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Physical Properties of Impregnated Cantaloupe and Apple Affected by Different Pressure Levels

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ABSTRACT— ***This study aimed to understand the effect of different pressure levels between 50 and 1013.25 (atmospheric pressure) mbar on the physical characteristics of impregnated cantaloupe and apple pieces. The impregnation treatment was carried out at 25ºC in sucrose solution. Analyses of impregnated cantaloupe and apple showed that pressure levels during impregnation significantly affected all of the physical characteristics of the studied fruits, including lightness, water loss (WL), solid gain (SG), firmness, volume of fruit occupied by impregnation solution (X-value), fruit volume deformation (γ value), fruit porosity (ε_r) and effective porosity (ε_e)(P<0.05). At the highest vacuum pressure level of 50 mbar, the fruits exhibited the lowest lightness and ε_r values, but they had the highest values of WL, X, γ and ε_e. Apple samples significantly had higher X and γ values than those of cantaloupe at 50 mbar vacuum pressure. A higher ε_e value was also found in apple compared to that of cantaloupe at the range of studied pressure levels (P<0.05). Finding in this study demonstrated that higher vacuum pressure would be better to impregnate external solution into fruit samples. High fruit porosity would also facilitate better impregnation capacity.***

Keywords— Vacuum impregnation, Vacuum pressure, Impregnation medium, Cantaloupe, Apple

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1. INTRODUCTION

Cantaloupe (*Cucumis melo* L.) is cultivated in all the tropical regions of the world and recognized as an economically important crop [1]. The total production of the fruit in the world is around 27x10^6 ton per year [2]. The consumption of the fruit is steadily increased in Thailand. This could be partly due to the awareness for the presence of phytonutrients, ascorbic acid, vitamins A, folic acid, potassium and β-carotene in the fruit [3-4]. Cantaloupe is regarded as a seasonal crop and contains a high moisture content that causes the fruit to be very sensitive to microbial spoilage [2]. The short post-harvesting life of cantaloupe [5] creates difficulties during commercialization and transportation that leads to an increase in fruit losses. A further processing of the fruit by incorporating antimicrobial agents and/or reducing the moisture content of the fruit is desirable to extend the fruit shelf life.

Apple (*Malus sylvestris*, Mill) is one of the most widely cultivated tree fruits [6]. Growing apple could be done at high altitudes in Northern Thailand and the fruit has gained its popularity in the country. Some imported apple varieties are commonly sold in local markets of Thailand at rather low prices [7]. To overcome this, processing the fruit as a functional apple product will increase the fruit shelf life and provide a convenient way for consumers to handle and keep longer the product.

Fito *et al.* [8] has reported that both cantaloupe and apple had a significant amount of pores (intercellular spaces) to be occupied by external liquid through a vacuum impregnation (VI) process. The VI method of a porous food is a relatively new method to promote rapid compositional changes by introduction of desired food ingredients into products through its pores [9]. In a VI process, a porous product is immersed in a liquid medium. The product and its medium are subjected to a two-step pressure changes, including an application of pressure reduction and a restoration to atmospheric pressure. During the process of vacuum step, the internal gas in the product pores of the solid system is expanded and partially flowed out. At the same time, a limited amount of liquid penetrates the porous spaces adjacent to the liquid-solid interface through capillary forces. When the pressure is restored, the residual gas in the product pores is compressed and a bulk of external liquid penetrates into the product pores [10-13].

VI treatments have been studied to enrich food with nutritional and functional compounds to develop new food products and had been applied for fruits and vegetables without disrupting their cellular structure [8, 9, 14]. The VI process can be applied as a partial water removal before the main process, such as pasteurization, freezing and dehydration; solute impregnation with sugar or salt; product formulation and the combination of the previous three categories in successive processing steps [9, 15].

The quality of the final products after VI treatments was affected by several factors, such as pretreatment of samples, vacuum pressure, the length of time during vacuum period, the length of time of relaxation period, viscosity of external solution, temperature and concentration of solution, agitation, product/solution mass ratio and size and shape of the samples [9, 15]. A previous publication by Alzamora *et al.* [16], who reviewed about the effect of vacuum pressure levels between 75-425 mbar on apple cylinders, reported that the volumetric fraction of sample occupied by liquid was depended on the level of vacuum pressure. The higher the vacuum pressure, the volumetric fraction became larger. For the work of Mújica-Paz *et al*. [14], who investigated different vacuum pressure levels (135-674 mbar) and vacuum times (3-45 min) on mango, apple, papaya, banana, peach, melon and mamey, they reported that both the vacuum pressure level and time had a significant effect on the volume of isotonic solution impregnated in the studied fruits.

Several studies about VI have been conducted in narrow ranges of vacuum pressure level. In this present study broader pressure levels between 50 and 1013.25 mbar were applied and more physical parameters were also analyzed for the impregnated fruit samples to give a better understanding about the phenomena relevant with this process. Although some research works about VI fruits and vegetables have been reported, there was still limited information about cantaloupe. The objective of this study was to determine the effect of different pressure levels on the impregnated apple and cantaloupe. This information was expected to improve fruits processing for value-added and sustainable shelf life products.

2. MATERIALS AND METHODS

2.1 Sample preparation for impregnation treatments

Fresh apple (*Malus sylvestris*, Mill var. *Granny smith*) and cantaloupe (*Cucumis melo* L. var. *cantalupensis*) were purchased from a local market and selected according to a similar size, color and ripeness index (%Brix/acidity) in order to obtain homogeneous samples. Fresh cantaloupe and apple were kept in a refrigerator until used. On the experimental day, the edible portions of fruits were cut into 3.5×2.5×1.2 cm^3 piece. Impregnation solution was prepared by adding commercial sucrose into distilled water until the a_w of the solution was equaled with that of the corresponded fruit pieces [17]. For apple experiment, the a_w of the sucrose solution was adjusted to 0.993 ± 0.010, while the sucrose solution for cantaloupe had an a_w value of 0.992 ± 0.010. These solutions were used as a soaking medium during impregnation processes, which were conducted using a ratio of 1/5 (w/w) for fruit/sucrose solution. Throughout the impregnation treatment, fruit pieces were maintained to be immersed in the sucrose medium.

2.2 Impregnation treatments

The impregnation process with sucrose solution was performed at 25±0.5ºC in a vacuum oven (Binder VD23, Germany). The experiments were carried out using 4 levels of pressure, including 50, 100, 500 and 1013.25 (atmospheric pressure) mbar for 10 min. The application of 10 min impregnation time was correlated with the maximum SG that could be obtained within an impregnation period of 2 to 120 min [15]. After the impregnation treatment, fruit samples were left under the sucrose solution for an additional 10 min period [17] (recognized as a relaxation time). At the end of the impregnation process, the sucrose solution that adhered to the fruit surface was removed with a kitchen tissue paper. All experiments were run in triplicate. The samples were weighed at the beginning and at the end of the impregnation process to determine the amount of liquid incorporated into the fruit slices (X) using Eq. 1 [18] and the volumetric deformation of the fruit (γ) using Eq. 2 [19]

$$X = \frac{M_f - M_i}{\rho_s V_o} \qquad (1)$$

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) and ρ_s was the density of the sucrose solution (kg/m^3)

$$\gamma = \frac{Vt - Vo}{Vo} \qquad (2)$$

where v_0 was the initial volume of samples (m^3) and v_t was the final volume of samples (m^3).

The effective porosity (ε_e) was calculated using Eq. 3

$$X - \gamma = \varepsilon_e\left(1 - \frac{1}{r}\right) - \frac{\gamma}{r} \qquad (3)$$

where ε_e was the effective porosity and r value was a compression ratio (atmospheric pressure/vacuum pressure) [11].

