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ARTICLE

Influence of Formulation and Hot-Pressing Conditions on the Performance of Bio-Based Molasses Adhesive for Plywood

Jajang Sutiawan[1], Alifah Syahfitri[2], Sukma Surya Kusumah[1], Dede Hermawan[2,*], Rita Kartika Sari[2], Luthfi Hakim[3], Efri Mardawati[4,5] and Muhammad Adly Rahandi Lubis[1,4,*]

[1]Research Center for Biomass and Bioproducts, National Research and Innovation Agency, Cibinong, 16911, Indonesia

[2]Forest Product Department, Faculty of Forestry and Environment, IPB University, Bogor, 16680, Indonesia

[3]Department of Forest Products, Faculty of Forestry, Universitas Sumatera Utara, Medan, 20155, Indonesia

[4]Research Collaboration Center for Biomass and Biorefinery, BRIN and Universitas Padjadjaran, Bandung, 40600, Indonesia

[5]Department of Agro-Industrial Technology, Universitas Padjadjaran, Bandung, 40600, Indonesia

*Corresponding Authors: Dede Hermawan. Email: dedehe@apps.ipb.ac.id; Muhammad Adly Rahandi Lubis. Email: marl@biomaterial.lipi.go.id

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ABSTRACT

Molasses can serve as a natural adhesive for plywood and particleboard. However, several disadvantages remain, including lower dimensional stability and low bonding strength compared to other adhesives. Therefore, modifications are needed to use molasses as an adhesive for plywood. This research aims to improve bio-based molasses (MO) adhesive for plywood using citric acid (CA) adhesive. In addition, this research aims to analyze the effect of adding citric acid and to investigate the optimum hot-pressing temperature to produce the best quality plywood. In the first stage, the molasses and citric acid were combined in a ratio of 100:0, 75:25, 50:50, 25:75, 0:100 w/w%. Then, the second stage focuses on analyzing the influences of pressing temperature based on an optimum first stage. The research demonstrated that the addition of CA altered the gelation time, solid content, viscosity, and pH of the molasses adhesives. In addition, the thermal properties of molasses adhesives were changed after mixing with citric acid. These phenomena indicate changes in characteristics, such as the curing of adhesive. Overall, the characteristics of plywood showed a steady improvement as the CA ratio increased but revealed a significant decline for the 25:75 MO-CA ratio. By raising the pressing temperature from 180°C to 200°C, the quality of plywood was effectively improved. The plywood that was bonded using adhesives with a 50:50 MO-CA ratio exhibited superior mechanical properties and improved dimensional stability compared to the plywood bonded solely with MO. Furthermore, the optimal mechanical and physical properties resulted in plywood bonded with a 50:50 MO-CA ratio when subjected to a pressing temperature of 200°C. The Thermal and FTIR measurements revealed that CA established ester bonds with both the MO and wood veneers. In conclusion, the mechanical characteristics of plywood were improved, while maintaining its excellent dimensional stability.

KEYWORDS

Citric acid; composite; molasses; pressing temperature; plywood

1 Introduction

Urea Formaldehyde (UF) is an adhesive with several advantages. UF is one of the most economical adhesives [1]. Additionally, UF adhesives have a fast drying time, allowing for an efficient production process [2]. UF also has good adhesion to wood and wood-based materials [3]. UF also produces products with a good appearance compared to other adhesives, making UF widely used in bonding plywood and particleboard [4]. Although UF has many advantages, it also has several disadvantages that must be considered. One of the main disadvantages of UF adhesives is formaldehyde emissions [5]. Increased exposure to formaldehyde can negatively impact human health, causing respiratory problems, eye irritation, and potential cancer if exposed in large amounts [6]. In addition, UF also has lower moisture resistance than several other types of adhesives [7]. UF is also usually unsuitable for outdoor applications where it will be exposed to external weather [8].

To overcome this deficiency, manufacturers and industries often use UF with improved formulations or combine it with certain additional ingredients. In addition, managing formaldehyde emissions is also very important to protect the environment and human health [9]. Adding compounds such as resorcinol or phenol to UF adhesives can improve moisture and heat resistance properties [10]. This results in a UF adhesive that is more suitable for exterior applications or in environments with harsher conditions [11]. In addition, the addition of amines to UF adhesives can improve moisture resistance and reduce formaldehyde emissions [12]. UF adhesives can be modified for outdoor applications by adding UV stabilizers to protect the product from damaging ultraviolet rays [13]. UF adhesives with lower formaldehyde emissions were also developed to meet strict regulations on indoor formaldehyde emissions [14]. Some modifications of UF adhesives typically affect performance properties and cost [15]. Therefore, the modification choice must be according to the particular application's needs and meet applicable regulatory standards. In some cases, several alternative adhesives, such as natural adhesives based on organic acids, tannins, lignin, chitosan, and polysaccharides, such as molasses, are starting to be developed [16–20].

