Manufacture and Properties of Citric Acid-Bonded Composite Board made from Salacca Frond: Effects of Maltodextrin Addition, Pressing Temperature, and Pressing Method

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Non-woody fiber is a sustainable resource for composite products. In this study, salacca frond was used as a raw material, and the effects of citric acid-maltodextrin composition ratio, pressing temperature, and pressing method were investigated. The boards were manufactured under the conditions as follows: single-step press method, adhesive contents 20 wt%, pressing temperature (180 to 200 °C), and adhesive composition of citric acid/ maltodextrin (100/0; 87.5/12.5; 75/25; 62.5/37.5; 50/50 wt%). A three-step press cycle method was also applied to reduce the pre-drying time before hot pressing. The total pressing time was 10 min, and the breathing stage was applied at various times after the starting time. The results showed that salacca frond is a potential material for composite board. The addition of maltodextrin in certain ratios improved the mechanical properties. The mechanical properties of board prepared using citric acid/maltodextrin satisfied the requirement of the JIS A 5908 type 13 (2003) standard. Infrared analyses indicated that carboxyl groups of citric acid react with the hydroxyl groups of the maltodextrin and salacca frond. Furthermore, the three-step press cycle method was more effective than the single-step press method. Adding a breathing stage improved the quality of citric acid/maltodextrin bonded composite board.

Keywords: Salacca frond; Citric acid; Maltodextrin; Pressing temperature; Three-step press cycle; Breathing stage

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INTRODUCTION

The quality of composite products depends on the characteristics of the raw materials, the matrix or adhesive, and the manufacturing process. The utilization of natural fibers for producing biocomposite products has become more attractive due to environmental issues; their renewable, degradable, low density, and highly specific properties; and the generation of rural/agricultural-based economy (Mishra *et al*. 2004; Mohanty *et al*. 2005; Li *et al*. 2007). Non-wood fibers are usually classified as natural plants, industrial crops, and agricultural crops, which have various types, properties, and chemical compositions (Mohanty *et al*. 2005). Many natural fibers have been investigated as raw material for making composite board, such as bamboo, coconut husk fiber, elephant grass, ramie, sanseviera, kenaf, sisal, sorghum bagasse, sugarcane bagasse, *etc*. (Ndazi *et al*. 2006; Asasutjarit *et al*. 2007; Munawar *et al*. 2007; Rao *et al*. 2007; Kusumah *et al*. 2016; Widyorini *et al*. 2016).

Salacca (*Salacca zalacca* (Gaertner) Voss) is native to South Sumatra and Southwest Java. It is now widely cultivated in Thailand and throughout Malaysia and Indonesia as far as the Moluccas (Maluku). It has also been introduced into New Guinea, the Philippines, Queensland and the northern Territory in Australia, the Ponape Island (Caroline Archipelago), China, Surinam, Spain, and the Fiji Islands (Lim 2012). It is also known as "snake fruit" due to its reddish-brown scaly skin; people usually only eat the fruit. Large quantities of salacca fronds are disposed and not utilized. Darmanto *et al*. (2016) found that alkali-treated salacca frond fiber had a tensile strength of 275 MPa, indicating the potential utilization of salacca frond as a material for composite board.

In addition to natural fibers, developing bio-based adhesives for making environmentally friendly composite board has been an attractive topic to many researchers. Several bio-based adhesives that have been investigated include those based on tannin (Pizzi 2006; Mansouri *et al*. 2011; Moubarik *et al*. 2013; Nasir *et al*. 2013; Zhao and Umemura 2014), lignin (Angles *et al*. 2001; Mancera *et al*. 2011), protein (Kuo *et al*. 2001; Yang *et al*. 2006), citric acid (Umemura *et al*. 2011; Kusumah *et al*. 2016; Widyorini *et al*. 2016), and polysaccharide or monosaccharide (Tondi *et al*. 2012; Lamaming *et al*. 2013; Santoso *et al*. 2017).

Citric acid has been studied as a binder agent in particleboard made from wood and non-wood materials (Umemura *et al*. 2011, 2012; Kusumah *et al*. 2016; Widyorini *et al*. 2016), and those composite boards have good bonding properties. The chemical compositions of the fibers affect the bonding performance of the boards. To increase the bonding performance, citric acid has been combined with sucrose (Umemura *et al*. 2014) and starch (Widyorini *et al*. 2017). In addition, Castro-Cabado *et al*. (2016) proposed the usage of crosslinking systems based on maltodextrin and citric acid as a good alternative for binding glass or wood fibers. Maltodextrin is a starch-based polysaccharide with an average chain length of 5 to 10 glucose units/molecule; it has better adhesion properties than starch (Clare *et al*. 2002; Castro-Cabado *et al*. 2016). Santoso *et al*. (2017) reported that the physical and mechanical properties of maltodextrin-based particleboard from nipa frond were very low but tended to increase with the addition of citric acid to maltodextrin (up to 25 wt%). The hydroxyl groups of maltodextrin react with carboxyl groups in citric acid. However, the optimal combination of maltodextrin-citric acid and its bonding mechanism is not clear. Therefore, this paper studied the effect of maltodextrin addition in citric acid based adhesive on the properties of salacca frond composite boards.

