Myco-briquettes from sugar palm dregs fibre, cassava dregs and coconut shell charcoal with solid substrate fermentation technology

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Abstract. Myco-briquettes from sugar palm dregs fibre (SPDF), cassava dregs (CD), and coconut shell charcoal (CSC) have been prepared by the solid substrate fermentation method using Ganoderma lucidum. The purpose of this study was to determine the best formula and characteristics of the myco-briquette product. The myco-briquette were prepared by varying the composition ratios of the SPDF and CD i.e. 65:35; 50:50; and 35: 65% w/w) and then optimized by adding CSC to the selected formula with varying of CSC concentration such as 10%, 15%, and 20% of total solid weight. The stages of myco-briquette production include preparation of inoculum, material mixing, sterilization, inoculation, fermentation, pressing, drying, cutting, and packaging. The products of myco-briquette are then compared with the Indonesian Standard of wood pellets (Indonesian National Sandard (SNI): 8021: 2014). Based on the test results, the fermentation time is around 11-12 days. The best formula for myco-briquette products is 35: 65% w/w of composition ratio between SPDF and CD with the addition of 20% CSC. The optimum myco-briquette had a moisture content (7.55%), an ash content (3.06%), a heating value (4522.56 cal/g), a density (0.51g/cm³), volatile matter (61.64%) and fixed carbon (26.90%) fulfilled SNI 8021-2014 for wood pellet. However, the density and ash content of Myco-briquette did not satisfy SNI 8021-2014.

1. Introduction
As an integral part of the production process, the amount of waste biomass is quite abundant. The waste can be used as energy or other products according to the characteristics of the material. Biomass waste, such as dregs of cassava, sugar palm dregs fibre, and coconut shell can be used as a source of alternative energy raw materials. Solid waste from processing cassava into tapioca is about two-thirds of the amount of cassava used [1]. One of the cassava processing wastes is cassava dregs (onggok), which is a carbohydrate in the form of cellulose [2]. The fibre in cassava pulp consists of hemicellulose, pectin, and cellulose [3].

The trunk of the palm sugar tree has two main parts, namely the pith (central) and the periphery, which is black and hard [4]. The middle part (pith) is usually processed to produce palm sugar starch by leaving solid waste in the form of high-fibre dregs. The cellulose content of palm dregs is quite high [5]. The chemical composition of palm dregs waste is about 60.61% cellulose, 15.74% hemicellulose, 14.21% lignin, 7.87% water, 0.57% reducing sugar, and 1% others [6].
Coconut shell waste can be utilized in the form of charcoal which can be made by pyrolysis. Coconut shell charcoal is potentially used as a fuel due to its a high density and calorific value. Therefore, coconut shell charcoal is widely used as a raw material for activated charcoal and charcoal briquettes. Previous research has shown that the coconut shell has a density of 0.76 gr/cm³, a water content of 0.038%, an ash content of 1.47%, and a fixed carbon content of 97.03% [7].

The components of the biomass waste mentioned above include lignocellulosic. Naturally, lignocellulosic is relatively difficult to degrade. However, lignocellulosic degradation can be assisted by utilizing filamentous fungi which have the ability to produce various types of extracellular enzymes [8]. One of the filamentous fungi is Ganoderma lucidum, a white rot fungus capable of producing several types of enzymes, mainly ligninase, such as laccase, manganese-dependent peroxidase (MnP), and lignin peroxidase (LiP) [9].

Research and development of bio-based materials by utilizing the potential of mycelium from fungi as natural adhesives has not been widely carried out at this time. The purpose of this study was to obtain a product in the form of myco-briquettes and their characteristics from the main raw materials of cassava dregs, sugar palm dregs fibre, and coconut shell charcoal fermented using Ganoderma lucidum.

