Chapter 4

Results and Discussion

4.1 Raw material of papaya

This section studied the physicochemical properties of three ripening stages of papaya, including unripe, half ripe and fully ripe. Table 4.1 shows that all the papaya samples had high moisture contents, irrespectively to their ripening stage. The moisture contents of unripe, half ripe and fully ripe papaya were 91.60 ± 0.13, 90.50 ± 0.25 and 88.86 ± 0.34%, respectively. Fully ripe papaya significantly had the highest total soluble solids (TSS) than other fruit stages ($p<0.05$). The TSS was significantly increased from unripe papaya (6.5 ± 0.12% Brix) to half ripe papaya (9.5 ± 0.12% Brix) and the highest one was fully ripe papaya (10.1 ± 0.12% Brix) ($p<0.05$). Finding in this study was consistent with the report of Fuggate et al. (2010) that stated changing in TSS of ‘Pluk Mai Lie’ papaya fruit increased continuously from immature to fully ripe stages and the TSS of ripe papaya increased over the time. Total titrable acidities of unripe and half ripe papaya were not significantly different, while fully ripe papaya had a higher total acidity of 0.12 ± 0.01% citric acid. The titrable acidity value of fully ripe papaya in this study was closed to the data of Fuggate et al. (2010), which was 0.13% for fully ripe papaya. Similar finding was also reported by Nampairoj et al. (2011) that informed TSS of papaya during ripening was increased slightly and percentage titrable acidity had low values with a small change. Ripening index was the relationship with physical development that could be useful tools for defining appropriate papaya maturity index (Galli, 2007). For ripening index of in unripe, half ripe and fully ripe papaya were 93.34, 123.93 and 81.75% Brix/acidity, respectively.

Data of papaya total titrable acidity was consistent with pH results. The fully ripe papaya that had the lowest pH value contained the highest acidity compared to the other papaya stages. Results of a_w showed that this parameter values were closed for three different ripening stages of papaya (Table 4.1). All of the papaya samples at three different maturation stages had a_w values of 0.986 to 0.991.

Table 4.1 Physicochemical properties of different ripening stages of papaya

Properties	Ripening stages of papaya		
	Unripe	Half ripe	Fully ripe
Moisture content (%)	91.60 ± 0.13^{c}	90.50 ± 0.25^{b}	88.86 ± 0.34^{a}
pH value	5.51 ± 0.00^{c}	5.37 ± 0.01^{b}	4.90 ± 0.01^{a}
Water activity	0.991 ± 0.000^{b}	0.988 ± 0.000^{a}	0.986 ± 0.000^{a}
Total soluble solid (% Brix)	6.53 ± 0.12^{a}	9.47 ± 0.12^{b}	10.07 ± 0.12^{c}
Total titrable acidity (% citric acid)	0.07 ± 0.01 ^{a}	0.08 ± 0.01^{a}	0.12 ± 0.01^{b}
Ripening index (% Brix/acidity)	93.34 ± 1.65^{a}	123.93 ± 9.05^{b}	81.75 ± 4.26^{a}
Firmness (N)	23.52 ± 0.88^{c}	10.11 ± 0.19^{b}	0.76 ± 0.07^{a}
Apparent density (kg/m^3)	0.97 ± 0.01^{a}	1.05 ± 0.01^{b}	1.20 ± 0.01^{c}
Real density (kg/m^3)	1.06 ± 0.01^{a}	1.16 ± 0.01^{b}	1.34 ± 0.01^{c}
Real porosity (m^3 internal gas/m^3 fruit)	0.09 ± 0.00^{a}	0.10 ± 0.01^{b}	0.11 ± 0.01^{c}

$^{a-c}$ Values followed by different letters within the row are significantly different ($p<0.05$).

Regarding fruit texture, unripe papaya significantly had firmer texture than those of half ripe and fully ripe papaya ($p<0.05$). Fruit firmness was significantly decreased from 23.52 ± 0.88 to 0.76 ± 0.07 N due to ripening ($p<0.05$). It was reported that decrease in papaya firmness could develop dramatically after the quarter ripe or half ripe stage. This was partly due to the onset of ethylene in climacteric fruits causing the fruit pulp to become soft, indicating fruit ripening (Fuggate et al., 2010). Real porosity (ε_r) measured the empty space of fruit tissue that could be impregnated with impregnation liquid (Mújica-Paz et al., 2003a). Collected data showed that fully ripe papaya significantly had more empty space than those of half ripe and unripe papaya ($p<0.05$). The biggest empty space was found in fully ripe fruit (0.11 ± 0.01 m^3 internal gas/m^3 fruit) compared to half ripe (0.10 ± 0.01 m^3 internal gas/m^3 fruit) and unripe (0.09 ± 0.00 m^3 internal gas/m^3 fruit) (Table 4.1). This result suggested that the fully ripe papaya could have higher impregnation with impregnation solution compared to the other papaya stages. Mújica-Paz et al. (2003a), who studied about ε_r values of different fruits, reported that the largest ε_r value was determined in apple (0.273 m^3 internal gas/m^3 fruit), followed with medium ε_r values in mango (0.152 m^3 internal gas/m^3 fruit) and melon (0.133 m^3 internal gas/m^3 fruit), and small ε_r values in banana (0.016 m^3 internal gas/m^3 fruit) and papaya (0.058 m^3 internal gas/m^3 fruit).

Colour values of papaya peel and flesh were assessed using a colourimeter (Table 4.2). The colour values were measured as L* (whiteness or brightness/darkness), a* (redness/greenness) and b* (yellowness/blueness) values (Tirkey et al., 2014). There were significant changes in the colour of papaya peel and flesh ($p<0.05$; Table 4.2). The peel colour changed from dark green in unripe papaya to green with trace of yellow in half ripe fruit then it was fully yellow or yellowness skin in fully ripe stage. Changing colour of unripe, half ripe and fully ripe papaya peel colour could be observed from L* values that were increased in lightness values from 49.11 ± 1.88, 51.38 ± 1.39 to 67.10 ± 2.08, respectively. An increase in a* value indicated that less green colour from unripe papaya to fully ripe papaya (−17.04 ± 0.80 to −13.64 ± 4.12). The yellow colour of b* values were increased from 29.94 ± 2.12 to 52.35 ± 3.39 with papaya ripening progress of unripe to fully ripe stages. Similar results were observed in the study of Fuggate et al. (2010). They reported that papaya peel colour changed from dark green in immature fruit to orange red in fully ripe, as changing in L* value from 47.04 to 61.96 and b* from 27.65 to 50.06. For papaya flesh colour, it was found that the colour changed from bright green to yellow colour due to ripening. The L* value was decreased with an increase in a* and b* values. Table 4.2 shows the changing in L* value that was decreased from 74.13 ± 1.57 to 51.86 ± 2.27, an increase in the a* value from −3.73 ± 0.75 to 27.29 ± 4.42 and the b* value from 23.68 ± 2.36 to 31.90 ± 2.66. Likewise, Nampairoj et al. (2011) also stated that L*, a* and b* values of papaya peel colour were increased with papaya ripening. The workers displayed that pulp or flesh colour of papaya was decreased in L* value but a* and b* values were increased.

Measurement results in this section displayed that a_w and moisture contents of all papaya samples in three maturity stages were high. TSS of the papaya fruit increased as papaya maturity stages increased or ripen. On the other hand, fruit firmness decreased as ripeness stages of papaya increased. For pH values of papaya, they were correlated with total titratable acidity. The lowest pH value or the highest acidity of the fruit was determined in fully ripe papaya. The highest real porosity was also found in fully ripe papaya. Papaya peel colour was changed from green in unripe papaya to yellow in fully ripe papaya, which was indicated with increases in L*, a* and b* values. Regarding papaya flesh colour, it was transformed from bright green to yellow due to papaya ripeness. The alteration was shown by a decrease in L* value and increases in a* and b* values.

Table 4.2 Colour values of papaya peel and flesh affected by fruit ripening stages

Ripening stages of papaya	Papaya peel			Papaya flesh		
	L*	a*	b*	L*	a*	b*
Unripe	49.11 ± 1.88^{a}	-17.04 ± 0.80^{a}	29.94 ± 2.12^{a}	74.13 ± 1.57^{c}	-3.73 ± 0.75^{a}	23.68 ± 2.36^{a}
Half ripe	51.38 ± 1.39^{b}	-14.37 ± 1.04^{b}	32.79 ± 2.18^{b}	60.87 ± 5.79^{b}	18.32 ± 6.60^{b}	27.96 ± 2.63^{b}
Fully ripe	67.10 ± 2.08^{c}	-13.64 ± 4.12^{c}	52.35 ± 3.39^{c}	51.86 ± 2.27^{a}	27.29 ± 4.42^{c}	31.90 ± 2.66^{c}

$^{a-c}$ Values followed by different letters within the column are significantly different ($p<0.05$).

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4.2 Effect of ripening stages and fruit sizes on the physicochemical properties of vacuum impregnated papaya

Fresh papaya at different maturation stages was selected and cut into three different sizes, including 1 x 1 x 1; 2 x 2 x 2 and a slice of 0.5 x 2 x 7 cm^3. Different fruit sizes were impregnated with sucrose solution that had a_w similar to the papaya fruit (Table 4.1), which used 9, 12 and 13 g of sugar in 100 ml of distilled water for unripe, half ripe and fully ripe papaya fruits, respectively. The papaya pieces/slices were immersed under sucrose solution using ratio 1 to 5 (w/w) in a 1,000 ml beaker for 1,000 ml impregnation solution and gone through a vacuum impregnation process at 50 mbar for 10 min, followed with 10 min relaxation time at atmospheric pressure. After the impregnation process, papaya pieces were separated from the solution using a strainer and kept at low temperature to be analysed. Table 4.3 displays that moisture contents of half ripe and fully ripe papaya were not significantly differed ($p \geq 0.05$) and had values lower than those of unripe papaya samples. The a_w values of all papaya samples were closed to each other and in the range of 0.989 to 0.990. Results in this study were similar to the report of Udomkun et al. (2015b), who compared a_w values of fresh papaya and treated papaya by soaking in osmotic sucrose solution. The researchers found that the a_w values of the fruit were similar, which were 0.990 and 0.980, respectively. Compared to fresh papaya samples (Table 4.1), total soluble solids of unripe and half ripe impregnated papaya were increased, irrespectively to papaya sizes (Table 4.3). On the other hand, the total soluble solid of fully ripe impregnated papaya was not much differed than that of the fresh fruit (Table 4.1). Different sizes of papaya did not significantly affect the total soluble solid of impregnated papaya, except for the fully ripe papaya. The total soluble solid values of unripe, half ripe and fully ripe impregnated papaya in this study were 7.1-7.2, 10.0-10.2 and 10.1-10.9% Brix, respectively. An increase in the total soluble solid was mainly caused by vacuum impregnation processes. During the vacuum impregnation process, external (impregnation) liquid permeated into fruit porous tissue because of expansion of internal gas in food tissues (Zhao and Xie, 2004). A similar result had been reported by Udomkun et al. (2015b). The workers found that after an osmotic process, total soluble solid values of papaya samples increased due to osmotic pressure effect. In addition, limited transfer of sucrose into fruit tissue could be attributed to the presence of pectin and particular enzyme in the fruit (Silva et al., 2014). The hydrolysis of pectin methyl esters by pectin-methylesterase (PME) generates carboxyl groups that can interact with calcium, promoting cross-linking of the pectin polymer. These polymers could act as partial barrier to the diffusion of large molecules such as sucrose into the tissue. Sucrose was found in the osmotic or vacuum impregnation process in the form of sugar solution (Udomkun et al., 2015b). It was reported that some studies used low molecular weight carbohydrates for vacuum impregnation process of fruit samples because low molecular weight solutes quickly penetrated into the sample. In the case of glucose and sucrose, the diffusivity of sucrose was smaller than glucose because of the molecular weight of glucose was about one-half that of sucrose (Zhao and Xie, 2004).

For the results of titrable acidity and pH values of impregnated papaya (Table 4.3), they were found to be slightly differed to those of fresh papaya samples (Table 4.1). The pH values of unripe and half ripe impregnated papaya samples were slightly higher than those of the fresh papaya, while the pH value of fully ripe impregnated papaya was closed to those of the fresh papaya samples. On the other hand, all of the impregnated papaya samples had lower values of titrable acidity compared to those of the fresh ones. For most of the time, values of titrable acidity and pH values were inversely related, if total acidity values were decreased, then the pH values would be increased. A review by Zhao and Xie (2004) wrote that pH value of fruit before and after vacuum impregnation process was not significantly changed. A slightly different finding in this study could be affected by the application of isotonic solution. Isotonic solution was a solution that contained the same solute concentration both inside and outside the cell membrane. Using an isotonic solution, it should not have significant differences in fresh and vacuum impregnation sample (Zhao and Xie, 2004).

Table 4.3 Water activity and chemical properties of impregnated papaya affected by ripening stages and papaya sizes

Ripening stage of papaya	Size dimension (cm^3)	Water activity	pH value	Total soluble solid (% Brix)	Total titrable acidity (% citric acid)	Moisture content (%)
Unripe	1 x 1 x 1	0.990 ± 0.000^{ab}	5.63 ± 0.00^{f}	7.13 ± 0.12^{a}	0.05 ± 0.01^{a}	90.36 ± 0.34^{bc}
	2 x 2 x 2	0.990 ± 0.002^{a}	5.77 ± 0.00^{h}	7.20 ± 0.00^{a}	0.04 ± 0.01^{a}	90.99 ± 0.19^{c}
	0.5 x 2 x 7	0.992 ± 0.000^{b}	5.66 ± 0.00^{g}	7.20 ± 0.00^{a}	0.05 ± 0.01^{a}	90.98 ± 0.14^{c}
Half ripe	1 x 1 x 1	0.989 ± 0.001^{a}	5.45 ± 0.00^{e}	10.13 ± 0.12^{bc}	0.06 ± 0.01^{b}	89.13 ± 0.62^{a}
	2 x 2 x 2	0.990 ± 0.001^{ab}	5.44 ± 0.02^{e}	10.00 ± 0.00^{b}	0.06 ± 0.01^{b}	89.64 ± 0.52^{ab}
	0.5 x 2 x 7	0.989 ± 0.001^{a}	5.30 ± 0.00^{d}	10.20 ± 0.00^{c}	0.06 ± 0.01^{b}	89.37 ± 0.12^{a}
Fully ripe	1 x 1 x 1	0.989 ± 0.000^{a}	4.88 ± 0.00^{a}	10.07 ± 0.12^{bc}	0.08 ± 0.01^{c}	89.07 ± 0.52^{a}
	2 x 2 x 2	0.989 ± 0.001^{a}	4.98 ± 0.01^{c}	10.00 ± 0.00^{b}	0.09 ± 0.01^{d}	89.69 ± 0.95^{ab}
	0.5 x 2 x 7	0.990 ± 0.000^{ab}	4.91 ± 0.01^{b}	10.87 ± 0.12^{d}	0.08 ± 0.01^{c}	89.03 ± 0.50^{a}

[a-h] Values followed by different letters within the column are significantly different ($p<0.05$).

Table 4.4 Colour values and texture of impregnated papaya affected by ripening stages and papaya sizes

Ripening stage of papaya	Size dimension (cm^3)	L*	a*	b*	Firmness (N)
Unripe	1 x 1 x 1	33.82 ± 1.53^{cd}	3.33 ± 0.96^{a}	-1.47 ± 0.40^{a}	12.76 ± 0.43^{ef}
	2 x 2 x 2	30.37 ± 1.25^{bc}	3.74 ± 0.98^{a}	-1.30 ± 0.34^{a}	12.80 ± 0.44^{f}
	0.5 x 2 x 7	35.04 ± 1.02^{d}	4.59 ± 0.72^{a}	-2.16 ± 0.12^{a}	12.57 ± 0.25^{e}
Half ripe	1 x 1 x 1	26.81 ± 0.71^{ab}	7.19 ± 0.80^{a}	10.48 ± 0.94^{b}	8.56 ± 0.32^{d}
	2 x 2 x 2	32.75 ± 7.38^{cd}	13.43 ± 8.40^{b}	13.85 ± 6.34^{c}	8.38 ± 0.24^{cd}
	0.5 x 2 x 7	31.68 ± 0.69^{cd}	6.92 ± 1.05^{a}	10.68 ± 1.05^{b}	8.31 ± 0.41^{c}
Fully ripe	1 x 1 x 1	26.31 ± 0.66^{a}	5.63 ± 0.38^{a}	10.67 ± 0.36^{b}	0.59 ± 0.10^{a}
	2 x 2 x 2	26.59 ± 2.57^{ab}	4.27 ± 0.64^{a}	8.94 ± 1.34^{b}	0.83 ± 0.03^{b}
	0.5 x 2 x 7	30.91 ± 2.94^{c}	7.51 ± 1.60^{a}	10.41 ± 1.15^{b}	0.59 ± 0.12^{a}

$^{a-f}$ Values followed by different letters within the column are significantly different ($p<0.05$).