In composites with citric acid adhesive, the pre-drying of sprayed particles or fibers before making the mat is an important way to decrease the moisture content (Kusumah *et al*. 2016). Excess moisture content in the mat causes the delamination of the boards, due to the higher steam pressure and breaking of internal bonds. A breathing stage during press is used to release the steam produced during the first step and decrease the moisture content inside the mat (Angles *et al*. 1999). A breathing stage during press has never been applied in the manufacture of composite board using citric acid. Reducing the pre-drying time will decrease significantly the cost and energy used in board manufacturing.

In this research, the manufacture of composite board using salacca frond and citric acid/maltodextrin as adhesive was investigated. The effects of various compositions of citric acid/maltodextrin and pressing temperature were evaluated to find the optimum conditions. A three-step press cycle method was applied to reduce the pre-drying time before hot pressing. The bonding mechanism was examined using infrared analyses.

EXPERIMENTAL

Materials

Salacca (*Salacca* sp.) fronds were obtained from Yogyakarta province, Indonesia, and used as the raw material. The fronds were cleaned and cut into 2 m length from the bottom. Salacca frond particles were prepared using a chipper and grinder. The particles were screened *via* filter, and those that passed a 10 mesh-screen were used. All particles were air-dried to a moisture content of around 12%.

Citric acid (anhydrous; Weifang Ensign Industry Co. Ltd., Weifang, China) and maltodextrin DE 10-15 (Zhuceng Dongxiao Biotechnology Co. Ltd., Zhuceng, China) were used without further purification. No other chemical compounds were added. Citric acid and maltodextrin were dissolved in water under a certain ratio, and the solution concentration was adjusted to 59 to 60 wt%. The mixture ratios of citric acid/ maltodextrin (CA/M) were set as follows (wt%): 100/0; 87.5/12.5; 75/25; 62.5/37.5; and 50/50.

Methods

The salacca frond particles were sprayed with 20 wt% (based on dry weight particles) adhesive of various compositions of citric acid-maltodextrin. The moisture content of the sprayed particles was around 20.9%. According to previous research (Umemura *et al*. 2011), the sprayed particles were oven-dried at 80 °C for 18 h to reduce moisture content. In this study, the moisture content of the mat was around 3%.

The sprayed particles were hand-formed into a mat using forming box, followed by hot pressing into composite board. The dimensions of the boards were 25 cm × 25 cm with the target board density of 0.8 g/cm^3. The thickness bar was 1 cm to control the thickness of the board. The pressing conditions were as follows: time, 10 min and pressing temperature of 180 °C and 200 °C.

Other conditions were set as follows. The sprayed particles were oven-dried at 80 °C for 4 h (the moisture content of the mat was around 6.6%), followed by hand-forming into a mat, and hot pressing using a three-step cycle:

a. The mat was hot-pressed for 2.5 min, followed by 1 min for breathing stage and was hot-pressed again for 7.5 min (three-step 2.5)

b. The mat was hot-pressed for 5 min, followed by 1 min for breathing stage and was hot-pressed again for 5 min (three-step 5)

c. The mat was hot-pressed for 7.5 min, followed by 1 min for breathing stage and was hot-pressed again for 2.5 min (three-step 7.5)

The breathing stage was performed by opening the hot press for 1 min to release the steam produced during the first step and to prevent blowouts. In this section, the total pressing time was 10 min at a pressing temperature of 180 °C.

The manufacture conditions of all composite boards are shown in Table 1. Three replications of each manufacturing condition were applied in this study. Prior to the evaluation of the mechanical and physical properties, all boards were conditioned for 7 to 10 days at room temperature (26 to 29 °C) and a relative humidity of approximately 77%.

Table 1. Manufacturing Condition of Composite board made from Salacca Frond

Adhesive Content (wt%)	Adhesive	Ratio of Adhesive (wt%)	Pressing Temperature (°C)	Pressing Method
20	Citric acid	100	180	Single step
20	Citric acid/maltodextrin	87.5/12.5	180	Single step
20	Citric acid/maltodextrin	75/25	180	Single step
20	Citric acid/maltodextrin	62.5/37.5	180	Single step
20	Citric acid/maltodextrin	50/50	180	Single step
20	Citric acid/maltodextrin	100/0	200	Single step
20	Citric acid/maltodextrin	87.5/12.5	200	Single step
20	Citric acid/maltodextrin	75/25	200	Single step
20	Citric acid/maltodextrin	62.5/37.5	200	Single step
20	Citric acid/maltodextrin	50/50	200	Single step
20	Citric acid	100	180	Three-step cycle (2.5:1:7.5)
20	Citric acid	100	180	Three-step cycle (5:1: 5)
20	Citric acid	100	180	Three-step cycle (7.5:1:2.5)
20	Citric acid/maltodextrin	75/25	180	Three-step cycle (2.5:1:7.5)
20	Citric acid/maltodextrin	75/25	180	Three-step cycle (5:1: 5)
20	Citric acid/maltodextrin	75/25	180	Three-step cycle (7.5:1:2.5)