In order to calculate water loss (WL) and solid gain (SG), the equations of Paes *et al.* [18] that were displayed in Eq. 4 and 5, respectively, were applied

$$WL = \frac{W_{wo} - W_w}{W_o} \times 100 \qquad (4)$$

$$SG = \frac{W_s - W_{so}}{W_o} \times 100 \qquad (5)$$

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).

2.3 Physicochemical analysis

Moisture contents and total acidity were determined according to AOAC [20] methods no. 942.15 and 981.12, respectively. Total soluble solids were measured using a hand refractometer (ATAGO, Japan). Color parameters (CIE L*- lightness value) of the fruit was evaluated by a Minolta colorimeter (CR-300, Minolta Co. Ltd., Japan). The ripeness index for each fruits was calculated as the ratio of the total soluble solids content to acidity. Fruit apparent density (ρ_a) was measured in fruit pieces and real density (ρ_r) in fruit purees. Both densities were determined using a water displacement method with sucrose solution [17]. The real density was measured on the fruit pieces that was previously homogenized and de-aired (at a pressure of 260 mbar for 2 h) in order to withdraw the occluded air [18]. All determinations were made in triplicate for each fruit. Fruit porosity (ε_r) (also known as total or real porosity) of the fruit was calculated using apparent and real densities according to Eq. 6 [12]

$$\varepsilon_r = \frac{\rho_r - \rho_a}{\rho_a} \qquad (6)$$

where ρ_a was the apparent density of the fruit (kg/m^3) and ρ_r was the real density of the fruit puree (kg/m^3).

The firmness of apple and cantaloupe samples was analyzed based on the compression model (60% deformation) using a Texture Analyzer (TA-XT.Plus, Stable Micro systems, Surrey, UK) carried out at 25°C. Samples were compressed till 60% strain at a deformation rate 2 mm/s. A 25 mm diameter plate probe (P/25) with 25 kg load cell at 10.0, 2.0 and 10.0 mm/s of pre-test, test and post-test speeds, respectively. The maximum compressing force (N) was recorded as the firmness value of the fruit samples. The texture of each fruit samples was determined for ten times measurement.

2.4 Statistical analysis

The experiment was set up using a Complete Randomized Design with three replications. Analysis of variance (ANOVA-one way) was performed on the experimental results to determine the effect of the treatment on the impregnation parameters. Mean differences evaluated by Duncan's New Multiple Range Test were analyzed using SPSS for Windows version 17.0 serial number 5068035 (SPSS Inc., Chicago, USA). Statistical significance between sample treatments was defined at $P<0.05$.

3. RESULTS AND DISCUSSION

3.1 The lightness value of impregnated apple and cantaloupe

Table 1: Physicochemical characteristics of apple and cantaloupe

Characteristics	Apple	Cantaloupe
Moisture content (%)	89.00 ± 3.79	93.32 ± 0.13
Apparent density (kg/m^3)	0.84 ± 0.06	0.96 ± 0.05
Real density (kg/m^3)	1.05 ± 0.04	1.11 ± 0.05
Fruit porosity (%)	0.21 ± 0.06	0.14 ± 0.04
Ripeness index (%Brix/acidity)	25.89 ± 2.00	44.89 ± 3.73
Firmness (N)	14.49 ± 1.25	25.02 ± 3.34

The physicochemical characteristics of the studied fruits are presented in Table 1. Both apple and cantaloupe had high moisture contents, which were similar to the reports of Salvatori *et al.* [19] and Mújica-Paz *et al.* [14]. The ripeness index corresponded to the fruit firmness and its organoleptic characteristics [17]. The ripeness indexes of apple and cantaloupe in this study were 25.89 ± 2.00 and 44.89 ± 3.73%Brix/acidity, respectively. These showed that the studied fruits had a firm texture and good organoleptic characteristics [14, 18]. In the fresh samples, cantaloupe had a firmer texture than that of apple. Fruit or real porosity (ε_r) represented available empty space inside the fruit that could be impregnated with sucrose solution [18]. Apple tissue had 1.5 times more empty spaces than cantaloupe tissue (Table 1). The apple porosity in this study was corresponded to the one reported by Paes *et al.* [18] for Fuji apple that had a porosity of 0.205.

