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Optimizing calliandra (*Calliandra calothyrsus*) biomass pellets: Impact of particle size and bark composition

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ABSTRACT

Calliandra biomass pellets offer a promising alternative energy source to replace fossil fuels. Typically, these pellets are produced by directly processing the stem and bark of the calliandra (*Calliandra calothyrsus*) plant without separation, aiming for manufacturing efficiency. This study investigated the quality differences between calliandra biomass pellets with and without bark and varying particle sizes. Particle sizes used were 20 mesh, 40 mesh, and 60 mesh. The pellets were made using a 12 mm diameter biomass pellet mold and a manual hydraulic press with a pressure of 3 tons. Characterization involved assessing proximate analysis, calorific value, physical and mechanical properties, and Fourier Transform Infrared analysis. The test results were compared with biomass pellet standards from Indonesia, Japan, Korea, and Germany. Results indicate that bark affects several properties, with higher ash content observed in pellets with bark due to the higher mineral content in bark. Volatile matter decreases with finer particle size, influencing combustion rate. Moisture content is higher in pellets with bark, impacting combustion efficiency and smoke production. Fixed carbon values are influenced by moisture and volatile matter content. Calorific values are generally higher in pellets without bark and smaller particle sizes. Density and compressive strength increase with decreasing particle size. FTIR analysis reveals differences in functional groups between pellets with and without bark, indicating variations in chemical composition. Overall, this research provides insight into the potential of calliandra biomass pellets with bark and without bark along with particle size as a renewable energy source.

Keyword: Biomass, Caliandra, Pellet

1. Introduction

Indonesian society continues to rely on fossil fuel sources to meet their daily needs [1]. Fossil fuel is widely used for various purposes, such as electricity generation, transportation, and industrial processes [2]. Fossil fuel has environmental impacts, contributing to climate change due to its combustion process that emits carbon dioxide [3]. These fossil fuel sources will decrease due to continuous usage [4]. Therefore, there is a need for alternative energies to reduce reliance on fossil fuel sources. Study on alternative energy is ongoing to fulfill energy needs. Study on alternative energy continues to be carried out to meet energy needs. Globally there are three largest energies which provide around 86% of the world's energy needs. The three global energy sources include petroleum, natural gas and coal [6]. Apart from that, there are 2% renewable energy sources, one of which is biomass energy. Biomass energy comes from organic materials stored in agricultural and forest products. This biomass energy is part of renewable energy which can be in the form of wood pellets which can be used as an energy source. According to [7], compared to energy sources originating from coal, burning wood pellets is considered more economical. Biomass emerges as a choice to meet the demand as an energy source [5-8].

Biomass is an organic material produced through photosynthesis [9]. One of its advantages as an energy source is its carbon-neutral nature [10]. Untreated biomass has low density and high water absorption, making it difficult to handle [11-12]. Biomass can be converted through densification to address this weakness [13].

Densification aims to increase biomass density, enhance its calorific value, and facilitate storage and transportation due to uniform dimensions and quality [14]. One form of biomass densification process is biomass pelletization [15]. The quality of biomass pellets is influenced by the materials and particle sizes used in their production [16]. One biomass with potential as a raw material for biomass pellets is calliandra [17]. Calliandra (*Calliandra calothyrsus*) is a shrub species from the Leguminoceae family [18]. Calliandra is known for its fast growth and high survival rates, making it advantageous as a raw material for biomass pellet production [19-20].

Previous studies on biomass pellets from calliandra have been conducted [15, 21-23]. Reported [15] that pellets with calliandra material produce high calorific value and relatively have a better proximate value than gamal (*Gliricida sepium*) and meet the Indonesian National Standard. Reported [17] that caliandra pellets made using its stems and bark with a particle size that passes through a 60 mesh sieve, produce proximate value and calorific value that has met the Indonesian and European National Standards that can be used as a quality renewable energy source. In [22] conducted a study using calliandra with a size of 60 - 80 mesh and optimizing the character of the pellets through torrefaction. In [23] studied caliandra stem pellets without bark and with bark with a particle size of 5 mesh, showing the calorific value of pellets without bark is better than with bark and better than gamal and acacia (*Acacia mangium*).

As explained above, many studies have been conducted on calliandra pellets using stems and bark. However, the study on calliandra biomass pellets concerning particle size variations and the influence of bark is still limited. Therefore, this study aimed to characterize calliandra pellets made from calliandra stems with and without bark and various particle sizes of 20, 40, and 60 mesh.

2. Method

2.1. Materials

The material used in making biomass pellets is calliandra stems, aged 8 months. Pellets were produced by a manual pellet mold, which is pressed with a hydraulic press. Other tools used in making this pellet are electric scales (scale 0.0001g), wood cutters, ovens (BJPX - Summer, PT. Innotech System, Jakarta, Indonesia), hammer mill, and cutter. The tools used during the characterization analysis process are calipers, furnace (Thermo Scientific FB1410M - 33, ASHEVILLE, United States), oven (UN30, Memmert, Germany), calorimetric bomb (1108 Oxygen Combustion Vessel, Parr Instrument Company, United States), universal testing machine (UTM) (M500-50AT, Testometric, United Kingdom), and spectroscopy (Scimitar 2000, Varian, United States)Production of Calliandra Biomass Pellets

2.2. Time and Location

This research was conducted from November 2023 to January 2024 at the Forest Products Technology workshop, Faculty of Agriculture, University of Lampung. The pelletization process and testing of physical and mechanical properties were carried out at the Forest Products Technology Laboratory. Proximate analysis and calorific value testing were conducted at the Analysis and Instrumentation Laboratory, Department of Chemical Engineering, Faculty of Engineering, University of Lampung. FTIR testing was conducted at the Integrated Laboratory and Technology Innovation Center, Faculty of Mathematics and Natural Sciences, University of Lampung.