Evaluation of Board Properties

The boards were evaluated according to the Japanese Industrial Standard for Particleboards (JIS A 5908 2015). The physical and mechanical properties were tested. The thickness swelling (TS) as well as water absorption (WA) test were performed on a 5 cm × 5 cm × 1 cm specimen from each board after water immersion for 24 h at room temperature. The same size of the specimens of those used for the internal bond strength (IB) test. The specimen size for screw holding power test of the boards was 10 cm × 5 cm × 1 cm. The pulling out load speed was approximately 0.2 cm/min. The bending properties of the boards, *i.e.*, modulus of rupture (MOR) and modulus of elasticity (MOE), were evaluated by conducting static three-point bending tests on a 20 cm × 5 cm × 1 cm specimen for each board in dry conditions. The effective span and loading speed were 15 cm and 1 cm/min, respectively. Before the bending strength test, the specimens were tested for their average surface roughness (R_a) using an SRG 400 (Bosworth Instrument, Cleveland, OH, USA). Six measurements were randomly taken from both surfaces of each sample. The MOR, MOE, IB, and screw holding strength of the boards were corrected for each target density based on regression line between the actual values of the mechanical properties and the specimen densities. The experimental design in this study was completely randomized design with two different factors. Data of each test were statistically analyzed by two way analysis of variance followed by Tukey HSD (Honestly Significant Difference) test. Each experiment was performed in triplicate, and the average value and standard deviation were calculated.

Chemical Composition Analyses

The raw material of salacca frond that passed through a 40-mesh sieve and retained by a 60-mesh sieve were obtained as a material for chemical analysis. Cold and hot extractives contents were calculated by immersed the particles in the cold water at room temperature for 24 h and boiling water for 3 h, respectively. The particles were extracted successively with a mixed ethanol:toluene (2:1, v:v) for 6 to 8 h by refluxing. Holocellulose content was determined by the Wise method (Rabemanolontsoa and Saka 2011), followed by determining α-cellulose content by extracting the holocellulose using 17.5% NaOH solution. Hemicellulose content was then calculated by subtracting the α-cellulose content from the holocellulose content. The Klason method was used to determine the lignin content.

Fourier Transform Infrared (FTIR) Spectroscopy

The samples were boiled for 2 h, immersed in water at room temperature for 1 h, and dried at 80 °C overnight to remove unreacted citric acid. The samples were ground into powder and vacuum-dried at 60 °C for 12 h. The infrared spectral data were obtained with FTIR-4200 spectrophotometer (JASCO, Tokyo, Japan) using the KBr disk method. An average of 16 scans were recorded at a resolution of 4 cm^{-1}.

RESULTS AND DISCUSSION

Effects of Addition of Maltodextrin and Pressing Temperature

Table 2 shows the chemical composition of salacca frond particles. The lignin contents were similar to those of other agricultural plants, such as kenaf core (Widyorini *et al*. 2005), bamboo (Widyorini *et al*. 2016), and sorghum bagasse (Kusumah *et al*. 2016). The cellulose content was slightly lower compared with bamboo and wood materials (Widyorini *et al*. 2016; Spanic *et al*. 2018) but higher than sorghum bagasse (Kusumah *et al*. 2016). The cold and hot water extractive contents of salacca frond were relatively high, *i.e.* 11.55% and 13.13 wt%, respectively. The extractives are usually not compatible with synthetic adhesive; therefore it may also affect the bondability of citric acid bonded composite board.

Table 2. Chemical Composition of Salacca Frond

Component	Content (% dry weight)
Ethanol benzene extractive	5.15
Cold water extractive	11.55
Hot water extractive	13.13
Holocellulose	75.91*
Hemicellulose	32.20*
α-cellulose	43.71*
Lignin	26.33*

*Percentage based on free extractive

Maltodextrin is a starch-based polysaccharide with an average chain length of 5 to 10 glucose units per molecule (Clare *et al*. 2002; Castro-Cabado *et al*. 2016); it provides hydroxyl groups that react with citric acid. According to Table 3, the range of WA values of salacca frond boards was 46 to 84%. Increasing the pressing temperature decreased

WA values. Increasing the addition of maltodextrin tended to increase the WA values. Maltodextrin has similar characteristics to starch, which is strongly hydrophilic (Averous and Boquillon 2004). Therefore, the hydroxyl groups could form the hydrogen bonds with water (Ramirez *et al*. 2011).

Table 3. Thickness Swelling (TS), Water Absorption (WA), and Surface Roughness of Citric Acid/Maltodextrin-based Composite Board

CA/M (wt%)	TS (%)		WA (%)		Surface roughness (µm)	
	180 °C	200 °C	180 °C	200 °C	180 °C	200 °C
100/0	18.4 ± 4.1	13.6 ± 2.9	58 ± 3.2	46 ± 2.8	6.6 ± 0.2	7.6 ± 0.38
87.5/12.5	24.6 ± 1.5	15.3 ± 0.7	57 ± 4.3	48 ± 1.2	7.2 ± 0.03	6.9 ± 0.17
75/25	26.8 ± 1.0	20.2 ± 2.6	56 ± 2.8	48 ± 2.2	9 ± 0.55	8.4 ± 0.49
62.5/17.5	34.3 ± 1.0	20.7 ± 1.5	64 ± 2.8	49 ± 2.4	9.3 ± 0.53	9.9 ± 0.13
50/50	51.6 ± 3.5	31.6 ± 1.4	84 ± 4.8	59 ± 3.5	10.8 ± 0.22	10.6± 0.10

Table 3 shows that the range TS values of salacca frond boards was between 13.6 and 51.6%. Citric acid bonded composite board manufactured at 180 and 200 °C pressing temperatures had TS values that did not met the requirement of the JIS A 5908 (2003) standard (≤ 12%). However, after addition of maltodextrin in the adhesive (more than 25%), the dimensional stability remarkable decreased. This may due to the high wettability of maltodextrin that makes it easier to absorb water (Wang and Wang 2000). The increasing pressing temperature (180 to 200 °C) reduced the TS values by about 25 to 40% times at the same citric acid/maltodextrin composition. As mentioned by Umemura *et al*. (2012), crosslinking between citric acid and wood particles might occur at a higher rate at higher temperature, resulting in good water resistance. Based on Table 3, the effect of pressing temperature on dimensional stability was more significant compared with the adhesive composition of citric acid/maltodextrin.

The average surface roughness (R_a) values of boards made from salacca frond were measured, as shown in Table 3. Increasing pressing temperature did not significantly improve the R_a values. However, the addition of maltodextrin to the adhesive significantly affected the surface roughness. The surface roughness values of the boards ranged from 6.6 to 10.8 µm. This range was higher than the average R_a values for commercially manufactured composite board, which is 3.67 to 5.46 µm (Hiziroglu and Suzuki 2007). Compared with the R_a values of commercially manufactured particleboard made from rubber wood (8.2 µm) (Hiziroglu *et al*. 2004), the R_a values of salacca frond composite board using citric acid/maltodextrin (100/0 and 87.5/12.5 wt%) were found within the range.

Figure 1 shows the MOR and MOE values of salacca frond composite boards at various adhesive composition and pressing temperature. The range of MOR values was 13.4 to 15.6 MPa. All boards met the standard of type 8 (min. 8 MPa), and even type 13 (min. 13 MPa) of JIS A 5908 (2003) except for citric acid bonded composite manufactured at 180 °C. Interestingly, the interaction between pressing temperature and adhesive composition did not significantly affect the MOR values. However, there was a small increase in MOR values when the maltodextrin proportion was increased. For comparison, Santoso *et al*. (2017) reported that the MOR values of maltodextrin-bonded boards were 2.5 MPa and 10 MPa at pressing temperatures of 180 °C and 200 °C, respectively.

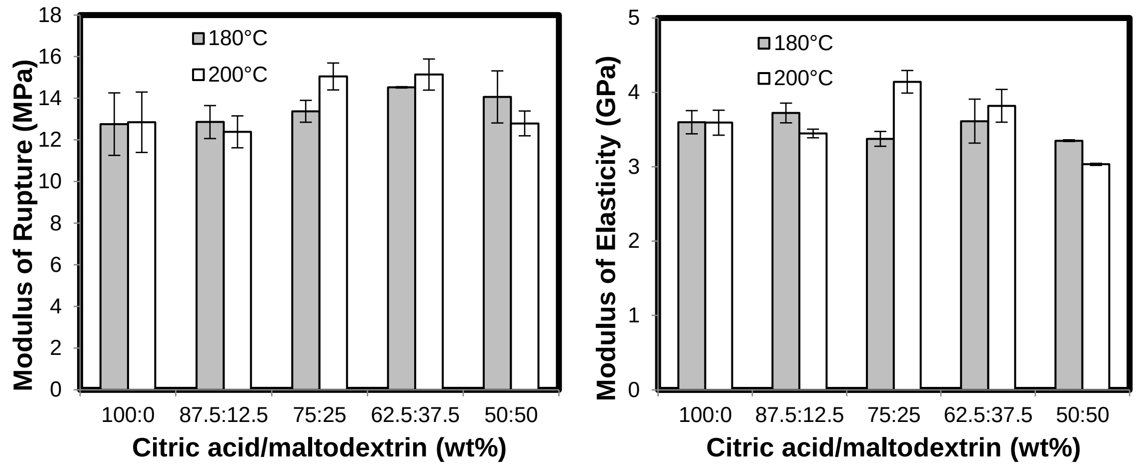

Fig 1. Bending properties of salacca frond composites at various adhesive compositions and pressing temperatures. Vertical lines through the bars represent the standard deviation from the mean.

