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Analysis of Calorific Value of Biopellet Diameter Variations through Proximate Test

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Abstract

This study aims to evaluate the quality of biopellets as biomass energy fuel, focusing on physical and chemical characteristics based on the SNI 8021:2014 standard. The research method used is experimental with a non-factorial Completely Randomized Design (CRD). The raw materials used are a mixture of rambutan wood waste (Nephelium lappaceum L) and bintaro (Cerbera manghas) with tapioca flour as an organic binder. Testing includes proximate analysis (moisture, ash, volatile matter, and fixed carbon) and calorific value using an oxygen bomb calorimeter. The results show that the produced biopellets meet several parameters of the SNI 8021:2014 standard, such as moisture content, volatile matter, and fixed carbon. However, there is significant variation in ash test results among different diameters of biopellets tested. ANOVA test results indicate that mold diameter has a notation that has a significantly affect several biopellet characteristics, such as density and calorific value. This study also observed the potential for increased combustion efficiency of the produced biopellets. The results indicate that the raw material mixture used can reduce pollutant emissions during combustion. The conclusion of this study is that the use of a mixture of rambutan wood waste and bintaro with tapioca flour as an organic binder can produce biopellets with quality that meets standards for biomass energy applications.

Introduction

The National Energy Council (DEN) reported that coal consumption accounted for 40.46%, petroleum 30.18%, natural gas 16.28%, and New Renewable Energy (EBT) 13.09%. The rising prices of energy commodities, which lead to increasing energy subsidies, is an issue for every country seeking solutions to reduce dependence on fossil fuels. It is necessary to sustain the use of alternative energy to reduce primary energy consumption, one of which is biomass energy. Biomass energy is a renewable energy source that is effective and easily converted into bioenergy output (Demirbas et al., 2009). However, limited resource conditions pose challenges in various industrial sectors, both small and large, as well as in biodiversity conservation as a solution to reduce CO2, NOx, and SOx gases. Biomass energy is divided into several types: solid, with products like bio-pellets and bio-briquettes; liquid, with products like bioethanol and biodiesel; and gas, with biogas products.

Indonesia has the potential for biomass resources equivalent to 56.97 GW of electricity. Biomass used in Indonesia, such as bio-pellets, requires a pellet mill machine for the densification process to increase density and calorific value (Sharma et al., 2015). This biomass can be obtained from agricultural waste such as palm oil and manufacturing waste

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such as sawdust, which produce combustion with biogenic CO2 output (Gori et al., 2013). The formation of bio-pellets not only comes from agricultural waste but also from wood waste found in residential areas, such as rambutan wood (Nephelium lappaceum L), which has the potential as a biomass fuel with low energy output if not processed specifically (Demirbas, 2004). However, through processing with improved pyrolysis conditions, there is an energy density increase of 8-36% (Chen & Kuo, 2010). Additionally, there is the bintaro plant (Cerbera manghas), a type of mangrove that is easy to plant and does not compete with food needs because its fruit is poisonous if consumed, containing about 40-65% oil (Herwanda, 2011).

Each fruit contains one seed that is toxic due to alkaloid compounds (cerberine, nitritolin, and thevetin), steroids, terpenoids, and saponins, which are poisonous and cause heart attacks (Musdja et al., 2019). However, bintaro seeds (Cerbera manghas) have a content of 54 wt% used as biodiesel raw material (Sutrisno et al., 2022). Biomass fuel derived from wood waste is an economical energy source. More than one type of biomass in biopellet production may increase the final parameters of the biofuel used (Dirgantara et al., 2020). The application of calorific value measurement of biopellet products through bomb calorimeter via proximate analysis plays a role as a prerequisite for the bomb calorimeter (Gheorghe & Neacsu, 2024). In proximate analysis, parameters such as ash content, moisture content, volatile matter content, and fixed carbon content are known to have a correlation to predict biopellet products (Akkaya, 2009). Then in the formation of biopellets, a binder is needed, which becomes an important material in its manufacture. This use aims to enhance the bond between particles (Lutfi et al., 2013), and one organic binder material is tapioca flour because it is easy to find and economical (Damayanti et al., 2021; Akkaya, 2016). Therefore, solid biomass, one of which is biopellets, has potential for the future.

This research aims to determine the calorific value content of biopellets as renewable biomass energy fuel. The observation includes the characteristics of biopellets based on SNI 8021:2014 through proximate analysis.

Methods

In this study, the author used an experimental method. The experimental method aims to predict the relationship between factors intentionally manipulated by the researcher and eliminate other factors that interfere with the experiment. The materials used in the study are waste from branches or twigs of rambutan wood (Nephelium lappaceum L) and the bintaro plant (Cerbera manghas) with an organic binder, tapioca flour. The waste branches or twigs of rambutan wood (Nephelium lappaceum L) and the bintaro plant (Cerbera manghas) were collected from the Sukmajaya District, Depok City. The sample composition percentages implemented are a mixture of rambutan wood waste (Nephelium lappaceum L) and bintaro plant (Cerbera manghas) each at 44.5%, water at 8%, and tapioca flour at 3%.

The tools used in the research include a set of biopellet production equipment: organic crusher, rotary dryer, magnetic screen vibration, disk mill silo, and pellet machine (with diameters of 6 mm, 8 mm, and 10 mm), and passed through a 60 mesh. Additionally, measuring tools such as calipers, digital scales, and thermometers were used. Furthermore, an Oxygen Bomb Calorimeter, porcelain crucible, desiccator, and furnace were used for testing in the study.

Mathematical Model

Density

The standard density value of SNI 8021:2014 is a minimum of 0.8g/cm^3, to determine the density value using the formula:

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$$\rho\ density\ (g/cm^3) = \frac{pellet\ mass\ (g)}{volume\ pellet\ (g)}$$

Water Content

The standard water content value of SNI 8021:2014 is a maximum of 12%, to determine the density value using the formula:

$$\text{Water content} = \frac{\text{(weight of cup +sample before drying (g))-weight of cup after drying (g)}}{\text{sample weight(g)}} \times 100\%$$

Ash Content

The standard ash content value of SNI 8021:2014 is a maximum of 1.5%, to determine the density value using the formula:

$$\text{Ash Rate} = \frac{\text{weight of crucible after kiln (g)-weight of empty crucible (g)}}{\text{sample weight (g)}} \times 100\%$$

Levels of Flying Substances

The standard volatile matter content value of SNI 8021:2014 is a maximum of 80%, to determine the density value using the formula:

$$\text{Volatile Matter Levels} = \frac{\text{weight of crucible after kiln (g)-weight of empty crucible (g)}}{\text{sample weight (g)}} \times 100\%$$

Bound Carbon Content

The bound carbon content value of the SNI 8021:2014 standard is a minimum of 14%, to determine the density value using the formula:

$$Bound\ Carbon\ Content =$$

$$100\% - \%Water\ Content - \%Ash\ Content - \%Flyable\ Substance\ Content$$

Calorific Value

The binding heating value of the SNI 8021:2014 standard is a minimum of 4000cal/g, to determine the density value using the formula:

$$Calorific\ Value\ (cal/g) = Fuel\ mass\ (g) \times \Delta T\ temperature\ change\ (℃) \times 2501\ water\ temperature\ and\ bomb\ calorimeter\ device\ (cal/℃)$$

Research design

The research used an experimental method design, namely a non-facto completely randomized design (CRD) with 3 codes and 2 treatments so that 6 sample variations were produced in Table 1.

Table 1. Design Testing Biopellets

Factor	Code	Treatment	
		1	2
F	A	A1	A2
	B	B1	B2
	C	C1	C2

Notes :
F : Composition
A : Diameter 6 mm
B : Diameter 8 mm
C : Diameter 10 mm

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Research Procedure

Reparation of Raw Materials and Manufacturing Process

The process of making biopellets into wood powder was carried out at the Waste Management Unit (UPS) in Depok City with a total raw material composition of 500 grams. The mixture consisted of 89 grams of rambutan wood waste (Nephelium lappaceum L) and bintaro plant (Cerbera manghas), 8 grams of water, and 3 grams of tapioca flour.

The raw materials, after undergoing chopping, drying, separation, and passing through a 60 mesh sieve, were then mixed with the binder and water. This mixture was then fed into a molding machine with varying diameter sizes of 6 mm, 8 mm, and 10 mm.

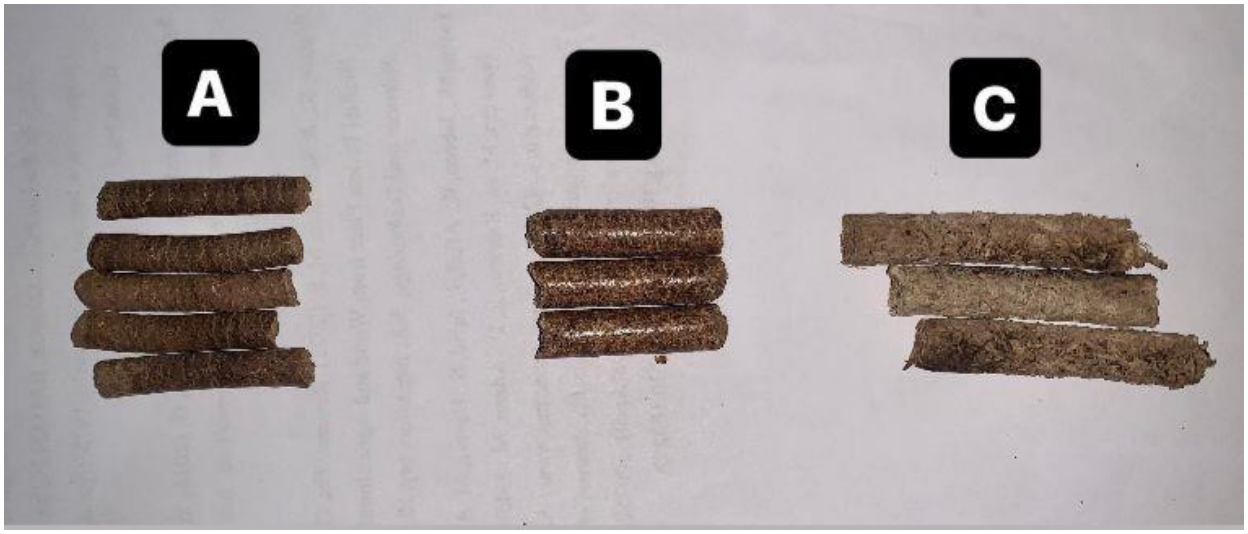

Figure 1. Product Biopellet Diameter Variations

(a) 6 mm diameter, (b) 8 mm diameter, and (c) 10 mm diameter.

Source : Primary Data (2024).

Testing Method

In the research procedure, testing was conducted in accordance with SNI 8021:2014 standards, including density parameters that refer to SNI 8021:2014. Then, the parameters of moisture content, ash content, volatile matter content, and fixed carbon content in proximate analysis refer to ASTM D-3173 standards, and the calorific value in the Oxygen Bomb Calorimeter test refers to ASTM D 240 standards.

Data Analysis

The data variables collected in the previous process were then analyzed using Microsoft Excel 2016 and SPSS with ANOVA treatment tests.

Results and Discussion

Based on the research procedure, biopellet data was obtained and then verified according to the SNI 8021:2014 equation to determine whether the biopellets met SNI criteria. The results of the tests conducted according to the research procedure are presented in Table 2 as follows:

Table 2. Verification of Research Results with Test Standards (SNI 8021:2014)

Parameter	SNI	A1	A2	B1	B2	C1	C2	Information					
								A1	A2	B1	B2	C1	C2
Density	Min. 0.8g/cm3	1.15	1.19	1.23	1.28	0.70	0.71	m	m	m	m	TM	TM

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Water content	Max. 12%	10.95	10.95	8.49	8.35	11.85	11.28	m	m	m	m	m	m
Ash Content	Max. 1.5%	4.21	4.22	3.38	3.33	3.99	4.48	TM	TM	TM	TM	TM	TM
Flying Substance Levels	Max. 80%	69.74	69.79	65.74	65.14	69.31	69.42	m	m	m	m	m	m
Bound Carbon	Min. 14%	15.08	15.02	22.37	23.77	15.49	14.80	m	m	m	m	m	m
Calorific Value	Min. 4000cal/g	4265	4289	4674	4431	4048	4108	m	m	m	m	m	m

Notes:
M: Fulfilled SNI Test Standards
TM: Not Fulfilled SNI Test Standards

Density Value

Density is the measurement of mass per unit volume of an object. In solid fuels, a high-density value facilitates the storage process of biopellet products, but it can reduce the combustion rate due to the reduction in pore size (Amri et al., 2022). In the study, the density test results, shown in Table 3, indicate that some sample codes did not meet the SNI standards.

Table 3. Density Test Results

Code	Treatment		Average g/cm3	SNI	Information
	1	2			
A	1.15	1.19	1.17	Min. 0.8g/cm^3	Fulfil
B	1.23	1.28	1.25		Fulfil
C	0.70	0.71	0.70		Does not meet the
SNI 8021:2014					

In Table 3, the average density values obtained range from approximately 0.70 g/cm³ to 1.25 g/cm³. The lowest density, 0.70 g/cm³, was found in treatment C1 with a diameter of 10 mm, while the highest density, 1.28 g/cm³, was found in treatment B2 with a diameter of 8 mm. The density test results for the diameter variations of 6 mm and 8 mm in all treatments in groups A and B met the SNI 8021:2014 standard, which requires a minimum density of 0.8 g/cm³. However, the 10 mm diameter treatments in group C did not meet the SNI standard. This discrepancy is due to the specific gravity of the raw materials used in biopellet production affecting the product's density; larger biopellet particles have lower specific gravity and density. The increase and decrease in biopellet density are influenced by the pressure conditions during the pelletization process.

Table 4. ANOVA Analysis Results (Density Test Results)

Mark	Sum of Squares	Df	Mean Square	F	Sig.
Treatment	1,783	5	,357	136,170	,000
Error	,063	24	,003		
Total Correction	**1,846**	**29**			

Based on Table 4, the effect of mold diameter variation on the density value of biopellet products, tested using ANOVA with a 5% confidence level, indicates that the relationship between diameter variation and density is significantly accepted with a significance result of $0.00 < 0.05$. This signifies a significant effect on the different treatments of mold diameter variations, thus requiring further LSD testing.

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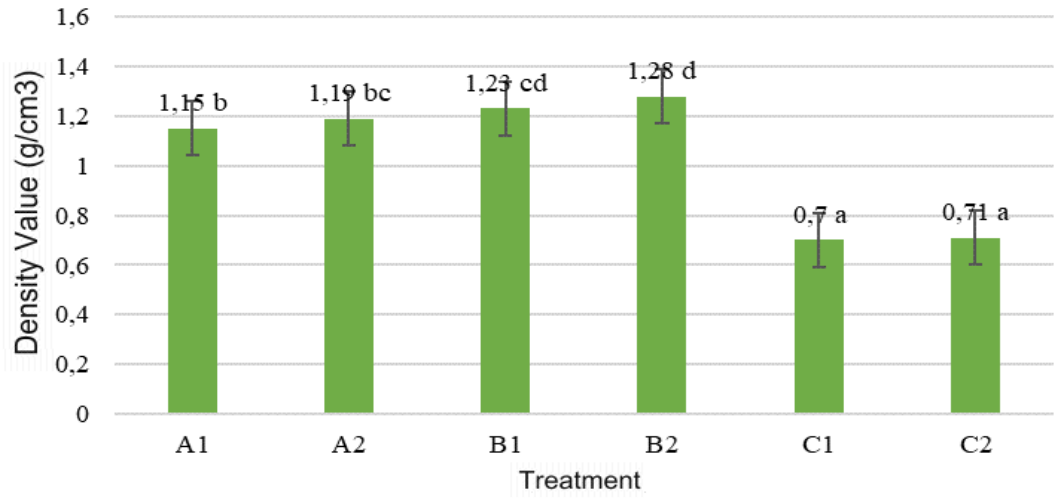

Figure 2. Advanced LSD Density Value Test

In Figure 2, for the diameter variation factor, treatment C1 labeled as 'a' shows no difference from C2 labeled as 'a', but it is significantly different from the other treatments. Treatment A1 labeled as 'b' does not significantly differ from A2 labeled as 'bc', but it is significantly different from treatments B1 labeled as 'cd', B2 labeled as 'd', C1 labeled as 'a', and C2 labeled as 'a'. In Figure 1, treatment A2 labeled as 'bc' does not significantly differ from A1 labeled as 'b' and B1 labeled as 'cd', but it is significantly different from the other treatments. Then, treatment B1 labeled as 'cd' does not significantly differ from treatment B2 labeled as 'd', but it is significantly different from the other treatments.

Moisture Content

Moisture content plays a role in the biopellet manufacturing process, affecting the net calorific value, combustion efficiency, and moisture balance through proximate analysis as shown in Table 5.

Table 5. Moisture Test Results

Code	Treatment		Average %	SNI	Information
	1	2			
A	10.95	10.95	10.95	Max. 12%	Fulfil
B	8.49	8.35	8.42		Fulfil
C	11.85	11.28	11.56		Fulfil
SNI 8021:2014					

Based on the data in Table 5, the average moisture content obtained ranges from approximately 8.42% to 11.56%. The lowest moisture content was 8.35% in treatment B2 with a diameter of 8 mm, while the highest was 11.85% in treatment C1 with a diameter of 10 mm. According to SNI 8021:2014, the average values of the treatments met the standard. Biopellets with a moisture content of less than 10% are known to have a compact pellet structure due to the water and lignin in the particles, which enhance the binding force between particles during the densification process. On the other hand, excessively high moisture content does not necessarily result in good quality, as it can facilitate mold growth and microorganism attacks (Rudolfsson, 2016).

Table 6. ANOVA Analysis Results (Moisture Test Results)

Mark	Sum of Squares	df	Mean Square	F	Sig.
Treatment	,005	5	,001	116.162	,000

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Error	,000	23	,000		
Total Correction	**,005**	**28**			

Through ANOVA testing with a 5% confidence level, as shown in Table 6, the relationship between diameter variation and moisture content is significant. The significance value of 0.00 < 0.05 indicates that there are significant differences in the average values of the treatments, thus requiring further LSD testing.

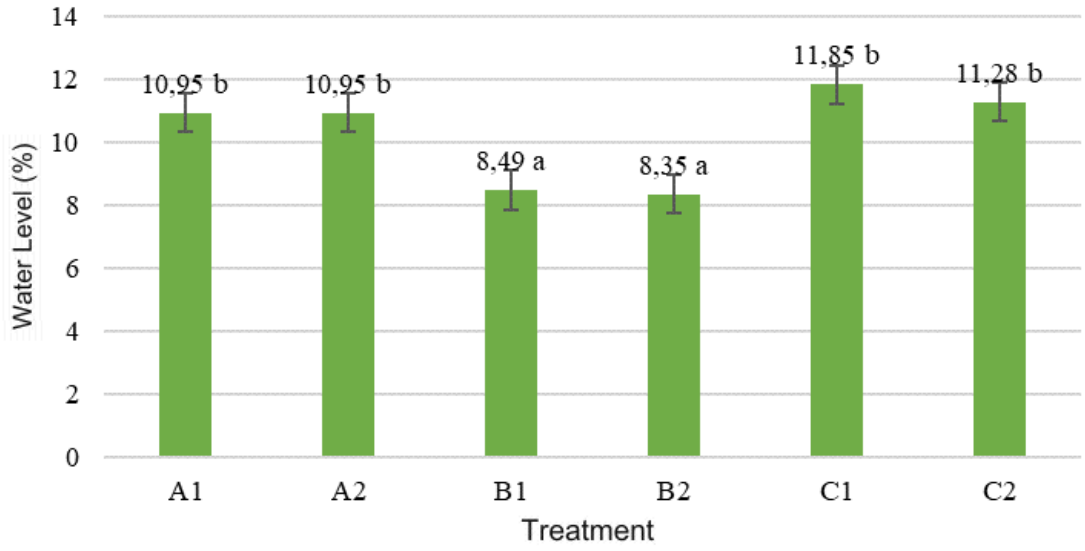

Figure 3. LSD Test for Water Content Advanced

Based on Figure 2, the diameter variation factor shows that treatment B1 labeled as 'a' differs from all other treatments except B2 also labeled as 'a'. Treatments A1 labeled as 'b', A2 labeled as 'b', C1 labeled as 'b', and C2 labeled as 'b' do not differ from each other but have no average difference compared to B1 and B2. This means that treatments AC and B result in biopellets with significantly different moisture content.

Ash Content (Ash)

Ash content is determined through the ashing method conducted in a furnace at 600°C for 2 hours. It has been explained that the binder materials, such as tapioca flour and sago, affect the ash content; an increase in ash content is related to a decrease in calorific value, which in turn lowers the quality of the biopellets. This condition can also be influenced by the tapioca flour binder ratio of 72.17% (Imanningsih, 2012). An increase in starch content is likely to result in a higher ash output (Syarief et al., 2021).

Table 7. Ash Test Results (Ash Test Results)

Code	Treatment		Average %	SNI	Information
	1	2			
A	4.21	4.22	4.21	Max. 1.5%	Does not meet the
B	3.38	3.33	3.35		Does not meet the
C	3.99	4.48	4.23		Does not meet the
SNI 8021:2014					

In Table 7, the average values obtained range from approximately 3.35% to 4.23%. The lowest value is 3.33% in treatment B2 with a diameter of 8 mm, while the highest value is 4.48% in treatment C2 with a diameter of 10 mm. None of the groups meet the SNI 8021:2014 standards. An increase in ash content poses risks such as the formation of mineral deposits or slag during combustion, leading to dirty furnace surfaces, corrosion, and reduced thermal conductivity, which degrades combustion quality. Low ash content indicates good-quality

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biopellets, and high ash content is due to unburned materials and other organic components contributing to ash, resulting in high silica content.

Table 8. ANOVA Analysis Results (Ash Test Results)

Mark	Sum of Squares	Df	Mean Square	F	Sig.
Treatment	,000	5	,000	14,771	,000
Error	,000	23	. 000		
Total Correction	**,001**	**28**			

According to Table 8, the effect of mold diameter variation on ash content values is significant. ANOVA testing at a 5% confidence level indicates that the relationship between diameter variation and ash content is significant, with a significance value of 0.00 < 0.05. This means there are significant differences in the average values of the treatments, requiring further LSD testing.

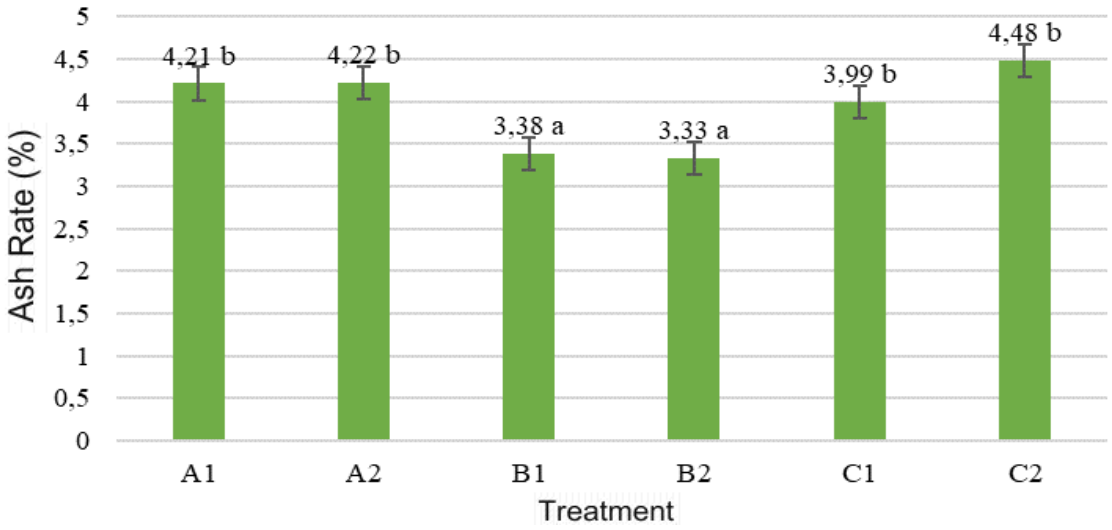

Figure 4. LSD Test Results for Ash Content

Based on Figure 3, the LSD test shows that treatment A1 labeled as 'b' does not differ from treatments A2 labeled as 'b', C1 labeled as 'b', and C2 labeled as 'b'. However, it does differ from treatments B1 labeled as 'a' and B2 labeled as 'a'. Similarly, treatments C1 labeled as 'b' and C2 labeled as 'b' also differ from treatments B1 labeled as 'a' and B2 labeled as 'a'. This indicates a significant difference in ash content between the diameter variations of AC and B.

Volatile Matter Content

Volatile matter content is determined through the ashing method conducted in a furnace at 950°C for 15 minutes. Pellets with higher volatile matter content can affect combustion performance and increase smoke production during combustion, while lower volatile matter content improves combustion efficiency and reduces smoke production. The carbonization process influences volatile matter components and leaves behind residual carbon in the product.

Table 9. Volatile Matter Test Results

Code	Treatment		Average %	SNI	Information
	1	2			
A	69.74	69.79	69.76	Max. 80%	Fulfil
B	65.74	65.14	65.44		Fulfil
C	69.31	69.42	69.36		Fulfil
SNI 8021:2014					

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Based on Table 9, the volatile matter content in the research has average values per group ranging from 65.44% to 69.76%. The lowest volatile matter content of 65.14% was found in treatment B2 with a diameter of 8 mm, while the highest volatile matter content of 69.79% was found in treatment C2 with a diameter of 6 mm. It can be concluded that all treatments meet the SNI 8021:2014 standard, which has a maximum allowable value of 80%. The study used a mixture of bintaro plant (Cerbera manghas) and rambutan wood (Nephelium lappaceum L) that underwent a carbonization process. The purpose of carbonization is to reduce the volatile matter content, which causes smoke, and to increase the calorific value of combustion (Mustamu & Pattiruhu, 2018).

Table 10. ANOVA Analysis Results (Volatile Matter Results)

Mark	Sum of Squares	Df	Mean Square	F	Sig.
Treatment	,009	5	,002	632,407	,000
Error	. 000	21	0.00		
Total Corrections	,009	26			

In Table 10, the effect of mold diameter variation on volatile matter content was tested using ANOVA with a 5% confidence level. Based on the table, the significance value of 0.00 < 0.05 indicates that the relationship between diameter variation and volatile matter content is significant. The average values of the treatments show significant differences, thus requiring further LSD testing.

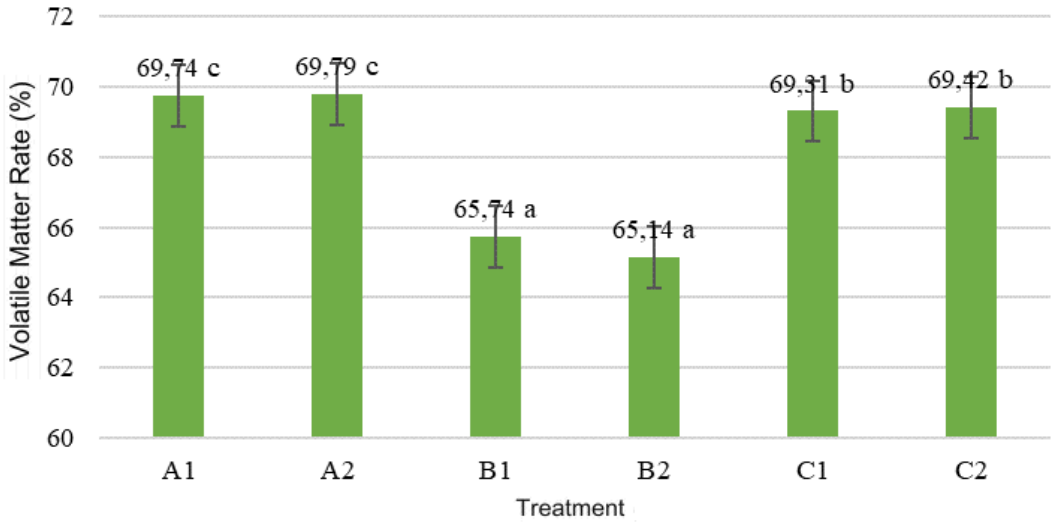

Figure 5. LSD Test Results for Volatile Matter

From Figure 5, the LSD test shows that treatment A1 labeled as 'c' and A2 labeled as 'c' differ from treatments B1 labeled as 'a', B2 labeled as 'a', C1 labeled as 'b', and C2 labeled as 'b'. Additionally, treatments B1 labeled as 'a' and B2 labeled as 'a' significantly differ from treatments C1 labeled as 'b' and C2 labeled as 'b'. This indicates significant differences in the effect of mold diameter variation on volatile matter content among the treatments.

Fixed Carbon Content

Fixed carbon content is the fraction of carbon in biomass influenced by its constituent elements such as carbon, hydrogen, and oxygen. Fixed carbon content is a parameter of fuel quality that affects the calorific value (Mustamu & Pattiruhu, 2018). The measurement of fixed carbon indicates the amount of solid material remaining after the removal of volatile components in the combustion process (Ståhl & Berghel, 2011). The results of the fixed carbon content test are shown in Table 11.

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Table 11. Fixed Carbon Test Results (Fixed Carbon Test Results)

Code	Treatment		Average %	SNI	Information
	1	2			
A	15.08	15.02	15.05	Min. 14%	Fulfil
B	22.37	23.77	23.07		Fulfil
C	15.49	14.80	15,14		Fulfil
SNI 8021:2014					

Based on Table 11, the average values per group range from 15.05% to 23.07%. The lowest value of 14.80% was observed in treatment C1 with a diameter of 10 mm, while the highest value of 23.77% was found in treatment B2 with a diameter of 8 mm. All treatments in the biopellet research meet the SNI 8021:2014 standard with a minimum requirement of 14%. This is because the content of ash and volatile matter affects the carbon content. An increase in volatile matter results in a decrease in carbon content, and vice versa. Fixed carbon content is the remaining carbon after the release of volatile matter during combustion, and its reaction is related to the calorific value (Sukarta & Ayuni, 2016). The mixed wood contains a high amount of lignin, at 18.034% (Suwaedi, 2018). Lignin, as an organic component, significantly contributes to and increases fixed carbon content, as well as affects the improvement of combustion and calorific value (Jacob et al., 2021).

Table 12. ANOVA Analysis Results (Fixed Carbon Results)

Mark	Sum of Squares	Df	Mean Square	F	Sig.
Treatment	.041	5	,008	156,625	,000
Error	,001	23	,000		
Total Corrections	**,042**	**28**			

Source : Primary Data (2024).

Based on Table 12, the effect of mold diameter variation on fixed carbon content was tested using ANOVA with a 5% confidence level. The table shows a significance value of 0.00 < 0.05, indicating that the relationship between diameter variation and fixed carbon content is significant. This means there are significant differences in the average values of the treatments, necessitating further LSD testing.

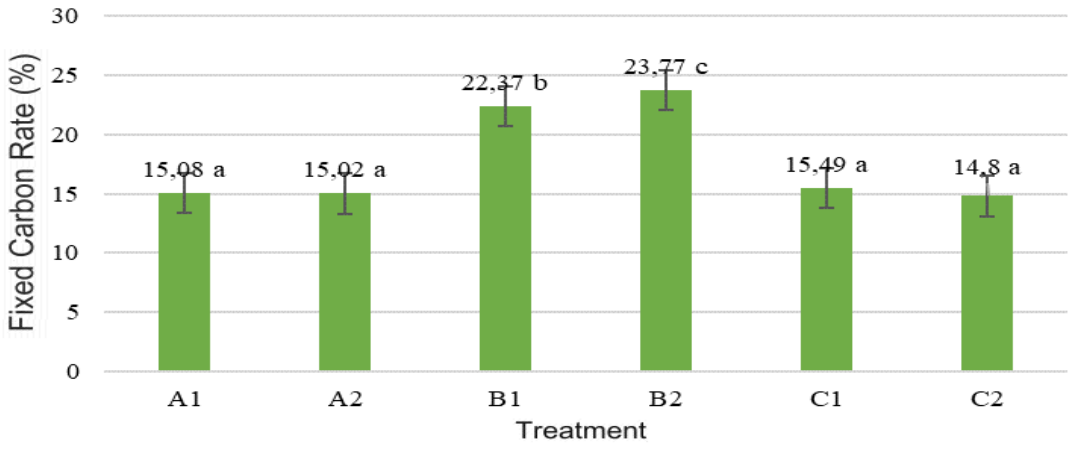

Figure 6. LSD Test Results for Fixed Carbon Content

From Figure 6, the LSD test shows that treatment A1 labeled as 'a' does not differ from treatments A2, C1, and C2. However, it differs from treatments B1 and B2, and treatment B1 labeled as 'b' also differs from treatment B2. This indicates that there are significant effects of diameter variation between treatments AC and B on the fixed carbon content.

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Calorific Value

The calorific value of biopellets depends on the combustion process, including factors such as ash content, moisture content, volatile matter content, and CO2 gas. In the study, the calorific value was tested using an Oxygen Bomb Calorimeter IKA C2000, with the results as follows:

Table 13. Calorific Value Test Results (Calorific Value Test Results)

Code	Treatment		Average cal/g	SNI	Information
	1	2			
A	4265	4289	4277	Min. 4000cal/g	Fulfil
B	4674	4431	4539		Fulfil
C	4048	4108	4078		Fulfil
SNI 8021:2014					

From Table 13, the average calorific values obtained range from approximately 4078 kcal/g to 4539 kcal/g. The lowest calorific value of 4048 kcal/g was observed in treatment C1 with a diameter of 10 mm, while the highest calorific value of 4674 kcal/g was found in treatment B1 with a diameter of 8 mm. According to SNI 8021:2014, the minimum calorific value for wood pellets is 4000 kcal/g, and the results indicate that the calorific values in this study meet the standard. Calorific value is inversely related to moisture content; as moisture content in the fuel increases, the calorific value decreases. Calorific value is positively influenced by fixed carbon and negatively influenced by volatile matter and ash. According to research Nosek et al. (2016), generally, the calorific value of wood logs is higher, while the percentage of ash follows the opposite trend.

Table 14. ANOVA Analysis Results (Calorific Value Test Results)

Mark	Sum of Squares	df	Mean Square	F	Sig.
Treatment	1291339.344	5	258267.869	87,897	,000
Error	70519.365	24	2938.307		
Total Correction	**1361858.709**	**29**			

Next, to analyze the effect of the combination of raw materials on the calorific value of the biopellet products, ANOVA testing with a 5% confidence level was performed, as shown in Table 14. The results indicate that the relationship between diameter variation and calorific value is significant, with a significance value of 0.00 < 0.05. This means that there are significant differences in the average values among the treatment groups, and further LSD testing is required.

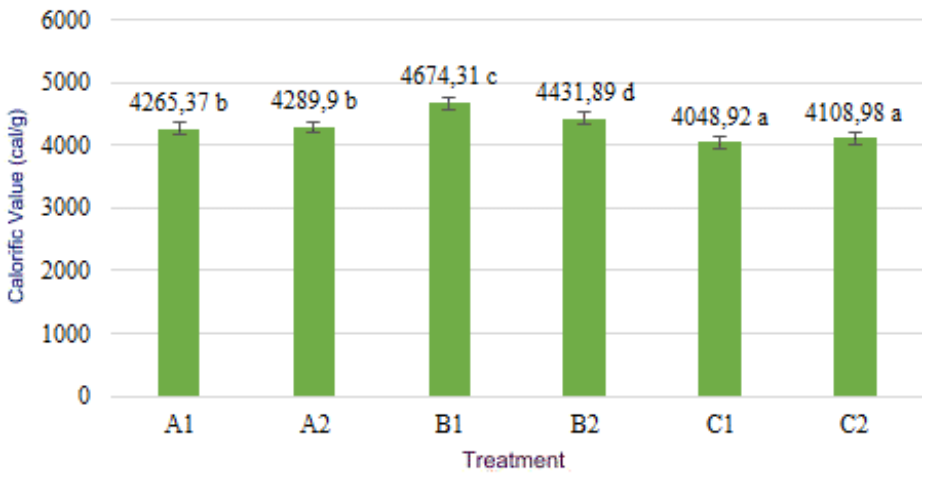

Figure 7. LSD Test Results for Calorific Value

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From Figure 7, the LSD test reveals that treatment A1 labeled as 'b' does not differ from treatment A2 also labeled as 'b'. However, it does differ from treatments B1 labeled as 'c', B2 labeled as 'd', C1 labeled as 'a', and C2 labeled as 'a'. Similarly, treatment C1 labeled as 'a' does not differ from C2 labeled as 'a', but does differ from other treatments. Treatment B1 labeled as 'c' differs from other treatments, as does treatment B2 labeled as 'd'. It can be concluded that there are significant differences among the treatment groups ABC in terms of diameter variation and calorific value.

Conclusion

Based on the research conducted, from the three groups with a total of six treatments, it was found that the biopellets made from rambutan wood waste (Nephelium lappaceum L) and bintaro plants (Cerbera manghas) meet the SNI 8021:2014 standards, except for the density parameter for sample code C (10 mm diameter) and moisture content for sample codes A, B, and C. The same composition used in all three groups affects the characteristics of mold diameter variations, and the composition is suitable for a diameter variation of 8 mm or code B. It can be concluded that the selection of raw material mixtures with high carbon content and the biopellet production process play a role in influencing the physical properties and quality of the products.

References

Akkaya, A. V. (2009). Proximate analysis based multiple regression models for higher heating value estimation of low rank coals. *Fuel Processing Technology*, *90*(2), 165–170. https://doi.org/10.1016/j.fuproc.2008.08.016

Akkaya, E. (2016). ANFIS based prediction model for biomass heating value using proximate analysis components. *Fuel*, *180*, 687–693. https://doi.org/10.1016/j.fuel.2016.04.112

Amri, I., Cahyono, A. A., & Bahruddin. (2022). Upgrading characteristics of empty fruit bunch biopellet with addition of bintaro fruit as co-firing. *Journal of Bioprocess, Chemical, Environmental Engineering and Science*, *2*(2), 1–8. https://doi.org/10.31258/jbchees.3.1.1-8

Chen, W. H., & Kuo, P. C. (2010). A study on torrefaction of various biomass materials and its impact on lignocellulosic structure simulated by a thermogravimetry. *Energy*, *35*(6), 2580–2586. https://doi.org/10.1016/j.energy.2010.02.054

Damayanti, A., Musfiroh, R., & Andayani, N. (2021). The effect of tapioca flour adhesives to the biopellet characteristics of rice husk waste as renewable energy. *IOP Conference Series: Earth and Environmental Science*, *700*(1). https://doi.org/10.1088/1755-1315/700/1/012028

Demirbas, A. (2004). Combustion characteristics of different biomass fuels. *Progress in Energy and Combustion Science*, *30*(2), 219–230. https://doi.org/10.1016/j.pecs.2003.10.004

Demirbas, M. F., Balat, M., & Balat, H. (2009). Potential contribution of biomass to the sustainable energy development. *Energy Conversion and Management*, *50*(7), 1746–1760. https://doi.org/10.1016/j.enconman.2009.03.013

Dirgantara, M., Karelius, K., & Ariyanti, M. D., Tamba, S. A. K. (2020). Evaluasi prediksi higher heating value (HHV) biomassa berdasarkan analisis proksimat. Risal. *Fisika*, *4*(1), 1–7. https://doi.org/10.35895/rf.v4i1.166

Gheorghe, D., & Neacsu, A. (2024). The influence of additives upon the energetic parameters and physicochemical properties of environmentally friendly biomass pellets. *Chemical Society Journal*, *68*(3), 438–454. