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Effect of ripening stage and vacuum pressure on vacuum impregnated mango 'Chok Anan'

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Abstract

Mango is a climacteric fruit that has attractive color, delicious taste and provides high contents of ascorbic acid and phenolic compounds. In the current study, mango 'Chok Anan' at different ripening stages was subjected to a vacuum impregnation process at various vacuum pressures (between 50 and 1013.25 mbar). The flesh of mango fruit was cut into 3.0x2.0x1.0 cm^3, vacuum impregnated with sucrose solution for 10 min at room temperature, left for another 10 min in the sucrose solution at atmospheric pressure, removed from the solution and analyzed for its physicochemical characteristics. Collected data showed that the ripening stage of the mango affected color values of a^* and b^*, pH, hardness and solid gain (SG) of the vacuum impregnated mango. Different vacuum pressures that applied to mango pieces influenced fruit porosity (ε_r) and effective porosity (ε_e) of the final mango product. On the other hand, a combination of both parameters studied in the research had a significant effect on a color value of L^*, water loss (WL), volume of fruit occupied by impregnation solution (X value) and fruit volume deformation (γ value) of the processed mango. The pieces of unripen mango impregnated at 50 mbar significantly had the lowest ε_r of 0.03±0.01%, the lowest WL of -14.63±0.74% and the highest X value of 0.22±0.02 m^3 liquid/m^3 sample ($p<0.05$). Finding in this study demonstrated that the ripening stage and vacuum pressure levels were important parameters to be considered in the application of vacuum impregnation to introduce desirable solute into a porous structure of fruit.

Introduction

Mango (*Mangifera indica* L.) is a climacteric fruit that belongs to the family Anacardiaceae (Ornelas-Paz *et al*., 2008; Kim *et al*., 2010; Tovar *et al.,* 2011). It is one of the most important tropical fruits, in which Asia accounts for approximately 77% of global mango production and America and Africa produce for the remaining 23% (Kim *et al*., 2010; Ribeiro and Schieber, 2010). After harvesting, the ripening process of mango fruit occurs rapidly, which is affected by cultivar, stage of maturity at harvest and postharvest conditions (Ketsa *et al*., 1999; Ornelas-Paz *et al*., 2008). According to Ketsa *et al.* (1999), changes in the mango ripening can take place within 7 to 10 days at ambient temperature.

Consumption of mango flesh can be done in various forms both ripe and unripe stages. Although it is common to eat fresh fruit, the fruit flesh is also processed into different food products, including puree, nectar, powder, pickles, canned mango slices, chutneys, dried fruit, juices and desserts (Dissa *et al*., 2008; Ribeiro and Schieber, 2010; Kim *et al*., 2010; Liu *et al*., 2013). Processing mango into different food products is one way to reduce the fruit losses at its peak harvest periods (Ribeiro and Schieber, 2010). Nevertheless, some of the mango preservation methods need a pretreatment before the main process, which is aimed to maintain the nutritional compounds in the raw material and/or improve the quality of the final product (Nieto *et al*., 2001; Chen *et al*., 2007; Liu *et al*., 2014). An unconventional pretreatment process that can be applied to mango flesh is vacuum impregnation. This process can be done prior to the main procedure of canning, freezing, frying, drying and pasteurization (Zhao and Xie, 2004). Besides improving the quality of the final product, this particular pretreatment could also be used to develop a compositionally formulated product by introducing functional food ingredients, such as anti-browning agent, pH reducer, firming agent, antimicrobial agent or nutraceutical compounds (Mújica-Paz *et al*., 2003a; Zhao and Xie, 2004; Perez-Cabrera *et al*., 2011).