Figure 1 shows that the MOE values of salacca frond boards were between 3.0 and 4.1 GPa, which met the requirement of standard JIS A 5908 (2003) standard type 18. The highest value of MOE (4.1 GPa) was reached with 75/25 wt% citric acid/maltodextrin at the pressing temperature of 200 °C. The lowest of MOE (3.3 GPa) was achieved at the citric acid/maltodextrin ratio of 50/50 wt%. The decreasing of citric acid content in the adhesive composition caused the decreasing of carboxyl groups of citric acid that reacted with the hydroxyl groups of salacca frond and maltodextrin. Santoso *et al*. (2017) added only maltodextrin; the MOE of nipa frond particleboard was 0.5 GPa and 2.8 GPa at pressing temperatures of 180 and 200°C, respectively.

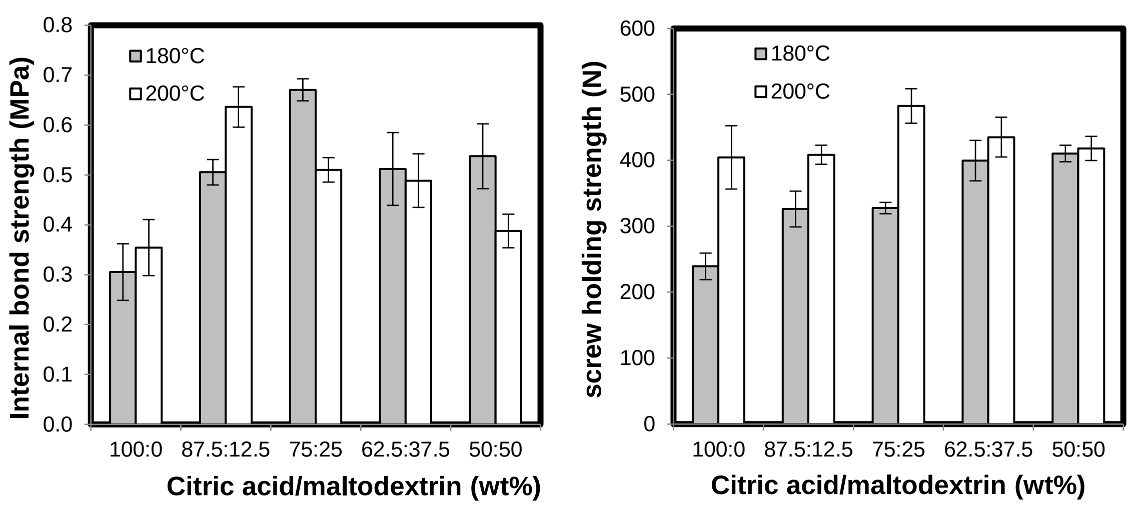

Fig. 2. Internal bond strength and screw holding strength values of salacca frond composite board at various adhesive composition and pressing temperature. Vertical lines through the bars represent the standard deviation from the mean.

Figure 2 shows that the value of internal bonding strength of boards had values of 0.31 to 0.67 MPa, which met the requirement of the 18 types of JIS A 5098 (2003). The IB strength of citric acid bonded composite board was 0.31 to 0.35 MPa, while the range of IB strength for citric acid/maltodextrin bonded composite boards was 0.39 to 0.67

MPa. There was a significant effect between pressing temperature and citric acid/ maltodextrin composition on IB values, at 99% confidence level. The highest IB value was obtained with 180 °C pressing temperature with the adhesive made of 75/25 (wt%) citric acid/maltodextrin. Based on the results in this study, it was supposed that the hydroxyl groups from maltodextrin reacted with carboxyl groups from citric acid, providing the good performance of the boards. Based on Castro-Cabado *et al*. (2016), the crosslinking systems based on maltodextrin and citric acid could be a good eco-friendly alternative for binding glass or wood fibers. Other results from Ghanbarzadeh *et al*. (2011) showed that citric acid acts as both a plasticizer and a crosslinking agent in the starch film. Santoso *et al*. (2017) reported that the internal bond strength of maltodextrin-bonded particleboard made from nipa frond was only 0.05 MPa at 180 °C pressing temperature, and it increased to 0.1 MPa at the citric acid/maltodextrin ratio of 25/75. However, when the pressing temperature was 200 °C, the internal bond strength of maltodextrin-bonded nipa frond particleboard was 0.16 MPa. Thus, maltodextrin needs a crosslinking agent and higher pressing temperature to improve its bondability.