Molasses is a by-product of the cane sugar production process, which contains sugar, water, minerals, and several organic components [21]. The development of molasses-based adhesives may not be commonplace but could be interesting for certain applications. Molasses as an adhesive has been successfully developed in previous research. Prior investigation has documented that molasses could serve as a natural adhesive for plywood and particleboard [19,22]. However, there are still several disadvantages to developing molasses-based adhesives, such as plywood and particleboard adhesives. These disadvantages include lower dimensional stability and bonding strength compared to other adhesives. Therefore, modifications are needed to use molasses as an adhesive for plywood and particleboard.

Modifications that have the potential to be developed include combining it with citric acid. Previous studies reported that using citric acid improved the quality of particleboard bonded with maltodextrin [23–25]. Previous reports show that citric acid can be used post-modification for low urea formaldehyde adhesive [26]. Citric acid is successfully applied and improves the quality of formaldehyde-free binders based on carbohydrates, lignin, and starch [27–29]. Furthermore, Amirou et al. have demonstrated the feasibility of using citric acid as a natural waterproofing ingredient in wood welding [30]. Therefore, this research combined molasses with citric acid to produce good-quality plywood. This research aims to improve bio-based molasses adhesive for plywood using citric acid adhesive. In addition, this research aims to analyze the effect of adding citric acid and to investigate the optimum hot-pressing temperature to produce the best quality plywood.

2 Material and Methods

2.1 Material

A 2 mm thick veneer made from Jabon (*Anthocephalus cadamba* (Roxb.) Miq) measuring 30 × 30 cm^2 was acquired from the Forestry Standardization Center of the Ministry of Environment and Forestry in Bogor, Indonesia. The veneers were dried using an oven at 60°C until they reached less than 5% moisture content. Meanwhile, molasses (MO) and citric acid (CA) were obtained from Limited Liability Company Perkebunan Nusantara and Telaga Sakti Utama, Indonesia. The MO are dissolved in water until they reach a solid content of 59% [19]. Meanwhile, CA was prepared by mixing with water at a temperature of 60°C to reach a concentration of 59% under continuous stirring of 200 rpm for 25 min [31]. The MO and CA were combined in a ratio of 100:0, 75:25, 50:50, 25:75, 0:100 w/w%.

2.2 Characterization of Adhesive

2.2.1 Solids Content

Adhesive solid content testing measures the amount of solids or solid components in an adhesive. Solids content measurement is important in understanding adhesive composition [32]. The test was conducted by drying 2 g of adhesive samples in an oven (Memmert UN55, Berlin, Germany) at 105°C ± 2°C for 3 h.

2.2.2 Gelation Time

Adhesive gelatinization testing is used to understand adhesive characteristics during the heating or activation. Gelatination changes an adhesive to cure or melt when exposed to a certain temperature [33] using a gel time meter (Techne GT6, Coleparmer, Washington DC, USA).

2.2.3 Viscosity

Adhesive viscosity testing measures how viscous or fluid an adhesive is at various temperatures or deformation rates. Viscosity measurements are critical in understanding adhesive flow properties and consistency [34]. Adhesive viscosity was analyzed using a Rotational Rheometer (RheolabQC, AntonPaar, Graz, Austria) at 27°C ± 2°C with a shear rate of 500/s.

2.2.4 pH Value

Adhesive pH testing is important in measuring an adhesive's acidity or alkalinity level [35]. The test used a pH meter (Orion Star A211, Thermo Scientific, Waltham, MA, USA). The test begins by calibrating using a reference solution with a pH of 4.0, 7.0, and 10.0. After calibration, the pH meter probe is dipped into the adhesive sample, and the results are read on the pH meter screen.

2.2.5 Curing Behaviors

The curing behaviors of adhesives were investigated using thermogravimetric analysis (TGA) (Perkin Elmer Inc., Waltham, MA, USA) and differential scanning calorimetry (DSC) (Perkin Elmer Inc., Waltham, MA, USA). The specimens utilized in the thermal analysis were MO-CA mixed solutions in varied proportions. As previously stated, all specimens were dried at room temperature for one day and pulverized to a mesh size of less than 60. The specimens were freeze-dried for one hour.

TGA is a procedure used to understand the characteristics of adhesives reacting to changes in temperature in the context of weight loss or thermal decomposition. This analysis provides information about the thermal properties and stability of the adhesive under various temperature conditions [36]. TGA (TGA-4000, Perkin Elmer Inc., Waltham, MA, USA) was carried out to determine the thermal stability of the samples. Samples were analyzed at a temperature of 25°C–400°C with a heating rate of 10°C/min under an N_2 gas flow of 20 mL/min.

DSC is a method used to understand changes in the thermal properties of adhesives concerning temperature changes [37]. DSC measures the heat capacity, enthalpy, phase transition, and other thermal properties of adhesives. DSC analysis (DSC-4000, Perkin Elmer Inc., Waltham, MA, USA) was carried out to determine the thermal and kinetic processes occurring in the sample. Samples were analyzed at a 25°C–300°C temperature with a heating rate of 10°C/min under an N_2 gas flow of 20 mL/min.

