The potential of using agricultural waste: Corn husk for particleboard raw material

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Abstract. The development of manufactured particleboard using non-wood raw materials has been significant due to the decrease of wood as the main raw material for the particleboard industry. In this study, corn husk, an agricultural waste, was used for experimental manufacturing of particleboard bonded with natural and synthetic adhesives. The influence of adhesive types and concentration on the physical and mechanical properties of particleboard were investigated. The synthetic adhesive types used were urea-formaldehyde (UF) and phenol-formaldehyde (PF) with 8,10 and 12 wt\% adhesive concentration. The natural adhesive used was citric acid with 15, 20, and 25 wt\% adhesive concentration. The target density of particleboard was set at 0.80 g/cm\textsuperscript{3}. The boards were manufactured at a pressing temperature of 130\degree C for UF, 150\degree C for PF and 200\degree C for citric acid, pressing time of 10 minutes, and 2.5 MPa for hot-pressing pressure. Generally, this study confirms that types of adhesive and adhesive concentrations influence the properties of particleboard. Results show that particleboard with citric acid adhesive has better physical and mechanical properties than particleboard bonded with UF and PF adhesives.

1. Introduction
Particleboard has become one of the most popular wood-based composite materials for decorating materials due to its low density, good thermal insulation, sound absorption, and incredible machining properties. The primary lignocellulosic material used in the particleboard industry is wood [1]. Besides, deforestation and over-harvesting have created environmental issues. In contrast, increasing demand for forest resources in various applications has led to the shortages of wood supply in most developing countries [2]. It has led to a growing interest for a substitute material other than wood in the development of particleboard. Furthermore, the substitution material should be marketable ready and lower the production cost of particleboard. Agricultural wastes are considered as the potential materials with comparatively unique possibilities for the design of particleboard.

In this context, the use of agricultural wastes as a raw material in the replacement of wood seems a promising solution mainly due to their wide variety of lignocellulosic materials worldwide. Among various agricultural wastes, the stems of annual plants are attractive because they are abundant, renewable, and currently undervalued. The agricultural waste used in particleboards usually corresponds to the locally available agro resources. Research has been carried out on a wide variety of
non-wood plant fibers and agricultural wastes such as kenaf fibers [3], coconut husk and bagasse [4], sorghum [5], bamboo [6], rice straw [7] and rice husk [8].

Generally, particleboards manufactured from wood particles are bonded with synthetic adhesives, such as urea-formaldehyde (UF) or phenol-formaldehyde (PF). These binders bring some environmental problems because they release formaldehyde emissions, which can be toxic to human health and for the environment. That is why particleboard manufacturers are looking for more environmentally friendly adhesives. A lot of bio-source compounds have been envisaged to replace the currently used synthetic adhesives. Various natural molecules have been studied for their adhesive properties on plant particles, such as lignin [9], lignosulfonates [10], proteins [11], polysaccharides [12,13] and citric acid [14].

In this research, we have studied the potential of using corn husk as agricultural waste to manufacture particleboards. Corn or maize is the second-largest crop in Indonesia after rice. As information, Indonesia corn production in 2015 was 19.61 million tons, which increased from 19.01 million tons in 2014 [15]. The increase of corn production is also followed by the increase of its solid waste, such as corn husk, so it will take an effort in handling this waste. Cornhusk, which has become a lot of waste and has not been used optimally, also can be obtained and collected from the traditional market in Indonesia regions. This study presents a comparison between particleboards bonded with synthetic adhesive (UF and PF) and natural adhesive (citric acid).

The objectives of the research were to determine the effect of some variable parameters on the physical and mechanical properties of particleboard samples.

2. Material and methods

The materials used in this research were corn husks, urea-formaldehyde (UF), and phenol-formaldehyde (PF). The corn husks were collected from the traditional market in Bogor, West Java. They were separated from corn cob after the stripping process. Corn husks were washed by water to remove soil and other impurities. Corn husks were processed into particles by a ring flaker machine. The particles were then screened using a horizontal vibration sieve to obtain particles of uniform sizes. Particles size used in this research passed through 4 mesh and was retained at 14 mesh screens. The particles were dried at 105°C in a technical oven until they reached 5% moisture content. Then, the corn husk particles were stored at ambient conditions.