The effects of the adhesive composition and pressing temperature on the screw holding strength of composite boards are shown in Fig. 2. Both factors significantly affected the screw holding strength. The increasing strength was clearly obtained with the increasing pressing temperature at adhesive composition of citric acid/maltodextrin (100/0, 87.5/12/5, and 75/25 wt%). However, addition of more than 25% maltodextrin in the adhesive gave no significant increase in screw holding strength. Except for composite boards made from salacca frond with adhesive composition of citric acid/maltodextrin (100/0 wt%) at 180 °C of pressing temperature, all of the screw holding strengths of the composite boards met the requirement of the JIS A 5098 (2003), which is a minimum strength of 300 N. This value was in line with other mechanical properties. The values of the screw holding strength and the mechanical properties are important for the use of composite panels in furniture and cabinet manufacturing.

To investigate the bonding mechanism of the board, FTIR analysis were measured, as shown in Fig. 3. Figure 3a shows that salacca frond (a) do not have clear peaks at around 1734 cm^{-1} that it was typically ascribed to C=O stretching due to carbonyl groups and or the C=O ester groups (Yang *et al*. 1996). The peak at 1241 cm^{-1} was related to the C-O stretching vibration band of ester groups (Aflori and Drobota 2015). After addition of 20 wt% citric acid (b), the absorption peaks at 1734 cm^{-1} and 1241 cm^{-1} became clear. These peaks were attributed to the formation of ester linkages (Umemura *et al*. 2011), resulting from the reaction between the carboxyl groups of citric acid and the hydroxyl groups of salacca. The combination of citric acid and maltodextrin (c-f) also provided the same peaks at 1734 cm^{-1} and 1241 cm^{-1}. A peak at around 1734 cm^{-1} was clear at 180 °C and citric acid/maltodextrin (75/25 wt%) compared than other conditions. It indicated that the carboxyl groups of citric acid reacted with the hydroxyl groups of salacca frond and maltodextrin. Addition of maltodextrin in adhesion composition caused the decreasing of carboxyl groups of citric acid, resulting decreasing of ester linkages. This was consistent with the results of Fig. 2 and Table 3. Figure 3 shows that those peaks at 180 °C were clearer than at 200 °C at the same ratio of citric acid/maltodextrin. This was consistent with the results of Fig. 2, where the internal bond strength of the composite board pressed at 180 °C was higher than that at 200 °C at both citric acid/maltodextrin compositions (75/25 wt% and 50/50 wt%). Formation of ester linkages would improve the adhesiveness; therefore, the internal bond strength and the physical properties of the boards would also be increased.

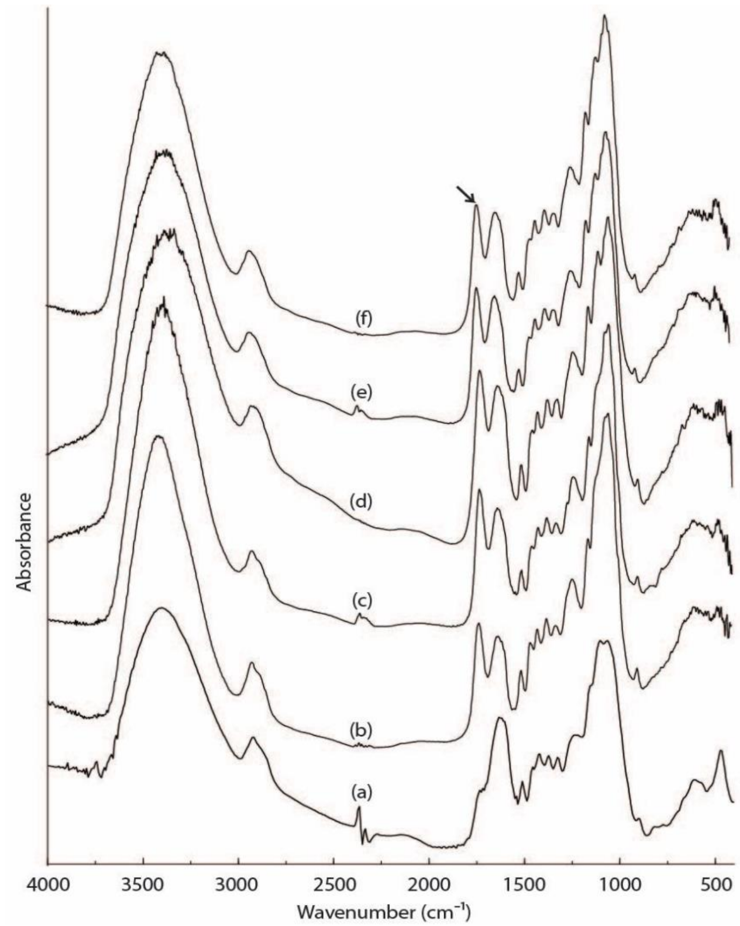

Fig. 3. Fourier transform infrared (FTIR) spectra of several samples (a) salacca frond, (b) composite board (citric acid/maltodextrin: 100/0%; 180°C), (c) composite board (citric acid/maltodextrin : 75/25%; 180°C), (d) composite board (citric acid/maltodextrin : 50/50%; 180°C) (e) composite board (citric acid/maltodextrin: 75/25%; 200°C) and (f) composite board (citric acid/maltodextrin : 50/50%; 200°C).