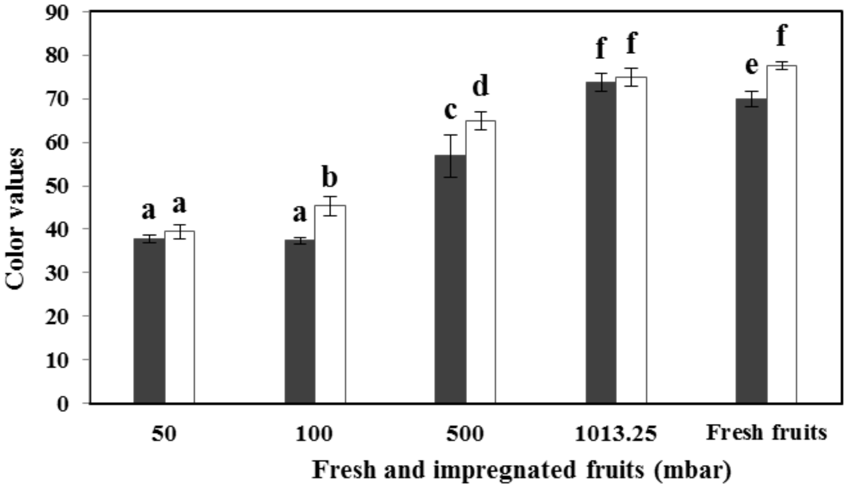

Figure 1: Lightness of fresh and impregnated cantaloupe (■) and apple (☐) affected by different pressure levels

Pressure levels significantly ($P<0.05$) affected the lightness of impregnated apple and cantaloupe (Figure 1). The lightness of impregnated apple and cantaloupe was reduced as the vacuum pressure levels increased to 50 mbar. However, at atmospheric pressure treatment the lightness of the samples was not significantly decreased compared with those of fresh fruits. Reduction in the lightness value was mainly affected by the replacement of air in the fruit pores with sucrose solution during the VI treatment, causing a more homogenous refractive index throughout the fruit sample [9, 21]. Although the color values of a* and b* were measured, the result trends were not as clear as the data of L* value. The impregnated cantaloupe experienced reductions in red and yellow color intensities as the vacuum pressure increased, while the impregnated apple had less green and yellow color intensities with higher vacuum pressure levels (data no shown). This finding was in an agreement with the report of Zhao and Xie [9], who reported a lightening and less color saturation of vacuum impregnated samples.

3.2 Water loss and solid gain

Applying different pressure levels significantly affected WL and SG of cantaloupe and apple (Table 2). The negative values of WL indicated that there was a water gain caused by impregnation of the sucrose solution in the fruit tissue [14]. As the vacuum pressure increased to 50 mbar, there was significantly more sucrose solution incorporated into the cantaloupe and apple ($P<0.05$). This implied that at higher vacuum pressure level, higher release of native liquid and gases was occurred [15]. Negative values of WL at atmospheric pressure could be due to impregnation of some external solution into the fruit tissues through capillary forces, which could occur in the area of liquid-solid interfaces [13]. Data in the Table 2 also demonstrated that impregnated apple gained more sucrose solution compared to that of cantaloupe at vacuum pressures of 50 to 500 mbar. The result could be affected by higher fruit porosity of apple than that of cantaloupe (Table 1) [15]. Zhao and Xie [9] reviewed that tissue structure (pores and size distribution) was one of the parameters affected the phenomena of gas outflows and liquid influx during VI treatment.

