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Valorization of Palm Kernel Cake as Bioadhesive for Particle Board

YW Sari*, MM Silviana1, M Kurniati1 and I Budiman2

1 Biophysics Research Group, Department of Physics, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Indonesia
2 Research Center for Biomaterials, Indonesian Institute of Sciences, LIPI, Indonesia

*email: yessie.sari@apps.ipb.ac.id

Abstract. The palm oil industry is one of the strategic industries in Indonesia. The annual increasing of oil palm production provides negative impact on the environment. This is related to waste of production. There are two types of waste production of crude palm oil, namely solid waste and liquid waste. Palm kernel cake (PKC) is an example of solid waste. PKC processing technology innovation is expected to improve sustainability of crude palm oil production. This study investigated the possible valorization of PKC protein as bioadhesive for particle board application. Empty Fruit Bunches (EFB) was used as the fiber for particle board production. This study indicated the possibility to valorize PKC as bioadhesive.

1. Introduction
The palm oil industry is one of the strategic industries in Indonesia. This industry has the potential to generate economic and social development. Oil palm is listed as one of the 10 main export commodities of Indonesia [1]. Crude palm oil production has increased significantly over the past 7 years. This is indicated, among others, by the increasing area of oil palm plantations. The area of oil palm plantations in 2015 was recorded at 11.44 million hectares. The data shows an increase of 6% over the previous year. The increase in the area of oil palm is accompanied by an increase in production by 6.8% from 2014 to 2015 [2]. Increased production of crude palm oil is expected to continue. One of the triggers is the potential of crude palm oil as raw material for biodiesel production.

It can not be denied that the annual increasing of oil palm production provides negative impact on the environment. This is related to waste of production. There are two types of waste production of crude palm oil, namely solid waste and liquid waste. Palm kernel cake (PKC) is one example of solid waste. Palm oil production can produce PKC up to 45-46% of the palm kernel, or about 2.5% of the weight of the palm bunches.

The utilization of PKC has been limited to ruminants feed. The content of crude fiber and a rough protein that makes PKC balanced can be used as a source of energy and protein sources [3]. PKC as an energy source feed is generally given on ruminants, whereas as a source of protein is given to poultry. However, the use of PKC as a protein source has constraints caused by low levels of digestibility in poultry [3, 4] limiting the utilization of PKC as animal feed.

To reduce the negative impact of the increasing number of PKC waste, the need for new breakthrough and innovation of PKC processing technology has been emerged. PKC processing technology innovation is expected to improve sustainability of crude palm oil production. This
innovation can be done, among others, with advanced material engineering. PKC has a high protein content [5] that can be used as an adhesive in fiber board production.

Utilization of PKC protein as adhesive has not been done. Currently the commonly used adhesive on the particle board industry is urea formaldehyde, petrochemical based adhesives [6]. The use of urea formaldehyde has recently been restricted due to formaldehyde emissions that could interfere with human health [7]. PKC protein is expected to be used as an environmentally friendly particle board adhesive and is able to reduce the use of synthetic adhesives obtained from the petrochemical industry. This study investigated the possible valorization of PKC protein as bioadhesive for particle board application. Empty Fruit Bunches (EFB) was used as the fiber for particle board production.

2. Materials and methods

2.1. Materials
Palm kernel cake was obtained from palm oil milling located in North Sumatera, Indonesia. NaOH, HCl, and urea formaldehyde were used as chemical reagents.

2.2. Methods

2.2.1. Extraction of PKC Protein. PKC was ground and filtered into homogenous size, 100 mesh. Protein extraction was conducted following method developed in previous study[8]. Grind PKC was suspended in. Protein extraction was conducted by mixing BIS powder with 250 ml of 55 mM NaOH solution with a ratio of 1: 10 (g / ml). The PKC and NaOH suspension was stirred for 24 hours at 25 °C and 60 °C. After 24 hours, the suspension was centrifuged (HIMAC R 12 A) at a speed of 10,000 rpm at 4 °C for 15 minutes. Protein solubilized in the supernatant was further precipitated using isoelectric precipitation method. HCl was used as the reagent for precipitation. Extraction was conducted in duplo.

2.2.2. Particle board manufacturing. EFB was cut into 1 cm and further sun dried to reduce the water content up to 10%. To produce particle board, mixture of urea formaldehyde (UF), as synthetic adhesive, and PKC protein, as bioadhesive, was used. A ratio of 3:1 and 1:1 was selected. Detail of particle board composition can be seen in Table 1.

| PKC (g) | NaOH 55 mM (ml) | Extraction Temperature (°C) | Fiber mass (g) | Total Adhesive Weight Percentage (%) | Ratio of Adhesive Protein : UF | Sample Code |
|---------|-----------------|----------------------------|---------------|-------------------------------------|-------------------------------|-------------|
| 25      | 250             | 25                         | 279           | 7                                   | 1 : 3                         | A1 a        |
| 25      | 250             | 25                         | 279           | 7                                   | 1 : 1                         | A1 b        |
| 25      | 250             | 60                         | 279           | 7                                   | 1 : 3                         | A2 a        |
| 25      | 250             | 60                         | 279           | 7                                   | 1 : 1                         | A2 b        |