The industrial adhesives used in this research were UF (50% solids and pH 7.6) and PF (45% solids and pH 8.0), which were obtained from PT Pamolite Adhesive Industry, Probolinggo, East Java. This research was also used natural adhesive, anhydrous citric acid (dissolved in water at a concentration of 59%), which was obtained from EMD Millipore Corporation Billerica USA. The variety of adhesive content applied in this research was 8, 10, 12 wt% for UF and PF; and 15, 20, 25 wt% for citric acid. The adhesives solution was sprayed onto dried particles by a spray gun in a drum mixer. Afterwards, these particles were formed into mats using a forming box. The dimensions of particleboards were 30 x 30 x 0.9 cm. The pressing was performed in a hydraulic hot press for press pressure of 2.5 MPa and 10 min at a temperature of 130°C (UF), 150°C (PF), and 200°C (citric acid). The target density of particleboard was 0.8 g/cm³. After this process, the particleboards were acclimatized for 24 h at room temperature.

The physical properties such as density, thickness swelling and water absorption; and mechanical properties such as modulus of elasticity, modulus of rupture, internal bonding and screw holding power from particleboard were tested according to JIS A 5908:2003 [16] standard for particleboard.

3. Results and discussion

3.1. Physical properties

The targeted density of boards for this study was 0.8 g/cm³. The range density of boards in this study was 0.76-0.96 g/cm³ (Figure 1). The standard, according to JIS, was on the range 0.4-0.9 g/cm³. The bulk density of corn husk particles dried at 105°C for 24 h was 0.04 g/cm³. The boards bonded with
UF and PF adhesive had high density, which even exceeds the target density, while the boards bonded with a citric acid approached to target density. This trend has also been reported by Widyorini et al. on their research on the utilization of several types of bamboo for particleboard using citric acid [17].

Figure 1. The density of the particleboards.

The dimensional stability evaluation of particleboard was conducted by measuring the thickness swelling (TS) and water absorption (WA). The TS and WA are the percent change in dimensions of board thickness and weight after they were immersed in water for 24 hours. TS caused by the residual stresses is applied to the particleboard, so the thickness of the board will increase as an effort of stress release. Figure 2 shows the TS of the particleboards from corn husk particles. The TS decreases with the increase of adhesive content, in the case of boards bonded with UF (from 145% to 75.16), or PF (from 82.33% to 65.57%), so it does not meet the standard (maximum of 12%). While the TS of boards with citric acid (from 4.82% to 5.30%) meets the TS standard. The high percentage of TS can be enhanced by increasing the percentage of adhesive or coating applications using hydrophobic materials on the board [18].

The smallest percentage of thickness swelling, which is the best result, indicates the best mechanical adhesion on the panels. The adhesion that occurs in the corn husk-based panels bonded with UF and PF adhesives shows interesting adhesion properties. Still, this process does not achieve sufficient water-resistance of the panels compared to panels bonded with citric acid and binderless boards.

The mass percentage of water absorbed (WA) is presented in Figure 3. The water absorption of all boards bonded with UF and PF adhesives is high, with the values between 89.63% to 185.03%. The high percentage of WA due to the lignocellulosic fiber is highly hydrophilic since it contains an abundance of hydroxyl groups. Additionally, large numbers of porous tubular structures which are present in fiber accelerate the penetration of water by the capillary action [5]. The boards made with citric acid binders have better WA r (32.93% to 44.58%) than boards bonded with UF and PF. It means that corn husk particles are more compatible with citric acid adhesives than UF and PF adhesives. These results confirm research from Widyorini et al. [17] that the particleboards bonded with citric acid perform lower WA than those with UF and PF. The poor absorption resistance of the cellulosic material is mainly due to the presence of polar groups, which can attract water molecules through hydrogen bonding. Besides, any pores or voids that are present after fabrication will help accommodate some of the swellings of the fiber. This phenomenon leads to a moisture build-up in the
fiber cell wall (fiber swelling) and also in the fiber–adhesive interface. It also causes the changes in the dimension of particleboards, particularly in the thickness and the linear expansion, due to reversible and irreversible swelling of the boards.