2.3 Manufacture of Plywood

The glue spread level and pressing time was determined based on prior research, namely 134 g/m^2 and 10 min, respectively [22,31]. The veneers were bonded with adhesives containing various MO:CA ratios (Table 1), and then were dried at 80°C for 12 h to achieve a moisture content of about 10%. Afterward, the veneers were hot-pressed (Shinto, Kyoto, Japan) at different temperatures under 1.3 MPa of hydraulic pressure.

Table 1: Conditions of manufacture plywood

Steps	Composition of MO:CA (w/w%)	Pressing temperature (°C)
1	100:0	190
	75:25	190
	50:50	190
	25:75	190
	0:100	190
2	50:50	180
	50:50	190
	50:50	200

2.4 Determination of Plywood Performance

Following a week of conditioning at room temperature (20°C) and roughly 60% relative humidity, the plywood were evaluated. Using a circular saw, each specimen was cut from the manufactured plywood for testing of its mechanical such as bending characteristics and tensile shear strength (TSS), and physical such as density, moisture content (MC), thickness swelling (TS), and water absorption (WA). The mechanical and physical properties were evaluated according to the Japanese Agricultural Standard No. 233 [38].

2.4.1 Density

Density testing involves measuring the mass of plywood per unit volume, and the results provide information about the density level of the plywood, which is a key factor in determining its strength and stability [39]. Density testing uses samples measuring 7.5 cm × 7.5 cm × 0.6 cm in length, width and thickness. Density determination is expressed as a comparison between the mass and volume of the plywood.

2.4.2 Moisture Content (MC)

Testing plywood moisture content affects many aspects of plywood performance, including dimensional stability and moisture resistance [40]. Moisture content was tested using samples measuring 7.5 cm × 7.5 cm × 0.6 cm. Moisture content testing was calculated based on the initial and final mass after drying in an oven for 24 h at a temperature of 103°C ± 2°C.

2.4.3 Water Absorption (WA)

Water absorption testing is important in determining plywood's resistance to moisture, swelling, and shrinkage [41]. Water absorption was tested using samples of 5 cm × 5 cm × 0.6 cm. Water absorption was obtained from the difference in mass before and after soaking for 24 h.

2.4.4 Thickness Swelling (TS)

Plywood thickness swelling testing is performed to understand how much plywood can expand or contract in response to changes in humidity. Thickness swelling testing evaluates the dimensional stability of a plywood product to ensure that the product will maintain dimensions appropriate to a particular application [42]. Thickness swelling was tested using 5 cm × 5 cm × 0.6 cm samples. Thickness swelling is obtained from the difference between the initial thickness before and after soaking for 24 h.

2.4.5 Modulus of Elasticity (MOE) and Rupture (MOR)

Modulus of elasticity (MOE) and rupture (MOR) testing are important tests for measuring the mechanical properties of plywood. MOE measures the stiffness or ability of plywood to return to its original shape after the load is removed. Meanwhile, MOR measures the maximum strength of plywood before it breaks [43]. MOE and MOR tests were carried out using samples measuring 20 cm × 5 cm × 0.6 cm in length, width and thickness. Testing was done using a Universal Testing Machine (UTM, AGS-X series 10 kN, Shimadzu, Tokyo, Japan) with a 10 mm/min loading speed.

2.4.6 Tensile Shear Strength (TSS)

Tensile testing of plywood is an important parameter for evaluating the adhesion between plywood sheets [44]. TSS testing was carried out using samples measuring 7.5 cm × 2.5 cm × 0.6 cm in length, width and thickness. Samples were pulled to maximum load using a Universal Testing Machine (UTM, AGS-X series 10 kN, Shimadzu, Tokyo, Japan) with a 2 mm/min loading speed.

2.5 Functional Group Analysis

Fourier Transform Infrared Spectroscopy (FTIR) testing of plywood is used to analyze the chemical composition and identify various organic compounds in plywood [45]. The testing process refers to a previous study [31]. The plywood was analyzed for changes in absorption bands at various wave numbers. Analysis was carried out using FTIR (Perkin Elmer Inc., Waltham, MA, USA). Universal Attenuated Total Reflectance (UATR) Accessory sample analysis was performed by placing 2 mg of the sample. All spectra will be recorded at a temperature of 24°C.

2.6 Statistical Analysis

Every test's data was statistically examined. The statistical significance of the variation between components and levels was assessed using the analysis of variance. Duncan's *post hoc* test was used to compare the means to determine which groups differed from the others significantly, with a 95% confidence level.