EFB was added to the mix adhesive and further stirred until all components were well blended. Afterwards, the mixture was subjected to hot pressing to produce a solid and strong board sheets. The hot press was conducted at 100 °C, 25 kgf/cm², 10 minutes. Particle board was made in the size of 25 cm x 25 cm x 0.8 cm. Following hot pressing, the obtained particle board was further cooled to room temperature and kept at room temperature for 7 days before further analysis21.
2.2.3. Analysis of Protein Extracted from PKC. Protein extracted from PKC at 2 different temperatures was analysed using Kjeldahl method and Differential Scanning Calorimeter (DSC). Kjeldahl method was selected to analyse the protein content in extracted PKC, while DSC was conducted to obtain information of protein denaturation temperature. This information was further used as consideration in selecting temperature of hot processing step. DSC was conducted up to 200 °C with heating rate of 2 °C/min (ref #19) using Perkin Elmer DSC 4000.

2.2.4. Analysis of Particle Board. Particle board obtained in this study was analysed for its density and water content. In addition, to analyse the mechanical quality of particle board [9], modulus of rupture, modulus of elasticity, and internal bond strength was analysed using . The modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB) were quantified for samples cut according to JIS A5908, Japanese Industrial Standards[10] and then samples were tested by Universal Testing Machine (SHIMADZU, AG-I/20 kN- 50 kN).

3. Results and discussion

3.1. Extraction of PKC protein at different temperature
Table 2 indicated the protein content in the samples following protein extraction with 55 mM NaOH. The protein content at 25 °C extraction temperature is 20.731 %, while the protein content at 60 °C extraction temperature is 28.152 %. These results indicate that, extraction temperature is very influential on protein content. Extraction at 60 °C produces the highest protein content which may be due to the disruption of the PKC cell wall thus accelerates the protein extraction.

| Sample | Extraction temperature (°C) | Protein Content (%) |
|--------|-----------------------------|---------------------|
| A1     | 25                          | 20.731 ± 0.395      |
| A2     | 60                          | 28.152 ± 0.155      |

Differential Scanning Calorimeter (DSC) is used to determine the maximum temperature of protein denaturation. Furthermore, the data were further used to regulate the temperature of the hot press at the time of particle board. Figure 1 and 2 showed and A2, respectively. From these figures, protein A1 and A2 may be denatured at temperature of 94.95 and 102.21 °C, respectively. Considering that UF is commonly used at high temperature during hot pressing and both samples may be denatured at temperature higher than 100 °C, 100 °C was selected as hot pressing temperature.
3.2. Particle board manufacturing

Particle boards have been successfully manufactured in this study using PKC protein as substitution agent for UF. Figure 3 depicted the particle boards. Particle boards manufactured in this study had densities ranged from 0.391 to 0.798 g/cm$^3$ (Table 3). This indicating that some of the particle boards have density lower than JIS A 5908 which is 0.6 g/cm$^3$.

![Figure 3. Particle boards manufactured in this study, protein extracted from PKC was used as substitution agent for UF.](image)

**Table 3. Density of particle boards**

| Sample code | Density (g/cm$^3$) |
|-------------|-------------------|
| A1 a        | 0.443 ± 0.044     |
| A1 b        | 0.391 ± 0.019     |
| A2 a        | 0.798 ± 0.098     |
| A2 b        | 0.447 ± 0.064     |
3.3. Mechanical properties of particle board

MOR of particle boards was in the range of 18.64 – 124.82 kg/cm² (Figure 4). JIS A 5908 requires an MOR value of 80 kg/cm². The MOR values are influenced by the content and type of adhesive used, the adhesive bundle, and the particle size. The figure indicates weak elasticity on boards A1 a, A1 b, and A2 b. Correlating with the density of the particle board, the result obtained in this study is in accordance with previous studies indicating that MOR increase along with an increase in density [10, 11].

MOE of particle boards was in the range of 2210 – 12991 kg/cm². JIS A 5908 requires a minimum MOE value of 2000 kg/cm². Similar to the density, not all particle boards have the MOE that meet the industrial standard. (Figure 5). In this study, samples A2a which is board made of protein extracted at 60 °C and with protein : UF ratio of 1:3. This indicates the potency of PKC protein to substitute UF.

Figure 4. MOR of particle boards.

Figure 5. MOE of particle boards.
The IB values of this study range from 0.66-4.577 kg/cm² with an average of 1.85 kg/cm². The value of IB that meets the JIS A 5908 standard is of board A2 a. The board has the highest density to produce good mechanical properties according to the particle board-making theory. During experiment, it was observed that the particle boards A1 a, A1 b, and A2 b were still fragile when drawn during IB testing.

4. Conclusion
This study indicated the possibility to valorize PKC as bioadhesive. Protein of PKC was extracted using NaOH 55mM. Extraction at 60 °C yield higher protein content in the sample compare to extraction at 25 °C. Furthermore, protein extracted at 60 °C helps in improving particle boards mechanical properties compare to protein extracted at another temperature. The use of protein : UF ratio of 1:3 indicated the potency of PKC protein in substituting UF as bioadhesive. Further investigation is required to improve the mechanical properties of particle boards manufactured with protein.

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