![Figure 2. Thickness swelling of corn husk particleboards.](image1)

![Figure 3. Water absorption of particleboards.](image2)

3.2. Mechanical characteristics

In general, the results show that the variable parameters significantly influence the mechanical properties of the boards. The average values of modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding strength (IB), and screw holding power (SHP) of corn husk particleboards are presented in Figure 4-7. Based on the JIS standard, 2.0 GPa is the minimum requirement for the MOE of particleboards for base particleboard. On the other hand, the minimum requirements for the MOR are 8 MPa (Type 8), 13 MPa (Type 13), and 18 MPa (Type 18) for base particleboard. The range of data in the MOE is from 1.06 to 2.75 GPa (Figure 4). Except for board bonded with citric acid
adhesive, all other boards, made with UF and PF adhesives, has lower MOE than JIS standards requirements. Maloney [19] mentioned that MOE was affected by several factors such as adhesive content, adhesive type, bonding performance, and fiber length. However, all boards bonded with UF, PF, and citric adhesives with difference adhesive concentration meet the minimum MOR requirement of the JIS standards for base particleboard (Figure 5). The MOR values range from 8.62–18.40 MPa. The highest MOR is performed by corn husk particles mixed with 12 wt% UF and PF. However, MOR value from boards bonded citric acid is lower than other boards. It can be concluded that the higher the percentage of adhesive, the higher the MOR value of the boards. This result corresponds to the research conducted by Mohsen [20] and Samson [21] that MOE and MOR are influenced by panel density, percentage of adhesive, and particle geometry. In the context of the adhesive effect, a high percentage of adhesive increases the bond contact between individual particles [22].

![Figure 4. Modulus of elasticity from corn husk particleboards.](image1)

![Figure 5. Modulus of rupture values of particleboards.](image2)

Internal bond (IB) data range from 0.10 to 0.46 MPa. The minimum requirements of IB strength in the JIS standards are 0.15 MPa for Type 8, 0.2 MPa (Type 13), and 0.3 MPa (Type 18). As can be
seen from Figure 6, the boards bonded with UF and PF (8 and 10 wt%) adhesives have a low IB, and IB increases slightly on 12 wt% adhesive content. Only the boards bonded with citric acid adhesive has a high IB and meets the JIS standards. Compatibility properties between adhesive and particles enhance the IB value of the board. Umemura et al. [14] argue that the adhesiveness on the inner layer of particleboard has influenced the IB value.

Figure 6. Internal bond value of particleboards.

Another property investigated in this study was screw holding power (SHP) values. The values range between 107.29-232.04 N. All manufactured boards have SHP values that do not meet the JIS Standard. However, particleboards bonded with PF adhesive have higher SHP than other boards. Poor SHP values on corn husk particleboards are influenced by the wide surface area of the particle. Then it leads to low adhesive absorption. We can notice that the higher adhesive concentration makes the particleboard brittle, thereby it can reduce the SHP values.

Figure 7. Screw holding power value of particleboards.

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4. Conclusion
Cornhusk as agricultural waste can be used as raw material for particleboards. The different adhesive type and concentration influence the board properties. Generally, the board's properties were enhanced by increasing adhesive content. According to the results, corn husk particles seem more suitable to be used as boards raw material bonded with a citric acid binder. The particleboards bonded with citric
acid has the best physical and mechanical properties and met the requirement of standard (JIS A 5908:2003) except for SHP properties.

Acknowledgments
The authors acknowledge the Japan ASEAN Science Technology and Innovation Platform (JASTIP)-Strategic International Collaborative Research Program (SICORP)-Japan Science and Technology Agency (JST) for supporting this research.

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