Firmness of impregnated papaya was depended on biological characteristic of the fruit and ripening stages. It was determined that unripe impregnated papaya significantly had the the highest firmness values, followed by half ripe impregnated papaya and fully ripe impregnated papaya ($p<0.05$; Table 4.4). The result was consistent with the finding in the previous section for fresh papaya fruit (Table 4.1). The firmness values of three different papaya sizes (1 x 1 x 1; 2 x 2 x 2 and a slice of 0.5 x 2 x 7 cm^3) were 12.76, 12.80 and 12.57 N, respectively, for unripe impregnated papaya, while the half ripe impregnated papaya had 8.56, 8.38 and 8.31 N, respectively, and the fully ripe impregnated ones had 0.59, 0.83 and 0.59 N, respectively. This data showed that the unripe and fully ripe impregnated papaya with the dimension of 2 x 2 x 2 cm^3 had the highest firmness value compared to those of the other papaya sizes. On the other hand, the firmmess of half ripe impregnated papaya was not significantly affected by the fruit size ($p\geq0.05$). If the texture of impregnated papaya was compared with the fresh fruit sample (Table 4.1), it could be seen that the impregnation process caused the firmness of all papaya samples to be decreased. The result in this study was similar to the report of Nimmanpipug and Therdthai (2013) that informed hardness values of papaya after papaya cube immersed in sucrose solution for 4 h at 40ºC was decreased because of water migration from fruit cells. Water loss caused a decrease in the tension that the liquid exerted against the fruit cell wall. Firmness of a sample could be reduced when the sample was dehydrated, which occurred simultaneously. The dehydration further promoted the losses of cell turgor and elasticity, alteration of cell resistance, the changes in air and liquid volume fractions in the product and change in the sample size and shape (Zhao and Xie, 2004). Fito et al. (2001) reported that vacuum impregnation process might change the structure of fruit tissue. In vacuum impregnation process, during the solution was in the pores, the force balance on the double layer plasmalemma-cell wall led to later separation because plasmalemma shrank in line with water loss with little deformation of cell wall. When the process under atmospheric pressure a gas phase in the intracellular space was occurred, plasmalemma shrank together with the cell wall.

Table 4.4 demonstrates colour values of impregnated papaya samples. The impregnation process directly affected the L* and b* values of all papaya samples, while the process did not produce much effect in a* value. After the impregnation process, it was determined that the L* values of all impregnated papaya samples were decreased by almost half compared to those of fresh papaya samples (Table 4.2). Unripe impregnated papaya samples significantly had the highest lightness colour, which was in the range of 30.37 – 35.04 ($p<0.05$), followed by half ripe and fully ripe impregnated papaya samples that had almost similar L* values of 26.81 − 32.75 and 26.31 – 30.91, respectively. In a study of slice apple, the luminosity was significantly reduced in vacuum impregnation treated samples compared with the fresh samples. The difference in luminosity was associated with a gain in transparency due to air loss, an effect that was produced by a total or partial substitution of air in the pores by the vacuum-impregnated solution (Moreno et al., 2016). Likewise, Zhao and Xie (2004) referred that the light colour in fruits might sensitive to an enzymatic browning discolouration due to during vacuum impregnation process air was pulled out from fruits pores. Therefore, oxygen concentration was reduced resulting in slowing down in oxidative reaction rates and led to a good natural colour of the final product. For the b* value, this criterion was significantly affected by ripening stages compared to fruit sizes (Table 4.4). The half and fully ripe impregnated papaya significantly had more yellow colour compared to those of the unripe impregnated papaya ($p<0.05$). Zhao and Xie (2004) wrote that after vacuum impregnation process, the colour of fruit might change. Comparing vacuum impregnation processed samples with fresh sample, it was reported that the processed samples had lower values of clarity and chrome colour coordinates and small changes in hue. This could be occurred because an exchange of gas–liquid in fruit that caused the sample had more homogeneous refraction index. A research work by Nimmanpipug and Therdthai (2013) also showed that lightness value of papaya sample after osmotic dehydration was decreased. A similar finding was also determined in this study that the a* and b* values of impregnated papaya were reduced after vacuum impregnation process. Similarly, less colour saturation in impregnated samples was noted by Zhao and Xie (2004). Moreover, Igual et al. (2008) explained that in vacuum impregnated fruit, there was a replacement of gas occluded in the pores by the liquid phase, as a consequence of the vacuum impregnation process. This mechanism caused relevant changes in product density, colour, texture and also optical properties.

Real porosity was calculated from apparent density and real density (Mújica-Paz et al., 2003a). Real porosity constitutes a measurement of empty space inside the fruit tissue and represents the maximum space that could be impregnated with impregnation solution (Müjica-Paz et al., 2003a; Paes et al., 2008). Real porosity of all impregnated papaya was reduced compared to those of the fresh papaya sample (Tables 4.1 and 4.5). Between different papaya dimensions investigated in this section, lower real porosity values were determined in papaya samples with sizes of 1 x 1 x 1 and 2 x 2 x 2 cm^3. The shape of the solid material was another important factor because the geometry of sample affects the behaviour of the osmotic concentration due to the variation of the surface area per unit volume (Ramya and Jain, 2016). Among various ripening stages, higher values of real porosity were found in unripe impregnated papaya, followed by half and fully ripe impregnated papaya. Therefore, lower values of real porosity were discovered in fully ripe impregnated papaya with sizes of 1 x 1 x 1 and 2 x 2 x 2 cm^3. This finding indicated that fully ripe papaya was more suitable to be processed by vacuum impregnation processes due to lower empty space was left available in the fruit matrix. The real porosity values of fully ripe impregnated papaya with sizes of 1 x 1 x 1; 2 x 2 x 2 and a slice of 0.5 x 2 x 7 cm^3 were 0.0115, 0.0111 and 0.0149 m^3 internal gas/m^3 fruit, respectively. Real porosity values of apple impregnated with isotonic solution were 0.205 (Paes et al., 2008). Müjica-Paz et al. (2003a) had reported that real porosity was affected by fruit types, including large porosity for apple (0.273%), medium for mango (0.152%) and small for other fruits, such as papaya (0.058%).

X value was the volumetric fraction of the sample occupied by an external liquid (Gras et al., 2003; Müjica-Paz et al., 2003a; Paes et al., 2008; Zhao and Xie, 2004). Different papaya size investigated in this study significantly affected X value of impregnated papaya ($p<0.05$; Table 4.6). From collected data, it could be observed that papaya sample with a size of 2 x 2 x 2 cm^3 had higher X values in different ripening stages of impregnated papaya. The highest X value of 0.0841 m^3 liquid/m^3 sample was found in the half ripe impregnated papaya with a size of 2 x 2 x 2 cm^3. In fact, different sizes of half ripe impregnated papaya did not significantly affect the X value of the samples ($p\geq0.05$). Higher X values of unripe and fully ripe impregnated papaya were found in the size of 2 x 2 x 2 cm^3, which were 0.0567 and 0.0560 m^3 liquid/m^3 sample, respectively. Finding in this study was consistent with the report of Müjica-Paz et al. (2003a), who found that the average volume of fruit impregnated with sucrose in isotonic solution (X) in papaya varied between 0.026 and 0.061 m^3 liquid/m^3 fruit. In this study, the workers also determined that the X values of apple of 0.081 and 0.341 m^3 liquid/m^3 fruit were higher than those of the papaya. The volume fraction of a sample impregnated by external solution when mechanical equilibrium was achieved had been modelled as a function of compression ratio, sample effective porosity and sample volume deformation at the end of the process (Zhao and Xie, 2004). The parameters that affected the X value were the mechanical and structural properties of fruit tissue (Gras et al., 2003).

The value of γ was referred to the volumetric fraction of the sample that was deformed at the end of vacuum impregnation process (Gras et al., 2003; Paes et al., 2008). In this study, a papaya size of 2 x 2 x 2 cm^3 had higher γ value compared to those of the other papaya dimensions for all ripening stages (Table 4.6). The highest γ value was found in half ripe impregnated papaya with the size of 2 x 2 x 2 cm^3, which was 0.0607 m^3/m^3 initial sample. Andrés et al. (2001) stated that the value of γ showed the solid matrix deformation due to volume swelling that was occurred because of the internal gas inside fruit tissue was expanded during vacuum time. The γ values of impregnated papaya in this study were in the range of 0.021 to 0.061 m^3/m^3 initial sample.

Table 4.5 Real porosity (ε_r), apparent (ρ_a) and real densities (ρ_r) of impregnated papaya affected by ripening stages and papaya sizes

Ripening stage of papaya	Size dimension (cm^3)	Apparent density (ρ_a) (kg/m^3)	Real density (ρ_r) (kg/m^3)	Real porosity (ε_r value) (m^3 internal gas/m^3 fruit)
Unripe	1 x 1 x 1	1.2291 ± 0.0717^{b}	1.2517 ± 0.0738^{b}	0.0184 ± 0.0012^{bc}
	2 x 2 x 2	1.0587 ± 0.0005^{a}	1.0799 ± 0.0033^{a}	0.0201 ± 0.0026^{c}
	0.5 x 2 x 7	1.0554 ± 0.0033^{a}	1.1097 ± 0.0030^{a}	0.0515 ± 0.0061^{e}
Half ripe	1 x 1 x 1	1.2391 ± 0.0473^{b}	1.2549 ± 0.0475^{b}	0.0128 ± 0.0018^{ab}
	2 x 2 x 2	1.0723 ± 0.0064^{a}	1.0839 ± 0.0058^{a}	0.0108 ± 0.0009^{a}
	0.5 x 2 x 7	1.0712 ± 0.0018^{a}	1.1021 ± 0.0075^{a}	0.0288 ± 0.0060^{d}
Fully ripe	1 x 1 x 1	1.2183 ± 0.0086^{b}	1.2323 ± 0.0089^{b}	0.0115 ± 0.0007^{a}
	2 x 2 x 2	1.0599 ± 0.0007^{a}	1.0718 ± 0.0014^{a}	0.0111 ± 0.0018^{a}
	0.5 x 2 x 7	1.0658 ± 0.0048^{a}	1.0817 ± 0.0066^{a}	0.0149 ± 0.0015^{abc}

[a-e] Values followed by different letters within the column are significantly different ($p<0.05$).

Table 4.6 Effective porosity (ε_e), X and γ values of impregnated papaya affected by ripening stages and papaya sizes

Ripening stage of papaya	Size dimension (cm^3)	X value (m^3 liquid/m^3 sample)	γ value (m^3/m^3 initial sample)	ε_e value^{ns} (%)
Unripe	1 x 1 x 1	0.0435 ± 0.0060^{ab}	0.0415 ± 0.0034^{abc}	0.0206 ± 0.0205
	2 x 2 x 2	0.0567 ± 0.0035^{bc}	0.0493 ± 0.0027^{bc}	0.0153 ± 0.0078
	0.5 x 2 x 7	0.0231 ± 0.0142^{a}	0.0214 ± 0.0125^{a}	0.0225 ± 0.0214
Half ripe	1 x 1 x 1	0.0762 ± 0.0013^{c}	0.0526 ± 0.0099^{bc}	0.0307 ± 0.0083
	2 x 2 x 2	0.0841 ± 0.0001^{c}	0.0607 ± 0.0088^{c}	0.0224 ± 0.0138
	0.5 x 2 x 7	0.0829 ± 0.0478^{c}	0.0289 ± 0.0191^{ab}	0.0139 ± 0.0032
Fully ripe	1 x 1 x 1	0.0397 ± 0.0055^{ab}	0.0314 ± 0.0085^{ab}	0.0370 ± 0.0474
	2 x 2 x 2	0.0560 ± 0.0131^{bc}	0.0432 ± 0.0107^{abc}	0.0157 ± 0.0106
	0.5 x 2 x 7	0.0336 ± 0.0184^{ab}	0.0357 ± 0.0223^{ab}	0.0106 ± 0.0007

$^{a-c}$ Values followed by different letters within the column are significantly different ($p<0.05$).

^{ns} Not significantly different.

Table 4.7 Water loss, solid gain and weight reduction of impregnated papaya affected by ripening stages and papaya sizes

Ripening stage of papaya	Size dimension (cm^3)	Water loss^{ns} (WL, %)	Solid gain (SG, %)	Weight reduction^{ns} (WR, %)
Unripe	1 x 1 x 1	-3.1894±4.4921	0.5919±0.1529^{a}	-3.5579±4.2483
	2 x 2 x 2	-3.7828±1.9004	1.1301±0.3909^{ab}	-4.9643±1.5898
	0.5 x 2 x 7	-16.0838±9.9200	2.6188±1.3958^{b}	-18.7026±11.2738
Half ripe	1 x 1 x 1	-3.3949±3.2462	0.9247±0.4660^{ab}	-4.3196±3.0514
	2 x 2 x 2	-13.9403±3.1719	2.2096±0.6373^{ab}	-16.1499±3.5519
	0.5 x 2 x 7	-3.8091±20.8979	0.5389±2.3754^{a}	-4.3481±23.2695
Fully ripe	1 x 1 x 1	-19.4034±7.8668	2.1839±0.7091^{ab}	-21.5873±8.5061
	2 x 2 x 2	-11.0396±10.2105	2.2281±0.4041^{ab}	-13.2677±10.0126
	0.5 x 2 x 7	-14.0137±4.5835	1.9743±0.7863^{ab}	-15.9880±4.7879

$^{a-b}$ Values followed by different letters within the column are significantly different ($p<0.05$).

^{ns} Not significantly different.

Measurement results of effective porosity (ε_e value) of impregnated papaya can be seen in Table 4.6. The ε_e value determined fruit volume that could be occupied by the external solution into the fruit tissue (Zhao and Xie, 2004). The effective porosity was related with parameters of X value, γ value and compression ratio (r = atmospheric pressure/ vacuum pressure). The highest ε_e value was determined in the fully ripe impregnated papaya with a size of 1 x 1 x 1 cm^3, followed by half ripe impregnated papaya at similar dimension. Mújica-Paz et al. (2003a) reported that the effective porosity of apple (ε_e = 0.336 m^3 internal gas/m^3 initial fruit) was higher than that of melon (ε_e = 0.071 m^3 internal gas/m^3 initial fruit) and papaya (ε_e = 0.042 m^3 internal gas/m^3 initial fruit). A comparison of the real porosity values (ε_r) and the effective porosity (ε_e) of the studied fruit exhibited that $\varepsilon_r > \varepsilon_e$ in different ripening stages of impregnated papaya with a size of 0.5 x 2 x 7 cm^3 (slice size). These indicated that there was still free volume for impregnation in this papaya dimension. There was a possibility that due to capillary effects or structural modifications, the free volume was not completely filled (Mújica-Paz et al., 2003a). Similarly, in melon, papaya, peach and mango these researchers found that the real porosity values (ε_r) were higher than the effective porosity (ε_e).

Table 4.7 displays the results of water loss, solid gain and weight reduction of impregnated papaya affected by ripening stages (unripe, half ripe and fully ripe) and fruit dimensions (1 x 1 x 1; 2 x 2 x 2 and a slice of 0.5 x 2 x 7 cm^3). For water loss, all of impregnated papaya had negative values. The negative values of water loss meant that there was a water gain caused by impregnation process of the impregnation solution into the fruit tissue (Mújica-Paz et al., 2003b). In each papaya ripening stage, different papaya dimensions affected the water loss. Higher water loss was found in a slice size for unripe impregnated papaya (-16.08%), in 2 x 2 x 2 cm^3 for half ripe impregnated papaya (-13.94%) and in 1 x 1 x 1 cm^3 for fully ripe impregnated papaya (-19.40%). The effect of osmotic solution concentration on water loss had been investigated by Mújica-Paz et al. (2003b). They found that after impregnation process mango had greater water loss value than melon and apple. In addition, Zhao and Xie (2004) wrote that vacuum impregnation process significantly increased the water loss rate, leading to a significant reduction in processing time compared with osmotic dehydration. Compared to water loss, solid gain values of impregnated papaya had positive values

(Table 4.7). For each ripening stage, unripe impregnated papaya had higher solid gain in a slice size (2.62%), while half and fully ripe impregnated papaya had higher solid gain in 2 x 2 x 2 cm^3, which were 2.21 and 2.23%, respectively. An increase in solid gain at high vacuum pressure levels and osmotic solution concentration could be attributed to a deformation of the tissue structure by the action of vacuum. This deformation would allow penetration of the concentrated osmotic solution, in which due to its high viscosity would not flow out of the fruit during the relaxation period (Mújica-Paz et al., 2003b). Moreover, the application of high vacuum pressure could open the fibrous structure of fruit, producing spaces that could be filled with a low concentration osmotic solution (low viscosity), which could exit the tissue together with native liquid during the relaxation period at atmospheric pressure, yielding low SG values (Mújica-Paz et al., 2003b). Nimmanpipug and Therdthai (2013) also informed that a decrease in water loss could occur, while soluble solid in osmotic agent actively migrated into cells and penetrated into intracellular spaces, increasing solid gain value. Water loss and solid gain were mainly controlled by raw material characteristics (Paes et al., 2008). Furthermore, Igual et al. (2008) informed that impregnation level or fill the pores with an external solution depended on the porosity of the tissue and its viscoelastic response under pressure gradients.

From different ripening stages and papaya sizes, it was concluded that fully ripe papaya with a size of 1 x 1 x 1 cm^3 should be further studied. This papaya sample significantly had the lowest ε_r value and water loss together with the highest ε_e value.

4.3 Effect of impregnation solution ratio, vacuum time and relaxation time on the physicochemical characteristics of vacuum impregnated papaya

In this section, a papaya specification that was continued to be studied was fully ripe papaya with a size of 1 x 1 x 1 cm^3. For this section, the main investigated parameters were impregnation solution ratios, including 1:5 and 1:10 that was carried out in a 1,000 ml beaker size, together with vacuum impregnation conditions, which were vacuum times of 5 and 10 min and relation times of 10 and 30 min. Each experiment utilised 825 ml of impregnation solution, which was sucrose liquid. Physicochemical properties of impregnated papaya affected by impregnation solution ratios and vacuum impregnation conditions are shown in Tables 4.8-4.12. Data in Table

4.8 displayed that different impregnation solution ratios and vacuum impregnation conditions did not significantly affect moisture content, total titrable acidity and total soluble solid of impregnated papaya ($p \geq 0.05$). However, different impregnation conditions studied in this section significantly affected colour values of impregnated papaya (Table 4.9). Significant different lightness values were determined in impregnated papaya processed by a solution ratio of 1:10 with 5 min vacuum time and 10 and 30 min relaxation times. The lowest lightness value was found in impregnated fruit treated in a solution ratio of 1:5 with 10 min vacuum and impregnation times. For a* value, it could be seen that longer vacuum (impregnation) time generally increased the a* value of the impregnated papaya, while longer relaxation time largely reduced the a* value of the papaya samples. On the other hand, there was not any specific tendency for changing in b* value. Firmness of impregnated papaya in this section was not significantly affected by different impregnation solution ratios and vacuum impregnation conditions ($p \geq 0.05$; Table 4.9). The firmness values of all the papaya samples were in the range of 0.028 – 0.029 N.