2.3. Production of Calliandra Biomass Pellets

Calliandra biomass pellets were produced using 8-month-old calliandra stems. The stems were divided into two types: stems with and without bark. The pellet material was crushed and sieved to 20, 40, and 60 mesh sizes. The composition of materials used in the production of calliandra biomass pellets is presented in Table 1.

Table 1. Composition of calliandra biomass pellet

Material type	Mesh sieve size	Description
Calliandra without bark	20	TK1
	40	TK2
	60	TK3
Calliandra with bark	20	DK1
	40	DK2
	60	DK3

The calliandra powder was then pelletized by compacting it using a manual hydraulic press with a force of 3 tons in a pellet mold with a diameter of 12 mm. Three grams of wood powder were used in the pelletization process. The formed pellets were then subjected to testing for biomass pellet quality.

2.4. Evaluation of Calliandra Biomass Pellet Characterization

2.4.1. Color testing

The color change test was conducted using a colorimeter (AMT507, Amtast, Qingdao, China) equipped with the CIE-Lab system. Three random measurements were taken on a stack of samples. This test used the parameters L*, a*, and b*. The L* symbol represents the brightness level, with a minimum value of 0 (perfectly dark) and a maximum value of 100 (perfectly bright), the a* symbol is a representation of red/green chromaticity, the b* symbol is a representation of yellow/blue chromaticity [28].

2.4.2. Proximate Analysis

Proximate testing consists of ash content (ASH), moisture content (MC) according to ASTM: E1755-01, volatile matter (VM) content according to ASTM: E872-82, and fixed carbon (FC) content according to SNI 8675:2018.

2.4.2.1. Ash content (ASH)

The ash content value was obtained from the test results using a furnace (Thermo Scientific FB1410M - 33, ASHEVILLE, United States). This analysis follows the procedure outlined in ASTM standard: E1755-01, where the biomass sample was placed in the furnace at a temperature of 600°C for 6 hours to obtain the ash content, which was calculated using the following Equation 1.

$$\text{Ash (\%)} = \frac{\text{ash weight (g)}}{\text{oven}-\text{dry weight (g)}} \times 100\ \% \tag{1}$$

2.4.2.2. Moisture content (MC)

Moisture content analysis was conducted to determine the ratio of pellet weight after heat treatment to the initial sample weight. The testing was performed using an oven (UN30, Memmert, Germany) at a temperature of 105°C until a constant weight was achieved. Following ASTM procedure: E1756-01, the moisture content was calculated using the following Equation 2.

$$\text{MC (\%)} = \frac{(initial\ weight\ (g) - oven{-}dry\ weight\ (g)}{oven{-}dry\ weight\ (g)} \text{ x } 100\% \tag{2}$$

2.4.2.3. Volatile matter (VMC)

Volatile matter refers to the mass loss after heating without air. Volatile matter was obtained through testing using a furnace (Thermo Scientific FB1410M - 33, ASHEVILLE, United States). This analysis followed the procedure outlined in ASTM standard: E872-82, by placing the sample in the furnace for 16 hours at a temperature of 103°C, followed by cooling and repeating the process in the furnace for 2 hours at 103°C. The volatile matter content was calculated using the following Equation 3.

$$\text{VMC (\%)} = \frac{\text{Weight loss of sample (g)}}{\text{oven}-\text{dry weight (g)}} \times 100\ \% \tag{3}$$

2.4.2.4. Fixed carbon (FC)

Fixed carbon is the content found in the sample other than ash content, moisture content, and volatile matter. This analysis refers to SNI 8675:2018 standard and calculated using the following Equation 4.

$$\text{FC (\%)} = 100\% - (ash\ content + moisture\ content + volatile\ matter) \times 100\% \tag{4}$$

2.4.3. Calorific value

The calorific value was tested using a calorimetric bomb (1108 Oxygen Combustion Vessel, Parr Instrument Company, United States) following SNI 01-6235:2000, with results conforming to the SNI 8675:2018 standard, yielding the calorific value in MJ/kg units.

2.4.4. Physical properties

2.4.4.1. Density

The density of calliandra biomass pellets made from 3 grams of calliandra powder when molded will yield mass density compared to pellet volume according to SNI 8021:2014. Density was determined using the following Equation 5.

$$\text{Density (g/cm}^3\text{)} = \frac{Pellet\ mass\ (g)}{Pellet\ volume\ (cm^3)} \quad (5)$$

2.4.5. Mechanical properties

2.4.5.1. Compressive strength

The compressive strength test was conducted using a universal testing machine (UTM) (M500-50AT, Testometric, United Kingdom). The compressive strength value was calculated using the following Equation 6.

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Maximum compressive load (N)}}{\text{Sample surface area (mm}^2\text{)}} \quad (6)$$

2.4.6. Chemical properties

2.4.6.1. Fourier Transform Infrared (FTIR)

FTIR was performed using Fourier Transform Infrared spectroscopy (Scimitar 2000, Varian, United States) with the KBr method. Using a sample of calliandra pellet particle powder with a weight of 3gr.

3. Results and Discussion

The visual appearance of the calliandra biomass pellets that have been produced is shown in Figure 1. Pellets with a particle size of 20 mesh show a smoother surface than the other two particle sizes. This is in line with research [25] explained that pellets with a particle size of 20 mesh have a smoother surface than those with a particle size of 60 mesh. In [26] explained that pellets from sawn residue with increasingly fine particles will cause cracks on the surface of the pellets.

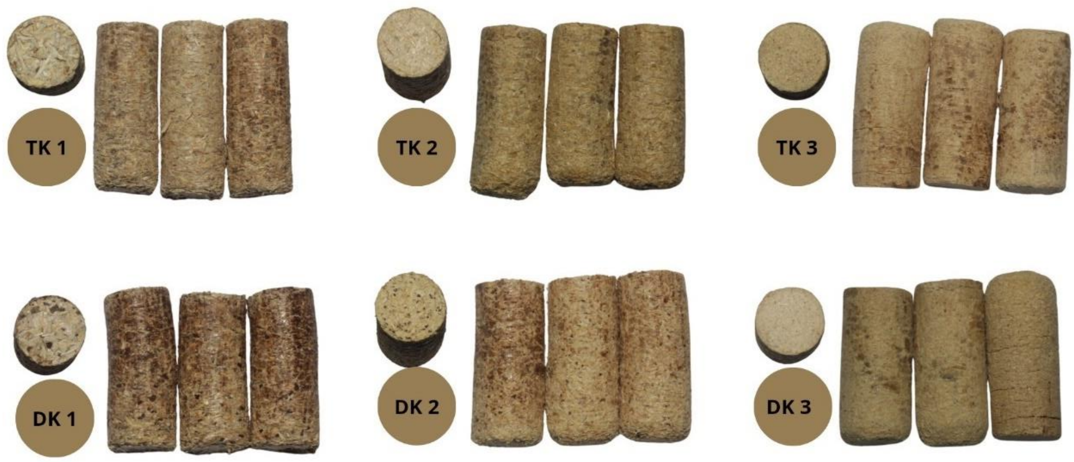

Figure 1. The appearance of calliandra pellets after molding (Notes: TK1 = calliandra without bark with 20 mesh sieve size; TK2 = calliandra without bark with 40 mesh sieve size; TK3 = calliandra without bark with 60 mesh sieve size; DK1 = calliandra with bark with 20 mesh sieve size; DK2 = calliandra with bark with 40 mesh sieve size; DK3 = calliandra with bark with 60 mesh sieve size)

In addition, after the measurement, the values of L*, a* and b* are presented in Figure 2, showing the different between pellets with and without bark. The produced pellets without bark show a higeh L* value than pellets with bark. Pellets with bark mixed with bark tend to be dark in color due to the drying process and result in a darker pellet color than pellets without bark. Likewise, [24] also reported that spruce pellets with bark had a darker color and had black bitterness on the surface.

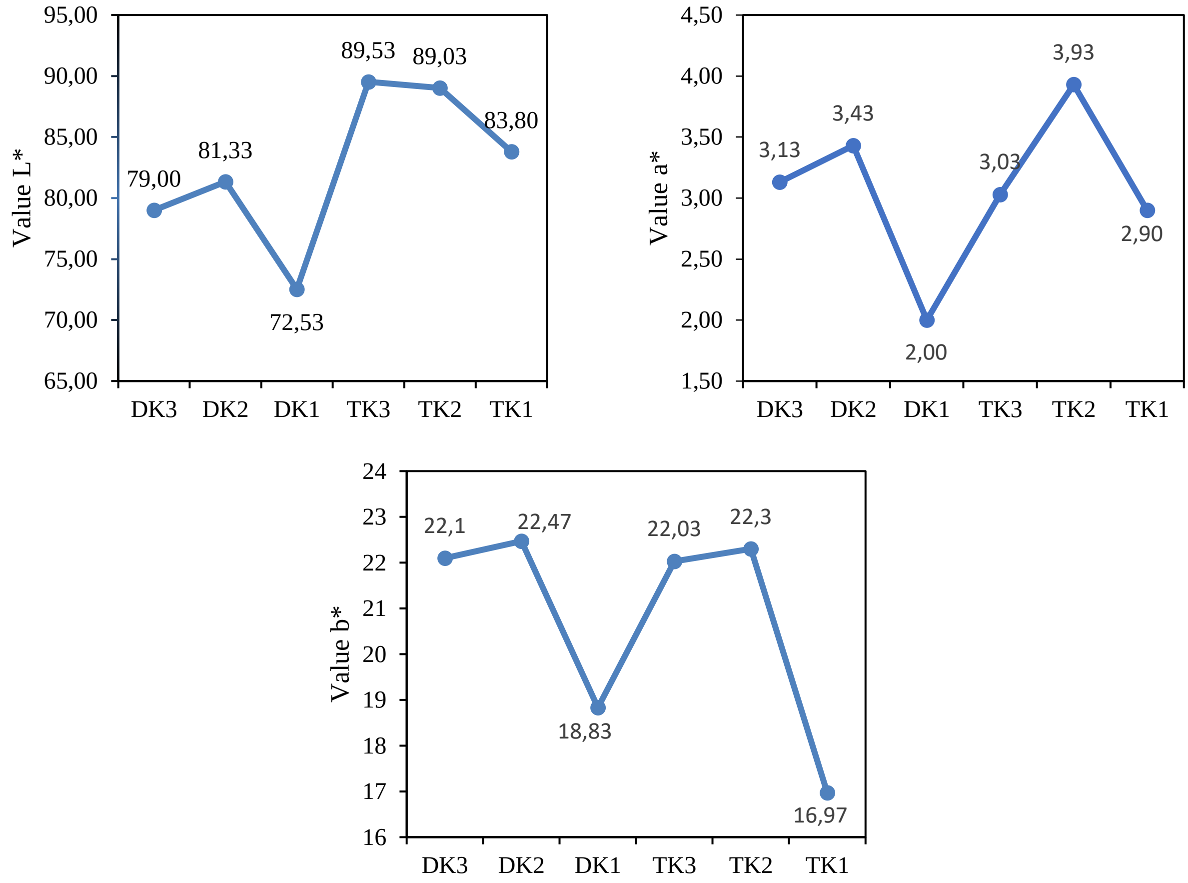

Figure 2. L*, a*, and b* value in calliandra pellets with bark and without bark

In the value of lightness (L*) with values ranging from 0 - 100, if the value of L* = 0 means dark color, while the value of 100 means bright color [13]. In this study, the L* value in pellets without bark ranged from 89.53 to 83.80 and in pellets with bark ranged from 72.53 to 81.33, which means that the color of pellets without bark is brighter than pellets with bark. In addition, the redness (a*) value in without bark pellets is higher than the value of pellets with bark. The value of yellowness (b*) in both pellets is not too significant the difference produced with the value of pellets without bark ranging from 16.97 - 22.30 while pellets with bark 18.83 - 22.47. The lower the a* value will produce a greener color while the greater the a* value will produce a redder color. The lower the b* value will produce a bluish color if the higher the value will produce a yellowish color [28].

3.1. Proximate analysis

The proximate analysis was performed to determine the combustion efficiency of biomass (fuel pellet) [54]. Biomass consists of several components such as ash content, volatile matter, moisture content, and fixed carbon. The results of the proximate analysis in this study have also been compared with several national and international standards consisting of Indonesian (SNI 8675:2018), German (DIN 51731), Korean (KFS), and Japanese (JA2021-0148) standards. The results of testing calliandra pellets on the effect of the bark appear to have an effect on the proximate results which can be seen in Table 2.

Table 2. Test Results Data

Analysis	Calliandra pellet combinations						Standardization			
	20 mesh		40 mesh		60 mesh		DIN 51731 (German)	KFS (Korea)	JA2021-0148 (Japan)	SNI 8675:2018 (Indonesia)
	TK 1	DK 1	TK 2	DK 2	TK 3	DK 3				
ASH (%)	1.29	1.98	1.04	1.37	1.51	2.01	1.5 maks	1.5 maks	2 maks	5 maks
VM (%)	81.09	80.14	80.92	76.07	79.26	77.17	-	-	-	80 maks
MC (%)	7.37	8.00	6.73	7.94	6.81	8.53	12 maks	10 maks	10 maks	12 maks
FC (%)	10.25	9.88	11.30	13.71	12.42	12.29	-	-	-	14 min
Calorific value (Mj/Kg)	18.87	18.85	20.59	20.55	21.35	21.40	17.5 min	18 min	16.5 min	16.5 min

Notes: TK is pellet without bark, DK is pellet with bark, ASH is ash content, VM is volatile matter, MC is moisture content, and FC is fixed carbon

3.1.1. Ash content

Ash content represents the residue from the combustion of biomass that does not contain carbon or calorific value. Components contained in biomass ash include calcium, potassium, magnesium, and silica [29]. The results of the ash content of the calliandra pellet can be seen in Figure 2. Research on the ash content of calliandra pellets without bark ranged from 1.04% to 1.51%, and with bark ranged from 1.37% to 2.01%. The lowest ash content values were observed in each material variation at the particle size of 40 mesh. In contrast to the results of the research by [21] reported that the smaller the particle size, the lower the ash content. Particles with smaller sizes have a larger surface area per unit mass, which increases contact with oxygen during combustion. This leads to more efficient and complete combustion, reducing the amount of unburned residue and thus reducing ash content. According to [15], the ash content obtained from calliandra stems using a machine with a 500 kg/day capacity resulted in a value of 0.91%. Calliandra pellets with a compression strength of 100 kg/cm² and a particle size of 60 mesh obtained an ash content of 1.68% [22]. The results of this study are consistent with previous research indicating that bark on calliandra stems affects the ash content [23].

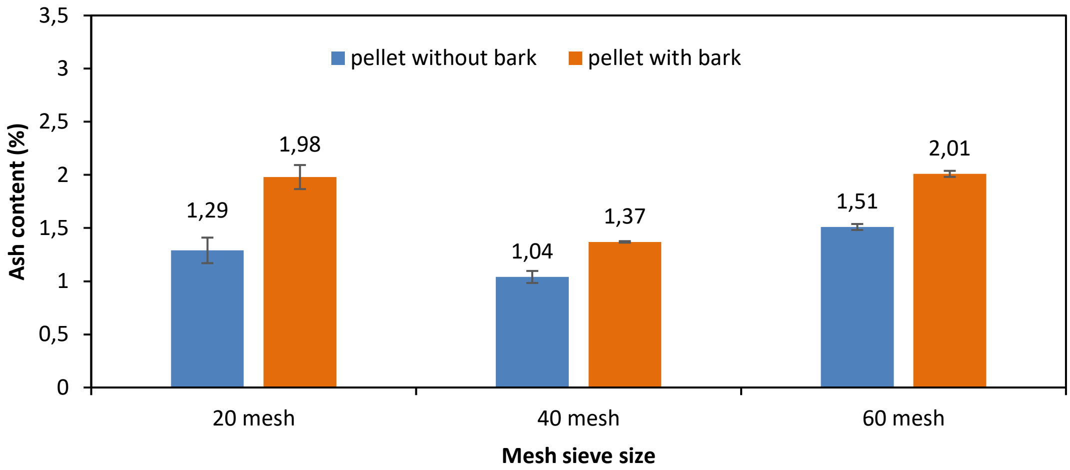

Figure 3. Ash content of calliandra pellets

Calliandra has a relatively high mineral content [30]. The mineral content in calliandra is more abundant in the bark than in the stem [31]. The amount of ash content is also influenced by the quantity of minerals contained in biomass; the more minerals in biomass, the higher the ash content. This tendency was reflected in the data from calliandra pellets with bark (1.37% to 2.01%), resulting in higher ash content compared to pellets without bark (1.04% to 1.51%) [32]. The mineral content of raw materials such as N, P, K, Ca, Mg, and S affects the high and low levels of ash content. The more minerals present, the higher the ash content produced [21]. Compared to standards such as SNI 8675:2018, DIN 51731, KFS, and JA2021-0148, pellets without bark at 20 mesh, 40 mesh, and pellets with bark at 20 mesh meet the standards of several countries. As for SNI 8675:2018, all pellets meet the standard.

3.1.2. Volatile matter

Volatile matter is the mass lost due to heating in the absence of external air and is corrected for the amount of water in a sample [15]. The results of the volatile matter can be seen in Figure 3. The volatile matter values in calliandra pellets are approximately 79.26% to 81.09% for pellets without bark and 76.07% to 80.14% for pellets with bark. The pellets without bark from calliandra produce consistently higher average values than those with bark. This tendency happens because the bark inhibits the combustion process [33]. Volatile matter decreases with finer pellet material [21, 35]. The volatile matter results of calliandra biomass pellets at 60 mesh have met SNI 8675:2018 standards.

Figure 4. Volatile matter of calliandra pellets

According to Irwansyah et al. [36], the influence of particle size variation on volatile matter indicates that finer particle sizes result in higher volatile matter values. The volatile matter content enhances the combustion rate of wood pellets [37]. The combustibility of a fuel is determined by its volatile matter content. Fuels with higher volatile matter release most of their heat as combustion vapor, thus accelerating combustion [35].

3.1.3. Moisture content

Moisture content is determined as the ratio of the water content lost during the drying process compared to the initial weight of the material [39-42]. Moisture content is one of the parameters determining the quality of biomass pellets, affecting combustion calorific value, ignitability, combustion power, and the amount of smoke produced during combustion [40-44]. The moisture content values in this study can be seen in Figure 4. The lowest moisture content is indicated in calliandra pellets without bark for each particle size, while the highest moisture content is observed in calliandra pellets with bark. This result indicated that more moisture is contained in the bark of calliandra, resulting in higher moisture content (8 to 8.53%). The moisture content of calliandra pellets in this study ranges from 6.73% to 8.53%, meeting DIN 51731, KFS, JA2021-0148, and SNI 8675:2018 standards, as shown in Figure 4.

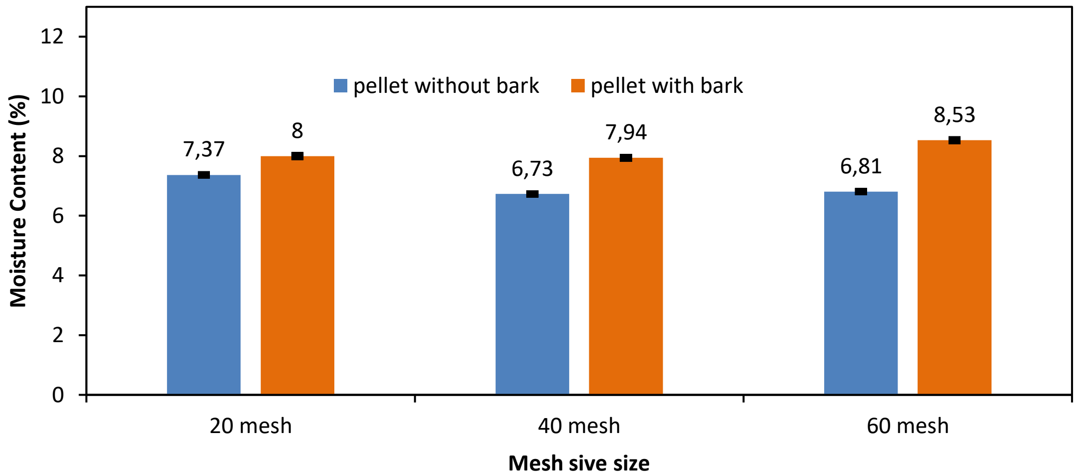

Figure 5. Moisture content of calliandra pellets

The research results indicate that higher moisture content corresponds to finer particle sizes used, consistent with several previous studies [38, 40]. According to [21], the highest moisture content is found in calliandra pellets at 60 mesh, presumably because particle size affects the moisture content contained in the pellets. Using finer particle sizes provides a larger surface area, making moisture absorption easier than larger particle sizes of raw materials [21]. High moisture content will affect combustion by reducing conversion efficiency and performance due to water evaporation during the combustion process [43, 49-50]. High moisture content will also produce smoke and prevent exhaust gases from escaping. Low moisture content will accelerate the heat transfer and increase combustion efficiency [42, 45].

3.1.4. Fixed carbon

Fixed carbon is the amount of solid material that burns after volatile components are removed from the volatile matter [45]. The fixed carbon values can be seen in Figure 5. Calliandra pellets without bark obtained values of 10.25%, 11.3%, and 12.42%, while calliandra pellets with bark obtained values of 9.88%, 13.71%, and 12.29% for each particle size, respectively. The highest carbon content value was found in calliandra pellets with bark at a particle size of 40 mesh, while the lowest value was in calliandra pellets with bark at a particle size of 20 mesh. Carbon remains affected by moisture content, volatile matter and ash content, 40 mesh particles are higher due to the value in ash content with 40 mesh particles higher [52].

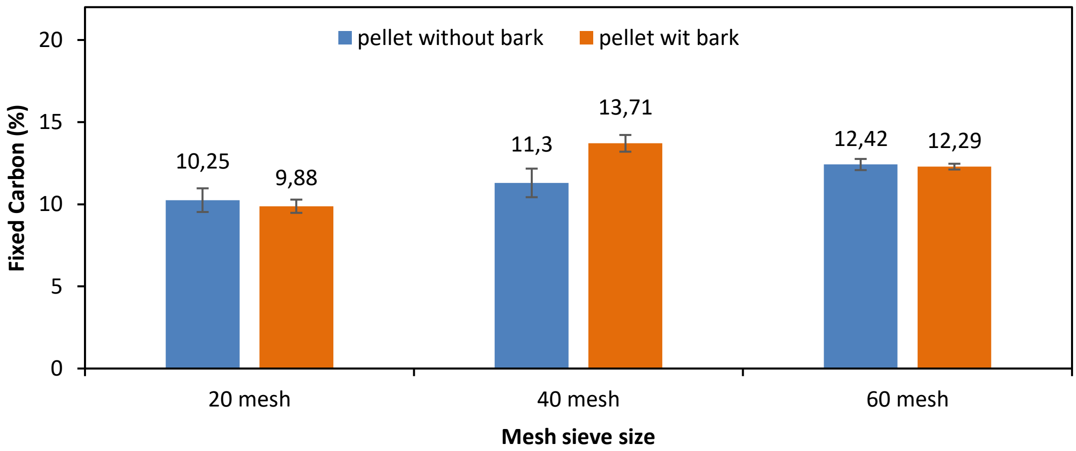

Figure 6. Fixed carbon of calliandra pellets

The smaller the particle size, the higher the fixed carbon value. Smaller particle sizes increase the specific surface area, which can speed up the burning rate. More efficient combustion typically produces less unburned carbon residue and can increase the total bound carbon released as energy [34]. SNI 8675:2018, which sets the standard for fixed carbon in biomass pellets, establishes a minimum standard of 14%. Thus, the calliandra pellets from this study do not meet this standard. High values are obtained when moisture content, volatile matter, and fixed carbon have low values [35]. According to [37], fixed carbon indicates how much solid material can burn after removing volatile components from the fuel. The fixed carbon value affects the calorific value; the higher the fixed carbon, the higher the calorific value, and vice versa [50].

3.2. Calorific value

The calorific value is crucial in characterizing calliandra pellets because it affects the combustion value produced. The heat generated from the combustion process can be observed from the calorific value present in the pellets [51, 53]. The calorific value of the research results can be seen in Figure 6. The calorific value obtained in calliandra pellets without bark ranges from 18.87 MJ/kg to 21.35 MJ/kg, and wood pellets with bark from 18.85 MJ/kg to 21.40 MJ/kg. The lowest calorific value is found in calliandra pellets with bark at a particle size of 20 mesh (18.85 MJ/kg), and the highest value is found in calliandra pellets without bark at 60 mesh (21.35 MJ/kg). The calorific value shows relatively high values in calliandra pellets without bark. Smaller particle sizes influence the calorific value of pellets, resulting in higher calorific values.

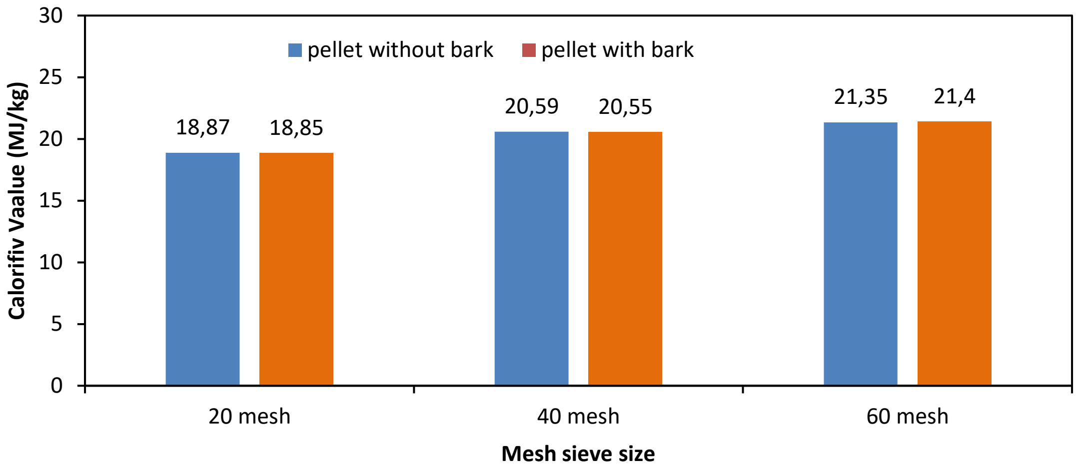

Figure 7. Calorific value of calliandra pellet

The research results of the calorific value of calliandra pellets align with previous studies where finer particles were used to result in higher calorific values [21, 37, 53-55]. The obtained results from calliandra pellets with and without bark have met all the standards used (DIN 51731, KFS, JA2021-0148, and SNI 8675:2018). Based on the results of the analysis, it is known that the composition of bark and particle size affects the calorific value. Calliandra pellets without bark have higher values than pellets with bark, and the larger mesh size also results in higher calorific values.

3.3. Physical and Mechanical Properties

3.3.1. Density

Density is a physical property of calliandra biomass pellets. Density is the ratio of the mass of calliandra pellets to the volume of calliandra pellets [55]. The particle size used in making calliandra pellets affects the pellet density. The density of the calliandra pellets from the study results can be seen in Figure 7. The density of calliandra pellets without bark obtained values at 20, 40, and 60 mesh sizes of 0.93, 0.89, and 0.94 g/cm^3 in the air-dried state, and after drying in an oven at 100°C for 24 hours, the results were 0.92, 0.88, 0.92 g/cm3. Calliandra pellets with bark obtained values of 0.90, 0.94, and 0.89 g/cm^3 in the air-dried state and 0.90, 0.92, and 0.88 g/cm^3 after oven drying. The pellets with the highest density were obtained from the oven-dried 20 mesh pellets with bark, with a value of 0.92 g/cm^3. This is in line with research by [21] that the smaller the particle size and the higher the compression pressure, the higher the density of the wood pellets produced.

The density values in oven-dried conditions are higher than in air-dried conditions. Oven drying reduces the mass of pellets that initially contained moisture, and after oven drying, the moisture content decreases, resulting in lighter pellet mass. This tendency causes oven-dried pellets to have a higher average density than air-dried pellets [48-49]. Density values are essential to determine the improvement of the quality of the pellets, as pellets with relatively high density will facilitate handling, transportation, and storage [59].

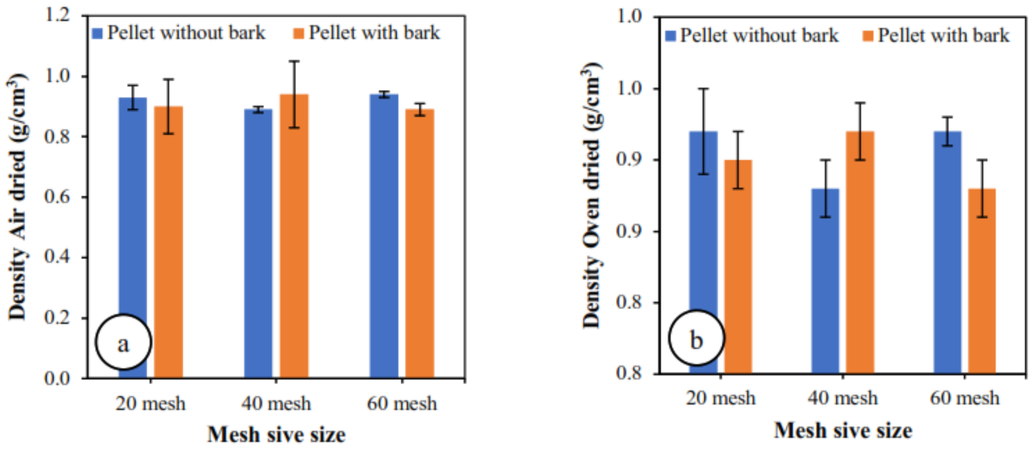

Figure 7. Density of calliandra pellet

3.4. Compressive strength

Compressive strength indicates the ability to withstand the load received by the pellet until it breaks. Compressive strength is the strength of a carbon pellet to withstand the given load until the pellet fractures [32]. The research results related to compressive strength can be seen in Figure 8. Based on the Univariate ANOVA test, the type of material obtained a p-value < 0.001. This value is < 0.05 (significant level), meaning that the material type and particle variation significantly affect the compressive strength. The compressive strength of samples without bark with particle sizes of 20, 40, and 60 mesh obtained results of 51.92, 75.53, and 84.65 N/mm^2. Calliandra pellet samples with bark with particle sizes of 20, 40, and 60 mesh obtained results of 36.87, 65.75, and 71.89 N/cm^2.

The compressive strength results show that the smaller the particle size, the greater the compressive strength because of the more uniform and strong bonding between particles. Reported [59] that the difference in particle size affects the compressive strength in their study, with the compressive strength of 60 mesh size being higher than that of 20 mesh size. The research results on compressive strength are consistent with previous studies; the finer the material used, the greater the compressive strength [21, 37].

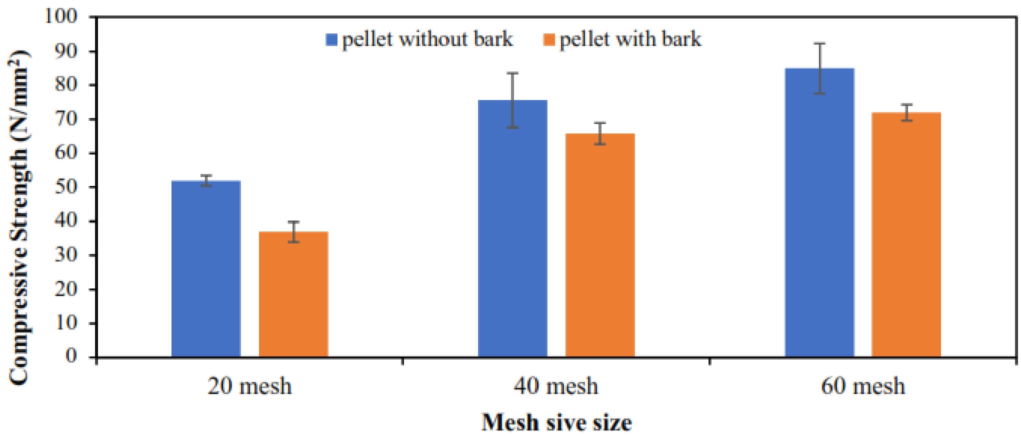

Figure 8. Compressive strength of calliandra pellet

3.5. FTIR Analysis

FTIR analysis is conducted to determine the chemical composition of biomass and changes in functional groups. The differences in functional groups present in Calliandra pellet without bark and with bark are examined to understand the chemical composition visible in the FTIR process [12]. The results of the FTIR analysis are shown in Figure 9.

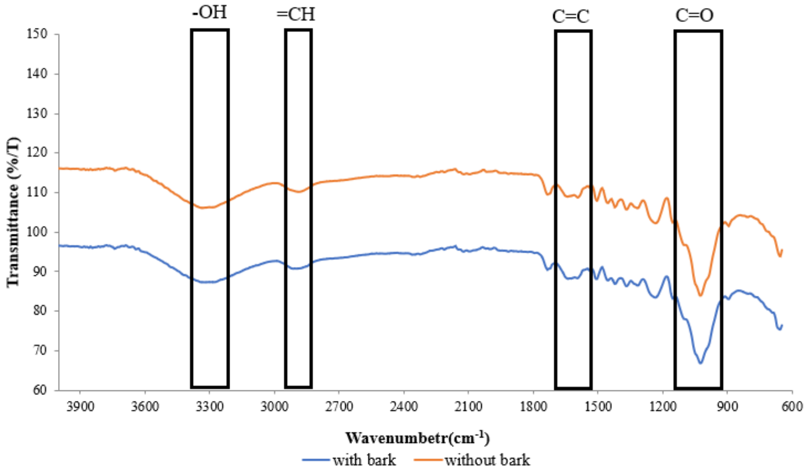

Figure 9. FTIR analysis of calliandra pellet with and without bark

Table 3. Functional groups in calliandra pellets

Wavenumber (cm^{-1})	Functional Group	Compound Type	Calliandra pellet	
			Without bark	With bark
1,000–1,300	C-O	Ethanol	Peak	Decreased
1,500–1,800	C=C	Benzene	Decreased	Peak
2,700–3,000	C-H	Alkane	Peak	Decreased
3,300–3,600	O-H	Acid, Methanol	Peak	Decreased

Sources: Rani et al., (2020); and Saputra et al., (2022)

The results showed differences in the functional groups of calliandra pellets with and without bark at several wave number ranges. Figure 9 shows the variation of functional groups between the two pellets. The wave numbers showing O-H and C-H groups were found at 3300-3600 cm^{-1} and 2700-3000 cm-1, respectively. At wave numbers 1500-1800 cm^{-1} there is a C=C group which is the structure of lignin [12]. In the C = O functional group at 900 - 1200 peaks are produced in polysaccharide carbohydrates. This range contains several peaks associated with C-O bonds in alcohols, esters, and ethers, which are common in cellulose, hemicellulose, and lignin [60-61]. The C-H functional group found in the peak range of 2700-3000 cm^{-1} [62], is composed of hemicellulose and cellulose. This peak is related to aliphatic C-H bonds in methylene (CH^2) and methyl (CH_3) groups found in cellulose and hemicellulose [63]. O-H This broad peak indicates the presence of hydroxyl groups, which are common in cellulose, hemicellulose, and lignin. C=C Peaks in this range indicate aromatic rings, which are the main component of lignin [64].

The results in Figure show that the graph on the pellets without bark decreased in the functional groups C-O, C-H, and O-H. The bark content of the pellets is seen to affect the graph on the FTIR results. The content of alkanes, acids, and methanol in calliandra pellets with bark is higher than pellets without bark. This is because the bark contains more minerals [21, 65]. The lower OH content in pellets without bark occurs due to the lower water content of the pellets (Table 1). According to [49], biomass pellets that undergo torrefaction will experience chemical degradation resulting in fewer OH groups. Figure 9 shows that the C=C group in the pellets without bark is higher than the pellets with bark. The C=O group in the 900-1200 cm^{-1} wave number range shows that the pellets with bark have a greater C=O group content than the pellets without bark.

4. Conclusion

The conclusion of this study is that the bark and particle size affect the quality of calliandra pellets. the visual appearance of calliandra pellets can be seen that pellets without bark have a brighter color than pellets with bark. the proximate value of calliandra pellets is affected by calliandra bark. the calorific value of calliandra pellets can be seen that the bark does not really provide a significant change in the amount of calorific value in calliandra pellets. The functional groups of ethanol, alkane, and acid in pellets without bark are steeper than pellets with bark. The benzene compound of pellets with bark is steeper than pellets without bark.

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