Changes in the SG of cantaloupe and apple after impregnation processes were less than those of the WL (Table 2). This fact could be affected by differences in the molecular size of water and sucrose that influenced the diffusion coefficient of the molecules [9, 22]. At the pressure levels of 500 and 1013.25 mbar, cantaloupe and apple encountered loss of solid, which could be due to higher native liquid came out from the fruit pieces, particularly during the vacuum period [9, 15, 17, 23], compared to the entering sucrose solution. Xie and Zhao [24] and Lozano [25] explained that the native liquid of fruit contained natural acids that could be present as a complex with mineral substances or other molecules, such as lecithin. The leaching of these components might not be fully replaced by the incoming sucrose in the impregnation solution, causing reduction in the fruit dry solid. Paes *et al.* [26] also mentioned that the use of sucrose solution that had similar water activities with the fruit samples assured for a similar water chemical potential, but it was not a similar chemical potential. Therefore, the application of a similar water activity for fruit sample and sucrose solution did not completely prevent the mass transfer between them. As the vacuum pressure increased to 50 mbar, there was a positive SG found in the studied fruits. This finding was in an agreement with the report of Maneepan and Yuenyongputtakul [27], who found that the SG of coconut samples under a vacuum treatment of 50 mbar was higher than those at 65 mbar. Results in the Table 2 also displayed that applying a vacuum pressure of 100 mbar significantly produced higher dry solids in cantaloupe and apple than those of 50 mbar. This could be affected by the modification of the fruit tissues at vacuum pressure of 50 mbar resulted in shrinkage that might lead to a decrease in the fruit pore space and consequently increase in the resistance to impregnation by external solution [19].

Table 2: Water loss, solid gain and firmness values of cantaloupe and apple after impregnation process affected by different pressure levels

Fruit	**Vacuum pressure (mbar)**	**Water loss (%)**	**Solid gain (%)**	**Firmness (N)**
Cantaloupe	50	-23.10 ± 3.39^{a}	1.43 ± 0.10^{c}	14.40 ± 4.09^{a}
	100	-15.15 ± 0.48^{b}	4.10 ± 0.10^{d}	22.01 ± 1.09^{b}
	500	-8.07 ± 0.52^{c}	-0.18 ± 0.13^{b}	25.97 ± 2.36^{c}
	1013.25	-2.40 ± 0.31^{d}	-0.80 ± 0.10^{a}	26.73 ± 1.09^{c}
Apple	50	-27.73 ± 1.08^{e}	0.88 ± 0.13^{g}	9.85 ± 3.04^{d}
	100	-18.68 ± 0.47^{f}	1.65 ± 0.10^{h}	10.22 ± 2.45^{d}
	500	-13.33 ± 0.38^{g}	-0.52 ± 0.11^{f}	12.96 ± 1.08^{e}
	1013.25	-2.72 ± 0.26^{h}	-1.00 ± 0.11^{e}	14.35 ± 2.20^{e}

Means with different superscripts within a column of each fruit type are significantly different P<0.05 (n=3)

Pressure levels during impregnation process and types of the fruit significantly (P<0.05) affected the firmness values of the impregnated apple and cantaloupe (Table 2). Treatment of cantaloupe and apple at 1013.25 mbar slightly affected the fruit firmness as compared with the fresh sample (Tables 1 and 2). An increase in the vacuum pressure levels to 50 mbar caused a decline in the apple and cantaloupe firmness values, which could be due to a greater structural deformation at higher vacuum pressure levels. A similar finding has been reported by Maneepan and Yuenyongputtakal [27] for coconut samples. The main alteration induced by a high vacuum pressure level on the structural matrix of the fruit samples was a loss in cell turgor pressure and cell deboning during impregnation process [18]. The loss of cell turgor and elasticity were then responsible for alterations in the cell resistance, changes the air and volume fractions of the fruit samples and changes in the sample shape [27]. Xie and Zhao [24] stated that a decrease in the maximum firmness values could also be attributed to the air liquid exchange during the vacuum operation.

