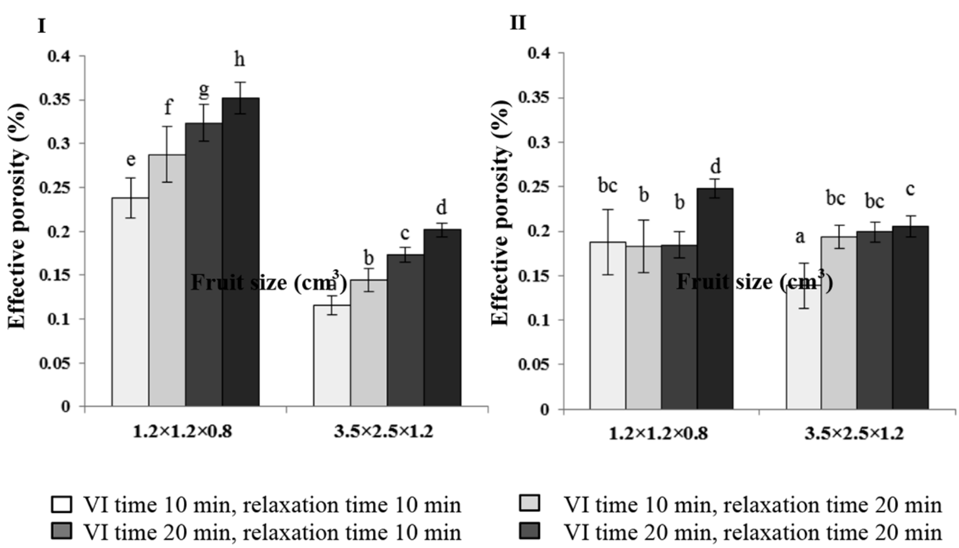

Figure 2. Effect of fruit size and impregnation time on the effective porosity (ε_e) of apple (left) and cantaloupe (right) after vacuum impregnation.

The fruit size and processing time significantly affected ($p<0.05$) both the water loss and solid gain of impregnated cantaloupe and apple (Table 1). In general, smaller fruit pieces and longer processing time increased absorption of the liquid into the fruit pieces. The water loss increased with longer vacuum impregnation and relaxation times. However, an increase in solid gain with the processing times was mainly observed in cantaloupe.

Table 1. Water loss and solid gain of vacuum impregnated cantaloupe and apple pieces.

Fruit type	Fruit size (cm^3)	Vacuum impregnation time (min)	Relaxation time (min)	Water loss (%)	Solid gain (%)
Apple	1.2×1.2×0.8	10	10	-24.73±2.86^{fg}	3.07±0.55^{h}
		20	10	-34.44±1.46^{a}	1.48±0.26^{e}
		10	20	-27.61±3.02^{de}	1.43±0.14^{e}
		20	20	-34.68±5.52^{a}	3.07±0.47^{h}
	3.5×2.5×1.2	10	10	-18.18±1.04^{i}	2.28±0.31^{g}
		20	10	-26.46±0.85^{ef}	1.78±0.24^{f}
		10	20	-23.59±0.76^{g}	0.73±0.11^{c}
		20	20	-30.37±2.71^{bc}	1.14±0.14^{d}
Cantaloupe	1.2×1.2×0.8	10	10	-26.98±2.11^{ef}	0.21±0.13^{ab}
		20	10	-29.63±1.61^{cd}	0.71±0.14^{c}
		10	20	-25.37±2.20^{efg}	0.30±0.07^{ab}
		20	20	-30.06±1.58^{bc}	0.92±0.14^{c}
	3.5×2.5×1.2	10	10	-20.78±2.38^{h}	0.14±0.05^{a}
		20	10	-24.91±1.46^{fg}	0.41±0.08^{b}
		10	20	-23.13±1.12^{g}	0.36±0.07^{ab}
		20	20	-32.19±1.48^{b}	0.87±0.12^{c}

Note: *The value presented is mean + standard deviation. Different letters within a column are significantly different ($p<0.05$).

DISCUSSION

The volumetric fraction of apple occupied by the impregnation liquid was higher than that of cantaloupe, indicating the difference in their tissue microstructure (Mújica-Paz et al., 2003a). The low impregnation level of cantaloupe could be affected by its fruit tissue structure that might involve an overlapping of different transport mechanisms during vacuum impregnation (Derossi et al., 2010). The insignificant effect of the processing time for cantaloupe in this study had also been reported for eggplant, carrot and mushroom (Gras et al., 2003). However, in general, longer processing time provided longer mass transportation time, which resulted in a higher volume of the external liquid being incorporated. The higher surface area of the small-sized apple samples also significantly ($p<0.05$) contributed to the transport mechanism as compared with the larger sample size.

The effective porosity, or ε_e, was described as the volume of the sample that could be occupied by the external liquid in the product tissue (Zhao and Xie, 2004). Longer processing time provided higher space for liquid penetration, which was probably due to attainable mechanical equilibrium (Cháfer et al., 2003). Krasaekoopt and Suthanwong (2008) reported a similar finding with the present study for guava and papaya.

All of the impregnated fruits had negative water loss values, indicating that the fruit samples absorbed the liquid during the impregnation process (Mújica-Paz et al., 2003b). The vacuum impregnation time had a much stronger effect on the water loss value than the relaxation time. Generally, water loss increased with longer vacuum impregnation and relaxation times. However, an increase in solid gain with longer vacuum impregnation and relaxation times was mainly observed in cantaloupe. This finding was similar to a previous report for mango (Khan et al., 2008). Martinez-Valencia et al. (2008) also reported increased water loss and solid gain of melon with increased immersion times, although the increase in water loss was higher than solid gain. At 10 min relaxation time, the solid gain of apple reduced at the longer vacuum impregnation time. The finding was affected by the fact that during reduced-pressure, native solution leached from the fruit intercellular spaces (Carciofi et al., 2012; Jacob and Paliyath, 2012). The loss of this native solution might not be fully replaced by solids in the impregnation solution both by the infused amount of the solution, which was due to a short relaxation time, and/or the low molecular weight of the solids in the external solution.

CONCLUSION

This present study demonstrated that fruit type, fruit size and impregnation processing time (both vacuum impregnation and relaxation times) played an important role in the mass transport phenomena during vacuum impregnation. Proportionally large surface area samples and long processing times provided better impregnation in terms of some vacuum impregnation parameters – mass fraction of fruit occupied by impregnation liquid, effective porosity, water loss and solid gain.

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