Effect of Pressing Method

To decrease the pre-drying time, the three-step press cycle was applied. Figure 4 shows thickness swelling and water absorption values of salacca frond composite board at both pressing methods and various compositions of citric acid/maltodextrin. The TS value of citric acid bonded composite board was 18.4% (single step press) and decreased to 14.8 to 16.2% (three-step press cycle). The same trend could be found on the citric acid/maltodextrin (75/25 wt%) bonded composite board, where the TS value was decreased from 26.8% (single step press) to 10.6 to 14.4% (three-step press cycle), indicating that pressing method affected the TS values of the composite boards. Based on statistical analysis, the interaction between the pressing method and citric acid/ maltodextrin composition significantly affected the TS values at the 95% confidence level. Breathing stage starting at 7.5 min provided the lowest TS value of the citric acid/maltodextrin (75/25 wt%) bonded composite board which it met the requirement of the standard JIS A 5908 (less than 12%). This clarified that the three-step press cycle could be an effective method for manufacturing composite board using citric acid/maltodextrin (75/25 wt%) as adhesive. In this study, three-step press cycle was applied on the mat (moisture content at around 6.6%) after 4 h of pre-drying time at 80 °C, while one step press cycle was applied on the mat (moisture content at around 3%) after 18 h of pre-drying time at 80 °C. The breathing stage was needed to release steam produced during the previous step and reduced the moisture content inside of the mat (Angles *et al*. 1999). This stage was an effective method to reduce the pre-drying time of mat before hot pressed.

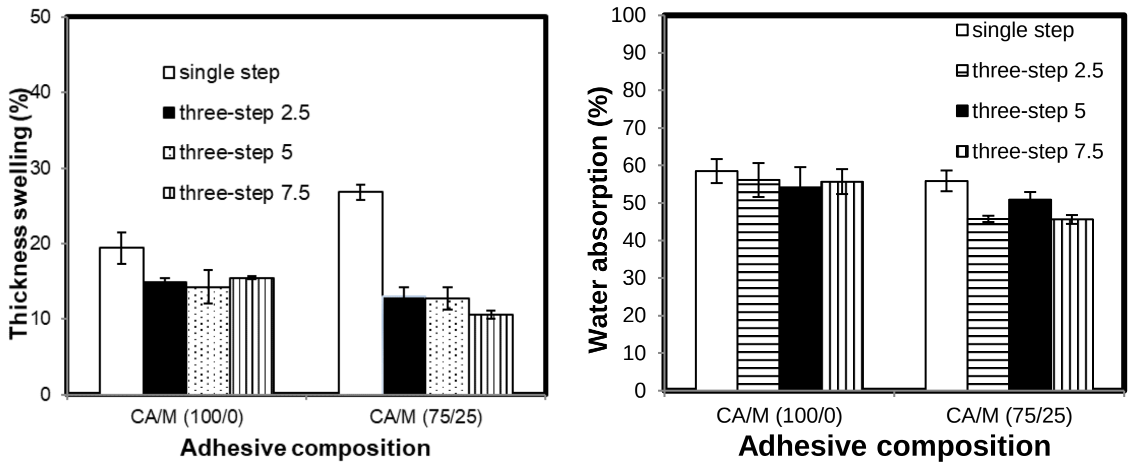

Fig. 4. Thickness swelling (TS) and water absorption (WA) values of salacca frond composite board at various pressing method and composition of citric acid/maltodextrin (CA/M).

The same trend was also found for the water absorption (WA) value, where the WA value of citric acid bonded composite board was 58.5% (single step press) decreased to 54.2 to 56.2% (three-step press cycle). The WA of citric acid/maltodextrin (75/25 wt%) bonded composite board was 55.9% (single step press) and decreased to the range 45.6 to 50.9% (three-step press cycle). The optimum dimensional stability could be obtained using three-step press cycle with breathing stage started at 7.5 min.

Figure 5 shows the internal bond strength of composite board made from salacca frond. Compared with the single step pressing method, the three-step press cycle caused the IB values to increase 1.5- to 1.8-times or 1.1- to 1.3-times for citric acid or citric acid/maltodextrin (75/25 wt%) bonded composite boards, respectively. Excess moisture content in the mat caused the delamination of the boards, due to the high steam pressure inside broke the internal bond within particles. Ndazi *et al*. (2006) reported that high moisture content in the particles caused poor adhesion between the adhesive and the particles, resulting in poor mechanical properties. Based on this result, the three-step press cycle was an effective method to improve the bonding performance of the boards. Based on statistical analysis, the press cycle in which the breathing stage started at 7.5 min was more effective to improve IB value than the breathing stage that started at 5 or 2.5 min.

