Combination of citric acid and maltodextrin as bonding agent in sorghum bagasse particleboard

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Abstract. The interest of using natural binder in particleboard production is still the primary concern of many researchers. The use of citric acid as an adhesive has been investigated and show satisfying results, especially in particleboard physical properties. However, the particleboard had low bending strength due to high content of citric acid on the particleboard affected the brittleness of the particles. Therefore, the application of citric acid in particleboard production usually combined with other natural adhesives. In this study, a combination of citric acid (CA) and maltodextrin (MD) was used in the production of sorghum bagasse particleboard with a ratio of 1:1. The particleboard was produced with a target density of 0.8 g/cm³, using 15%, 20%, 25% and 30% CA-MD content, hot-pressed at 200°C and 5 MPa for 8 or 10 minutes. The mixture of citric acid and maltodextrin (1:1) was successfully acting as bonding agent in sorghum bagasse particleboard production, mainly when used at 30% adhesive content. The particleboard modulus of rupture and modulus of elasticity, fulfilled the standard of type 8 particleboard, according to JIS 5908. The particleboard physical properties were excellent, proved by the value of particleboard thickness swelling, which was under 12%. This is due to the superb bonding from the combination of citric acid and maltodextrin, as shown by the internal bond values, which exceeded 0.3 N/mm², the minimum requirement for type 18 particleboards based on JIS A 5908.

1. Introduction

Exploring the potential of non-wood lignocellulose as particleboard raw material, still become many researchers concern due to limitation of wood resources. Some considerations to provide sustainable particleboard production were the availability and continuity of the raw material resources. Sweet sorghum bagasse (Sorghum bicolor L. Moench) is one of agricultural by products that has been utilized for particleboard raw material, using urea formaldehyde [1] or citric acid [2] as adhesive.

According to Vukusic et al. [3], citric acid (CA) is an organic poly-carboxylic acid, which contains three carboxyl groups and has been considered as a cross-linking agent for wood. The use of citric acid as an adhesive in the study by Umemura et al. [4,5] showed better results on the physical and mechanical properties of the sweet sorghum bagasse (SSB) particleboard. However, Kusumah et al. [6] reported the screw holding power of SSB-CA particleboard was lower than the requirements of JIS A 5908-2003 for type 18 particleboard. According to Jonsson and Martin [7], amorphous polysaccharides from lignocellulose are easily degraded by acid compounds. Amorphous polysaccharide degradation is likely
to be a major factor affecting fragility in wood [8]. Based on this description, reducing the content of citric acid, is an alternative for resolving the amorphous polysaccharides degradation and fragility in particleboard produced with citric acid as bonding agent.

Maltodextrin is a starch-based polysaccharide produced by the hydrolysis of starch into glucose polymers with an average chain length of 5-10 glucose units. Maltodextrin is soluble in water, which makes it more attractive for industrial applications compared to insoluble starch. Maltodextrin has the potential as a natural binder for the replacement of synthetic adhesive based on petroleum and has a better adhesion to the starch properties [9,10]. The results of Santos et al. [11] research, in the use of sucrose, maltodextrin or citric acid as adhesive in nipa-fronds particleboard production, showed that the particleboards fulfill the JIS A 5908-2003 standard, on mechanical and physical properties. Although it did not work well when pressed at 180°C with maltodextrin. Therefore, in this study, maltodextrin was added to citric acid in the manufacturing of particleboards from sorghum bagasse. The role of maltodextrin is to reduce the amount of citric acid as a major factor affecting particleboard fragility and improve its mechanical and physical properties. This study aims to determine the effect of the pressing time and levels of citric acid and maltodextrin adhesives on the mechanical and physical properties of sorghum bagasse particleboard.

2. Materials and Method

This study uses sweet sorghum bagasse which were obtained from the experimental garden at LIPI-Cibinong Science Center. The sorghum bagasse was a by-product from the process of sorghum juice extraction from its stalks. The bonding agents used were citric acid powder and maltodextrin.

2.1. Raw material preparations

Sorghum bagasse was processed by ring flakers to obtain particles, then the particles was screened to obtain particles that passed through a 4-mesh and retained on a 14-mesh screen. All of the particles were dried in oven of 60°C until particles moisture content of around 5%.

Citric acid (anhydrous) of technical grade was used without further purification. Citric acid was dissolved in water at a concentration of 59%, and maltodextrin was added with ratio of 1:1. This solution was used as the binder. No other chemical compounds were used.

2.2. Methods

2.2.1. Particleboard production

Sorghum bagasse particles were weighed. Then sorghum bagasse particles were put into a drum mixer and sprayed with a mixture of citric acid and maltodextrin (1:1), with adhesive level of 15%, 20%, 25% or 30% using a spray gun. After mixed evenly, the raw material was dried in an oven at 80°C for 12 hours to reduce the moisture content of the material to less than 5%.