2. Materials and method

The equipment used in this research includes glassware (such as erlenmeyer, beaker, measuring cup, measuring flask, pipette, petri dish, burette, etc.), autoclave, micropipette, tray dryer, press machine, hot plate stirrer, analytical balance, furnace, simple incubator, bomb calorimeter (Parr 1341 Plain Jacket Calorimeter). Ganoderma lucidum culture was obtained from the Central Inter-University Mycology Laboratory (PAU) ITB, sugar palm dregs (obtained from the sugar palm starch production business unit in Subang district), cassava dregs (obtained from the cassava starch production business unit in Subang district), rice bran, gypsum and lime (from material building shop), coconut shell charcoal, potato dextrose agar (PDA) (Merck), D(+) Glucose monohydrate (Merck), KH₂PO₄ (Merck), K₂HPO₄ (Merck), MgSO₄.7H₂O (Merck), yeast extract (Merck), NH₄Cl (Merck), and K₃Cr₂O₇ (Merck).

2.1. Material Pretreatment

Sugar palm dregs fibre was obtained by separating from other solids in the form of a powder. Palm sugar dregs are drained and dried in a tray dryer at a temperature of ± 75 °C, for ± 72 hours. The fiber is then separated from the powder material and chopped to a length of about 1.5 cm. The wet cassava dregs continue to be drained and dried with a tray dryer at a temperature of ± 60 °C, for ± 72 hours. After that, the dry cassava dregs are ground using a flouring machine (disk mill FFC 23). Coconut Shell Charcoal, obtained from the pyrolysis of coconut shells in a furnace. The dried shell charcoal was then grounded using an FFC 23 disk mill machine.

2.2. Preparation of Inoculum

2.2.1. Preparation of Potato Dextrose Agar (PDA) Medium. A total of 7.8 grams of Potato dextrose agar (Merck) was dissolved in a 1,000 ml Erlenmeyer flask with 200 ml of distilled water. The solution was sterilized by heating in an autoclave at a temperature of 121°C, a pressure of 15 Psi for 15 minutes. The solution was removed from the autoclave at a temperature of about 70°C and after the temperature reached about 45°C, it was poured into sterile petri dishes under aseptic conditions according to the protocol of the Merck Microbiology Manual.

2.2.2. Preparation of Glucose Liquid Medium. Liquid medium was prepared according to the method [10]. A total of 30g glucose; 0.5g KH₂PO₄; 0.5g K₂HPO₄; 0.5g MgSO₄·7H₂O; 1g yeast extract (Merck); and 4g of NH₄Cl dissolved with 1,000 ml of distilled water until homogeneous in a 2,000 mL Erlenmeyer. Then 100 ml of each solution was poured into a 250 ml Erlenmeyer flask. The solution was then sterilized using an autoclave at a temperature of 121°C and pressure of 15 psi for 15 minutes.
2.2.3. **Starter preparation on PDA solid medium.** Approximately 5 x 5 mm fungal mycelium in agar stock culture was sliced and transferred to fresh PDA medium in petri dishes about 10 cm in diameter. The culture medium was then incubated for 10 days at room temperature (± 30°C) [10].

2.2.4. **Inoculum Preparation on Glucose Liquid Medium.** Approximately 5 x 5 mm of starter of PDA medium was inoculated into a 250 ml Erlenmeyer containing 100 ml of liquid medium. The medium was then incubated for 8 days and manual shaking was performed for 30 seconds every 1 x 24 hours (modification of [10]).

2.3. **Manufacturing of Myco-Briquette**

2.3.1. **Preparation of Production Medium.** In this study, three variations of the formulation were carried out based on the ratio of the percentage of sugar palm dregs fibre (SPDF) and cassava dregs (CD), such as 65:35 (BR-A); 50:50 (BR-B); and 35:65 (BR-C). The percentage of total weight of SPDF and CD in the solid medium mixture is 88%. Each variation was repeated 3 times. The composition of the formulation ingredients can be seen in Table 1.