3.3 Volumetric deformation of fruits and volume of fruit occupied by impregnation liquid

Different pressure levels applied during impregnation treatments significantly (P<0.05) influenced the X and γ values of cantaloupe and apple (Figure 2). The X value referred to the volumetric fraction of the sample occupied by the sucrose solution [17]. When the vacuum pressure level increased to 50 mbar, the X values of cantaloupe and apple were significantly increased. This indicated that higher vacuum pressure levels promoted more incorporation of the external solution into the fruit pores. This finding was parallel with the fact that higher release of native liquid and gas was occurred at higher vacuum pressure levels [9, 15], which could provide more spaces for the incoming sucrose solution. Similar results had also been reported by Andrés *et al.* [11] for apple and Alzamora *et al.* [16] for *Bifidobacterium* spp. At the highest vacuum pressure of 50 mbar, apple significantly had higher X value compared to that of cantaloupe. This result could be affected by the higher fruit porosity of apple (Table 1) and the cellular structure of the fruits. It was reported that apple had a rigid cellular structure that suffered a small texture deformation during VI treatments [18], whereas cantaloupe had a thin non-lignified walls, which produced a weak structure [28]. Derossi *et al.* [15] added that a high rigidity of sample tissue could have reduced the rate of compression phenomena and increased the liquid penetration.

The γ values represented the net volume changed at the end of the VI process, resulted from an initial swelling throughout the vacuum step and the later compression during the relaxation time [9, 11]. Both cantaloupe and apple experienced a significant increase (P<0.05) in the volume deformation as the vacuum pressure increased to 50 mbar (Figure 2). This finding was consistent with the review of Chiralt *et al.* [10]. Andrés *et al.* [11] stated that the volume deformation of a food sample could increase the sample pore volume for impregnation process. Therefore, apple samples that encountered more volume deformation provided more fruit pore for the external solution. At atmospheric pressure, apple fruit encountered negative fruit volume deformation or decrease in the pore volume, which could be due to loss of native liquid from the apple tissues [9, 23]. The volume deformation of a sample during VI was associated with raw material characteristics (porosity, size and shape) and VI conditions (type and concentration of solution, vacuum level and time) [9].