The dried sorghum bagasse particles mixed with adhesives were put into the mould with the size (30x30) cm, then hot-pressed with the pressure of 5 MPa, the temperature of 200°C, for 8 or 10 minutes. The particleboard thickness was 1 cm, with the target density of the particleboard was 0.8 g/cm³. After conditioning for one week at a room temperature of about 26°C and relative humidity of approximately 72%, the boards were tested according to the Japanese Industrial Standards for particleboards (JIS A 5908-2003), including physical and mechanical properties.

2.2.2. Particleboard mechanical properties analysis

The bending properties of the boards, i.e., the modulus of rupture (MOR) and the modulus of elasticity (MOE), were evaluated by conducting a three-point bending testing on 200×30×10 mm of board specimen under dry conditions. The loading speed and effective span were 10 mm/min and 150 mm, respectively. The internal bonding (IB) strength investigated using a 50×50×10 mm board specimen. The screw holding power (SHP) was analysed by pulling out the screws that vertically screwed into the two positions in test pieces vertically. In this test, the pulling-out load speed shall be approximately 2 mm/min.
2.2.3. Evaluation of particleboard physical properties after cyclic aging treatment

The thickness swelling (TS) and water absorption (WA) values of each board after water immersion at 20°C for 24 hours, were measured for board specimens of the same size as those used for the IB testing. Particleboard physical properties were thickness swelling and water absorption. Tests carried out using a board specimen with a size of 50×50×10 mm. Analysis of board water absorption was done by measuring the difference in board specimen mass before immersion (B1) and board specimen mass after being immersed for 24 hours (B2). Analysis of board thickness swelling done by measuring the difference in board specimen initial thickness before immersion (T1) and board specimen thickness after being immersed for 24 hours (T2).

To observe particleboards thickness swelling in severe condition, specimens were subjected to a cyclic aging treatment (drying at 105°C for 10 hours, warm-water immersion at 70°C for 6 h, drying at 105°C for 10 hours, immersion in boiling water for 4 hours, and drying at 105°C for 10 hours). The thickness and weight changes of the specimens that occurred throughout the treatment were determined. Each experiment was performed in five replications, and the average values and standard deviations were calculated.

3. Results and Discussion

The mechanical properties of particleboards are modulus of rupture, modulus of elasticity, internal bond and screw holding power. Those mechanical properties must fulfill the minimum requirement based on standard JIS A 5908-2003. During particleboards utilization as a shelf in clothes wardrobe or book rack, the force from the book or other materials put on the shelf will give the load to the particleboard. Particleboard type 8, is the lowest standard of particleboard, as a benchmark of the minimum requirement for particleboards utilization.

All modulus of rupture (MOR) of sorghum bagasse particleboards bonded with citric acid and maltodextrin were above 8 N/mm². Sorghum bagasse bonded with 30% citric acid and maltodextrin (CA-MD) showed the highest MOR, which was 12.66 N/mm² when hot-pressed for 8 minutes and 12.59 N/mm² when hot pressed for 10 minutes (Figure 1). The particleboard MOR were higher with the increment of bonding agent content.

Sorghum bagasse particleboards bonded with citric acid and maltodextrin in this study show higher MOR values compare to alang-alang particleboard bonded with 10%, 15% and 20% citric acid [12], which were 10.59 MPa, 7.82 MPa and 6.54 MPa respectively. Still, they show lower MOR values compare to sugarcane bagasse particleboard bonded with 15%, 20%, 25% citric acid [13], which were 17.38 MPa, 18.22 MPa, 21.88 MPa, respectively. Meanwhile, MOR of particleboard from a combination of sorghum bagasse and wood-shaving bonded with urea-formaldehyde were in the range of 7.32-10.47 MPa [1]. Particleboards made from Nipa fronds using citric acid as adhesive showed MOR of 10.41 MPa, and in a variety of 2~ 5 MPa when using maltodextrin [14].
Figure 1. Modulus of rupture of particleboards with 15% (A), 20% (B), 25% (C), 30% (D) citric acid+maltodextrin, hot pressed in 8 min or 10 min

The particleboard modulus of elasticity showed the same trend. The highest particleboards MOE was presented by sorghum bagasse particleboards bonded with 30% citric acid and maltodextrin (CA-MD), and it was the only sorghum bagasse particleboards type which fulfilled the requirement of MOE type 8 particleboards (Figure 2). The boards were tough enough to withstand the load. According to Sulastiningsih et al. [15], particle length uniformities affected particleboard MOE. In this study, sorghum bagasse particles size was quite uniform that pass 4 mesh and retain 14 mesh screens. So that particleboard MOE values were affected by citric acid and maltodextrin content. Santoso et al. [14] compared the characteristics of nipa fronds particleboard bonded with three different natural binders, which were citric acid, sucrose and maltodextrin. MOE of nipa fronds particleboard bonded with citric acid (3.65 GPa) was higher compared to nipa fronds particleboard bonded with sucrose or maltodextrin. The MOE of sorghum bagasse bonded with 30% CA-MD was 2.66 GPa when hot pressed for 8 min and 2.56 GPa when hot-pressed for 10 min.