| Materials                        | Composition (%) | BR-A | BR-B | BR-C |
|----------------------------------|----------------|------|------|------|
| Sugar palm dregs fibre (SPDF)    | 57.2           | 44.0 | 30.8 |
| Cassava dregs (CD)              | 30.8           | 44.0 | 57.2 |
| Rice bran                       | 10.0           | 10.0 | 10.0 |
| Lime                            | 1.5            | 1.5  | 1.5  |
| Gypsum                          | 0.5            | 0.5  | 0.5  |
| Total percentage                | 100.0          | 100  | 100  |
| C/N ratio                       | 79.45          | 76.85| 74.24|

The percentage in the table is the percentage of the total ingredients used in the mixture (formula). BR-A, BR-B, and BR-C = formula briquettes with composition A, B, and C.

Sugar palm dregs dregs, cassava dregs, rice bran, gypsum, lime and water are mixed as homogeneously as possible and poured into a container for mold during fermentation. The mixture was sterilized by autoclaving at a temperature of 121°C, a pressure of 15 Psi for ± 60 minutes. After sterilization, the mixture of production media materials is then cooled for about one night and then inoculated [11].

2.3.2. **Inoculation and Fermentation.** The production medium was then inoculated with 3 mL of liquid inoculum for every 100 grams of total dry matter weight. The production medium was then fermented until all parts were covered with mycelium, which was about 11-12 days. Fermentation is carried out in an incubator at a temperature of about ±30°C [12].

2.3.3. **Pressing, Drying and Cutting.** After being covered with mycelium, the production media is then pressed in wooden molds using a hydraulic pump until it reaches a thickness of about 10 mm when pressing. The pressing results are then dried using a drying rack at a temperature of around 55°C – 60°C for ±18 hours or until dry. After drying, it is then cooled and packaged in plastic. The resulting dry product sample with a size of about 12.5 x 12.5 x 1.5 cm³ was then cut into pieces to obtain a product measuring about 4 x 4 x 1.5 cm³ and hereinafter referred to as Myco-Briquettes.

2.4. **Myco-Briquette quality testing**

The quality of myco-briquettes was investigated by testing it according to SNI 8021-2014 regarding wood pellets, which includes parameters such as density, moisture content, ash content, calorific value, volatile matter, and fixed carbon.
2.5. Optimization of Myco-Briquette Manufacturing
Optimization of briquette manufacturing was done by adding coconut shell charcoal powder as a substitute for SPDF and CD components to the selected initial formula, BR-C. The addition of coconut shell charcoal powder was varied into 3 variations content, such as 10, 15 and 20%. Furthermore, the code of each formula is written sequentially with BRC-A, BRC-B, and BRC-C.

3. Result and discussion
Research on the manufacture of myco-briquettes was carried out in two main stages, namely preliminary studies and optimization. Preliminary research was conducted to determine the effect of the comparison of the composition of the main raw materials of sugar palm dregs fibre (SPDF) and cassava dregs (CD) on the characteristics of the resulting myco-briquettes. Based on the results of the preliminary study, myco-briquette products have not met the standard requirements used, namely the Indonesian National Standard (SNI) for charcoal briquettes or for biopellets. As an effort to improve the quality of myco-briquettes, the optimization process is then carried out. Optimization is carried out mainly to increase the calorific value and density of myco-briquettes. Efforts to increase the calorific value and density were carried out by adding coconut shell charcoal powder to the mixture of raw materials.

3.1. Raw Materials Characteristics
The results of the characterization of raw materials which include moisture content, ash content, calorific value, and C/N ratio can be seen in table 2.

| Materials            | Moisture content (%) | Ash content (%) | Calorific value (calori/g) | C-Organic | N-Organic | Protein (%) |
|----------------------|----------------------|----------------|---------------------------|-----------|-----------|-------------|
| Sugar palm dregs     | 7.17                 | 1.16           | 3,925                     | 50.01     | 0.21      | 1.33        |
| dregs                |                      |                |                           |           |           |             |
| Cassava dregs        | 8.85                 | 0.57           | 3,490                     | 50.99     | 0.27      | 1.67        |
| Rice bran            | 5.76                 | 3.67           | 3,678                     | 47.95     | 1.13      | 7.09        |
| Coconut charcoal     | 9.17                 | 2.66           | 7,289                     | *         | *         | *           |

Note: * Not analyzed

3.2. Myco-Briquette Product
In the preliminary study of making myco-briquettes, trials were conducted to determine the effect of composition ratio between the main raw materials, such as SPDF and CD on the three formulas BR-A = 65:35; BR-B = 50:50; and BR-C = 35:65 (%). The C/N ratio values of each formula were 79.45, 76.85, and 74.24, respectively. The resulting myco-briquette products can be seen in figure 1.
main comparison refers to the SNI for wood pellets. Based on the results of the analysis, it is known that the myco-briquette product has a moisture content between 6.42 – 7.02%, ash content between 5.03 – 5.37%, density between 0.26 – 0.46g/cm3 and a calorific value between 3594 – 3692 cal/g. The results of this preliminary study indicate that only the water content parameters have met the SNI standard for wood pellets.

Tabel 3. Myco-briquette test results and comparison with the standard.

| Treatment and Standard | Moisture content (%) | Ash content (%) | Density (g/cm³) | Calorific value (cal/g) |
|------------------------|----------------------|----------------|----------------|------------------------|
| BR-A                   | 7.02±0.24 a          | 5.37±0.66 a    | 0.26±0.06 a    | 3,692±56.49 b         |
| BR-B                   | 6.42±0.34 a          | 5.15±0.29 a    | 0.36±0.04 b    | 3,644±28.89 a         |
| BR-C                   | 6.80±0.66 a          | 5.03±0.30 a    | 0.46±0.04 c    | 3,594±56.79 a         |
| SNI for wood charcoal briquettes | Max 8                | Max 8          | -              | Min 5,000             |
| SNI for coal briquette | Max 17               | -              | -              | 4,000-5,000           |
| SNI for wood pellet    | Max 12               | 1.5            | Min 0.8        | Min 4,000             |

3.2.1. Moisture content. The moisture content in all samples of the myco-briquette formula was in accordance with the requirements of SNI for charcoal briquettes, coal briquettes and wood pellets, which was between 6.42 – 7.02%. The value of the moisture content of wood pellets from wood industry waste, reported by [13], ranged from 4.43 to 9.98%. The moisture content of pellets mixed with elephant grass (Pennisetum purpureum) and nyamplung (Calophyllum inophyllum) shell in various combinations ranged from 3.34 to 4.11% [14]. The moisture content of wood pellets from rubber wood waste ranges from 15.06 – 17.26% [15].

3.2.2. Ash content. The ash content of the three formulas ranged from 5.03% – 5.37% and was still higher than the SNI for wood pellets. The high ash content of the sample is mainly due to the high ash content of the materials used. The increase in ash content can also occur due to changes in the composition or chemical components of the material during the fermentation process, namely the decomposition of the original compound and the formation of new compounds. The value of the ash content of wood pellets from various types of wood waste and their combinations ranged from 0.88% - 2.5% [13], wood pellets from a mixture of elephant grass and nyamplung shell ranged from 7.71-17.5% [14].

Increasing the ash content of a fermented product is a common thing. [16], reported that there was an increase in ash content which reached 6.06 - 79.43% in various treatments of palm dregs fermentation using Rhizopus oligosporus. R. oligosphorus can also increase the ash content by 37.36% in the fermented plantain peel [17].

The fermentation process in the manufacture of Myco-briquettes produces a number of mycelia. chemical compound of mycelia include chitin, cellulose, protein and other compounds [18]. As an analogy, the mycelium of shitake mushrooms contain minerals such as Na (1646-5322 mg/kg), K (5379-10320 mg/kg) and P (3201-8184 mg/kg) as well as several other heavy metals such as Zn, Fe, Cu, Mn, Pb and N [19]. Metallic elements usually associate with other compounds to form salts. The increased ash content can also be caused by the high content of cellulose, which can turn into organic acid compounds which can be hydrolyzed into other compounds, including minerals [16].