Figure 6 shows that by using three-step press cycle, the MOE values of composite board were 2.8 to 3.2 GPa and 3.1 to 3.2 GPa for citric acid and citric acid/maltodextrin (75/25 wt%) bonded boards, respectively. In addition, the MOR values of composite board were 10.1 to 11 MPa and 12.3 to 12.8 MPa for citric acid and citric acid/maltodextrin (75/25 wt%) bonded boards, respectively. Compared with the three-step press cycle method, the MOR and MOE values of citric acid/maltodextrin (75/25 wt%) bonded boards from the single step press method were 3.4 GPa and 13.4 MPa, respectively. Based on statistical analysis, the pressing method affected significant only on the MOE values boards, however, the citric acid/composition affected the MOR values of boards. In addition, starting time for breathing stage did not affect the MOE and MOR of the composite boards. Based on the obtained results, the optimum properties of composite board could be achieved by using citric acid/maltodextrin (75/25 wt%) as adhesive and a three-step press cycle with a breathing stage at 7.5 min.

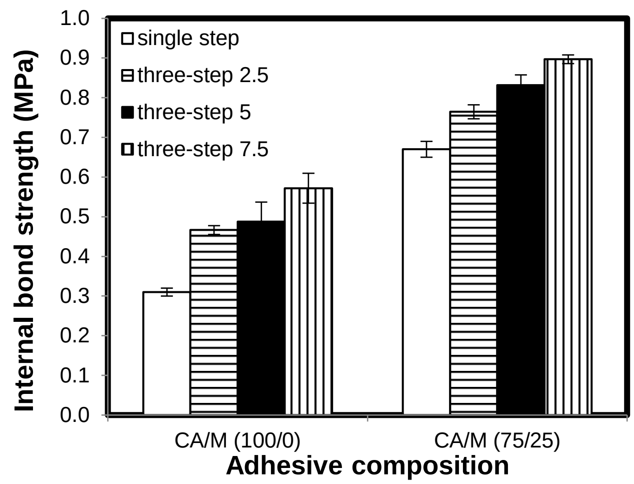

Fig. 5. Internal bonding strength (IB) values of salacca frond composite board at various pressing method and composition of citric acid/maltodextrin. Vertical lines through the bars represent the standard deviation from the mean.

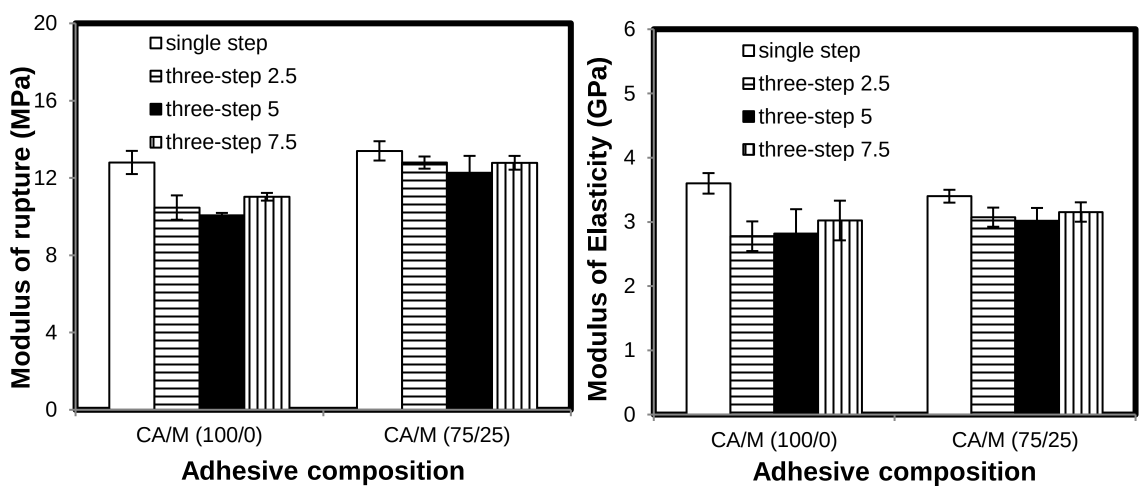

Fig. 6. Modulus of rupture (MOR) and modulus of elasticity (MOE) values of salacca frond composite board at various pressing method and composition of citric acid/maltodextrin (CA/M). Vertical lines through the bars represent the standard deviation from the mean.

CONCLUSIONS

1. Salacca frond is as potential material for making composite boards.
2. The addition of maltodextrin at certain ratio increased the mechanical properties of the boards. The board prepared using citric acid/maltodextrin satisfied the mechanical

requirements of the JIS A 5908 (2003) type 13 standard.

3. The infrared analyses indicated that carboxyl groups of citric acid reacted with the hydroxyl groups of the maltodextrin and salacca frond, forming ester linkages.
4. The three-step press cycle method produced composite boards with higher dimensional stability and internal bond strength compared with the single step press method.
5. The optimum condition was achieved by using citric acid/maltodextrin (75/25 wt%) as adhesive and a three-step press cycle method with breathing stage at 7.5 min.

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