Vacuum impregnation is a method that is carried out by immersing a sample in an adequately formulated solution under specific conditions of

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pressure (González-Fésler *et al*., 2008). During the vacuum impregnation process, the initially occluded air in pores of the sample is replaced by the external formulated solution (Schulze *et al*., 2014). By doing this, desired food ingredients in the external solution can be directly impregnated into the sample pores in a controlled way (Zhao and Xie, 2004). Several parameters affecting the effectiveness of vacuum impregnation are vacuum pressure levels, the length of vacuum pressure treatment, the length of relaxation period (the period to restore atmospheric pressure while maintaining the sample in the solution), viscosity of external solution, temperature, concentration of solution, product/solution mass ratio, size and shape of the sample and the mechanical properties of biological tissues (Derossi *et al*., 2012). Derossi *et al*. (2010) studied a reduction of the pH of pepper by different vacuum pressure levels and reported that a greater impregnation level was obtained when the vacuum acidification of pepper was done at 200 mbar compared to those at 400 mbar. Another research work by Mújica-Paz *et al*. (2003a) that investigated about different vacuum pressure levels (135-674 mbar) and vacuum times (3-45 min) to impregnate isotonic solution in mango, apple, papaya, banana, peach, melon and mamey showed that the vacuum pressure level and time gave a significant effect on the volume of the isotonic solution impregnated in the studied fruits. Although different vacuum pressure levels had been studied for some fruit and vegetables, there was not any publication that examined the relationship between fruit ripening and vacuum pressure levels during vacuum impregnation. The knowledge of vacuum impregnation treatment for different stages of fruit ripening was important, since fruit ripening would rapidly change the fruit firmness due to the natural degradation of fruit cell wall (Toivonen and Brummell, 2008). Therefore, this research was focused on the effectiveness to impregnate an external solution into mango flesh from three ripening stages of mango 'Chok Anan' processed at different vacuum pressure levels.

Materials and Methods

Mango samples

Fresh mango variety 'Chok Anan' was purchased from a local market in Chiang Mai, Thailand. The mango fruit was divided into 3 different ripening stages based on the mango peel color (Nordey *et al*., 2014) and hardness (Kim *et al*., 2010) to be unripen, half ripen and ripen mangoes. The ripening indexes of different ripening stages of the mango samples were 12.37±0.28, 19.16±2.33 and 49.80±0.38 % Brix/acidity, respectively. Prior to be used in the experiment, all of the mango fruit was washed with tap water and left to dry at room temperature for 30 min. After removing the skin and seed of the mango fruit with a sharp knife, the mango flesh was cut into 3.0 x 2.0 x 1.0 cm^3. Fresh mango meat was kept in a refrigerator until being used in a vacuum impregnation process.

Vacuum impregnation process

Impregnation solution was prepared by adding commercial sucrose (Lin, Thailand) into distilled water (Polestar, Thailand) until the a_w of the sucrose solution was equivalent with that of the corresponded mango pieces (Mújica-Paz *et al*., 2003b). The aw of unripen and half ripen mangoes was 0.990±0.000, while the aw of ripen mango was 0.992±0.001. In each of the vacuum impregnation processes, mango samples were immersed in the impregnation solution at a ratio of 1:5 (w/w). During the impregnation treatment, mango pieces were maintained to be submerged in the sucrose solution.

The impregnation process of mango fruit in sucrose solution was carried out at 25±1ºC in a vacuum oven (Binder VD23, Germany). The process of impregnation was done at different vacuum pressure levels of 50, 100, 500 or 1013.25 (atmospheric pressure) mbar for 10 min (Gras *et al*., 2003; Rongkom *et al*., 2013). Following the impregnation treatment, mango samples were further left under the sucrose solution for an additional time of 10 min, which was also recognized as a relaxation time (Gras *et al*., 2003; Mújica-Paz *et al*., 2003b). After the impregnation process, the mango fruit was separated from the sucrose solution using a household strainer and left for a further 10 to 20 min at room temperature to remove any excess sucrose solution that was adhered to the fruit surface. The vacuum impregnated mango samples were then stored at a refrigerator for physicochemical analyses. All experiments were performed in triplicate.