Table 4.10 displays water loss (WL) and solid gain (SG) of vacuum impregnated papaya. It was found that both WL and SG of the papaya samples were significantly affected by all parameters studied in this section, including impregnation solution ratios and vacuum and relaxation times ($p<0.05$). All data of the WL values were in negative values, indicating that the impregnated papaya samples gained water in their tissues from the impregnation of external solution (Müjica-Paz et al., 2003b; Rongkom et al., 2013). The highest water gain in the papaya samples was determined in the sample treated with 1:10 water ratio and processed for 10 min impregnation time and 30 min relaxation time, which had a value of −15.22 ± 3.65%. In general, it could be seen that longer impregnation and relaxation periods led to lower WL values. This suggested that higher impregnation could occur at longer processing time.

Vacuum impregnation was a process, where gas and native liquid inside sample pores were replaced with external solution (Zhao and Xie, 2004). The permeation of the external solution could affect the amount of solid in the sample tissues. In this section, SG values of vacuum impregnated papaya were increased with higher solution ratios and longer impregnation and relaxation periods (Table 4.10). Higher solid gain with extended vacuum and relaxation times for apple cylinders submitted to vacuum osmotic dehydration at 40 mbar had also been cited by Derossi et al. (2012). An increase in SG values could be attributed to deformation of sample structures by vacuum action (Mújica-Paz et al., 2003b). These researchers also explained that high vacuum pressure could help to open the fibrous structure of mango, producing spaces that could be filled with external solution.

X and γ values of vacuum impregnated papaya in this section were significantly affected by impregnation solution ratios and impregnation periods ($p<0.05$; Table 4.11). X value was recognised as the volume of fruit impregnated with external solution (Fito et al., 2001; Gras et al., 2003), while γ value was deformation of sample volume after a vacuum impregnation process (Fito et al., 2001). The X value of vacuum impregnated papaya was varied between 0.102 and 0.241 m^3 liquid/m^3 sample. These values were slightly higher than those reported by Mújica-Paz et al. (2003a), which were 0.026 to 0.061 m^3 liquid/m^3 samples. Differences in the finding could be affected by different papaya varieties, dimension of papaya samples and vacuum impregnation conditions, including vacuum pressure and impregnation and relaxation periods. In this study, the highest X value was determined in the vacuum impregnated papaya that was processed with a solution ratio of 1:10 and had impregnation and relaxation times of 10 and 30 min, respectively. It could also be observed that the X value of the papaya samples increased with higher solution ratios and longer impregnation and relaxation periods. This finding was in an agreement with the result of Mújica-Paz et al. (2003a).

Table 4.8 Water activity and chemical properties of impregnated papaya affected by impregnation solution ratio and vacuum impregnation condition

Papaya: solution ratio (w/w)	Impregnation time (min)	Relaxation time (min)	a_w	pH	Total soluble solid^{ns} (% Brix)	Total titrable acidity^{ns} (% citric acid)	Moisture content^{ns} (%)
1 : 5	5	10	0.992±0.001^{ab}	4.55±0.01^{a}	9.73±0.12	0.05±0.00	89.81±0.32
1 : 5	5	30	0.993±0.001^{b}	4.55±0.01^{a}	9.60±0.20	0.05±0.00	89.92±0.23
1 : 5	10	10	0.993±0.000^{b}	4.58±0.01^{b}	9.66±0.12	0.06±0.01	89.84±0.07
1 : 5	10	30	0.993±0.001^{b}	4.56±0.01^{a}	9.80±0.20	0.05±0.01	89.74±0.04
1 : 10	5	10	0.992±0.001^{ab}	4.66±0.01^{c}	9.80±0.00	0.05±0.00	89.73±0.12
1 : 10	5	30	0.993±0.000^{b}	4.76±0.01^{e}	9.73±0.12	0.05±0.00	89.93±0.24
1 : 10	10	10	0.993±0.001^{b}	4.69±0.01^{d}	9.73±0.12	0.06±0.01	89.74±0.09
1 : 10	10	30	0.992±0.001^{a}	4.69±0.01^{d}	9.80±0.20	0.05±0.01	89.63±0.32

$^{a\text{-}e}$ Values followed by different letters within the column are significantly different ($p<0.05$).

^{ns} Not significantly different.

Table 4.9 Colour values and texture of impregnated papaya affected by impregnation solution ratio and vacuum impregnation condition

Papaya: solution ratio (w/w)	Impregnation time (min)	Relaxation time (min)	L*	a*	b*	Firmness^{ns} (N)
1 : 5	5	10	32.37±1.41^{abc}	15.25±1.32^{b}	8.67±2.08^{bc}	0.029±0.004
1 : 5	5	30	32.90±1.55^{bc}	14.58±1.10^{ab}	7.28±1.70^{abc}	0.028±0.004
1 : 5	10	10	30.38±1.22^{a}	17.67±0.88^{c}	9.11±0.48^{c}	0.029±0.004
1 : 5	10	30	30.97±1.73^{ab}	15.92±2.46^{bc}	9.07±2.06^{c}	0.028±0.003
1 : 10	5	10	31.41±2.13^{ab}	16.27±1.72^{bc}	8.98±1.42^{bc}	0.028±0.004
1 : 10	5	30	35.23±1.07^{d}	12.74±1.16^{a}	6.10±0.98^{a}	0.028±0.004
1 : 10	10	10	33.84±1.32^{cd}	14.44±1.23^{ab}	6.66±1.68^{ab}	0.029±0.002
1 : 10	10	30	33.67±0.74^{cd}	14.95±0.82^{b}	8.35±2.14^{abc}	0.028±0.003

$^{a-d}$ Values followed by different letters within the column are significantly different ($p<0.05$).

^{ns} Not significantly different.

Table 4.10 Water loss, solid gain and weight reduction of impregnated papaya affected by impregnation solution ratio and vacuum impregnation condition

Papaya: solution ratio (w/w)	Impregnation time (min)	Relaxation time (min)	Water loss WL (%)	Solid gain SG (%)	Weight reduction WR (%)
1 : 5	5	10	-3.8172±1.6440^{c}	0.1908±0.5927^{a}	-4.0080±1.9046^{d}
1 : 5	5	30	-12.7193±2.3067^{ab}	1.2425±0.4869^{ab}	-13.5185±3.0431^{ab}
1 : 5	10	10	-11.8899±4.9170^{ab}	0.9511±0.6698^{ab}	-8.6888±5.9399^{bcd}
1 : 5	10	30	-14.1296±3.7626^{ab}	1.7015±1.0908^{b}	-15.8311±4.8481^{a}
1 : 10	5	10	-14.7823±3.9676^{ab}	2.0076±0.7009^{b}	-11.3309±4.6033^{abc}
1 : 10	5	30	-14.8389±2.6737^{ab}	1.8386±0.4090^{b}	-13.9908±1.3113^{ab}
1 : 10	10	10	-8.0867±4.1975^{bc}	2.0835±0.3565^{b}	-6.6045±1.2297^{cd}
1 : 10	10	30	-15.2216±3.6451^{a}	3.3607±0.3684^{c}	-14.6655±3.3952^{ab}

$^{a-d}$ Values followed by different letters within the column are significantly different ($p<0.05$).

Table 4.11 X value, γ value and effective porosity of impregnated papaya affected by impregnation solution ratio and vacuum impregnation condition

Papaya: solution ratio (w/w)	Impregnation time (min)	Relaxation time (min)	X value (m^3 liquid/m^3 sample)	γ value (m^3/m^3 initial sample)	ε_e value[ns] (%)
1 : 5	5	10	0.1017±0.0099[a]	0.0387±0.0099[a]	0.0774±0.0010
1 : 5	5	30	0.1311±0.0106[ab]	0.0449±0.0170[a]	0.0895±0.0253
1 : 5	10	10	0.1066±0.0068[a]	0.0421±0.0306[a]	0.0810±0.0107
1 : 5	10	30	0.1511±0.0080[b]	0.0409±0.0075[a]	0.0924±0.0304
1 : 10	5	10	0.2283±0.0199[c]	0.0785±0.0559[ab]	0.0979±0.0136
1 : 10	5	30	0.2326±0.0199[c]	0.1141±0.0558[ab]	0.0983±0.0175
1 : 10	10	10	0.1516±0.0572[b]	0.0864±0.0584[ab]	0.0702±0.0121
1 : 10	10	30	0.2408±0.0074[c]	0.1415±0.0338[c]	0.1060±0.0450

[a-c] Values followed by different letters within the column are significantly different ($p<0.05$).

[ns] Not significantly different.

Table 4.12 Apparent density, real density and real porosity of impregnated papaya affected by impregnation solution ratio and vacuum impregnation condition

Papaya: solution ratio (w/w)	Impregnation time (min)	Relaxation time (min)	Apparent density (kg/m^3)	Real density (kg/m^3)	Real porosity[ns] (m^3 internal gas/m^3 fruit)
1 : 5	5	10	1.1322±0.0252[a]	1.2434±0.0181[a]	0.2469±0.0936
1 : 5	5	30	1.1259±0.0426[a]	1.3160±0.0210[ab]	0.2334±0.0555
1 : 5	10	10	1.2541±0.0107[bc]	1.3362±0.0945[ab]	0.2526±0.1225
1 : 5	10	30	1.2295±0.0502[bc]	1.4776±0.0684[c]	0.2645±0.0614
1 : 10	5	10	1.2133±0.0254[bc]	1.4038±0.0883[bc]	0.2429±0.0214
1 : 10	5	30	1.1998±0.0185[b]	1.4769±0.0926[c]	0.1777±0.0246
1 : 10	10	10	1.2490±0.0302[bc]	1.4000±0.0844[bc]	0.1886±0.0928
1 : 10	10	30	1.2791±0.0669[c]	1.5024±0.0510[c]	0.1631±0.0119

[a-c] Values followed by different letters within the column are significantly different ($p<0.05$).

[ns] Not significantly different.

These workers described that X value had a linear effect on papaya, in which the value increased with higher vacuum impregnation times between 3 and 25 min.

Sample volume deformation or γ value revealed the net volume changed at the end of vacuum impregnation process (Rongkom et al., 2013). The γ value of vacuum impregnated papaya was found to be increased between 0.039 and 0.142 m^3/m^3 initial sample at higher solution ratios and longer impregnation and relaxation times (Table 4.11). The result of relaxation time could be affected by the fact that at the last step of vacuum impregnation treatment, when atmospheric pressure was returned to the vacuum impregnation system, the residual gas inside sample tissues was compressed and external solution could flow into the sample pores as a function of the compression ratio (Ursachi et al., 2009; Zhao and Xie, 2004). The highest γ value was determined in the vacuum impregnated papaya treated with a solution ratio of 1:10 and had 10 min vacuum time and 30 min relaxation time.

Effective porosity (ε_e value) determined the volume of samples that could be occupied by external solution in the sample tissue (Zhao and Xie, 2004). Collected data of the ε_e value of the vacuum impregnated papaya displayed that the parameter value was generally increased with longer vacuum and relaxation times (Table 4.11). This result was consistent with the finding of WL values, in which the values were decreased with extended vacuum impregnation periods (Table 4.10). Higher water gain (lower WL values) would increase the volume of papaya tissues that was impregnated with the external solution (ε_e value). However, a statistical analysis showed that there was not any significantly different between the ε_e values of different papaya treatments ($p \geq 0.05$). The ε_e values of the vacuum impregnated papaya were in the range of 0.077-0.106%. Mújica-Paz et al. (2003a) also found that the ε_e value of papaya increased with an increase in vacuum impregnation time. The authors suggested that the vacuum impregnation time should be taken into account when applying vacuum impregnation methods into food products, since the processing time played an important role on ε_e value.

Table 4.12 shows real porosities of vacuum impregnated papaya affected by solution ratios and impregnation periods. Real porosity (ε_r value) constituted a measure of the empty spaces in fruit tissue and represented the maximum space that could be impregnated with an external solution (Paes et al., 2007). After vacuum impregnation processes, the ε_r values of different papaya samples impregnated with a solution ratio of 1:10 were reduced at longer vacuum and relaxation periods (Table 4.12). This was consistent with the result of ε_e value, indicating at extended period of vacuum impregnation processes, empty spaces in the papaya samples were decreased, replaced by the external solution. Zhao and Xie (2004) also reported that the volume of external solution impregnated into food samples significantly depended on vacuum impregnation time.

A comparison between ε_r and ε_e values of vacuum impregnated papaya displayed that the ε_r values were higher than those of the ε_e values. This finding was similar to the report of Mújica-Paz et al. (2003a) for melon, papaya and peach. This indicated that there was still free volume in the fruit samples for impregnation. However, capillary effects or structure modifications might cause this free volume for not to be completely filled (Mújica-Paz et al., 2003a).

This section was emphasised to understand the optimum vacuum impregnation condition to permeate external solution into porous structures of papaya fruit. From collected data, it was clearly demonstrated that papaya samples treated with a solution ratio of 1:10 with 10 min vacuum time and 30 min relaxation time produced the lowest water loss (the highest water gain) and ε_r together with the highest solid gain, X, γ and ε_e values. In other words, this particular fruit treatment had the largest fruit volume occupied by the external solution and also the smallest empty space inside the fruit structure. Therefore, this vacuum impregnation condition was selected to be further utilised in the next section.

4.4 Effect of drying methods and drying temperatures on the physicochemical of partially dried papaya

Fully ripe papaya with a size of 1 x 1 x 1 cm^3 was impregnated with sucrose solution using an impregnation condition at 50 mbar for 10 min vacuum period and 30 min relaxation time. The ratio between fruit sample and the external solution was 1:10. After the impregnation process, impregnated papaya was dried by hot air drying or vacuum drying using various drying temperatures of 40, 50 and 60ºC. Papaya samples were dried until a_w value of the fruit reached 0.6 or below. Water activity (a_w) is a physical property that has an impact on microbiological safety of food. Water activity was very useful to predict the shelf life of food. Normally, microorganisms grew best between a_w values of 0.99-0.98. For convectively dried fruits, they should be kept in water activity range of 0.46 - 0.63 (Šumić et al., 2013).

Since there were two drying methods and three drying temperatures were investigated in this study, drying times of each treatment combination were differed. It was found out that hot air drying used less drying time compared to that of vacuum drying for each drying temperature. In both hot air and vacuum drying methods, applying a high temperature of 60ºC used less drying times than those of other drying temperatures. The required drying times to dry 100 g papaya samples to reach a_w of 0.6 ± 0.02 at drying temperatures of 40, 50 and 60ºC in the hot air drying were 16, 8 and 4 h, respectively. On the other hand, in the vacuum drying method the drying times to remove water from 100 g papaya samples at 40, 50 and 60ºC with a drying pressure of 50 mbar were 30, 14 and 10 h, respectively (Table 4.13). It displayed that the vacuum drying process utilised longer drying times to dehydrate papaya samples than those of the hot air drying. Finding in this section was in an agreement with the report of El-Aouar et al. (2003). These workers also wrote that an increase in air temperature caused reduction of product drying time. Similarly, Udomkun et al. (2014) reported that drying time of papaya was reduced when drying temperatures were increased from 50 to 80ºC. Fernando et al. (2008), Yousefi et al. (2013) and Kurozawa et al. (2014) stated that higher drying temperatures caused quick removal of moisture and produced shorter drying periods. In addition, Udomkun et al. (2015a) informed that drying rate was depended on drying method, air temperature, relative humidity and air velocity.

Physicochemical characteristics of dried papaya after a drying process by hot air drying or vacuum drying at three different temperatures of 40, 50 and 60ºC are presented in Tables 4.13-4.15. Partially dried papaya had a_w in the range of 0.589 to 0.627 (Table 4.13). Higher a_w values at higher drying temperatures could be affected by different drying times applied in each drying temperature. Although drying methods did not significantly affect the a_w of partially dried papaya ($p \geq 0.05$), the combination of drying methods and temperatures significantly affected pH, titrable acidity and moisture content of the final papaya product ($p<0.05$; Table 4.13). The pH of different intermediate moisture papaya was between 6.47 and 6.60. For total titrable acidity, it was found that the acidity of papaya samples processed by the vacuum drying was significantly higher than those of samples treated by the hot air drying. Artnaseaw et al. (2010) stated that vacuum drying method might help to maintain the quality such as nutritive value of dried product. Comparing the acidity between impregnated papaya (Tables 4.3 and 4.8) with the partially dried papaya (Table 4.13), it could be observed that the total acidity value of the papaya samples were increased. This could be affected by removal of water from the papaya samples, causing an increase in citric acid concentration. The moisture contents of partially dried papaya processed by the hot air drying were significantly increased with higher drying temperatures ($p<0.05$). This finding was consistent with the results of the a_w. On the other hand, the moisture content of intermediate moisture papaya treated with the vacuum drying was not significantly affected by the drying temperatures ($p\geq0.05$). Sogi et al. (2015), who dried Tommy Atkins mango cubes, reported that acidity of dried mango was lower in samples processed by cabinet drying and vacuum drying compared to those treated by freeze drying. Total soluble solid of partially dried papaya was not significantly affected by different drying methods and temperatures applied in this section ($p\geq0.05$; Table 4.13).