3.2.3. Density. The density values of each treatment BR-A, BR-B, and BR-C were respectively 0.26; 0.36; and 0.46 g/cm3. The density value is directly proportional to the increasing amount of cassava dregs. The density of wood pellets from rubber wood waste has a density of between 0.408-0.628 g/cm³ [15]. Wood pellets from wood industry waste have a density of between 0.51-0.78 g/cm³ [13]. In pellets made from a mixture of elephant grass and nyamplung shell, the density increases with the increasing amount of nyamplung charcoal powder, which is between 0.641 - 0.706 g/cm³ [14]. The value of myco-briquette density can be influenced by several factors, including particle size of the material, amount of
adhesive, pressing temperature, pressing method and, pressure strength. The density of wood pellets increases with the addition of tapioca flour, which is small and at the same time, acts as an adhesive [15]. In addition, density can also be influenced by the type of wood and the level of dryness of the material [13].

3.2.4. Calorific value. The calorific value of myco-briquettes from all treatments, namely BR-A, BR-B and BR-C, was still below the standard required by SNI, both for SNI for wood charcoal briquettes, coal briquettes, and wood pellets. These values were 3,692, 3,644 and 3594 cal/g respectively. This result also shows that the calorific value of myco-briquettes is still lower than some wood pellets. The calorific value of rubber wood waste wood pellets ranges from 4,029 – 4,106 cal/g [15], wood pellets from industrial waste wood ranged from 3,920,13 – 4,254.91 cal/g [13], and pellet mixture of elephant grass and nyamplung shell ranged from 5,468.63 – 6,258.87 cal/g [14]. The calorific value produced by myco-briquettes is not significantly different from the calorific value calculated from the calorific value of the constituent materials [14]. The calorific value of pellet or briquette products is directly proportional to the lignin and cellulose content of the constituent materials [14].

3.3. Optimization Result of Myco-Briquette Product

The results of the measurement of myco-briquette product characteristics after optimization can be seen in the table 4.

![Figure 2. Appearance of myco-briquette products after optimization.](image)

| Sample code and standard | Moisture content (%) | Ash content (%) | Calorific value (cal/g) | Calorific value (cal/g) prediction * | Density (g/cm3) | Volatile matter (%) | Fixed carbon (%) |
|-------------------------|---------------------|----------------|------------------------|-------------------------------------|----------------|---------------------|-----------------|
| BRC-A                   | 8.19±0.18           | 3.98±0.10      | 3,963.06±46.42         | 3.937.22 ±0.45±0.02                 | 67.43±0.98     | 20.42±1.09          |
| BRC-B                   | 7.94±0.17           | 4.03±0.12      | 4,251.47±114.99        | 4,119.55 ±0.47±0.04                 | 65.02±0.02     | 22.96±0.18          |
| BRC-C                   | 7.55±0.24           | 3.06±0.27      | 4,522.56±113.09        | 4,301.89 ±0.51±0.04                 | 61.46±1.24     | 26.90±1.32          |
| SNI for wood pellets    | Max 12              | 1.5            | Min 4,000              | -                                   | Min 0.8        | Max 80              | Min 14          |

Note: * The calorific value is based on the calculation of the calorific value of the material. Fixed carbon is calculated as (100% - % moisture content - % ash content - % volatile matter).

The results of myco-briquette optimization showed a significant change in characteristics in almost all parameters except water content. However, although the ash content decreased and the density increased, these two parameters still did not meet the SNI standard for wood pellets. The other
parameters such as water content, calorific value, volatile matter and fixed carbon have met the requirements.