Physicochemical analyses

Weight of mango samples was measured at the beginning and at the end of the impregnation process to determine the amount of liquid impregnated into the fruit pieces (X value) according to Eq. 1 (Mújica-Paz *et al*., 2003a) and volumetric deformation of the fruit samples (γ value) based on Eq. 2 (Salvatori *et al*., 1998).

$$X = \frac{M_f - M_i}{\rho_s V_o} \tag{1}$$

Where, M_f was the final mass of mango (kg), M_i was the initial mass of mango (kg), V_o was the initial volume of mango pieces (m^3) and ρ_s was the density of the sucrose solution (kg/m^3).

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

Where, Vo was the initial volume of mango samples (m^3) and Vt was the final volume of mango samples (m^3).

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

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

Where, ε_e was the effective porosity and r value was the compression ratio (atmospheric pressure/vacuum pressure) (Andrés *et al*., 2001).

In order to calculate water loss (WL) and solid gain (SG), the equations of Paes *et al.* (2008), which were shown in Eq. 4 and 5, respectively, were applied.

$$WL = \frac{Wwo - Ww}{Wo} \times 100 \quad (4)$$

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

Where, w_{wo} was the initial weight of water in the mango sample (kg), w_w was the weight of water in the mango sample at the end of the treatment (kg), w_o was the initial weight of the mango 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 mango sample (kg).

Color parameters of mango flesh, including L^* (lightness), a^* (red color coordinate for positive value and green color coordinate for negative value) and b^* (yellow color coordinate for positive value) was measured by a Minolta colorimeter (Minolta CR-300, Japan). Total soluble solids of mango samples were determined using a hand refractometer (ATAGO, Japan). The measurement of pH of mango samples was carried out using a pH meter (Consort C830, Belgium). Fruit porosity (ε_r), which was also known as total or real porosity was calculated using apparent and real densities according to Eq. 6 (Krasaekoopt and Suthanwong, 2008; Rongkom *et al.*, 2013).

$$\varepsilon r = \frac{\rho r - \rho a}{\rho a} \quad (6)$$

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

Hardness or firmness of mango flesh was examined based on a compression model (60% deformation) using a Texture Analyzer (Stable Micro systems TA-XT Plus, Surrey, UK), which was performed at 25ºC. Mango samples were compressed until 60% strain at a deformation rate of 2 mm/s. A 25 mm diameter plate probe (P/25) with 25 kg load cell was used at 10.0, 2.0 and 10.0 mm/s of pre-test, test and post-test speeds, respectively. The maximum compression force (g force) was recorded as the hardness value of mango samples. The firmness of each mango sample was determined for ten times measurement (Rongkom *et al*., 2013).

Statistical analysis

The experiment was prepared using a Completely Randomized Design with three replications. Analysis of variance (ANOVA-one way) was performed for the experimental results to determine the effect of treatments on the physicochemical parameters of impregnated mango. Mean differences were evaluated by Duncan's new multiple range test (DMRT), which was analyzed using SPSS for Windows version 17.0 serial number 5068035 (SPSS Inc., Chicago, USA). Statistical significance between sample treatments was defined at $p<0.05$.

Results and Discussion

Some physicochemical properties of vacuum impregnated mango, including color values, pH, total soluble solids and hardness, are displayed in Table 1. The color data of L^* value of the mango samples showed clearly that both ripening stages and vacuum impregnation levels significantly affected the mango lightness ($p<0.05$). The L^* values of fresh mango flesh were 86.35±1.62, 79.38±3.25 and 72.11±0.94 for unripen, half ripen and ripen mango, respectively. Higher L^* value of unripen mango flesh had been reported by Kim *et al*. (2010). Applying lower vacuum pressure levels during impregnation treatments significantly produced lower L^* value of the mango samples ($p<0.05$). This finding could be affected by gas-liquid exchange in mango pieces during the impregnation process, producing a more homogenous refraction index throughout the sample (Zhao and Xie, 2004). A similar outcome was also found by Rongkom *et al.* (2013) for apple and cantaloupe. For the a^* and b^* values of the vacuum impregnated mangoes, they were more affected by the ripening stages of the mango compared to the vacuum pressure levels (Table 1). As the mango samples become ripen, they have red color with more yellow color directions. Padda *et al.* (2011) also reported that during ripening of 'Keitt' mango fruit at 20ºC for 14 d, the L^* value of the fruit was decreased with an increase in the a^* and b^* values. It was worthy to be noted that doing a vacuum impregnation for ripen mango fruit could significantly decrease its b^*