Table 4.13 Water activity and chemical properties of partially dried papaya affected by drying methods and temperatures

Drying treatments	Drying times (h)	Water activity	pH	Total titrable acidity (% citric acid)	Total soluble solid ^{ns} (%Brix)	Vitamin C (mg/100ml)	Moisture content (%)
Hot air drying at 40ºC	16	0.589 ± 0.001^{a}	6.57 ± 0.06^{ab}	0.39 ± 0.00^{ab}	7.67 ± 0.12	294.24 ± 0.01^{ab}	36.1514 ± 0.6996^{a}
Hot air drying at 50ºC	8	0.598 ± 0.008^{ab}	6.53 ± 0.06^{ab}	0.42 ± 0.03^{b}	7.80 ± 0.20	317.92 ± 0.01^{b}	40.2640 ± 0.0456^{b}
Hot air drying at 60ºC	4	0.614 ± 0.005^{bc}	6.60 ± 0.00^{b}	0.38 ± 0.02^{a}	7.73 ± 0.12	301.03 ± 0.00^{ab}	44.1482 ± 1.1782^{c}
Vacuum drying at 40ºC	30	0.589 ± 0.010^{a}	6.50 ± 0.10^{ab}	0.49 ± 0.01^{cd}	7.73 ± 0.12	267.76 ± 0.04^{a}	38.3476 ± 1.0275^{ab}
Vacuum drying at 50ºC	14	0.610 ± 0.005^{bc}	6.50 ± 0.00^{ab}	0.52 ± 0.02^{d}	7.73 ± 0.12	316.60 ± 0.01^{b}	37.8445 ± 1.1111^{ab}
Vacuum drying at 60ºC	10	0.627 ± 0.018^{c}	6.47 ± 0.06^{a}	0.49 ± 0.00^{c}	7.73 ± 0.12	286.25 ± 0.02^{ab}	38.8301 ± 4.3525^{ab}

$^{a-d}$ Values followed by different letters within the column are significantly different ($p<0.05$).

^{ns} Not significantly different.

Table 4.14 Yield, texture, real porosity and sample volume deformation of partially dried papaya affected by drying methods and temperatures

Drying treatments	Shrinkage	Yield (%)	Firmness (N)	Real porosity (m^3 internal gas/m^3 fruit)	γ value [ns] (m^3/m^3 initial sample)
Hot air drying at 40ºC	71.1682 ± 1.0985[d]	15.10 ± 0.30[ab]	4.700 ± 0.642[a]	0.2307 ± 0.0225[ab]	0.1144 ± 0.0286
Hot air drying at 50ºC	56.0043 ± 1.6496[a]	15.79 ± 0.46[abc]	4.807 ± 1.492[a]	0.2638 ± 0.0211[b]	0.1190 ± 0.0452
Hot air drying at 60ºC	62.4278 ± 1.4165[c]	16.93 ± 0.25[c]	4.260 ± 1.197[a]	0.3142 ± 0.0127[c]	0.1285 ± 0.0127
Vacuum drying at 40ºC	91.2046 ± 1.1747[e]	14.95 ± 0.16[a]	7.473 ± 1.170[b]	0.7265 ± 0.0546[e]	0.1187 ± 0.0288
Vacuum drying at 50ºC	59.6745 ± 1.0898[b]	15.29 ± 0.58[ab]	7.356 ± 0.594[b]	0.5835 ± 0.0432[d]	0.1244 ± 0.0067
Vacuum drying at 60ºC	62.6677 ± 1.3538[c]	16.35 ± 0.86[bc]	7.622 ± 0.747[b]	0.2021 ± 0.0468[a]	0.1123 ± 0.0267

[a-e] Values followed by different letters within the column are significantly different ($p<0.05$).

[ns] Not significantly different.

Results of vitamin C measurement in intermediate moisture papaya can be seen in Table 4.13. Generally, vitamin C is relatively unstable to heat (Chen et al., 2016; Šumić et al., 2013). Therefore, vitamin C was usually considered as an index of nutrient quality during processing of food. If vitamin C was still well retained, the other nutrients were also well retained (Duzzioni et al., 2013; Kurozawa et al., 2014). This particular vitamin could be degraded by many factors, such as temperature, pH, light, time, presence of enzymes, oxygen and metallic catalysers (Kurozawa et al., 2014). The highest vitamin C content in the partially dried papaya was found in the samples that were processed at 50ºC, either by hot air or vacuum drying, which had values of 317.92 ± 0.01 and 316.60 ± 0.01 mg/100ml, respectively. Between two drying methods investigated in this section, hot air drying could retain more vitamin C compared to the vacuum drying. The vitamin C contents in the intermediate moisture papaya processed by hot air drying at 40, 50 and 60ºC were 294.24, 317.92 and 301.03 mg/100ml, respectively. This finding indicated that even though drying times of each drying temperature were differed, the destruction of vitamin C was a combination result of drying time and temperature. Šumić et al. (2013) observed that dried sour cherries had lower vitamin C compared to fresh sample after processed by vacuum drying. Sogi et al. (2015), who investigated about ascorbic acid content or vitamin C in dried mango, reported that there was a negative effect of heat damage on the vitamin in the final product. A study about drying acerola using drying temperatures of 40-60ºC found that the highest vitamin C content of acerola was determined in the sample processed at 60ºC (Duzzioni et al., 2013). According to Santos-Sánchez et al. (2012), the best temperature to dry tomato was at 60ºC that minimized the degradation of vitamin C content. Vitamin C was considered to be a quality indicator of processed food due to its low stability during heat treatments (Duzzioni et al., 2013). Although temperature had the greatest effect on ascorbic acid content, long drying times also promoted an ascorbic acid reduction. Drying at low temperatures could also cause ascorbic acid degradation with an increase in drying time (Santos-Sánchez et al., 2012). A similar result had been reported that drying carrot at high temperature could have greater retention of vitamin C because of less drying time (Chen et al., 2016). On the other hand, Kurozawa et al. (2014) evaluated the vitamin C degradation during drying of papaya. They described that higher retention of this nutrient at the end of drying process occurred at low temperatures of 40 and 50ºC for 52 and 49%, respectively, while at temperatures of 60 and 70ºC, the workers found that vitamin C retention were only 34 and 24%, respectively. In addition, they informed that vitamin C compound was highly thermo-sensitive. Thus an increase in drying temperatures resulted in a decrease in vitamin C content.

Each drying method had its own advantages and limitations. The final product obtained might differ in physicochemical and nutritional properties (Udomkun et al., 2015a). High air temperature might result in undesirable nutritional quality degradation. At higher air temperature, there was a higher temperature gradient between the sample and the drying air, resulting in a greater heat transfer into the sample and thus, bigger evaporation rate (Kurozawa et al., 2014). Thermal damage in fruit during drying process could occur directly from the process time. As longer time fruits remained in the dryer was conducted, the longer exposed time for fruits with hot air were obtained and, consequently, the higher nutrient degradation was observed (Kurozawa et al., 2014).

Yield of partially dried papaya is shown in Table 4.14. The highest yield was determined in papaya samples processed with hot air drying at 60ºC. On the other hand, the lowest yield was found in papaya samples treated with vacuum drying at 40ºC. At each drying temperature, the yield of intermediate moisture papaya with hot air drying was higher than that dried with vacuum drying. Using hot air drying at 40, 50 and 60ºC, the yields of partially dried papaya were 15.10, 15.79, and 16.93%, respectively, while the yields of papaya processed by vacuum drying were 14.95, 15.29 and 16.35%, respectively.

In shrinkage determination, sample dimension was measured and the change in volume reduction of samples was evaluated (Udomkun et al., 2014). Shrinkage parameter was evaluated by comparing dimension of impregnated papaya with dimension of partially dried papaya using toluene displacement method. The shrinkage results for intermediate moisture papaya are displayed in Table 4.14. The highest shrinkage value was found in papaya samples treated with vacuum drying at 40ºC (91.20), followed by samples processed using hot air drying at 40ºC (71.17). On the other hand, the lowest shrinkage value was discovered in papaya samples dried with hot air drying at 50ºC (56.00). Generally, it could be seen that hot air drying method produced lower shrinkage values than those of vacuum drying, which could be affected by less drying time. Udomkun et al. (2014) reported that an increase in drying temperature resulted in an increase in shrinkage values. Applying drying temperatures from 50 to 80ºC caused shrinkage to be increased by 12.7%. These workers explained that drying temperature had a considerable effect on sample shrinkage. Shrinkage increased as the volume of water removed, since dehydration induced stresses in the sample by contraction. Another study showed that the highest temperature of 70ºC caused higher shrinkage values (Kurozawa et al., 2012). The researchers explained that at high temperature shrinkage almost entirely compensated for moisture loss or in the other word, change in material volume was equal to the volume of removed water. In contrast, at low drying temperature, the volume of water removed was greater than the fruit volume reduction during all drying process. In addition, Udomkun et al. (2014) wrote that size and shape alterations could occur through shrinkage when water was removed from the fruit tissues. Furthermore, Kurozawa et al. (2012) indicated that the extension of shrinkage varied during a drying process. The rate of volume change was fast at the beginning of the process. As drying progresses, material shrank continously at lower rate. In many studies, it was indicated that shrinkage behaviour might be associated with various mechanisms, such as glass transition, pore pressure and mechanical strength of the matrix (Udomkun et al., 2014).

Drying is a commonly applied technique which is known to induce adverse effects, such as structural change, in food (Udomkun et al., 2014). Firmness of partially dried papaya affected by different drying conditions is demonstrated in Table 4.14. It was found that drying temperatures did not significantly affect papaya firmness ($p \geq 0.05$). Firmness of intermediate moisture papaya samples processed by vacuum drying was significantly higher than that of samples treated with hot air drying ($p<0.05$). The texture values of partially dried papaya produced by hot air drying were in the range of 4.260 to 4.807 N, while the papaya samples made through vacuum drying had the texture values in the range of 7.356 to 7.622 N. Šumić et al. (2013) had reported that firmness of dried sour cherries processed by vacuum drying increased with an increase in drying temperatures.

Real porosity constitutes a measurement of empty space inside the fruit tissue (Mújica-Paz et al., 2003a; Paes et al., 2008). Real porosity of partially dried papaya was significantly affected by different drying methods and temperatures ($p<0.05$; Table 4.14). The highest real porosity value was determined in papaya samples dried with vacuum drying at 40ºC (0.73 ± 0.05 m^3 internal gas/m^3 fruit), while the lowest value was revealed in papaya samples processed by vacuum drying at 60ºC. An increase in drying temperatures using hot air drying resulted in an increase in real porosity values, while an inverse relationship between drying temperatures and real porosity was found in vacuum drying processes. Sample volume deformation or γ value revealed the net volume changed at the end of drying process (Rongkom et al., 2013). Drying methods and temperatures investigated in this section did not significantly affect sample volume deformation of intermediate moisture papaya ($p>0.05$; Table 4.14).

Table 4.15 Colour values of partially dried papaya affected by drying methods and temperatures

Drying treatments	L* (Brightness)	a* (Red-Green)	b* (Yellow-Blue)
Hot air drying at 40ºC	25.79 ± 1.61^{a}	29.13 ± 1.48^{a}	24.32 ± 0.78^{a}
Hot air drying at 50ºC	31.78 ± 2.69^{b}	36.04 ± 3.02^{b}	27.84 ± 3.64^{ab}
Hot air drying at 60ºC	32.04 ± 4.47^{b}	38.81 ± 7.82^{b}	34.17 ± 10.86^{b}
Vacuum drying at 40ºC	27.18 ± 1.59^{a}	30.49 ± 1.79^{a}	24.61 ± 1.04^{a}
Vacuum drying at 50ºC	29.70 ± 4.02^{ab}	28.68 ± 3.91^{a}	23.08 ± 1.63^{a}
Vacuum drying at 60ºC	32.50 ± 2.20^{b}	39.01 ± 4.03^{b}	33.45 ± 4.23^{b}

$^{a-b}$ Values followed by different letters within the column are significantly different ($p<0.05$).

Colour is one of the visual appearances that is used to measure consumer acceptance (Šumić et al., 2013). Visual appearance is a major quality measurement as it directly affects consumer acceptance. Fresh fully ripe papaya fruit had average values of 51.86, 27.29 and 31.90 for L*, a* and b* values, respectively (Table 4.2), while impregnated papaya processed using an impregnation solution ratio at 1:10 with vacuum impregnation time of 10 min and relaxation time of 30 min possessed average values of 30.97, 15.92 and 9.07, respectively (Table 4.9). These values could be compared with colour values of partially dried papaya affected by drying methods and temperatures as shown in Table 4.15. In this Table, difference colour values of papaya treatments were measured and used as indicators of product quality and process performance. It could be seen that the colour of intermediate moisture papaya was generally affected by drying temperatures. Higher drying temperatures generated higher L*, a* and b* values. There was not any significant effect of drying methods on the colour values of partially dried papaya ($p \geq 0.05$). Another study reported that using a vacuum dryer, there was less colour change in chilli compared than using conventional drying method under atmospheric pressure, which could be affected by the fact that under low pressure in drying chamber had less oxygen, which led to less enzymatic browning reaction. In addition, the workers also found that there was an increase in colour change with an increase in drying pressure (Artnaseaw et al., 2010). In this study, the colour values of partially dried papaya were lower than those of fresh papaya samples, indicating loss of lightness during processing of the papaya samples. Reduction in the lightness values might be due to the occurrence of enzymatic or non-enzymatic browning reactions during drying processes (Udomkun et al., 2014). Browning reactions had a large impact on colour changes of final food products. Enzymatic oxidation due to polyphenoloxidase (PPO) activity, Maillard reaction, chlorophylls and carotenoid degradation were the main factors that contributed to the colour changes during thermal processing (Udomkun et al., 2014; Udomkun et al., 2015a). According to the result of Santos-Sánchez et al. (2012), they found that tomato darkening occurred during drying process at 50ºC, a maximum darkening of 9.7%. In this study, the highest L*, a* and b* values were found at 60ºC in both hot air drying and vacuum drying. In the hot air drying method, L*, a* and b* values were increased with an increase in air temperature. Artnaseaw et al. (2010) stated that drying at higher temperature resulted greater colour change than drying at lower temperature because of enzymatic browning reactions were accelerated by temperature. In both hot air drying and vacuum drying methods (Table 4.15), L* values tended to be increased with an increase in drying temperatures. In contrast, Udomkun et al. (2014) found that dried papaya at high temperature (80ºC) was tended to have lower L* value than other low temperatures. In this study, partially dried papaya from fully ripe fruit had reddish tone colour. The a* value of the intermediate moisture papaya (Table 4.15) was higher than those of fresh and impregnated papaya samples (Tables 4.2 and 4.9). A similar result had been reported by Nimmanpipug and Therdthai (2013). They reported that redness or a* value was increased due to non-enzymatic browning reaction. Therefore, the partially dried papaya in this study had a reddish tone.

Beside physicochemical analyses, partially dried papaya was subjected to a sensory evaluation. The sensory examination was conducted using 50 panellists, comprising of undergraduate and postgraduate students of the Division of Food Science and Technology, Faculty of Agro-Industry, Chiang Mai University. The sensory evaluation was carried out using a nine point scale to evaluate several sensory attributes, including appearance, colour, aroma, flavour, texture and overall liking. The nine point scale to assess sensory attributes utilised 9 as extremely like, 5 as neither like nor dislike and 1 as extremely dislike. The intermediate moisture fruit pieces dehydrated by hot air drying and vacuum drying were analysed for their sensory differences using six coded samples. The panellists were randomly presented with the samples to evaluate and record the sample code and score. The results showed that the panellists gave partially dried papaya processed by hot air drying to have higher score than those of the samples produced by vacuum drying for all of the sensory attributes (Table 4.16). For the term of appearance, vacuum dried papaya samples had lower scores than hot air dried papaya samples. The highest sensory score of colour was determined in the hot air dried papaya sample processed at 50ºC. This particular sample also had the highest sensory scores for aroma and flavour. However, the panellists appraised that all of the papaya treatments were not significantly differed in the sensory terms of texture and overall liking ($p \geq 0.05$). The sensory scores of texture were in the range of 5.66 to 6.18, while the overall liking had scores of 5.78 to 6.32. For most sensory attributes, the panellists had

Table 4.16 Sensory preferences of partially dried papaya affected by drying methods and temperatures

Drying treatments	Appearance	Colour	Aroma	Flavour	Texture^{ns}	Overall liking^{ns}
Hot air drying at 40ºC	6.44 ± 1.11^{b}	6.62 ± 1.21^{bc}	5.74 ± 1.51^{ab}	5.84 ± 1.73^{abc}	5.88 ± 1.45	6.22 ± 1.40
Hot air drying at 50ºC	6.54 ± 1.25^{b}	6.78 ± 0.99^{c}	6.04 ± 1.31^{b}	6.34 ± 1.45^{c}	6.18 ± 1.51	6.36 ± 1.45
Hot air drying at 60ºC	6.18 ± 1.37^{ab}	6.28 ± 1.39^{abc}	5.90 ± 1.28^{ab}	6.08 ± 1.58^{bc}	5.92 ± 1.38	6.18 ± 1.27
Vacuum drying at 40ºC	6.18 ± 1.42^{ab}	6.14 ± 1.50^{ab}	5.40 ± 1.36^{a}	5.30 ± 1.45^{a}	5.66 ± 1.39	5.78 ± 1.43
Vacuum drying at 50ºC	5.78 ± 1.52^{a}	6.04 ± 1.50^{a}	5.48 ± 1.47^{ab}	5.70 ± 1.56^{abc}	5.84 ± 1.27	5.94 ± 1.35
Vacuum drying at 60ºC	6.12 ± 1.26^{ab}	6.42 ± 1.21^{abc}	5.64 ± 1.32^{ab}	5.64 ± 1.34^{ab}	5.68 ± 1.35	5.96 ± 1.43

$^{a-c}$ Values followed by different letters within the column are significantly different ($p<0.05$). For each attribute a higher number represents higher intensity on a 1-9 scale.
^{ns} Not significantly different.

higher preferences for hot air dried papaya processed at 50ºC compared to other papaya treatments.

Between two different drying methods investigated in this section, it was found that hot air drying papaya samples had better values for vitamin C, lower shrinkage values and higher preference from sensory panellists compared to those of vacuum drying treatments. Within the hot air drying treatment, a drying temperature of 60ºC produced the highest pH value, moisture content, yield and b* value together with the lowest total titrable acidity. Vitamin C of the papaya samples dehydrated by hot air drying at 60ºC was not significantly differed than that of the papaya product dried at 50ºC using a similar drying method. In addition, the shortest drying time of 4 h to process the partially dried papaya products at 60ºC in hot air drying was useful to save energy and processing time. Therefore, a combination treatment of hot air drying and a temperature of 60ºC was worth to be further investigated in the next research section.

4.5 Effect of calcium solutions on the physicochemical properties of partially dried papaya

This section was dedicated to investigate the addition of calcium salts, either calcium chloride or calcium lactate, at concentrations of 1-3% (w/v) in impregnation solution and impregnation temperatures of 25 or 45ºC on the physicochemical characteristics of intermediate moisture papaya. Fully ripe papaya with a size of 1 x 1 x 1 cm^3 was impregnated with sucrose liquid containing calcium solutions at a solution ratio of 1:10 in a 1,000 ml beaker at 50 mbar for 10 min impregnation time and 30 min relaxation time. The amount of impregnation solution was 900 ml for each impregnation treatment. Following the impregnation process, impregnated papaya was dehydrated at 60ºC in a hot air oven. The analyses results of the partially dried papaya affected by calcium solutions and impregnation temperatures are displayed in Tables 4.17-4.19. Moisture contents of control papaya treatments at 25 and 45ºC were 25.89 and 26.67%, respectively (Table 4.17). For the treated papaya samples, the highest moisture content of fruit sample impregnated at 25ºC was 28.25% in the papaya with 3% calcium chloride, while for impregnation at 45ºC the highest moisture content of 28.57% was determined in the papaya with 3% calcium lactate. The addition of calcium salts and/or impregnation temperatures did not show any specific effect on the moisture contents of the final papaya samples. Water activity of different partially dried papaya treatments was in the range of 0.517 to 0.641 (Table 4.17). Impregnation of calcium salts in the papaya samples significantly affected pH values of intermediate moisture papaya ($p<0.05$; Table 4.17). The pH values of control papaya at 25 and 45ºC were 6.26 and 5.91, respectively. All of the calcium treated papaya samples had pH values lower than those of the control papaya samples. Between different concentrations of calcium solutions, the highest pH values were determined in 1% calcium chloride and calcium lactate at both impregnation temperatures. An increase in calcium concentrations resulted in a decrease in pH values of the papaya samples. For total acidity, it was found that papaya treated with 1% calcium lactate had the highest total acidity values among calcium treated papaya samples at both impregnation temperatures (Table 4.17). Khurnpoon et al. (2010) reported that the application of calcium lactate did not affect total soluble solid and total acidity values of papaya.

The highest yield of partially dried papaya was found in the papaya samples with 3% calcium chloride at both impregnation temperatures of 25 and 45ºC, which were 17.45 and 17.57%, respectively (Table 4.17). On the other hand, the lowest yield value was determined in the control treatment at 45ºC, which was 12.67%. There was not any significance differences among yield results between papaya treatments impregnated at 25ºC ($p \geq 0.05$). The yields of papaya samples impregnated with calcium chloride and calcium lactate processed at 25ºC were in the range of 15.32 – 15.53 and 15.99 – 17.45%, respectively. Applying an impregnation temperature of 45ºC, there was not any significant difference in the term of yields among papaya samples treated with calcium chloride, which had values between 15.98 and 17.57%. In contrast, the yield of papaya samples permeated with calcium lactate at 45ºC was significantly different ($p<0.05$). Adding 1, 2 and 3% calcium lactate in papaya samples produced yields of 14.91, 15.89 and 16.30%, respectively. An increase in calcium lactate concentration produced higher yield.

Table 4.17 Water activity, chemical properties and yield of partially dried papaya affected by calcium types and concentrations and impregnation temperatures

Calcium treatments	Moisture content (%)	Water activity	pH	Total soluble solid (%Brix)	Total titrable acidity (% citric acid)	Yield (%)
Control at 25ºC	25.8939±0.6683[abc]	0.641±0.005[g]	6.26±0.03[i]	7.26±0.12[f]	0.62±0.01[e]	16.30±2.30[b]
1% Calcium chloride at 25ºC	26.4126±0.3695[abc]	0.612±0.001[f]	5.20±0.01[c]	6.80±0.20[b]	0.49±0.01[a]	15.99±0.90[b]
2% Calcium chloride at 25ºC	25.6376±0.4169[a]	0.564±0.007[d]	4.82±0.00[b]	7.07±0.12[de]	0.50±0.03[a]	16.48±0.13[b]
3% Calcium chloride at 25ºC	28.2516±0.1811[de]	0.545±0.005[c]	4.69±0.01[a]	7.27±0.12[f]	0.50±0.00[a]	17.45±0.81[b]
1% Calcium lactate at 25ºC	26.4609±0.3394[abc]	0.601±0.006[ef]	5.62±0.02[g]	6.20±0.00[a]	0.55±0.02[bc]	15.46±0.76[b]
2% Calcium lactate at 25ºC	25.7567±0.3578[ab]	0.551±0.012[c]	5.43±0.01[f]	7.20±0.00[ef]	0.51±0.02[a]	15.32±0.91[b]
3% Calcium lactate at 25ºC	26.1568±0.5042[abc]	0.531±0.003[b]	5.39±0.01[e]	7.07±0.12[de]	0.51±0.02[a]	15.53±1.04[b]
Control at 45ºC	26.6727±1.9221[abc]	0.544±0.013[bc]	5.91±0.01[h]	7.00±0.00[cd]	0.57±0.02[cd]	12.67±1.15[a]
1% Calcium chloride at 45ºC	26.5448±0.9068a[bc]	0.539±0.015[bc]	5.38±0.01[e]	7.00±0.00[cd]	0.52±0.00[ab]	15.98±1.72[b]
2% Calcium chloride at 45ºC	26.3694±0.6321[abc]	0.589±0.010[e]	4.83±0.00[b]	7.33±0.12[f]	0.51±0.01[a]	16.59±0.98[b]
3% Calcium chloride at 45ºC	27.2033±0.1130[cd]	0.601±0.006[ef]	4.81±0.01[b]	6.87±0.12[bc]	0.51±0.02[a]	17.57±0.95[b]
1% Calcium lactate at 45ºC	26.4815±0.5315[abc]	0.517±0.004[a]	5.61±0.01[g]	7.00±0.00[cd]	0.59±0.04[de]	14.91±0.74[a]
2% Calcium lactate at 45ºC	27.0744±0.4860[bcd]	0.605±0.005[f]	5.31±0.01[d]	6.87±0.12[bc]	0.56±0.00[c]	15.89±1.03[b]
3% Calcium lactate at 45ºC	28.5687±0.3968[e]	0.547±0.003[c]	5.37±0.01[e]	6.87±0.12[bc]	0.55±0.02[bc]	16.30±0.44[b]

[a-h] Values followed by different letters within the column are significantly different ($p<0.05$).

Table 4.18 Real porosity, γ value, shrinkage and texture of partially dried papaya affected by calcium types and concentrations and impregnation temperatures

Calcium treatments	Real porosity (ε_r) (m^3 internal gas/m^3 fruit)	γ value (m^3/m^3 initial sample)	Shrinkage	Firmness (N)
Control at 25ºC	0.2933±0.0111^{i}	0.1466±0.0061^{h}	74.0684±0.7709^{g}	3.271±0.511^{a}
1% Calcium chloride at 25ºC	0.2543±0.0104^{g}	0.1194±0.0082^{fg}	75.1316±1.0933^{h}	10.296±1.494^{c}
2% Calcium chloride at 25ºC	0.2503±0.0019^{g}	0.1122±0.0135^{ef}	73.8927±0.8805^{g}	17.432±0.995^{e}
3% Calcium chloride at 25ºC	0.2093±0.0069^{e}	0.0613±0.0026^{b}	71.6424±0.8429^{f}	22.591±1.041^{h}
1% Calcium lactate at 25ºC	0.2492±0.0047^{g}	0.1248±0.0074^{g}	73.7157±0.7228^{g}	7.849±0.981^{b}
2% Calcium lactate at 25ºC	0.2283±0.0050^{f}	0.1090±0.0017^{ef}	71.7543±0.6222^{f}	14.679±0.958^{d}
3% Calcium lactate at 25ºC	0.2020±0.0053^{de}	0.0737±0.0041^{c}	69.2192±0.9610^{e}	19.728±1.055^{f}
Control at 45ºC	0.2692±0.0136^{h}	0.1293±0.0091^{g}	70.8994±0.8071^{f}	3.041±0.566^{a}
1% Calcium chloride at 45ºC	0.2085±0.0070^{e}	0.0886±0.0057^{d}	68.8868±0.9771^{de}	14.211±0.938^{d}
2% Calcium chloride at 45ºC	0.2021±0.0072^{de}	0.0678±0.0070^{bc}	68.1218±0.6682^{d}	20.618±1.196^{g}
3% Calcium chloride at 45ºC	0.1874±0.0059^{c}	0.0496±0.0029^{a}	66.0728±0.5664^{b}	28.267±1.617^{i}
1% Calcium lactate at 45ºC	0.1923±0.0057^{cd}	0.1032±0.0047^{e}	69.0147±0.5996^{de}	14.827±1.252^{d}
2% Calcium lactate at 45ºC	0.1719±0.0158^{b}	0.0738±0.0028^{c}	67.0933±0.6657^{c}	20.082±0.855^{fg}
3% Calcium lactate at 45ºC	0.1529±0.0084^{a}	0.0656±0.0035^{bc}	64.9655±0.5504^{a}	23.390±1.807^{h}

$^{a-i}$ Values followed by different letters within the column are significantly different ($p<0.05$).

Some physical characteristics of partially dried papaya affected by calcium treatments and impregnation temperatures are shown in Table 4.18. Texture data in the Table showed that the control papaya samples processed at 25 and 45ºC had the lowest values of 3.27 and 3.04 N, respectively. It was reported that kiwi fruit in water combined with a heat treatment increased firmness of the sample higher than unheated sample because of the activity of pectin methyl esterase activity (PME) (Beirão-da-Costa et al., 2008). Heat treatment alone could affect cantaloupe firmness (Luna-Guzmán and Barrett, 2000). In addition, heat treatment alone or in combination with calcium treatment was effective affecting firmness of cantaloupe, which attributed to the action of PME (Luna-Guzmán and Barrett, 2000). A similar finding regarding a combination application with heat that maintained textural properties of fruit was also reported by Martín-Diana et al. (2006).

In this study, it was found out that calcium treated papaya samples at both impregnation temperatures significantly had higher firmness compared to those of untreated (control) papaya samples ($p<0.05$). A similar finding was also reported by Beirão-da-Costa et al. (2008). They determined that fruit treated with 1% $CaCl_2$ at 45ºC significantly had higher firmness values than fruit treated without calcium at the same temperature. Luna-Guzmán and Barrett (2000) observed that calcium lactate treatment at either 25 or 60ºC significantly produced firmer cantaloupe samples than water treatment. Anino et al. (2006) wrote that texture of fruits could strongly change during calcium impregnation processes because of the alterations of their structure. Calcium helped to maintain the cell wall structure of fruits and vegetables by interacting with pectin to form calcium pectate. Calcium was reported to maintain firmness by cross-linking with both cell wall and middle lamella pectin (Anino et al., 2006; Gras et al., 2003; Martín-Diana et al., 2006; Rico et al., 2007). Sample treated with calcium needed higher force to be pressed than non-treated sample. In an agreement with Martín-Diana et al. (2006), Rico et al. (2007) showed that sample treated with calcium lactate maintained texture better than sample treated with chlorine. A combination of impregnation solution with calcium could interact with the cellular matrix of fruit, which could modify fruits structural and mechanical properties (Gras et al., 2003). In this study, it was discovered that applying a high temperature of 45ºC did not significantly increase the firmness value in the control papaya samples ($p\geq0.05$; Table

4.18). At both impregnation temperatures of 25 and 45ºC, higher calcium concentrations significantly increased the firmness of the partially dried papaya samples ($p<0.05$). The capability of calcium chloride to increase papaya samples firmness compared to calcium lactate was more pronounced at impregnation temperature of 25ºC. In contrast, Luna-Guzmán and Barrett (2000) found that at 25ºC the firmness of cantaloupe treated with calcium lactate was higher than calcium chloride. For this study, at 45ºC impregnation temperature, there were no significant differences in the term of papaya firmness added with 1 and 2% of calcium chloride and calcium lactate ($p \geq 0.05$). Utilising 3% calcium salt solution, the papaya samples with calcium chloride (28.27 N) had higher firmness than that added with calcium lactate (23.39 N). Therefore, processing papaya samples at high temperature of 45ºC produced similar firmness values for both calcium salt types, except at 3% concentration level. In general, a combination of heat or high temperature and calcium treatments significantly increased the firmness values of papaya samples compared to those processed at 25ºC or non-heated treatment ($p<0.05$). A similar finding was reported for carrot by Rico et al. (2007). The researchers found an increase in carrot firmness resulted from a combination of heat-shock and calcium lactate treatment. Martín-Diana et al. (2006) also demonstrated that heat-shock treatment (at 50ºC) combined with calcium gave better textural properties compared with no heat-shock treatment. According to Beirão-da-Costa et al. (2008) and Trindade et al. (2003), calcium treatment combined with higher temperature resulted in more effective in maintaining food firmness quality. In addition, Martín-Diana et al. (2006) and Rico et al. (2007) stated that a combination of calcium agent with heat treatment could maintain the texture of various fruits. The effects heat treatments were attributed to the action of heat-activated PME. Moreover, heat treatment might induce to increase calcium diffusion into the tissue (Luna-Guzmán and Barrett, 2000).

Improvement in texture properties of intermediate moisture papaya was expected to influence for its shrinkage properties. Measurement results of shrinkage affected by calcium solutions at three different concentrations and two impregnation temperatures are presented in Table 4.18. It was mentioned earlier that shrinkage was a sample dimension that measured changing in volume (Udomkun et al., 2014). Higher shrinkage values would indicate smaller size and volume of papaya fruit sample. From collected data, it could be seen that control papaya samples significantly had higher shrinkage values than those of calcium treated papaya samples ($p<0.05$). All of the partially dried papaya treated with calcium at 45ºC significantly possessed lower shrinkage values compared to those of calcium added papaya samples impregnated at 25ºC. The shrinkage values of the control papaya samples treated at 25 and 45ºC were 74.0684 and 70.8994, respectively. Udomkun et al. (2014) noted that shrinkage occurred when water was removed from fruit tissues, causing size and shape alteration. In this study, it was also found that an increase in calcium concentration significantly decreased the shrinkage values ($p<0.05$). At 25ºC impregnation temperature, calcium chloride added papaya samples significantly possessed higher shrinkage values than those of calcium lactate impregnated papaya treatments. The shrinkage values of calcium chloride supplemented papaya samples at 1, 2 and 3% concentrations processed at 25ºC were 75.1316, 73.8927 and 71.6424, respectively; while the values of calcium lactate added papaya treatments were 73.7157, 71.7543 and 69.2192, respectively. At higher impregnation temperature of 45ºC, 1% calcium concentration did not produce any significant differences for shrinkage values of papaya samples treated with calcium chloride and calcium lactate. Applying this impregnation temperature, the shrinkage values of calcium chloride added papaya samples at 2 and 3% concentrations were 68.1218 and 66.0728, respectively, whereas the calcium lactate treated papaya samples had shrinkage values of 67.0933 and 64.9655, respectively. Results clearly indicated that calcium treatments improved shrinkage values of the intermediate moisture papaya products. An increase in calcium concentrations also reduced shrinkage values. Regarding firmness values, it was found that shrinkage and firmness values of the partially dried papaya were inversely related. Between two different calcium types, calcium lactate generally produced lower shrinkage values than that of calcium chloride. This indicated that calcium lactate added papaya samples endured less volume changing during drying processes.

Real porosity values of partially dried papaya can be seen in Table 4.18. Real porosity constituted a measurement of empty space inside fruit tissues (Mújica-Paz et al., 2003b; Paes et al., 2008). Data in Table 4.18 clearly displayed that control papaya samples at 25 and 45ºC impregnation temperatures significantly had higher real porosity values compared to those of calcium treated papaya products ($p<0.05$). The control papaya treatment at 25ºC also possessed higher real porosity value than that of the control papaya sample processed at 45ºC. This indicated that empty spaces in the control papaya tissues treated at 45ºC were less than that of the control papaya product processed at 25ºC. For calcium treated intermediate moisture papaya, higher impregnation temperature produced lower empty spaces inside the papaya tissue samples. The higher impregnation temperature might assist in the absorption of impregnation solution into papaya samples and improve the papaya structures (Paes et al., 2008). At 25ºC impregnation temperature, calcium chloride treated papaya samples at 1, 2 and 3% concentrations had real porosity values of 0.2543, 0.2503 and 0.2093 m^3 internal gas/m^3 fruit, respectively. On the other hand at similar impregnation temperature, the real porosity values of calcium lactate added papaya treatments were 0.2492, 0.2283 and 0.2020 m^3 internal gas/m^3 fruit, respectively. This result showed that calcium chloride impregnated papaya had higher real porosity values than those of calcium lactate papaya samples. Finding of the real porosity values of calcium treated papaya processed at 25ºC was consistent with the result of the papaya samples impregnated at 45ºC, in which the real porosity values of calcium lactate papaya samples were lower than those of papaya products supplemented with calcium chloride. The lowest real porosity value was determined in the partially dried papaya treated at 45ºC with 3% calcium lactate. At 45ºC impregnation temperature, the real porosity values of calcium chloride papaya samples at 1, 2 and 3% concentrations were 0.2085, 0.2021 and 0.1874 m^3 internal gas/m^3 fruit, respectively. For calcium lactate papaya treatments at similar impregnation condition, the real porosity values were 0.1923, 0.1719 and 0.1529 m^3 internal gas/m^3 fruit, respectively.

Sample volume deformation or γ value revealed the net volume changed at the end of drying process (Rongkom et al., 2013). The parameter results for intermediate moisture papaya affected by calcium types, concentrations and impregnation temperatures are exhibited in Table 4.18. The sample volume deformation of control papaya sample (untreated) at 25ºC, which was 0.1466 m^3/m^3 initial sample, was significantly the highest value compared to those of the control papaya treatment at 45ºC (0.1293 m^3/m^3 initial sample) and calcium treated papaya products ($p<0.05$). Both the control and calcium treated papaya samples at 25ºC impregnation temperature had higher sample volume deformation values than those of papaya processed at 45ºC impregnation temperature. The finding clearly suggested that impregnation temperature significantly influenced the sample volume deformation of the partially dried papaya ($p<0.05$). The presence of different calcium concentrations in impregnation solution was also affected the sample volume deformation of the intermediate moisture papaya products. Higher calcium concentrations were significantly reduced sample volume deformation of the final papaya products ($p<0.05$). Among calcium treated papaya samples, the highest sample volume deformation was found in the papaya samples added with 1% calcium lactate at 25ºC. The sample volume deformation of calcium chloride papaya samples with 1, 2 and 3% concentrations and the impregnation temperature of 25ºC were 0.1194, 0.1122 and 0.0613 m^3/m^3 initial sample, respectively. Applying the impregnation temperature of 45ºC, the calcium chloride papaya treatments had sample volume deformation values of 0.0886, 0.0678 and 0.046 m^3/m^3 initial sample, respectively. For calcium lactate papaya samples, the addition of 1, 2 and 3% calcium lactate at 25ºC produced sample volume deformation values of 0.1248, 0.1090 and 0.0737 m^3/m^3 initial sample, respectively. These values were reduced in the calcium lactate papaya samples treated at 45ºC to be 0.1032, 0.0738 and 0.0656 m^3/m^3 initial sample, respectively. These results showed that at both impregnation temperatures of 25 and 45ºC, calcium chloride produced lower sample volume deformation values in the papaya samples than those of calcium lactate. It was informed that calcium could interact with plant cellular matrix, leading to a more interconnected structure that limited water and solids exchange (Occhino et al., 2011). At the end of vacuum impregnation step, the volume deformation of samples (eggplant, carrot and oyster mushroom) was very small (Gras et al., 2003).

Table 4.19 Colour values of partially dried papaya affected by calcium types and concentrations and impregnation temperatures

Calcium treatments	L* (Brightness)	a* (Red-Green)	b* (Yellow-Blue)
Control at 25ºC	27.86 ± 1.06^{cdef}	33.15 ± 0.99^{de}	28.60 ± 0.68^{bc}
1% Calcium chloride at 25ºC	28.47 ± 0.70^{def}	30.86 ± 0.89^{bcd}	26.07 ± 3.87^{ab}
2% Calcium chloride at 25ºC	27.16 ± 3.02^{bcdef}	29.75 ± 0.72^{abcd}	24.06 ± 1.27^{a}
3% Calcium chloride at 25ºC	24.93 ± 1.51^{abcd}	27.83 ± 0.48^{abc}	24.02 ± 1.13^{a}
1% Calcium lactate at 25ºC	33.34 ± 1.23^{g}	38.67 ± 0.84^{f}	32.16 ± 0.77^{d}
2% Calcium lactate at 25ºC	29.04 ± 1.45^{ef}	33.78 ± 1.90^{de}	29.56 ± 2.27^{cd}
3% Calcium lactate at 25ºC	30.33 ± 3.69^{fg}	32.54 ± 2.37^{de}	31.19 ± 0.47^{cd}
Control at 45ºC	33.73 ± 2.15^{g}	36.17 ± 4.21^{ef}	30.50 ± 2.49^{cd}
1% Calcium chloride at 45ºC	23.63 ± 0.73^{ab}	26.89 ± 0.16^{ab}	23.99 ± 0.51^{a}
2% Calcium chloride at 45ºC	22.25 ± 1.32^{a}	27.68 ± 0.59^{abc}	23.52 ± 0.93^{a}
3% Calcium chloride at 45ºC	28.18 ± 2.04^{def}	25.89 ± 5.61^{a}	24.19 ± 2.16^{a}
1% Calcium lactate at 45ºC	27.97 ± 0.29^{cdef}	31.47 ± 0.81^{cd}	28.54 ± 0.28^{bc}
2% Calcium lactate at 45ºC	26.30 ± 0.79^{bcde}	29.88 ± 0.75^{abcd}	25.48 ± 0.55^{a}
3% Calcium lactate at 45ºC	24.38 ± 3.29^{abc}	27.99 ± 3.97^{abc}	25.07 ± 1.93^{a}

$^{a-g}$ Values followed by different letters within the column are significantly different (p<0.05).

Table 4.20 Sensory preferences of partially dried papaya affected by different calcium lactate concentrations

Calcium treatment	Sensory attributes					
	Appearance^{ns}	Colour^{ns}	Aroma^{ns}	Flavour	Texture	Overall liking
Control at 25ºC	6.10±1.27^{a}	6.06±1.50^{a}	5.72±1.62^{a}	6.28±1.60^{c}	6.20±1.75^{b}	6.24±1.59^{b}
1% calcium lactate at 25ºC	6.30±1.68^{a}	6.40±1.58^{a}	5.22±1.80^{a}	4.32±2.06^{a}	5.16±1.94^{a}	5.00±1.85^{a}
2% calcium lactate at 25ºC	6.30±1.39^{a}	6.12±1.49^{a}	5.64±1.61^{a}	5.72±1.80^{bc}	5.58±1.80^{ab}	5.86±1.64^{b}
3% calcium lactate at 25ºC	6.32±1.30^{a}	6.22±1.40^{a}	5.30±1.54^{a}	5.36±1.69^{b}	5.40±1.69^{a}	5.60±1.68^{ab}

$^{a-c}$ Values followed by different letters within the column are significantly different ($p<0.05$). For each attribute a higher number represents higher intensity on a 0-9 scale.

^{ns} Not significantly different.

Colour values of partially dried papaya were significantly affected by different calcium types, concentrations and impregnation temperatures ($p<0.05$; Table 4.19). L*, a* and b* values of control papaya samples treated at 45ºC were higher than those of the control papaya processed at 25ºC. At 25ºC impregnation condition, calcium lactate papaya treatments had higher L*, a* and b* values compared to those of the control papaya and calcium chloride papaya samples. Applying this impregnation temperature, the calcium treated papaya with 1% calcium lactate had the highest L* value of 33.34, a* value of 38.67 and b* value of 32.16. The colour values of this last papaya sample were also significantly higher than those of the calcium treated papaya at 45ºC ($p<0.05$). This result indicated that a combination of calcium treatment and high impregnation temperature of 45ºC generated lower colour values. Using the impregnation condition at 45ºC, the control papaya had higher colour values than those of calcium treated papaya. Finding in this study was not similar to the report of Silva et al. (2014), who observed that colour values of pineapples treated with and without calcium were not significantly different.

Supplementation of calcium solutions into intermediate moisture papaya was also subjected to a sensory evaluation. This examination was aimed to aid in comparing and selecting the optimum calcium type, concentrations and impregnation temperatures to be added in the partially dried papaya based on their sensory profiles. The sensory analysis was conducted by 50 panellists, mainly undergraduate and postgraduate students of the Division of Food Science and Technology, Faculty of Agro-Industry, Chiang Mai University. The assessment was carried out using a nine point hedonic scale for sensory attributes of appearance, colour, aroma, flavour, texture and overall liking. The nine point hedonic scale comprised of 9 as extremely like, 5 as neither like nor dislike and 1 was extremely dislike. The intermediate moisture papaya samples that were assessed in the sensory testing were control papaya and calcium lactate treated papaya processed at 25ºC. This impregnation temperature was selected because a similarity for physicochemical results and appearance between the papaya samples processed at 25 and 45ºC. It was expected that doing impregnation at ambient temperature could save energy and production cost than that at higher temperature of 45ºC. Calcium chloride papaya samples were not evaluated in the sensory analysis due to bitterness flavour of the sample. Martín-Diana et al. (2006) and Rico et al. (2007) had informed that calcium lactate was a good alternative compared to calcium chloride because the first calcium type prevented bitterness or off-flavours associated with the chloride salt. A similar result had been reported that 1% calcium lactate treated cantaloupe at 25ºC was not significantly differed in bitterness than those of 1% calcium lactate cantaloupe processed at 60ºC and control (non-treated) cantaloupe. On the other hand, cantaloupe treated with 1% calcium chloride at 60ºC was significantly scored to have more bitter taste than the control cantaloupe (Luna-Guzmán and Barrett, 2000). Beirão-da-Costa et al. (2008) cited that $CaCl_2$ could impart a bitter flavour to fruit samples. In this study, sensory panellists appraised that different partially dried papaya to be not significantly differed in the sensory characteristics of appearance, colour and aroma ($p \geq 0.05$; Table 4.20). For these sensory features, calcium lactate papaya was similar to that of the control papaya that was not supplemented with calcium lactate. In the flavour attribute, the highest score was determined in the control papaya (6.28), followed by 2% calcium lactate papaya with a sensory score of 5.72. Similar finding was also found for texture or firmness of papaya samples, in which the control papaya had the highest score of 6.20 and 2% calcium lactate papaya sample possessed the 2nd position with a score of 5.58. Therefore, the panellists gave the highest score of the overall liking of the papaya sample for the control papaya. The overall liking of this papaya sample was not significantly differed than that of the 2% calcium lactate papaya ($p \geq 0.05$). In addition, the panellist did not give any remarks about the presence of any strange flavour in the papaya samples.

Data in this section presented that calcium treatment in partially dried papaya supported the physical properties of the final papaya product. Higher calcium concentrations produced higher firmness and lower real porosity, shrinkage and sample volume deformation in the intermediate moisture papaya. Calcium chloride and an impregnation temperature of 45ºC produced higher firmness values. On the other hand, calcium lactate impregnated at 45ºC generated lower shrinkage and real porosity values. Since calcium chloride imparted bitterness flavour, the calcium treatment could not be studied further. For calcium lactate permeated at 25ºC, a sensory evaluation appraised a concentration of 2% to have similar flavour, texture and overall liking as a control papaya processed at 25ºC. Therefore, 2% calcium lactate and the impregnation temperature of 25ºC were selected to be further utilised in the next experimental section.

4.6 Supplementation of a lactic acid bacterium in partially dried papaya

In this section, fresh papaya was impregnated with lactobacilli, namely *Lactobacillus casei* TISTR 390. Another set of samples of control papaya, which was impregnated without the studied microorganisms, was also produced. The lactobacilli cultures were prepared by growing the cultures in de Man Rogosa Sharpe broth and incubated at 37ºC for 24 h. In the following day, 5 ml of the growth cultures were transferred into 45 ml sterile de Man Rogosa Sharpe broth and kept at 37ºC for 16 h. After the 2^{nd} step of resuscitation, the viable number of *L. casei* in the medium was 9.38 ± 0.01 log cfu/ml. A 10 ml of the cultured MRS broth was then centrifuged at 4,000 rpm for 20 min at 4ºC (section 3.4.6). The collected lactobacilli cells were washed two times with 0.1% sterile peptone water and the final cells of lactobacilli were aseptically transferred into 1,000 ml sterile impregnation medium of sucrose solution containing 2% calcium lactate. In this impregnation medium, the number of lactobacilli was 7.15 ± 0.04 log cfu/g. The concentration of probiotic in the impregnation solution had to be high enough to deliver adequate levels of probiotic in impregnated papaya tissues (Betoret et al., 2012). On the day of experiment, fresh fully ripe papaya was cut into 1 x 1 x 1 cm^3, impregnated in sucrose solution containing 2% calcium lactate and lactobacilli at a ratio of 1:10 at 50 mbar vacuum pressure and a temperature of 25ºC for 10 min vacuum time and 30 min relaxation time and dehydrated in a hot air oven at 60ºC for 4 h. For impregnation solution, it had an a_w of 0.986 and was produced by adding 13 g sucrose in 100 ml distilled water. The final product of partially dried papaya was subjected to physicochemical and microbiological analyses.

Based on microbiological examination, intermediate moisture papaya contained lactic acid bacteria of 6.09 ± 0.04 log cfu/g (Table 4.21). Krasaekoopt and Suthanwong (2008) reported that after impregnation of fruit juice containing 10^{10} cfu/ml *L. casei*, impregnated papaya samples had probiotic numbers in the range of 9.33 to 9.70 log cfu/g. In this study, vacuum impregnation and drying process produced a reduction in viable cells of *L. casei* by around one logarithmic cycle. According to Betoret et al. (2003), vacuum impregnation and air drying operation reduced probiotic microbial contents. By doing an air dried at 40ºC for 36 h, the survival number of *L. casei* in partially dried papaya was 8.85 log cfu/g from around 9.0 log cfu/g in impregnated papaya (Krasaekoopt and Suthanwong, 2008). A similar finding was also demonstrated by Betoret et al. (2012). These researchers found that air drying of impregnated apple sample resulted in a reduction of 1 log microbial content. Finding in this study for the number of lactic acid bacteria in the partially dried papaya, which was 6.09 ± 0. 04 log cfu/g, was considered to be sufficient for the number of probiotic in dehydrated food products. Betoret et al. (2003) had stated that probiotic dairy products should have a microbial level higher than 10^6 cfu/ml. Similarly, Yoon et al. (2006) also accounted that a minimum number of probiotic organisms in food product should be 10^6 cfu/g to deliver the maximum health benefit from the organisms. Another research study conveyed that *L. casei* in lychee juice that was spray dried at 80ºC had survival microbial cells up to 5.04 to 6.18 log cfu/g in the dried products (Kingwatee et al., 2015). For control samples in this study, no microorganism was detected in total microbial count and lactic acid bacteria examination that were conducted using the lowest dilution of 10^{-3}. Compared with microbial contents in other fruit, Betoret et al. (2012) reported that there was not any microorganism was detected in fresh apple sample. In contrast, another research work showed that fresh apple and cantaloupe contained lactic acid bacteria in the number of less than 0.46 log cfu/g (Wirjantoro et al., 2015).

For a physical property of partially dried papaya containing *L. casei*, real porosity of the final papaya product was measured (Table 4.21). Real porosity constituted a measurement of empty space inside fruit tissues (Mújica-Paz et al., 2003b; Paes et al., 2008). Comparing the real porosities of intermediate moisture papaya with and without *L. casei* (control sample), it was found out that the control papaya significantly had a higher real porosity value ($p<0.05$). The real porosity of the control papaya was 0.2249 m^3 internal gas/m^3 fruit, while the *L. casei* papaya sample had a value of 0.1523 m^3 internal gas/m^3 fruit. The real porosity values had a high correlation with impregnation of *L. casei* that was in sucrose or external liquid during vacuum impregnation. This indicated that empty space of intermediate moisture papaya containing *L. casei* was partially occupied by the probiotic organisms that were penetrated into the fruit tissue, causing it to be lower than the control papaya sample. This result also suggested that vacuum impregnation conditions in this study were able to introduce microbial cells into fresh papaya tissue through the addition of *L. casei* in the external or impregnation solution.

Colour of intermediate moisture papaya with *L. casei* showed that supplementation of the probiotic significantly increased L* value of the final papaya sample compared to that of the control papaya treatment ($p<0.05$; Table 4.21). The control papaya had the L* value of 29.28, whereas the *L. casei* papaya possessed the L* value of 32.87. On the other hand, there were no significant differences for a* and b* values between papaya samples with and without *L. casei* ($p\geq0.05$; Table 4.21). Similarly, moisture content, total soluble solid, total titrable acidity and firmness values of partially dried papaya were not significantly affected by the addition of *L. casei* ($p\geq0.05$; Table 4.21). The presence of *L. casei* in the intermediate moisture papaya significantly reduced pH value of the papaya compared to the control sample ($p<0.05$; Table 4.21). Luna-Guzmán and Barrett (2000) had informed that an addition of lactic acid bacteria could produce lower intracellular pH or reduce water activity of food products. Therefore, a_w of *L. casei* papaya significantly had a lower value than that of the control papaya treatment.

Table 4.21 Physicochemical and microbial properties of partially dried papaya supplemented with *Lactobacillus casei* TISTR 390

Physicochemical and microbial properties	Papaya treatments	
	Control without *Lactobacillus casei*	Supplemented with *Lactobacillus casei*
Moisture content[ns] (%)	27.3499±0.3284	28.2543±0.6177
Water activity	0.612±0.005[b]	0.594±0.004[a]
pH	5.59±0.02[b]	5.46±0.01[a]
Total soluble solid[ns] (% Brix)	6.00±0.00	6.00±0.00
Total titrable acidity[ns] (% citric acid)	0.50±0.02	0.53±0.02
L* (Brightness)	29.28±0.85[a]	32.87±0.41[b]
a*[ns] (Red-Green)	36.41±1.60	36.48±2.16
b*[ns] (Yellow-Blue)	27.89±0.92	26.78±1.96
Firmness[ns] (N)	7.725±0.355	7.705±0.434
Real porosity (m^3 internal gas/m^3 fruit)	0.2249±0.0095[b]	0.1523±0.0053[a]
Lactic acid bacteria (log cfu/g)	ND	6.09±0.04
Total microbial count (log cfu/g)	ND	6.09±0.08

[a-b] Values followed by different letters within the row are significantly different ($p<0.05$).
[ns] Not significantly different; ND: not detected at the lowest dilution used of 10^{-3}.

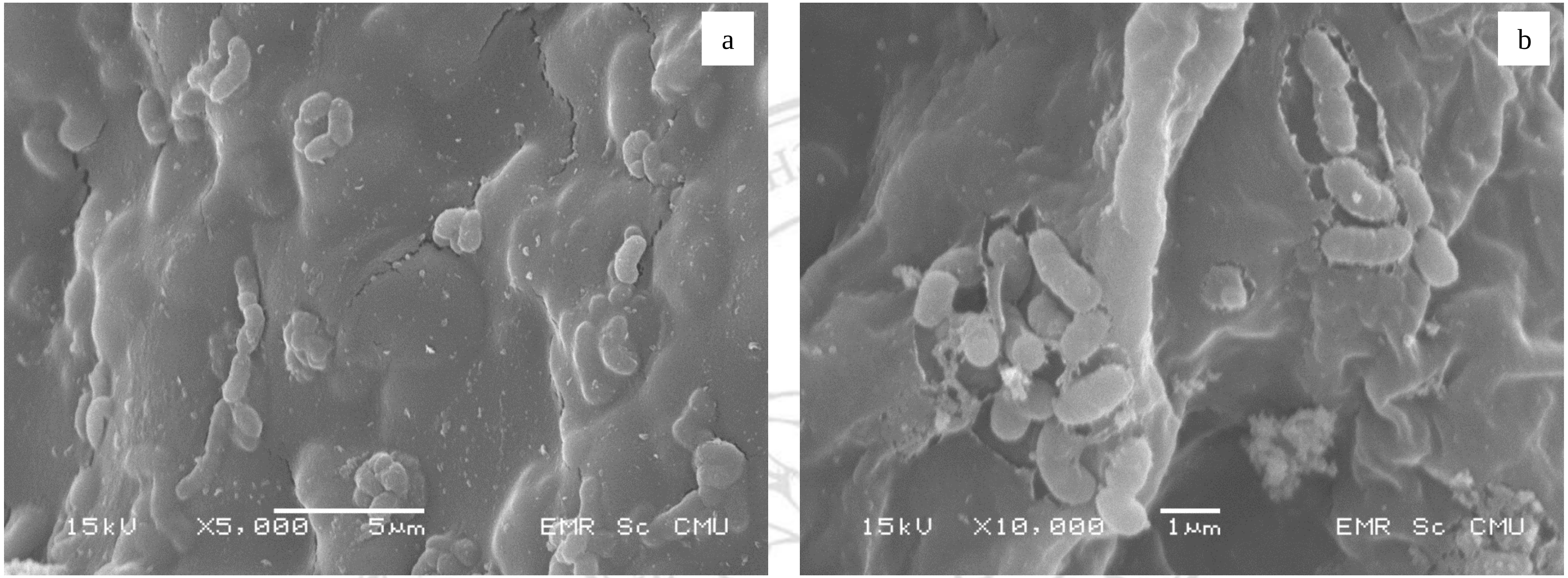

Figure 4.1 Scanning electron micrograph of vacuum impregnated papaya containing *Lactobacillus casei* TISTR 390 at magnification of 5,000 x (a) and 10,000 x (b)

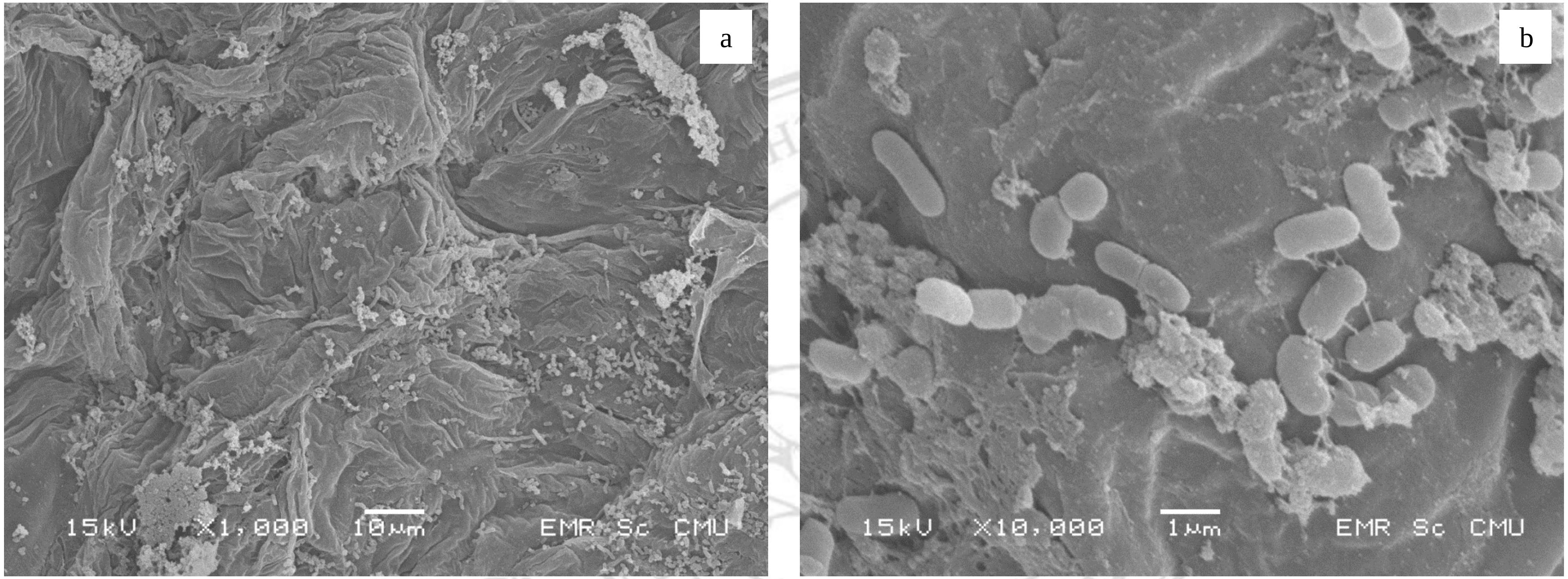

Figure 4.2 Scanning electron micrograph of partially dried papaya containing *Lactobacillus casei* TISTR 390 at magnification of 1,000 x (a) and 10,000 x (b)

To confirm the presence of lactobacilli cells in vacuum impregnated and partially dried papaya samples, representative papaya samples were prepared and observed under a scanning electron microscope. Scanning electron micrographs from the examination are shown in Figures 4.1 and 4.2. In Figure 4.1, it was displayed the presence of *L. casei* cells in papaya intracellular tissues after a vacuum impregnation process, whereas Figure 4.2 demonstrated the existence of lactobacilli cells inside the intermediate moisture papaya tissues. The results of microscopic observation and micrograph pictures provided clear evidences that *L. casei* TISTR 390 cells could penetrate into papaya tissues during vacuum impregnation. At the same time, pores of papaya tissues were larger than the lactobacilli cell size that could allow the probiotic cells into intracellular spaces of the fruit. Similar results had been reported for *L. casei* cells that were immobilised in papaya and guava pieces, indicating that size of intracellular spaces of fruit sample tissues were large enough to allow the probiotic cells passed through (Krasaekoopt and Suthanwong, 2008). Another report of Betoret et al. (2003) found a similar finding for apple samples and the size of the individual Lactobacillus cell was 0.7x1.6 µm which was smaller than the pore size of apple (6.64 ± 0.24 µm). Figure 4.2 confirmed the microbial analysis in Table 4.21 that lactobacilli cells were present in the partially dried papaya. The detection of lactobacilli cells in the final papaya products confirmed that a combination method of vacuum impregnation and hot air drying could permeate viable probiotic cells in papaya fruit tissues. This was consistent with a previous report of Betoret et al. (2012), who stated that vacuum impregnation was a potential method to produce fruit and vegetable enriched with probiotic microorganisms.

In this section, it was demonstrated that a vacuum impregnation process could permeate *L. casei* cells into papaya tissues. A drying process at 60ºC by a hot air oven that was utilised to reduce moisture content of impregnated papaya produced partially dried papaya with a viable lactic acid bacteria number of 6.09 ± 0.04 log cfu/g. Scanning electron micrographs confirmed the presence of *L. casei* in vacuum impregnated and intermediate moisture papaya samples. Based on the results in this section, the supplementation of *L. casei* was carried out in the next experimental section.

4.7 Survival of lactic acid bacteria in partially dried papaya during storage

In the last section of the research, physicochemical and microbial changes of partially dried papaya containing *L. casei* TISTR 930 during storage were monitored. Fresh fully ripe papaya was cut into 1 x 1 x 1 cm^3 and impregnated with sucrose solution containing 2% calcium lactate and *L. casei*. To increase the number of lactobacilli in the sucrose solution 1,000 ml of cultured de Man Rogosa Sharpe broth was washed, centrifuged and added in 100 ml of the solution. The sucrose or impregnation solution had an a_w of 0.986 The impregnation process was carried out using a ratio of 1:10 for 900 ml impregnation solution in a 1,000 ml beaker and treated at 50 mbar vacuum pressure with a temperature of 25ºC for 10 min vacuum time and 30 min relaxation time. Following the impregnation treatment, impregnated papaya samples with *L. casei* were dried at 60ºC by hot air drying until a_w of the final papaya product was lower than 0.6. After processing, the yield of partially dried papaya containing *L. casei* was 14.35±0.19%. The final dried papaya supplemented with *L. casei* was then divided, transferred into PET/PP/Al packaging bags, vacuum sealed and stored at different storage temperatures. Three storage temperatures that were investigated in this study were room temperature of 29 ± 4ºC, refrigerated temperature of 4 ± 1ºC and freezing temperatures of −18 ± 1ºC. During storage, representative papaya samples were analysed regularly. For room temperature storage, physicochemical and microbial examinations were performed on 0, 1, 2, 3 and 4 weeks of storage. On the other hand at lower storage temperatures of 4 and −18ºC, analyses for intermediate moisture papaya samples were done every 2 weeks for a total of 12 weeks storage period.

Measurement results for physicochemical properties of intermediate moisture papaya supplemented with *L. casei* are shown in Tables 4.22−4.24. In Table 4.22, a_w of the papaya samples during storage at room temperature for 4 weeks had values in the range of 0.583 to 0.597. The a_w values were fluctuated during storage, showing a tendency of reducing at the end of the storage period. For lower storage temperatures of 4 and −18ºC, the a_w of the papaya samples had closed values. The a_w values of the partially dried papaya at 4ºC were 0.580 – 0.627 (Table 4.23), while the papaya samples at −18ºC had values of 0.574 – 0.605 (Table 4.24). For moisture content of the partially dried papaya kept at room temperature, the values were not significantly different between at the beginning and at the end of the storage period ($p \geq 0.05$; Table 4.22), except a slight decline after one week storage. In contrast, the moisture content of the papaya samples stored at 4 and −18ºC was fluctuated during storage (Tables 4.23 and 4.24). The papaya samples at both storage temperatures had initial moisture contents of 27.55 and 27.33%, respectively. These values were significantly increased on the sixth and eight weeks of storage before decreased on the last four weeks of storage. Total soluble solids of the intermediate moisture papaya kept at different storage temperatures were not significantly affected by the storage period ($p \geq 0.05$; Tables 4.22-4.24). The total soluble solid values of the papaya samples stored at room temperature were 6.62 – 6.71% Brix, while slightly higher total soluble solids of 6.69 to 6.78% Brix were determined in the papaya samples kept at lower temperatures of 4 and −18ºC. For pH values of the partially dried papaya, the attribute had a tendency to be increased during the storage period, particularly at storage temperatures of 4 and −18ºC (Tables 4.22-4.24). On the other hand, total titrable acidities of the intermediate moisture papaya were found to be significantly decreased during the storage period, irrespectively to the storage temperatures ($p<0.05$; Tables 4.22-4.24). Vitamin C was often used to estimate the overall nutritional quality of fruits. Low degradation of vitamin C was required in any food processing unit operation (Wojdylo et al., 2016). The vitamin C of the partially dried papaya was significantly reduced throughout the storage period in all of the storage temperatures investigated in this study ($p<0.05$; Tables 4.22-4.24). The residual vitamin C in the papaya samples stored at −18ºC was 173.38 mg/100 ml, which was recorded as the highest residual at the end of the storage period. For the papaya samples kept at 4ºC, it had 119.01 mg/100 ml and the papaya samples stored at room temperature possessed a vitamin C of 152.22 mg/100 ml at the end of 4 weeks storage. Udomkun et al. (2016) wrote that degradation of vitamin C during storage was due to a_w and moisture content, since free water could act as a solvent for reactant and catalyst. In addition, the presence of fructose and sucrose at low pH could increase the rate of anaerobic degradation of vitamin C.

Table 4.22 Physicochemical properties of partially dried papaya containing *L. casei* TISTR 390 stored at room temperature

Physicochemical properties	Storage time (weeks)				
	0	1	2	3	4
Water activity	0.592±0.010^{bc}	0.589±0.007^{ab}	0.597±0.003^{c}	0.583±0.003^{a}	0.587±0.003^{ab}
Moisture content (%)	27.1556±0.4169^{b}	25.0131±2.0282^{a}	27.2847±0.6287^{b}	26.6125±0.4468^{b}	26.7331±0.5204^{b}
pH	5.34±0.05^{a}	5.42±0.06^{b}	5.34±0.03^{a}	5.37±0.06^{a}	5.37±0.05^{a}
Total soluble solid^{ns} (% Brix)	6.69±0.11	6.64±0.09	6.69±0.11	6.62±0.07	6.71±0.11
Total titrable acidity (% citric acid)	0.56±0.02^{c}	0.51±0.02^{a}	0.52±0.02^{a}	0.54±0.02^{b}	0.51±0.02^{a}
Vitamin C (mg/100 ml)	263.55±0.01^{d}	216.11±0.01^{c}	212.58±0.00^{c}	184.30±0.01^{b}	152.22±0.00^{a}
L*	31.91±2.67^{a}	32.99±3.95^{ab}	34.65±1.07^{b}	34.77±1.15^{b}	35.38±1.62^{b}
a*	36.63±3.96^{c}	26.71±5.29^{b}	22.73±1.07^{a}	23.90±1.96^{ab}	23.29±1.41^{a}
b*	29.08±1.95^{c}	14.06±6.48^{b}	6.93±1.08^{a}	6.52±0.85^{a}	8.30±1.14^{a}
Firmness^{ns} (N)	7.452±0.391	7.340±0.471	7.275±0.416	7.311±0.348	7.293±0.289

$^{a-d}$ Values followed by different letters within the row are significantly different ($p<0.05$).

Table 4.23 Physicochemical properties of partially dried papaya containing *L. casei* TISTR 390 stored at refrigerated temperature of 4ºC

Physicochemical properties	Storage time (weeks)			
	0	2	4	6
Water activity	0.596±0.005^{ab}	0.601±0.002^{ab}	0.589±0.004^{a}	0.627±0.088^{b}
Moisture content (%)	27.5507±0.5664^{c}	27.3317±0.8560^{c}	26.2759±0.6534^{b}	29.3872±0.6306^{d}
pH	5.36±0.04^{a}	5.37±0.02^{a}	5.36±0.04^{a}	5.37±0.02^{a}
Total soluble solid^{ns} (%Brix)	6.73±0.10	6.71±0.11	6.75±0.09	6.75±0.09
Total titrable acidity (% citric acid)	0.55±0.02^{d}	0.53±0.01^{c}	0.50±0.02^{b}	0.53±0.02^{c}
Vitamin C (mg/100 ml)	265.74±0.01^{g}	229.24±0.00^{f}	212.31±0.00^{e}	184.89±0.01^{d}
L*	30.17±3.21^{a}	33.65±2.44^{b}	34.66±1.46^{b}	33.78±1.62^{b}
a*	34.20±1.15^{d}	27.32±2.46^{c}	25.83±2.69^{bc}	25.80±2.39^{bc}
b*	28.83±4.76^{d}	12.27±3.20^{c}	8.35±1.66^{ab}	10.63±3.02^{bc}
Firmness (N)	7.466±0.404^{b}	7.306±0.339^{ab}	7.250±0.317^{a}	7.198±0.259^{a}

$^{a\text{-}f}$ Values followed by different letters within the row are significantly different ($p<0.05$).

Table 4.23 (continued)

Physicochemical properties	Storage time (weeks)		
	8	10	12
Water activity	0.586±0.008[a]	0.580±0.009[a]	0.582±0.008[a]
Moisture content (%)	33.2962±0.4174[e]	24.5530±0.4426[a]	24.5686±0.3589[a]
pH	5.40±0.03[b]	5.38±0.03[ab]	5.51±0.05[c]
Total soluble solid[ns] (%Brix)	6.78±0.07	6.75±0.09	6.69±0.11
Total titrable acidity (% citric acid)	0.52±0.02[c]	0.47±0.02[a]	0.50±0.01[b]
Vitamin C (mg/100 ml)	142.59±0.01[c]	125.90±0.01[b]	119.01±0.00[a]
L*	33.59±1.42[b]	34.41±0.85[b]	34.10±1.74[b]
a*	24.79±1.47[ab]	23.34±1.25[a]	24.54±1.47[ab]
b*	6.84±0.88[a]	9.35±1.78[ab]	9.08±1.78[ab]
Firmness (N)	7.260±0.379[a]	7.257±0.261[a]	7.223±0.299[a]

[a-f] Values followed by different letters within the row are significantly different ($p<0.05$).

Table 4.24 Physicochemical properties of partially dried papaya containing *L. casei* TISTR 390 stored at freezing temperature of −18ºC

Physicochemical properties	Storage time (weeks)			
	0	2	4	6
Water activity	0.578±0.014^{ab}	0.605±0.004^{d}	0.587±0.002^{bc}	0.592±0.007^{c}
Moisture content (%)	27.3323±0.4629^{c}	26.8918±0.4175^{bc}	26.3823±0.6275^{b}	29.7652±0.4327^{d}
pH	5.35±0.01^{bc}	5.31±0.08^{a}	5.34±0.01^{ab}	5.34±0.01^{ab}
Total soluble solid^{ns} (%Brix)	6.73±0.10	6.73±0.10	6.73±0.10	6.78±0.07
Total titrable acidity (% citric acid)	0.55±0.02^{c}	0.52±0.02^{ab}	0.50±0.02^{a}	0.53±0.02^{b}
Vitamin C (mg/100 ml)	255.38±0.01^{g}	246.78±0.01^{f}	238.40±0.00^{e}	222.54±0.00^{d}
L*	29.88±2.34^{a}	35.17±0.92^{c}	35.20±0.78^{c}	32.84±2.67^{b}
a*	35.02±3.01^{d}	26.82±1.38^{bc}	25.53±2.50^{ab}	25.49±2.00^{ab}
b*	25.91±3.04^{c}	10.34±1.84^{a}	9.61±3.27^{a}	9.48±2.25^{a}
Firmness (N)	7.452±0.369^{b}	7.302±0.333^{ab}	7.309±0.309^{ab}	7.274±0.276^{ab}

$^{a\text{-}g}$ Values followed by different letters within the row are significantly different ($p<0.05$).

Table 4.24 (continued)

Physicochemical properties	Storage time (weeks)		
	8	10	12
Water activity	0.577±0.012[a]	0.574±0.012[a]	0.580±0.008[ab]
Moisture content (%)	32.9359±0.6250[e]	23.5499±0.8255[a]	23.9943±0.5457[a]
pH	5.37±0.05[bc]	5.39±0.04[c]	5.51±0.01[d]
Total soluble solid[ns] (%Brix)	6.76±0.09	6.73±0.10	6.73±0.10
Total titrable acidity (% citric acid)	0.53±0.02[b]	0.50±0.02[a]	0.51±0.02[ab]
Vitamin C (mg/100 ml)	210.84±0.00[c]	190.06±0.00[b]	173.38±0.01[a]
L*	35.91±1.13[c]	32.31±1.65[b]	36.03±0.76[c]
a*	24.70±0.48[a]	28.12±1.48[c]	25.02±1.07[ab]
b*	8.46±1.27[a]	14.45±1.52[b]	8.48±1.02[a]
Firmness (N)	7.255±0.313[a]	7.295±0.287[ab]	7.221±0.309[a]

[a-g] Values followed by different letters within the row are significantly different ($p<0.05$).

Colour values of intermediate moisture papaya at different storage temperatures were found to be significantly changed during the storage period ($p<0.05$; Tables 4.22-4.24). L* value was significantly increased, while a* and b* values were significantly decreased throughout the storage period. The L* value of the papaya samples stored at room temperature had an increase from 31.91 to 35.38 at the end of 4 weeks storage. For the a* and b* values of the similar sample, they were reduced from 36.63 to 23.29 and from 29.08 to 8.30, respectively, within the similar storage period. For the increase of the L* value of the papaya samples maintained at 4ºC, it was recorded in the range of 30.17 to 34.10. A slightly higher increase in the L* value of the papaya samples kept at −18ºC of 29.88 to 36.03 was determined within 12 weeks storage period. The decrease in the a* and b* values of the papaya samples stored at 4ºC was established between 34.20 and 24.54 and between 28.83 and 9.08, respectively. A similar trend was also uncovered for the papaya samples hold at −18ºC that had changes from 35.02 to 25.02 and from 25.91 to 8.48, respectively. Finding for the a* and b* values in this study was in an agreement with the results of Germer et al. (2012). These researchers showed that throughout the shelf life of dried papaya samples, there was reduction in a* value, which could be related to carotenoids oxidation. This oxidation caused a reduction in papaya redness. A decrease in b* value indicated loss of yellowness during the storage time at 25 and 35ºC. Firmness of the partially dried papaya was found to decrease during the storage period (Tables 4.22-4.24). The decrease in firmness for the papaya samples kept at room temperature was not significant ($p \geq 0.05$) and had values of 7.452 − 7.293 N. This changing might be affected by heterogeneity in papaya samples from several production batches. In contrast, the firmness of the papaya treatments preserved at 4 and −18ºC was significantly reduced during the storage time ($p<0.05$) and had values of 7.223 and 7.221 N, respectively, at the end of 12 weeks storage period. Despite this finding, Germer et al. (2012) mentioned that temperature and storage time should not produce a significant effect on the texture of dried papaya during its shelf life.

Viability of microorganisms in partially dried papaya was regularly monitored during storage at three different storage temperatures and the results are exhibited in Figures 4.3-4.5. The papaya samples were subjected to microbiological examination of lactic acid bacteria, total microbial count and yeast and mould count. The papaya samples stored at room temperature were checked weekly during 4 weeks storage, while the samples that were kept at lower temperatures of 4 and –18ºC were assessed every 2 weeks for a period of 12 weeks. At the beginning of the storage period, all of the papaya samples had a number of lactic acid bacteria for more than 8.0 log cfu/g. The initial number of lactic acid bacteria in the papaya samples stored at room temperature was 8.86 ± 0.08 log cfu/g (Figure 4.3). The viability of both lactic acid bacteria and total microbial count in this papaya sample was significantly decreased throughout the storage period. A reduction for up to 2.43 log cfu/g every week was established in the viable numbers of lactic acid bacteria and total microbial count within 2 weeks storage at room temperature. At the end of the storage period at this ambient temperature, no viable lactic acid bacteria was detected, while the number of total microbial count was left to be 2.36 ± 0.22 log cfu/g. Although keeping food products at room temperature had an advantage of reducing storage cost and transport (Chang et al., 2016), but this study displayed that the shelf life of probiotic food products could be very limited or

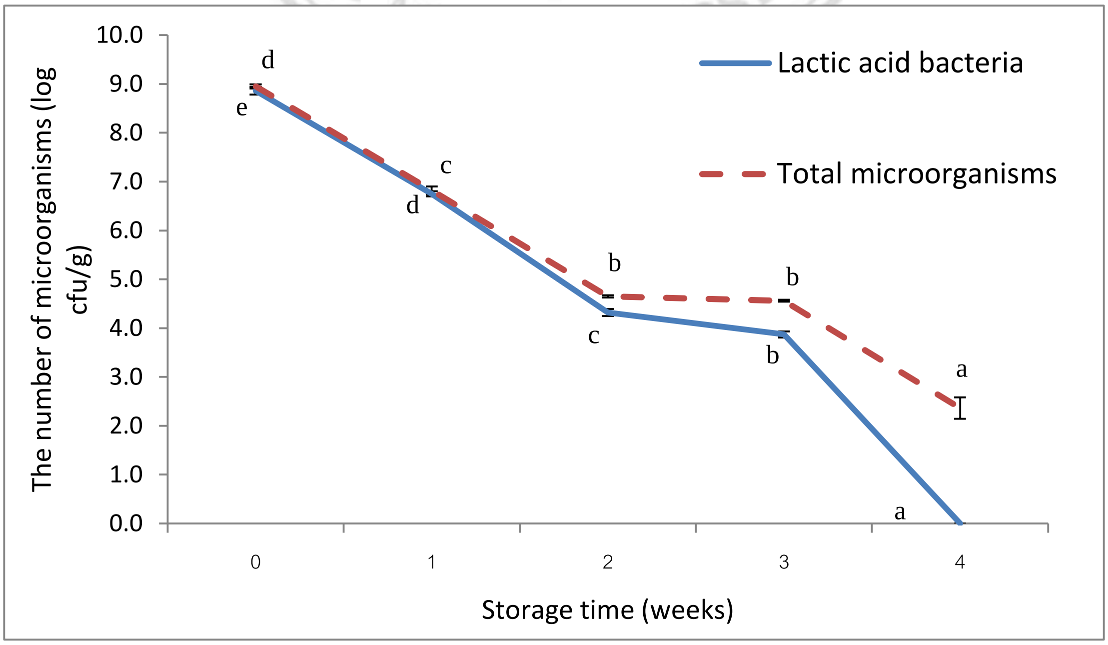

Figure 4.3 Lactic acid bacteria and total microorganisms (log cfu/g) in partially dried papaya containing *L. casei* TISTR 390 at room temperature for 4 weeks

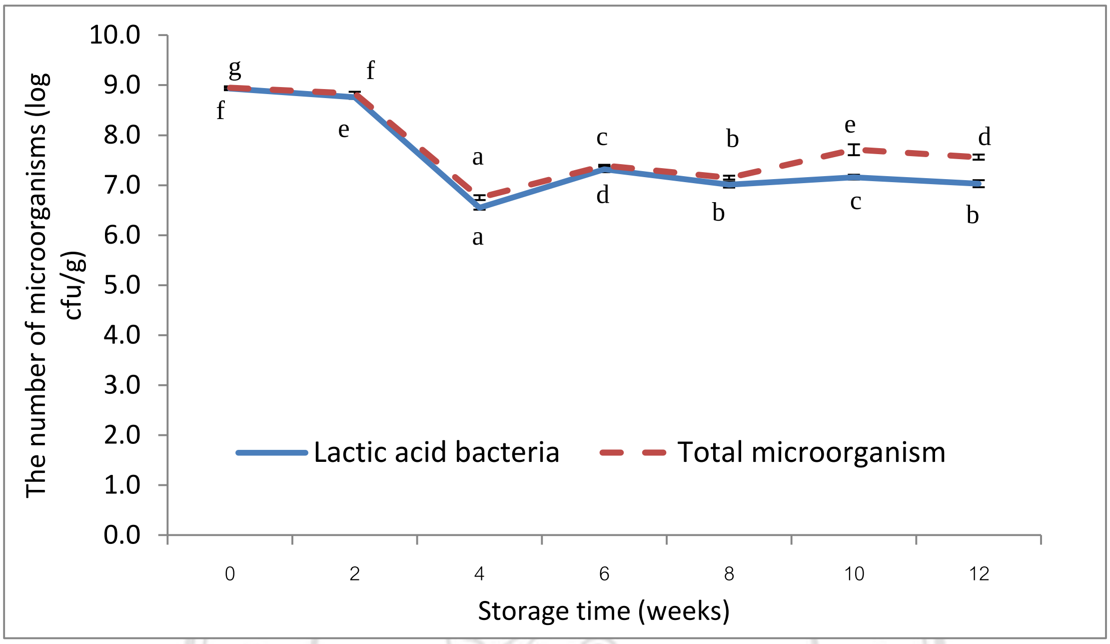

Figure 4.4 Lactic acid bacteria and total microorganisms (log cfu/g) in partially dried papaya containing *L. casei* TISTR 390 at refrigerated temperature of 4ºC for 12 weeks

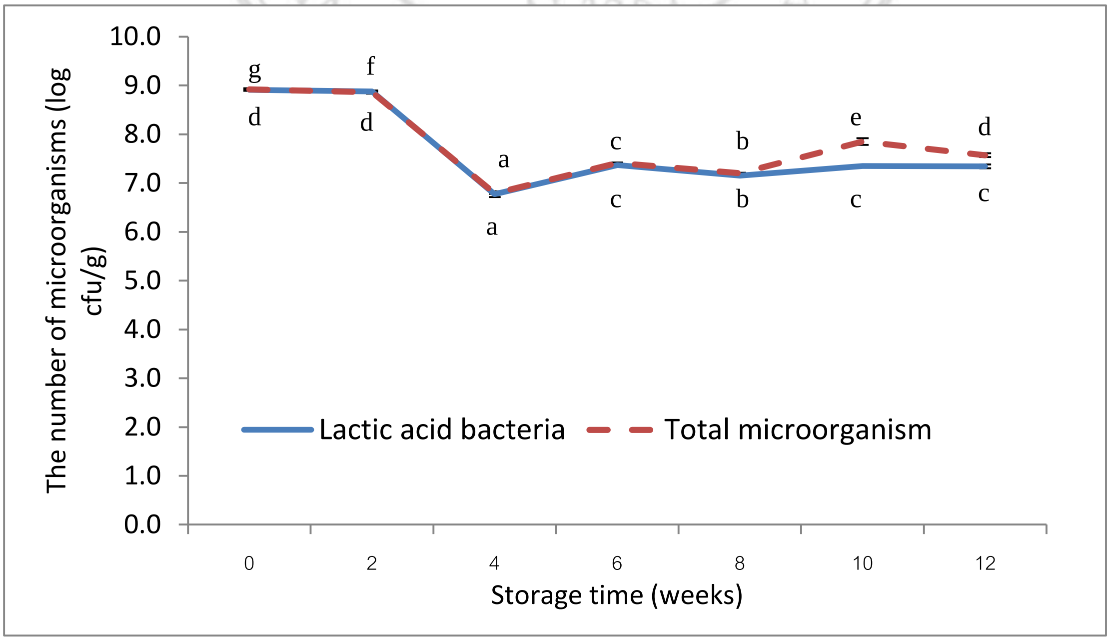

Figure 4.5 Lactic acid bacteria and total microorganisms (log cfu/g) in partially dried papaya containing *L. casei* TISTR 390 at freezing temperature of –18ºC for 12 weeks

had a short shelf life. By applying the ambient storage temperature, the intermediate moisture papaya with *L. casei* could only be kept for a week time because the minimum number of probiotic in the product should be equalled or more than 10^6 cfu/g (Betoret et al., 2003; Yoon et al., 2006).

The viability of lactic acid bacteria and total microbial count in intermediate moisture papaya kept at lower temperatures of 4 and −18ºC are shown in Figures 4.4 and 4.5. There was a similar reduction pattern for the viable microbial numbers in the papaya samples stored at these different storage temperatures for 12 weeks. At the beginning of the storage, the numbers of lactic acid bacteria in the papaya samples kept at 4 and −18ºC were 8.93 ± 0.03 and 8.91 ± 0.02 log cfu/g, respectively. Compared to the viable numbers of the papaya samples stored at ambient temperature (Figure 4.3), the reduction in the microbial viability of the papaya samples maintained at lower storage temperatures was occurred more slowly. Within the first 2 weeks of storage at low temperatures, the viability of lactic acid bacteria in the papaya samples was still high of more than 8.76 log cfu/g. Significant reduction in the number of lactic acid bacteria kept at low temperatures was mainly happened after 4 weeks of storage that had a reduction for up to 2.21 log cfu/g. Afterwards, the viability of lactic acid bacteria in the papaya samples stored at 4 and −18ºC was slightly increased and maintained for the samples preserved at −18ºC until at the end of the storage period. A similar result was reported by Krasaekoopt and Suthanwong (2008), who found that after one week of storage at 4ºC the number of probiotic in partially dried papaya was increased from 8.85 to 9.18 log cfu/g. The researchers explained that an increase in the number of lactic acid bacteria might imply that the environment inside packaging materials was suitable for the growth of lactic acid bacteria. The same explanation might be the rationality for a lactic acid bacteria increase in the papaya samples at 4ºC in this study. Glucose was also found to promote growth of the probiotic that gave the positive effects on the survival of probiotic microorganisms during storage (Tripathi and Giri, 2014). Moreover, the package which low oxygen permeability help maintained the viability of lactic acid bacteria during storage due to the oxygen was harmful by produced toxic to probiotic (Tripathi and Giri, 2014). In addition, the workers also reported that the number of probiotics was slightly dropped until at the end of storage. A similar finding was recorded for the number of lactic acid bacteria in the papaya sample hold at 4ºC in this study. At the end of storage, it was obtained that the lactic acid bacteria number in the papaya samples kept at −18ºC, which was 7.34 ± 0.04 log cfu/g, was higher than that of the papaya samples stored at 4ºC of 7.03 ± 0.07 log cfu/g. The presence of these viable numbers of lactic acid bacteria suggested that the *L. casei* impregnated papaya could deliver the health benefits of probiotic up to 12 weeks of storage at 4 and −18ºC due to the probiotic number that was higher than 10^7 cfu/g. Krasaekoopt and Suthanwong (2008) previously stated that to achieve the best beneficial effect of probiotics, the amount of probiotic bacteria in the product should be at least 10^7 cfu/ml. Changing of total microbial count in the partially dried papaya was similar as the finding of lactic acid bacteria. After 12 weeks of storage, the numbers of total microbial count in the papaya samples maintained at 4 and −18ºC were 7.56 ± 0.05 and 7.57 ± 0.04 log cfu/g, respectively. Microbial data in this section clearly exhibited that the intermediate moisture content containing *L. casei* had a longer shelf life when it was kept at low storage temperatures of 4 and −18ºC than that at room temperature.

As part of microbiological examination, the number of yeast and mould in the partially dried papaya was regularly monitored during storage at ambient temperature, 4 and −18ºC (Table 4.25). It had been reported that yeast and mould could cause various degrees of deterioration and decomposition in food products. The microorganisms could grow in any type of food during any storage time (Tournas et al., 2001). The highest number of yeast and mould in the papaya samples stored at room temperature was found in the samples after 3 weeks storage, which had a number of 8.00 ± 0.05 cfu/g. The number of yeast and mould was tended to be slowly increased during storage at ambient temperature. Applying lower storage temperatures of 4 and −18ºC, the number of yeast and mould was also slightly increased. The papaya samples maintained at −18ºC had lower numbers of yeast and mould than those stored at 4ºC. The highest number of the spoilage microorganisms was determined on the 8^{th} week of storage at both low storage temperatures. Results in this study indicated that low storage temperatures could slow down the growth of yeast and mould. Between different storage temperatures, the papaya samples kept at −18ºC had the lowest number of yeast and mould throughout the storage period. The number of yeast and mould in the papaya samples that was lower than 10 cfu/g during storage might also be affected by microbial growth inhibition from a competition with bacteria, particularly lactic acid bacteria. It was noted that lactic acid bacteria could be a protective antimicrobial barrier against foodborne pathogen in food (Luna-Guzmán and Barrett, 2000). Additionally, it was possible that the resulting in low water activity values does not permit the growth of harmful microorganism (Betoret et al. 2012).

Table 4.25 Yeast and mould (cfu/g) of partially dried papaya containing with *L. casei* TISTR 390 stored at different storage temperatures

Storage condition	Storage time (weeks)								
	0	1	2	3	4	6	8	10	12
Room temperature	1.67 ± 1.25^{b}	3.17 ± 0.29^{c}	3.33 ± 0.58^{c}	8.00 ± 0.50^{d}	0.00 ± 0.00^{a}	-	-	-	-
Refrigerated temperature of 4°C	1.17 ± 0.76^{a}	-	1.67 ± 0.58^{a}	-	1.50 ± 0.50^{a}	6.50 ± 1.32^{b}	10.50 ± 2.78^{c}	4.83 ± 0.29^{b}	1.33 ± 0.58^{a}
Freezing temperature of −18°C	1.50 ± 0.87^{a}	-	1.17 ± 0.76^{a}	-	1.17 ± 0.29^{a}	1.17 ± 0.29^{a}	3.00 ± 1.00^{b}	2.83 ± 0.29^{b}	0.83 ± 0.58^{a}

[a-d] Values followed by different letters within the row are significantly different ($p<0.05$).