3.3.1. **Calorific value.** The addition of coconut shell charcoal powder can significantly increase the calorific value of myco-briquettes. The calorific value of the myco-briquette product from the test results showed a higher value than the calorific value based on the calculation of the constituent materials. From the three treatments, the calorific value of the BRC-A sample was still below the SNI standard, which was 3,963.06 cal/g, but from the other two treatments, BRC-B and BRC-C, it had met the SNI standard, namely 4,251.47 cal/g and 4,522.56 cal/g. The calorific value of wood pellets from industrial waste from flower wood is 3,921.12 – 4,150.19 cal/g, acacia wood (subfamily of Mimosoideae) is 4,022.29 – 4,254.91 cal/g, and tarap wood (Artocarpus odoratissimus) is 3,920.13 – 4,125.28 cal/g [13], and pellets from a mixture of elephant grass and nyamplung shell in various treatments range from 5,468.63 - 6,905.28 cal/g [14]. The increase in calorific value was mainly due to the addition of coconut shell charcoal powder, which has a higher calorific value of about 7,289 cal/g. This is in line with the research results [20], which stated that the calorific value of wood chip charcoal briquettes increased with the addition of rubber seed shell charcoal.

3.3.2. **Volatile matter.** The volatile matter content and high carbon composition indicate good potential as a fuel [21], [22], revealed that high levels of volatile matter and fixed carbon indicate good potential for solid fuels for thermal conversion. The test results showed that of the three samples (BRC-A, BRC-B and BRC-C), each had a volatile matter content of 67.43, 65.02 and 61.46%. The three samples met the standard for the Indonesian standard for wood pellets, namely the maximum volatile matter content of 80%. The volatile matter content of pellets from a mixture of rice husks and sawdust ranged from 65.2 - 79.3% [22] and biopellets from a mixture of bagasse, peanut shells, and cocoa pods ranged from 31.67 - 50.81% [23]. According to [21], the volatile matter of palm fibre (has similar characteristics to palm pulp) is about 89.30%. Meanwhile, the volatile matter content of coconut shell charcoal is around 10.85% [24].

3.3.3. **Fixed carbon.** Based on the test results, the fixed carbon values of the myco-briquette samples BRC-A, BRC-B and BRC-C were 20.40, 22.98 and 27.03% respectively. This value of fixed carbon has met the Indonesian standard for wood pellets. The fixed carbon content of mixed biopellets from elephant grass and nyamplung shells ranged from 55.58 – 66.85% [14], biopellets from 100% bagasse, peanut shells, and cocoa shells were 61.42; 62.20 and 60.85% [23], mixed biopellets from rice husk and sawdust ranged from 16.4 – 17.6% [22]. The increasing levels of fixed carbon with the increasing number of coconut shell charcoals is because coconut shell charcoal has a higher fixed carbon content than other materials. The fixed carbon content of coconut shell charcoal is about 78.32% [24].

4. **Conclusion**

Based on the research results, it can be concluded that myco-briquette products can be made from sugar palm dregs fibre, cassava dregs and coconut shell charcoal by solid substrate fermentation technology using G. lucidum. The myco-briquette production process includes several stages, such as inoculum preparation, materials mixing, sterilization, inoculation, fermentation, pressing, drying, and cutting. Fermentation time is 11-12 days. The best formula of the myco-briquettes is the BRC-C formula with the addition of 20% coconut shell charcoal. The myco-briquette had the water content of 7.55%, ash content of 3.06%, calorific value of 4522.56 cal/g, density of 0.51 g/cm3, volatile matter of 61.64% and fixed carbon of 26.90%. The myco-briquette product fulfilled SNI 8021-2014 regarding wood pellets except for the ash content and density.

5. **References**

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Acknowledgment
Thanks to: The Indonesian Institute of Sciences for the study opportunities provided, The Ministry of Research, Technology and Higher Education of the Republic of Indonesia for the Scholarship, The School of Life Sciences (SITH) ITB, Research Center for Appropriate Technology-LIPI; Research Center for Biomaterials-LIPI and all its staff and employees for all their contributions.