Table 1. Effect of mango ripening stages and vacuum pressure levels on the color, pH, total soluble solid and hardness of vacuum impregnated mango 'Chok Anan'

Ripeness stage of mango	Vacuum pressure (mbar)	L*	a*	b*	pH	Total soluble solid (%Brix)	Hardness (g force)
unripen	50	60.98 ± 3.47^{c}	-7.93 ± 0.64^{a}	23.47 ± 2.01^{a}	2.91 ± 0.01^{a}	10.00 ± 0.00^{a}	505.43 ± 54.95^{b}
	100	61.74 ± 7.63^{c}	-7.33 ± 0.91^{ab}	25.62 ± 2.80^{a}	2.90 ± 0.02^{a}	10.00 ± 0.00^{a}	561.67 ± 61.69^{c}
	500	78.16 ± 3.99^{gh}	-7.80 ± 1.06^{ab}	25.88 ± 3.70^{a}	2.90 ± 0.03^{a}	10.00 ± 0.00^{a}	629.02 ± 104.89^{d}
	1013.25	82.09 ± 1.65^{h}	-7.30 ± 1.64^{abc}	27.62 ± 1.97^{a}	2.95 ± 0.05^{a}	10.00 ± 0.00^{a}	662.59 ± 124.13^{e}
Half-ripen	50	68.56 ± 4.40^{de}	-6.82 ± 1.70^{bc}	50.12 ± 3.25^{bcd}	3.34 ± 0.03^{b}	15.11 ± 1.76^{c}	31.37 ± 5.14^{a}
	100	69.80 ± 2.92^{ef}	-7.11 ± 0.88^{abc}	49.34 ± 3.10^{bcd}	3.39 ± 0.16^{b}	12.67 ± 1.00^{b}	34.53 ± 6.06^{a}
	500	74.16 ± 2.55^{fg}	-7.47 ± 1.29^{ab}	53.21 ± 2.56^{d}	3.36 ± 0.11^{b}	12.67 ± 1.00^{b}	43.35 ± 6.07^{a}
	1013.25	75.31 ± 4.84^{g}	-6.29 ± 1.42^{b}	51.47 ± 4.23^{cd}	3.40 ± 0.08^{b}	13.33 ± 1.00^{b}	60.57 ± 5.47^{a}
ripen	50	51.65 ± 7.25^{b}	1.72 ± 0.82^{d}	45.42 ± 4.96^{b}	4.42 ± 0.07^{c}	15.91 ± 0.63^{cd}	24.91 ± 4.06^{a}
	100	46.55 ± 3.17^{a}	3.49 ± 0.67^{e}	46.77 ± 8.75^{bc}	4.62 ± 0.14^{d}	16.91 ± 1.27^{d}	30.66 ± 3.69^{a}
	500	63.65 ± 5.84^{cd}	4.26 ± 0.96^{e}	65.53 ± 3.39^{e}	4.39 ± 0.07^{c}	15.91 ± 1.09^{cd}	35.17 ± 8.43^{a}
	1013.25	67.62 ± 4.33^{de}	3.75 ± 0.79^{e}	62.96 ± 5.21^{e}	4.33 ± 0.21^{c}	15.96 ± 0.80^{cd}	37.56 ± 6.10^{a}

$^{a-h}$ Different letters within a row are significantly different by DMRT at 95% confidence level ($p<0.05$).
The values are average of three experiments. The values are average ± standard deviation.

value ($p<0.05$). The possibility of some degradation or loss of fruit pigments during the impregnation process could not be ruled out (Chiralt and Talens, 2005).

For the pH, total soluble solid and hardness of mango fruit, the ripening stages of the raw material had a more pronounced effect than the different vacuum pressure levels applied during impregnation processes (Table 1). Significant higher pH values and total soluble solid with lower hardness of the ripen mango than those of the unripen samples were in an agreement with the reports of Joas *et al*. (2009) for mango 'Cogshall' and Padda *et al*. (2011) for mango 'Keitt'. Processing unripen mango with vacuum impregnation at higher vacuum pressure levels could significantly reduce its hardness value ($p<0.05$). Chiralt and Talens (2005) reported that some changes induced by osmotic treatments were loss of cell turgor, alteration of middle lamella, alteration of cell wall resistance, changes in air and liquid volume fractions in the sample and changes in sample size and shape. The effect of these changes was less noticeable in the half ripen and ripen mango samples, which could be due to lower firmness of mango cell walls from pectin methyl esterases, polygalacturonase, galactosidases and β-1,4-gluconanases degradation (Sane *et al*., 2005; Baloch and Bibi, 2012).

WL and SG values of vacuum impregnated mango can be seen in Figure 1. Negative values of WL indicated that there was water gain caused by impregnation of the sucrose solution in the mango tissue (Mújica-Paz *et al*., 2003a). The WL value was significantly affected by mango ripening stages and vacuum pressure levels ($p<0.05$). Higher sucrose solution was significantly impregnated in unripen mango samples treated at 50 mbar vacuum pressure than those of ripen samples processed at atmospheric pressure. The effect of vacuum pressure showed that at higher vacuum pressure to 50 mbar, there was higher release of native liquid and gases occurred (Derossi *et al*., 2012). The result in this study was consistent with the reports of Mújica-Paz *et al.* (2003a) and Rongkom *et al*. (2013). For the ripening stages of mango, the data clearly displayed that unripen mango fruit allowed more infusion of sucrose solution than those of ripen fruit (Figure 1a). This result could mainly be affected by the fruit texture that was changed as the fruit became mature (Table 1; Torreggiani and Bertolo, 2001). These workers also reported that there was higher water loss in kiwi fruit for the unripen fruit compared to those that were ripen. Toivonen and Brummell (2008) explained that during fruit ripening, fruit cell walls went through a natural degradation that led to reduction in cell wall firmness and intercellular adhesion. In addition, a decline in turgor properties of the fruit tissues during ripening was further contributed to the fruit textural changes.

After vacuum impregnation treatments, all of the mango samples experienced loss of their solid contents (Figure 1b). Negative values of solid gain demonstrated that more native liquid of mango fruit was leached out compared to the incoming sucrose solution (Mújica-Paz *et al*., 2003b). The effect was more pronounced in the unripen mango than those of the ripen fruit, which could be due to more

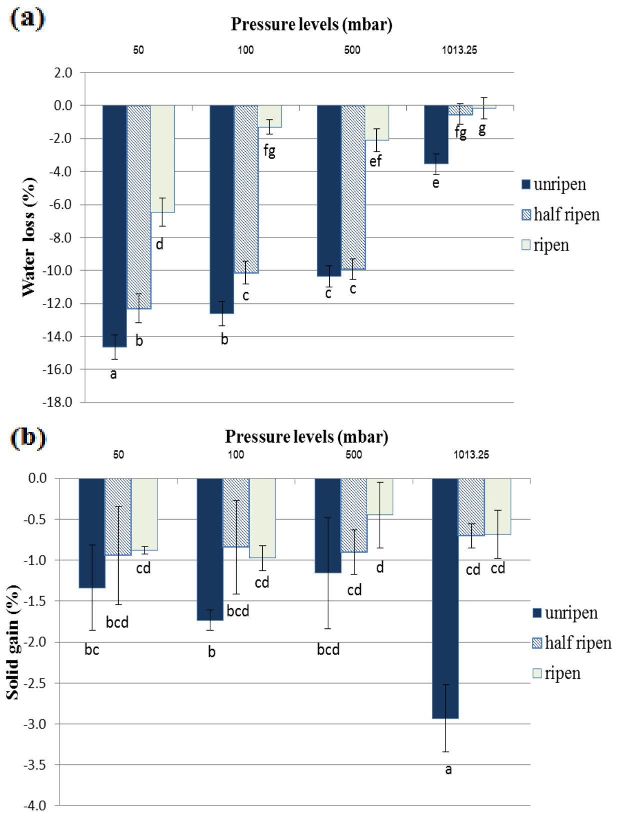

Figure 1. Water loss (%) (a) and solid gain (%) (b) of vacuum impregnated mango 'Chok Anan' affected by mango ripening stages and vacuum pressure levels

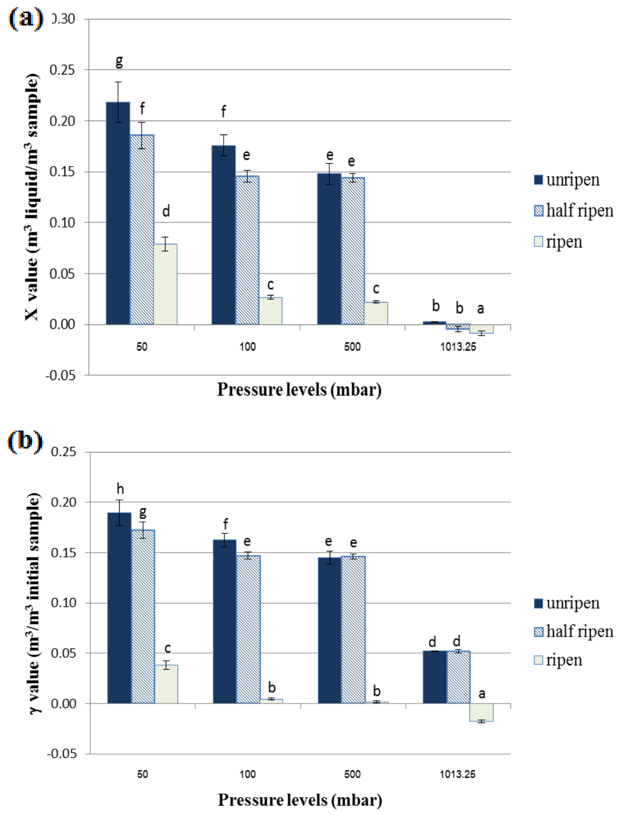

Figure 2. The volume of mango occupied by sucrose solution (X value) (a) and mango fruit deformation (γ value) (b) of vacuum impregnated mango 'Chok Anan' affected by mango ripening stages and vacuum pressure levels

deformation of the mango tissue structure at higher vacuum pressure in the ripen mango fruit than those of the unripen samples (Müjica-Paz *et al.*, 2003b; Zhao and Xie, 2004). Finding in this study was similar to the report of Torreggiani and Bertolo (2001) for kiwifruit. Since a high solid loss during vacuum impregnation was not desirable, processing unripen mango by vacuum impregnation needed to consider other treatment parameters that could reduce this phenomenon, such as viscosity of the impregnation solution and size and shape of food samples.

X value was recognized as the volumetric fraction of the mango sample occupied by the sucrose solution (Müjica-Paz *et al.*, 2003b; Krasaekoopt and Suthanwong, 2008). The X value of vacuum impregnated mango affected by mango ripening stages and vacuum pressure levels is exhibited in Figure 2a. It was clearly displayed that both parameters examined in this research had a significant effect on the amount of sucrose solution impregnated into the mango samples ($p<0.05$). The highest X value was found in the unripen mango sample processed at 50 mbar vacuum pressure, which was parallel with the WL result. The result of X value could be affected by higher hardness value of the unripen mango, causing less deformation in the mango tissues processed at the highest vacuum pressure level (Krasaekoopt and Suthanwong, 2008). Fito *et al.* (2001) reported the X value of mango 'Tommy Atkins' that was cut slices with a thickness of 10 mm was 14.2±0.5.

Deformation in the sample tissue could be measured by γ value, which represented the net volume changed at the end of the vacuum impregnation process, resulted from an initial swelling throughout the vacuum step and the later compression during the relaxation time (Andrés *et al.*, 2001; Zhao and Xie, 2004). The deformation of the mango solid matrix was significantly affected by the ripening stages and vacuum pressure levels applied during impregnation (Figure 2b). The result of γ value was corresponded to the finding of X value, suggesting that the mango matrix was responsible for these parameters (Zhao and Xie, 2004). Chiralt and Talens (2005) explained that when vacuum pressure was applied there was a possibility of mechanical damage in the cell arrangement, such as cell debonding that associated with sample deformation. Fito *et al.* (2001) had presented that the mango 'Tommy Atkins' deformation was 5.4±0.5 at the end of the vacuum step and 8.9±0.4 at the end of impregnation process, indicating that the mango samples were swollen after each step of the impregnation treatment (Gras *et al.*, 2002).

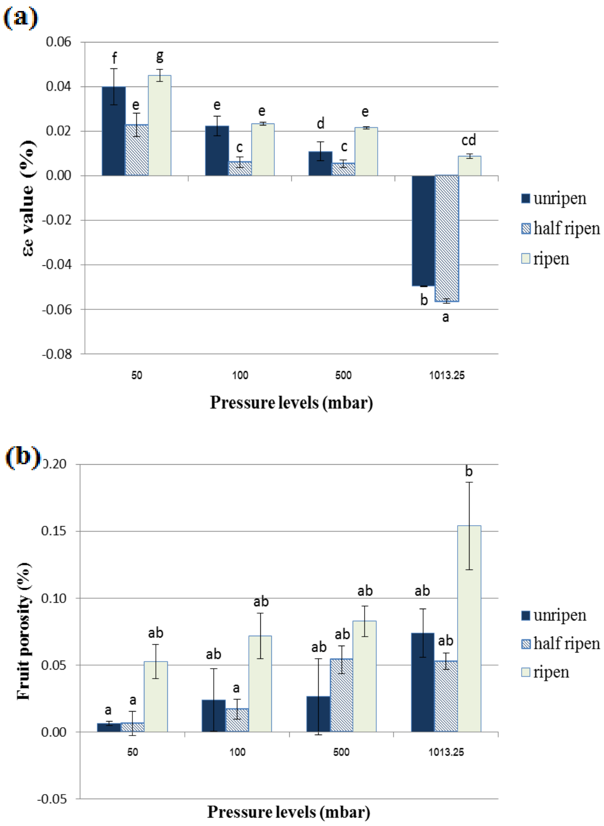

Figure 3. Effective porosity (ε_e) (a) and fruit porosity (ε_r) (b) of vacuum impregnated mango 'Chok Anan' affected by mango ripening stages and vacuum pressure levels

The values of ε_e and ε_r of the vacuum impregnated mango are presented in Figure 3. As general, it could be seen that the trend of ε_e was significantly increased as higher vacuum pressure was applied ($p<0.05$), while the tendency of ε_r was decreased. The ε_e value that symbolized the fruit volume that could be occupied by sucrose solution in the product tissue (Zhao and Xie, 2004) was correlated with an increase in the pore space of the mango tissues at higher vacuum pressure levels, as a result of high expansion and release of gas inside the pores of mango tissues (Rongkom *et al.*, 2013). Fito *et al.* (2001) had recorded that the ε_e of mango 'Tommy Atkins' slices with a thickness of 10 mm was 5.9±0.4. Different ε_e values found in this research could be affected by different mango varieties, type of impregnation solution and the size and shape of mango samples. On the other hand, the ε_r value described a measure of the empty space in mango fruit that could be impregnated with external solution (Chiralt *et al.*, 1999). Since at higher vacuum pressure levels, more of the sucrose solution occupied the pore of mango tissues, the empty space in the fruit would be decreased. A similar finding had been described by Rongkom *et al.* (2013) for apple and cantaloupe.

Conclusion

Vacuum impregnation was a mild pretreatment process that would be suitable for mango processing. Factors of mango ripening stages and vacuum pressure levels needed to be carefully considered in the application of the method. Higher vacuum pressure levels and firmer of mango texture were generally produced better impregnation of the external solution.

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