3 Result and Discussion

3.1 Characteristics of Adhesive

The research showed that the molasses adhesive's pH changed after mixing with citric acid (Table 2). The greater the percentage of citric acid added, the lower the pH of the molasses found. The highest pH is found in 100% molasses adhesive (4.40), while the lowest is in 100% citric acid adhesive (0.22). This result was similar to previous studies showing that the citric acid adhesive changes pH after combining with sucrose. Previous study reported the pH of citric acid of 0.9, pH of sucrose of 4.6, and pH 50:50% citric acid and sucrose of 1.2 [46]. Furthermore, molasses adhesive gelatinization changed after mixed

with citric acid (Table 2). The greater the percentage of citric acid added, the more the molasses gelatinization will be reduced. The highest gelatinization was found in the 100% citric acid adhesive, while the lowest gelatinization was found in the adhesive with a mixture composition of 50:50% molasses and citric acid.

Table 2: Characteristics of adhesive in this study

Composition MO:CA (w/w%)	Gelation time (min)	pH	Solid content (%)	Viscosity (mPa·s)
100:0	5.90	4.40	55.48	152.69
75:25	2.40	2.08	56.44	116.13
50:50	2.00	1.49	55.60	56.47
25:75	2.80	0.90	54.93	29.48
0:100	12.90	0.22	58.82	11.98

The viscosity in this study ranged from 11.98–152.69 mPa·s (Table 2). The addition of citric acid reduces the viscosity of molasses. The highest viscosity was found in the 100% molasses adhesive, while the lowest was in the 100% citric acid adhesive. This result was similar to previous studies showing that the citric acid adhesive changes viscosity after combining with sucrose. However, the viscosity in this study was lower [46]. An earlier study reported the viscosity of citric acid of 2 mPa·s, sucrose of 1770 mPa·s, and 50:50% citric acid and sucrose of 1290 mPa·s [46]. In addition, compared to conventional formaldehyde-based adhesives for plywood, like UF resins, which have an average viscosity of 250–400 mPa·s, the average viscosity of adhesive in this study is quite low [47]. In addition, the solids content in this study ranged from 54.93%–58.82% (Table 2). The solids content in this study has the same value as the established solids content target of 59%.

The results of the Thermogravimetric Analysis (TGA) analysis showed that there was a change in weight loss after the molasses was mixed with citric acid. The weight loss of 100% molasses and 100% citric acid at temperatures above 200°C is higher than other mixed compositions (Fig. 1A). This indicates that the mixture of citric acid and molasses mutually influences the thermal degradation of the adhesive and makes the mixture combination more stable. Moreover, Differential Scanning Calorimetry (DSC) analysis of adhesives is very useful in understanding the relationship between the thermal properties of adhesives and the quality of plywood [48]. The DSC results showed a shift in the first endothermic peak after the molasses was mixed with citric acid. The endothermic peak of adhesive with 100% citric acid composition is at 155°C, while the endothermic peak with 100% molasses is at 200°C. After molasses and citric acid were combined, the endothermic peak shifted to a temperature range of 130°C (Fig. 1B). This is, of course, supported by changes in the gelatinization time of the adhesive after molasses is combined with citric acid.

The 50:50 MO-CA ratio types exhibit an endothermic peak at around 130°C, while the MO show an endothermic peak at about 200°C (Fig. 1B). These observations show that adding CA to MO alters the melting point. The melting point of CA is shown by the first endothermic peak, which appears at 150°C, while the decomposition of CA is indicated by the second endothermic peak, which appears at 180°C [49]. Furthermore, the decomposition of MO was indicated by the endothermic peak, which was at about 225°C [19]. Some of the interactions or reactions between MO and CA were anticipated. Consequently, Fig. 1A illustrates how the interaction or reactions between CA and MO, which happened at a low temperature of roughly 130°C to 200°C, led to a more moderate decrease in the weight loss of the specimen of the 50:50 MO-CA ratio types, especially at temperatures higher than 200°C, than the only type.

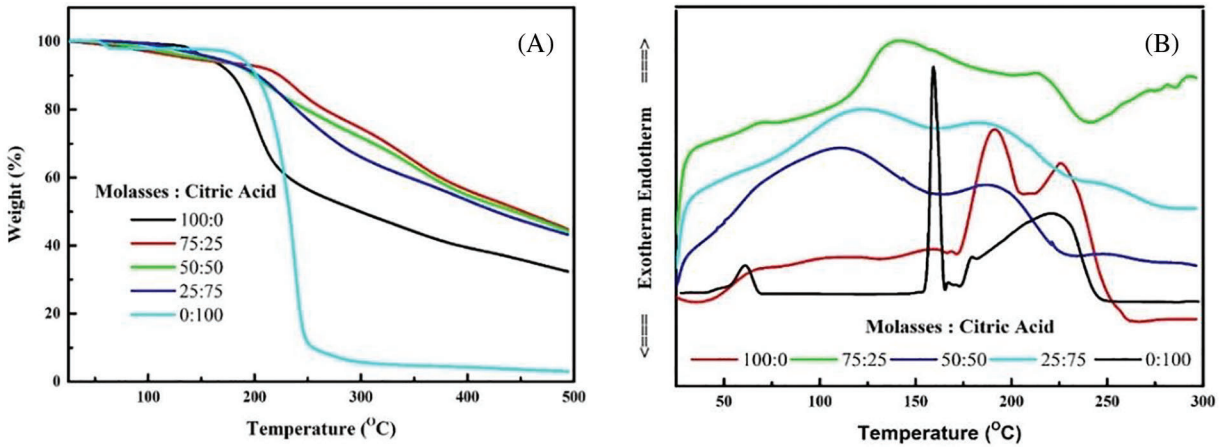

Figure 1: Characteristics thermal of adhesive in this study (A) TGA and (B) DSC

3.2 Influences Composition of Molasses and Citric Acid

The density and moisture content (MC) of plywood in this study ranged from 0.46–0.53 g/cm^3 and 6.76%–7.07%, respectively (Fig. 2A). The highest density was found in 50:50 MO-CA ratio types of plywood. However, the highest MC of plywood was found bonded with MO only, and the lowest was found in plywood bonded with CA only ($p > 0.05$, Tables 3 and 4). These phenomena are similar to previous studies. The plywood bonded with CA adhesive has good dimensional stability. The carboxyl groups of citric acid reacted with the hydroxyl groups of wood, forming ester linkages and producing dimensional stability [50]. According to Japanese Agricultural Standard No. 233 (JAS 2003), the MC of plywood in this study has met the standard (<12%).

Plywood thickness swelling (TS) and water absorption (WA) values with various MO and CA weight ratios are displayed in Fig. 2B. According to the values of the plywood types with a 50:50 MO-CA ratio, the TS and WA values of the plywood declined significantly as the CA ratio increased. However, when the plywood only employed MO, the values sharply increased ($p < 0.05$, Tables 3 and 4). This indicates that the drop in TS and WA was impacted by adding CA from the intermediate to the high ratio of CA. Otherwise, the plywood varieties with a 50:50 MO-CA ratio exhibited good dimensional stability. The veneer components with hydroxyl groups are pressed at 190°C for 10 min, and CA reacts with them effectively [31]. Furthermore, polysaccharides containing hydroxyl groups, like MO and its thermal derivatives, may react with CA [51]. It is possible that the creation of those chemical bonds prevented the plywood's TS and WA from developing during the water immersion procedure.

The bending characteristics of plywood at different weight ratios of MO and CA are displayed in Fig. 2C. As the CA ratio increased, the values of the modulus of elasticity (MOE) and modulus of rupture (MOR) increased progressively. The highest MOR and MOE average values ($p < 0.05$, Tables 3 and 4) were found in plywood with a 50:50 MO-CA ratio, at 60.76 and 6.10 MPa, respectively. These outcomes showed that the bending properties of plywood were significantly enhanced by the addition of CA. In Fig. 2D, the plywood's tensile shear strength (TSS) values are displayed. Plywood's TSS strengths grew steadily as the CA ratio increased, reaching a 50:50 MO-CA ratio. Subsequently, they significantly dropped for the plywood just bonded with CA ($p < 0.05$, Tables 3 and 4). The TSS strength of the 50:50 MO-CA ratio kinds was around twice as high as that of the MO that was employed exclusively with plywood. The binding between veneers was strengthened by the addition of CA. Based on the bending characteristics and TSS findings, as displayed in Fig. 2C,D, plywood variants with a 50:50 MO-CA ratio were found to have exceptional mechanical qualities (0.60 MPa). However, the

Japanese Agricultural Standard No. 233 (JAS 2003), which requires a minimum TSS of 0.70 MPa, was not met by the TSS of plywood in this investigation. Thus, the next step in this investigation was to assess the effective pressing time.

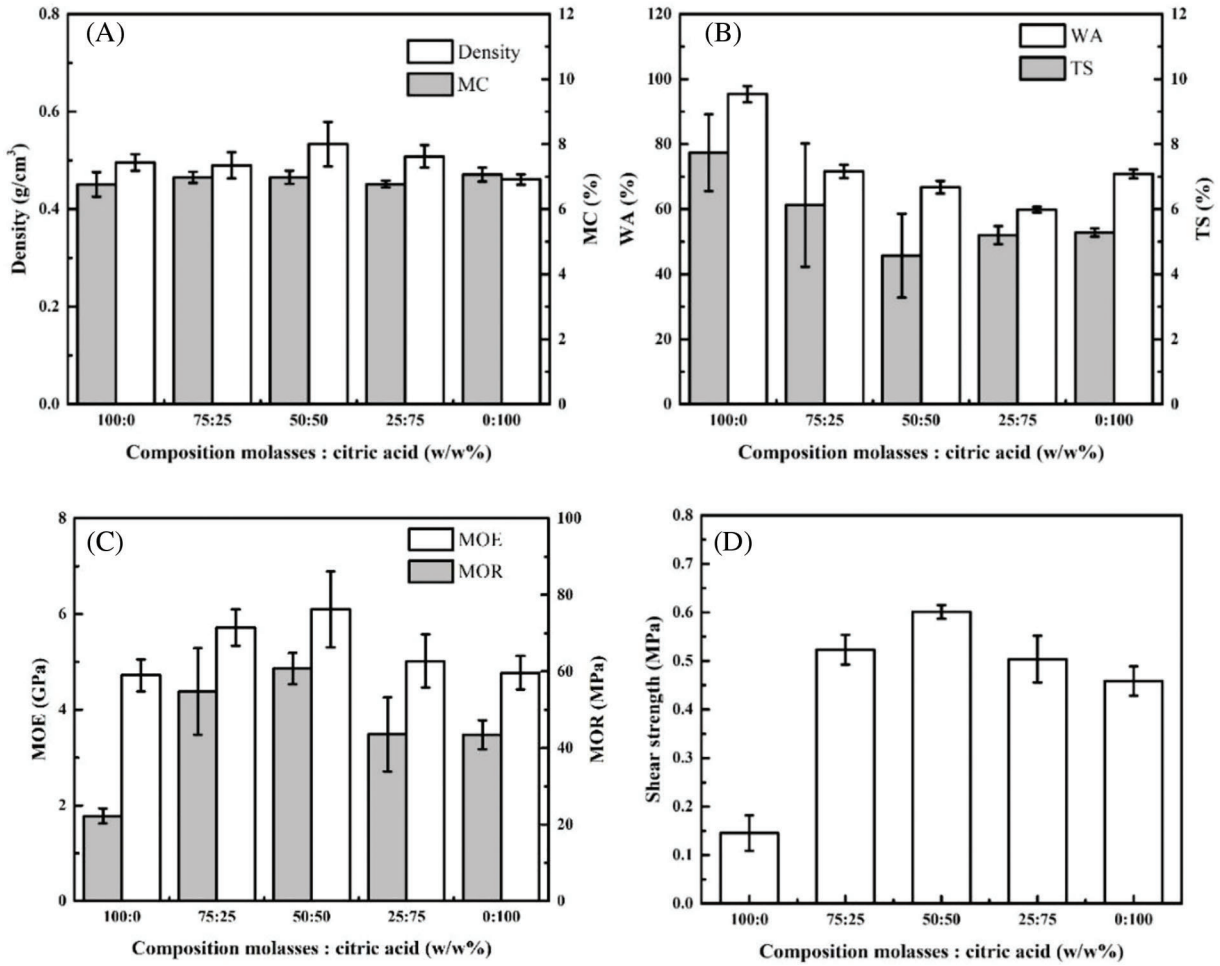

Figure 2: Influence composition of molasses and citric acid on the properties of plywood

Table 3: ANOVA of plywood properties at molasses and citric variation composition

Parameter	ANOVA
MOE	0.029 **
MOR	0.001 **
TSS	0.000 **
Density	0.117 nd
MC	0.429 nd
WA	0.000 **
TS	0.056 **

Note: nd not difference, ** difference.

Table 4: Duncan of plywood properties at molasses and citric variation composition

Composition of MO:CA (w/w%)	Density	MC	WA	TS	MOE	MOR	TSS
100:0	0.50 ab	6.76 a	95.39 d	7.74 b	4.72 a	22.26 a	0.15 a
75:25	0.49 ab	6.98 a	71.60 c	6.13 ab	5.72 ab	54.77 ab	0.52 c
50:50	0.53 b	6.98 a	66.75 b	4.57 a	6.10 b	60.76 c	0.60 d
25:75	0.51 ab	6.77 a	59.84 a	5.20 a	5.02 a	43.57 b	0.50 bc
0:100	0.46 a	7.07 a	70.97 c	5.28 a	4.77 a	43.49 b	0.46 b

Note: There is no difference between values with the same letter in a row.

3.3 Influences of Pressing Temperatures

The influences of pressing temperature were evaluated using composition 50:50 MO-CA ratio types of adhesives. The plywood density in this study ranged from 0.43–0.53 g/cm^3 (Fig. 3A). These density values are not statistically different ($p > 0.05$, Tables 3 and 4). This result for density is comparable to that of three-layer Jabon plywood bonded with phenol formaldehyde-black liquor (0.47–0.48 g/cm^3) [52]. Generally, the pressing temperature affects the density of plywood. Higher pressing temperature results in greater density of plywood due to the thermo-densification effect and curing of the adhesives. This study revealed that plywood with a pressing temperature of 200°C has the highest density ($p < 0.05$, Tables 5 and 6). The MC of plywood in this study ranged from 5.77%–7.13% (Fig. 3A). The pressing temperature affects the MC of plywood. Plywood with a pressing temperature of 200°C has the lowest MC ($p > 0.05$, Tables 5 and 6). According to Japanese Agricultural Standard No. 233 (JAS 2003), the MC of plywood in this study has met the standard (<12%).

The WA of plywood in this study ranged from 58.19%–83.93% (Fig. 3B). The pressing temperature affects the WA of plywood. Plywood with a pressing temperature of 200°C has the lowest WA ($p < 0.05$, Tables 5 and 6). Furthermore, this WA was less than the plywood bonded with PF adhesive (107.6%) reported in the earlier investigation [52]. The TS of plywood in this research ranges from 4.16%–8.08% (Fig. 3B). The pressing temperature affects the TS of plywood. Plywood with a pressing temperature of 190°C has the lowest TS.

This study's MOE and MOR of plywood ranged from 5.74–6.80 MPa and 31.17–63.77 MPa, respectively (Fig. 3C). Additionally, the MOR in this investigation was higher than the 43.14 MPa MOR of Jabon LVL bonded with PF resins [53]. The pressing temperature affects the MOE and MOR of plywood. Plywood with a pressing temperature of 200°C has the highest MOE and MOR ($p < 0.05$, Tables 5 and 6). This study's TSS of plywood ranged from 0.51–0.79 MPa (Fig. 3D). The pressing temperature affects the TSS of plywood. Plywood with a pressing temperature of 200°C has the highest TSS ($p < 0.05$, Tables 5 and 6). Furthermore, the plywood in this investigation had a higher TSS than the poplar plywood bonded with citric acid (0.35 MPa) and bonded with sucrose-citric acid 50:50 ratio (0.45 MPa) [46]. However, the TSS result was less than plywood bonded with PF and UF (1.0 MPa) [47,52].

3.4 Functional Group Analysis

To elucidate the impact of the CA addition on the chemical transformation of plywood, Fourier transform infrared (FTIR) measurements of plywood types with a 50:50 MO-CA ratio were made (Fig. 4). Clear evidence of an absorption peak at about 1727 cm^{-1} was seen in the plywood types with a 50:50 MO-CA ratio. Because of the carboxyl and C=O ester groups, the peak at 1727 cm^{-1} was commonly attributed to C=O stretching [54]. There was an extra absorbance intensity peak at 1245 cm^{-1} in the plywood types with a 50:50 MO-CA ratio. This peak was associated with the ester groups' C=O stretching vibration band [55].

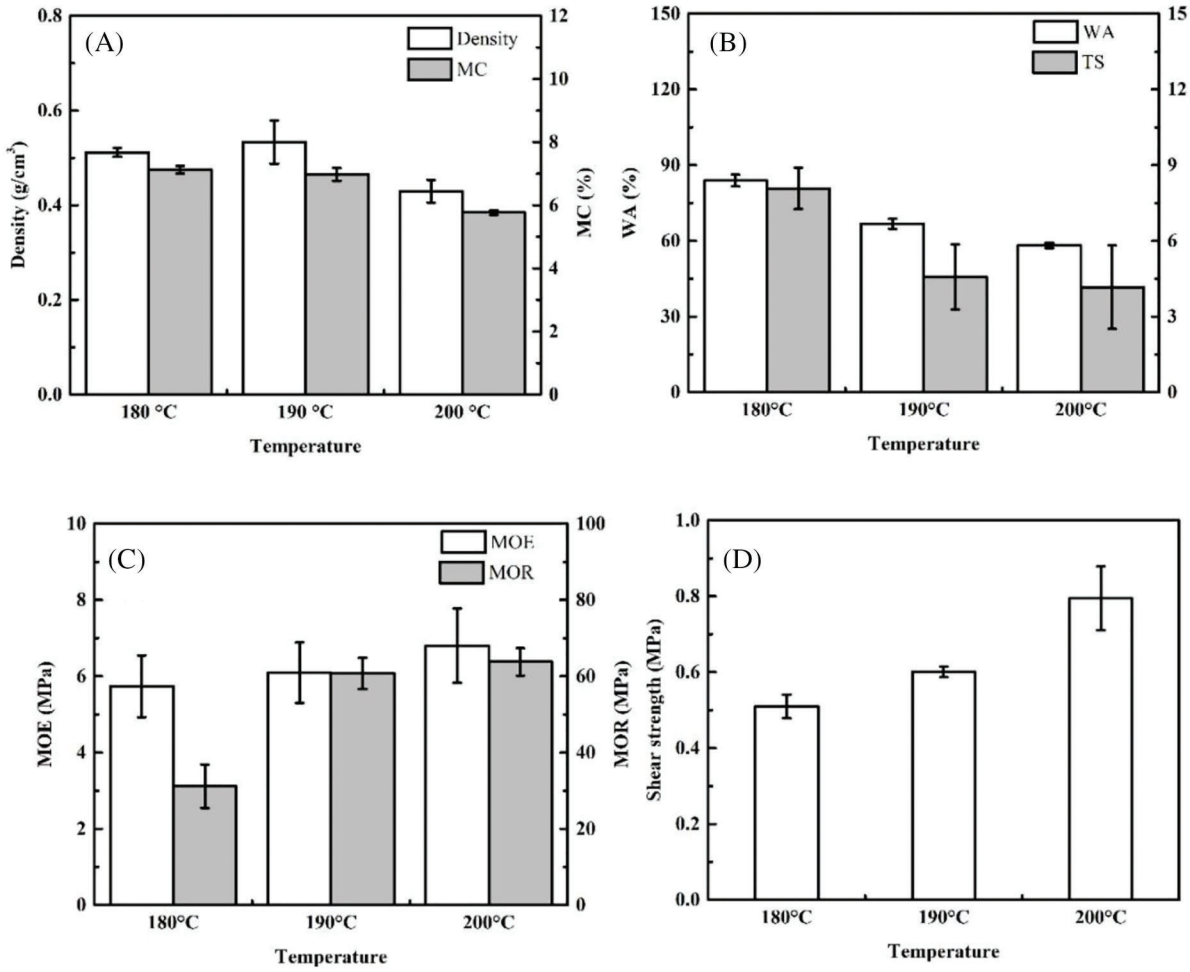

Figure 3: Influence of pressing temperature on the properties of plywood

Table 5: ANOVA of plywood properties at variation pressing temperature

Parameter	ANOVA
MOE	0.014 **
MOR	0.000 **
TSS	0.000 **
Density	0.019 **
MC	0.371 nd
WA	0.000 **
TS	0.002 **

Note: nd not difference, ** difference.

The presence of ester groups in the infrared spectra of plywood specimens with a 50:50 MO-CA ratio type suggests that ester linkages were formed by the reaction between the carboxyl groups of CA and the hydroxyl groups of veneer and MO [46]. MO was digested in the mixes of MO-CA solution to yield its

corresponding monosaccharides, glucose, and fructose [19]. These monosaccharides are typically found as hydroxyl-group-containing carbohydrates. Essentially, cellulose, hemicellulose, and lignin are the primary sources of hydroxyl groups found in lignocellulose materials [56]. As a result, compared to plywood bonded with MO alone, the plywood glued with the adhesive at a suitable weight ratio of CA to MO seemed to have more ester linkage branches. This resulted from a reaction between the hydroxyl groups of MO and veneers and the carboxyl groups of CA. As a result, ester bonds would form, which would increase the adhesiveness. As a result, applying CA enhanced the plywood's mechanical and physical qualities.

Table 6: Duncan of plywood properties at variation pressing temperature

Pressing temperature (°C)	Density	MC	WA	TS	MOE	MOR	TSS
180	0.51 b	7.13 b	83.93 c	8.08 b	5.74 a	31.17 a	0.51 a
190	0.53 b	6.98 b	66.75 b	4.57 a	6.10 a	60.76 b	0.60 a
200	0.43 a	5.77 a	58.19 a	4.16 a	6.80 a	63.77 b	0.79 b

Note: There is no difference between values with the same letter in a row.

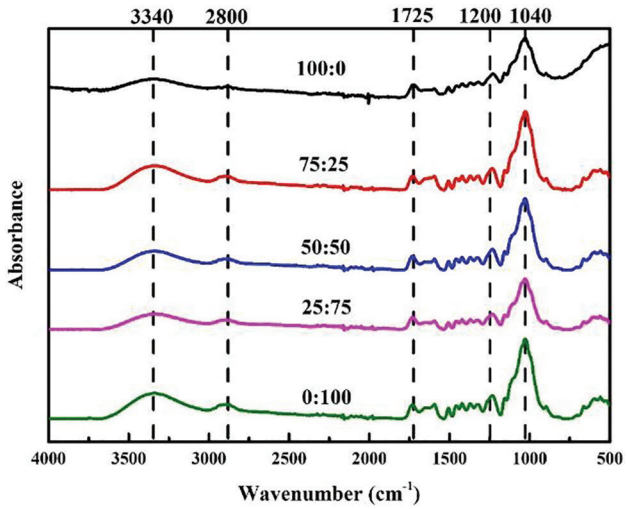

Figure 4: FTIR spectrum plywood of different composition of molasses and citric acid

4 Conclusion

The research showed that mixing with citric acid changed the molasses adhesive gelation time, pH, solid content, and viscosity. In addition, the thermal properties of molasses adhesives were changed after mixing with citric acid. These phenomena indicate changes in characteristics, such as the curing of adhesive. In general, the properties of plywood increased gradually as the citric acid ratio increased but exceedingly decreased for the 25:75 MO-CA ratio. Meanwhile, the quality of plywood was successfully enhanced by increasing the pressing temperature (180°C to 200°C). The plywood bonded with adhesives at a 50:50 MO-CA ratio had higher mechanical properties and better dimensional stability than those bonded only with MO. In addition, the pressing temperature of 200°C plywood bonded with a 50:50 MO-CA ratio has the best mechanical and physical properties. The Thermal and FTIR analyses demonstrated that CA formed ester linkages with the MO and wood veneers. Ultimately, the mechanical properties of plywood were enhanced, and the plywood still has good dimensional stability.

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Availability of Data and Materials: The authors confirm that the data supporting the findings of this study are available within the article.

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