Figure 2. Modulus of elasticity of particleboards with 15% (A), 20% (B), 25% (C), 30% (D) citric acid+maltodextrin, hot pressed in 8 min or 10 min
Similar to sugarcane bagasse, sorghum bagasse is also agricultural by products, which collected after extracting sorghum juice. Gnansounou et al. [16], stated that about 13% of the sugar will be in the sweet sorghum bagasse. Solihat et al. [17], reported that reducing sugar content in sweet sorghum bagasse could reach 45.57%, while sugarcane bagasse containing 61.5% glucose (lowering sugar) [18]. The internal bonds values of all sorghum bagasse particleboards in this study, were higher than 0.22 N/mm$^2$ (Figure 3), that fulfilled the minimum standard for type 13 particleboards (min 0.2 N/mm$^2$) according to JIS A 5908. Moreover, IB values of boards bonded with 30% CA-MD, reached 0.35 N/mm$^2$, that can categorize in type 18 particleboard (min IB 0.3 N/mm$^2$). Therefore, the reducing sugar in sorghum bagasse could act as bonding agent and gave synergetic effect with citric acid and maltodextrin in bonding particles.

![Figure 3. Internal Bond of particleboards with 15% (A), 20% (B), 25% (C), 30% (D) citric acid+maltodextrin, hot pressed in 8 min or 10 min](image)

One of the weaknesses of citric acid application as a bonding agent in particleboard production is that the screw holding power of particleboard was low. As presented in Figure 4, the screw holding power (SHP) values of all type sorghum bagasse particleboard in this study were lower than 300 N, which the minimum SHP values of the lowest type of particleboard (type 8). After heat treatment during hot pressing, citric acid reacted with the hydroxyl groups of sorghum bagasse particles to form ester linkages. The formation of ester linkages would result in good adhesive-ness and impart excellent physical properties to the boards [2]. Unfortunately, the particleboard tends to brittle as reported by Kusumah et al. [6], then reducing the CA content by adding sucrose was an effective method to decrease particleboard brittleness.
Figure 4. Screw holding power of particleboards with 15% (A), 20% (B), 25% (C), 30% (D) citric acid+maltodextrin, hot pressed in 8 min or 10 min

The change in the particleboard thickness and weight with varied CA-MD content and hot-pressed for 8 min, after cyclic aging treatment is presented in Figure 5. The expanded of particleboard thickness and weight change decreased with increasing of citric acid and maltodextrin content. The particleboard thickness and weight change bonded with 20% CA-MD and hot-pressed for 8 min (8B) after boiling treatment, presented better tenacity than the other particleboards. These mean that 20% CA-MD after heat treatment for 8 min could act as a good bonding agent for sorghum bagasse particles and had given good dimensional stability of particleboard even in the severe conditions.

Figure 5. Thickness change (%) and weight change (%) of particleboards with 15% (A), 20% (B), 25% (C), 30% (D) citric acid+maltodextrin, hot pressed in 8 min after cyclic aging treatment

The increasing of CA-MD content (30%) require more time to be cured and successful in bond sorghum bagasse particles. The change in the thickness and weight particleboard with varied CA-MD content and hot-pressed for 10 min, after cyclic aging treatment, is presented in Figure 6. The expanded of particleboard thickness and weight change decreased with increasing of citric acid and maltodextrin content. The depth and weight change of the particleboard bonded with 30% CA-MD and hot-pressed for 10 min (10D) after boiling treatment (Figure 6), showed better stability than the other particleboards. These mean that 30% CA-MD after 10 minutes heat treatment before could act as a suitable bonding agent for sorghum bagasse particles. All sorghum bagasse particleboards in this study, show excellent
physical properties, even after severe cyclic ageing treatment, proved by the thickness swelling was under 12%.

Figure 6. Thickness change (%) and weight change (%) of particleboards with 15% (A), 20% (B), 25% (C), 30% (D) citric acid +maltodextrin, hot pressed in 10 min after cyclic aging treatment

4. Conclusion
The mixture of citric acid and maltodextrin (1:1) was successfully acting as a bonding agent in sorghum bagasse particleboard production, especially when used at 30% adhesive content. The particleboard module of rupture and module of elasticity could fulfill the standard of type 8 particleboard, according to JIS A 5908-2003. The particleboard physical properties were excellent, proved by the value of particleboard thickness swelling, which was under 12%. This is due to the excellent bonding from the combination of citric acid and maltodextrin, as shown by the internal bond values, which exceeded 0.3 N/mm², minimum requirement for type 18 particleboards based on JIS A 5908-2003.

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