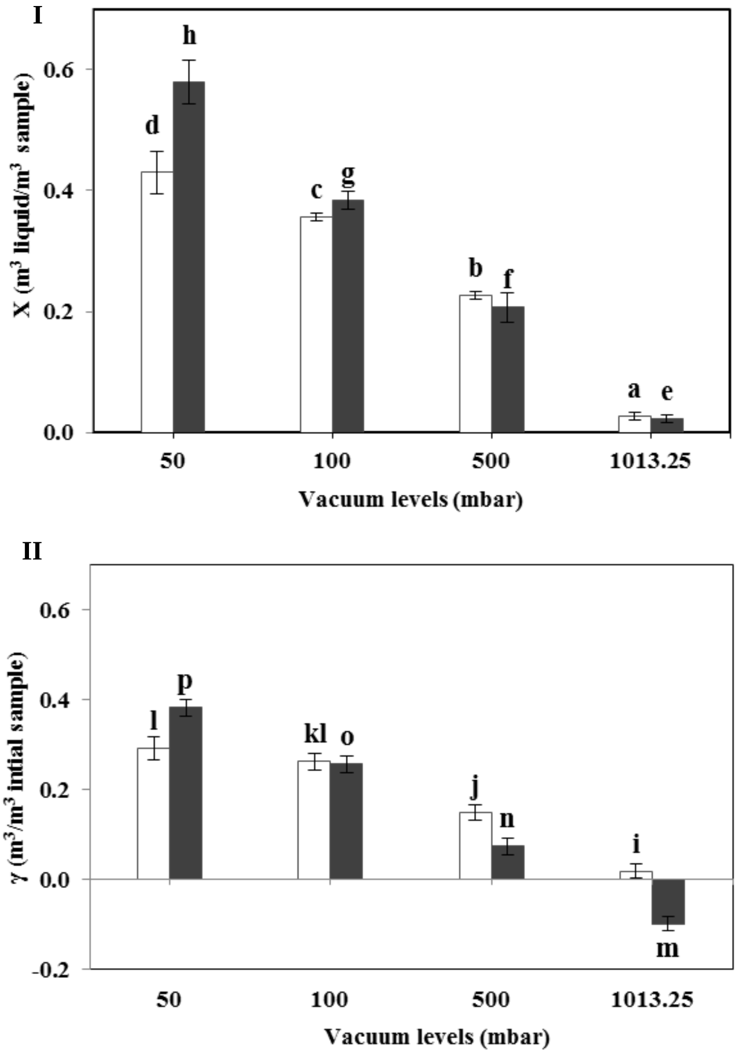

Figure 2: The volume of fruits occupied by sucrose solution (X) (I) and fruit volume deformation (γ) (II) of cantaloupe (☐) and apple (■) after vacuum impregnation process affected by different pressure levels

3.4 Effective porosity and fruit porosity

In the VI treatment, porosity of a solid matrix was the most significant structural property affected the VI effectiveness, since the porosity fraction exhibited the void space or empty area that was available to be impregnated with an external solution [10, 15]. The porosities of cantaloupe and apple, including effective (ε_e) and fruit (ε_r) porosities, are displayed in Figure 3. The ε_e values indicated the fruit volume that could be occupied by sucrose solution in the product tissue [9]. In this study, both cantaloupe and apple significantly ($P<0.05$) had an increase in the ε_e values as higher vacuum pressures were applied. This finding was correlated with an increase in the pore space of the studied fruit tissues at higher vacuum pressure levels, as a result of high expansion and release of gas inside the pores of fruit tissues. High vacuum pressure levels also allowed a greater removal of native liquid from the fruit tissue structure, producing higher volume of fruit pores to be available for the external solution [15]. The result in this study was corresponded well with the reports of Zhao and Xie [9] for mango and peach and Krasaekoopt and Suthanwong [12] for papaya and guava. Figure 3 also showed that apple had higher ε_e values compared to those of cantaloupe at the studied pressure levels. This could be affected by bigger porosity of the first fruit and its rigid cellular structure.

The ε_r value described a measure of the empty space in fruit that could be impregnated with external solution [10]. The ε_r values of cantaloupe and apple were significantly reduced as higher vacuum pressure was applied (Figure 3). This result was correlated with the findings of ε_e value and WL (Table 2). At higher vacuum pressure levels, the fruit samples provided more empty area for the external solution (ε_e value) due to higher release of gas from inside the fruit pores. However, most of these area were dominated by the incoming sucrose solution (WL), causing a decrease in the empty area of the fruit tissues (ε_r value). Doing impregnation treatment at atmospheric pressure did not significantly reduce the ε_r value (Figure 3 and Table 1), which was also shown by a low amount of sucrose solution entered the fruit tissues (WL in Table 2). This indicated that there was still a free volume available in the studied fruits to be impregnated with the external solution. The low impregnation result at atmospheric pressure could be influenced by the capillary effect that might inhibit the free volume to be completely filled by the sucrose solution [14].

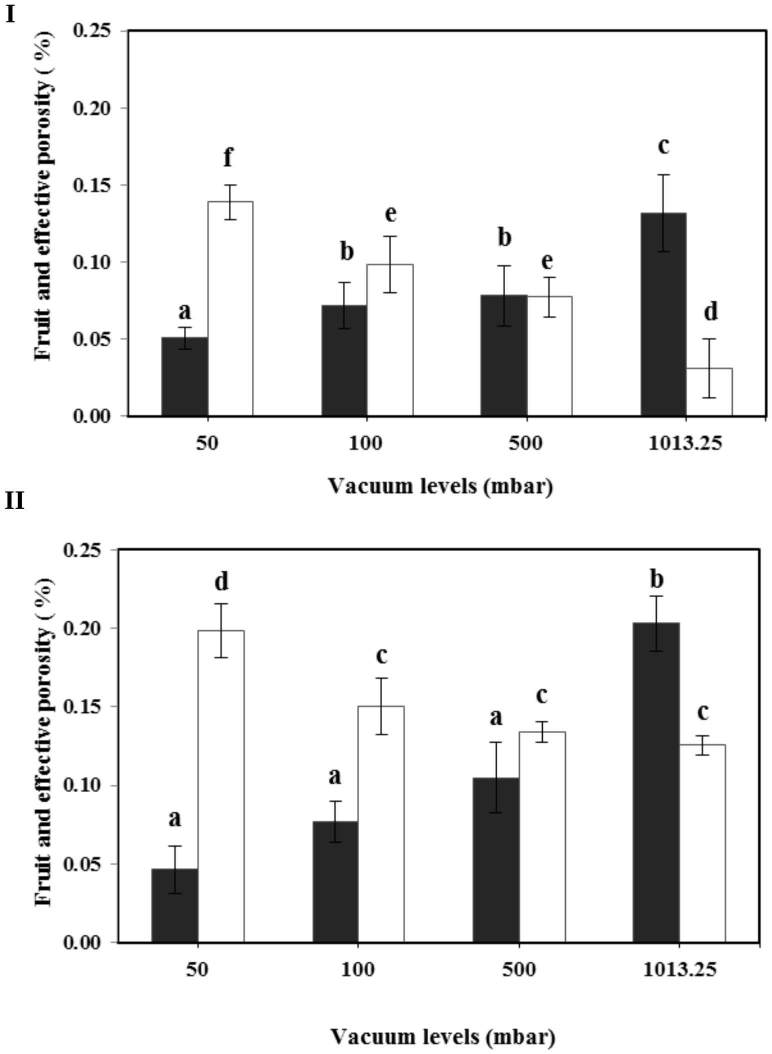

Figure 3: The fruit porosity (ε_r, %) (■) and effective porosity (ε_e, %) (☐) of cantaloupe (I) and apple (II) after vacuum impregnation process affected by different pressure levels

Salvatori *et al.* [19] suggested that a comparison between the fruit porosity and the effective porosity to be defined as the total fraction of the fruit pores available to be impregnated by an external solution. The $\varepsilon_e/\varepsilon_r$ ratio of cantaloupe and apple was within the range of 0.23-1.01 and 0.73-0.96, respectively, affecting by different pressure levels. This ratio clearly demonstrated that the pressure levels significantly affected the impregnation of sucrose solution into the fruit pores. Although apple had bigger fruit porosity to be impregnated, the application of vacuum pressure could significantly improve the impregnation capacity of cantaloupe through the release of native liquid and gasses and modification of the fruit tissue. Salvatori *et al.* [19], reported $\varepsilon_e/\varepsilon_r$ ratios of 0.59-0.76 for apple, mango and strawberry impregnated at 50 mbar for 5-15 min with sucrose solution. For different apple varieties, Andrés *et al.* [11] reported the $\varepsilon_e/\varepsilon_r$ ratios of 0.69, 0.88 and 0.94 for *Golden*, *Granny Smith* and *Red Chief*, respectively.

4. CONCLUSIONS

Collected data in this study clearly demonstrated that applying higher vacuum pressure levels significantly produced a better impregnation of the sucrose solution into the studied fruit tissues. The highest impregnation of the sucrose solution in cantaloupe and apple was achieved at a vacuum pressure of 50 mbar, which was accompanied by the highest fruit volume deformation. The application of this vacuum pressure level was also relevant with the general practice of industrial vacuum pumps that operated at 50 to 100 mbar [11]. Fruit characteristics, particularly porosity of the fruit tissue, had a significant effect on the application of VI. Fruit with high porosity, such as apple, also produced a high impregnation capacity.

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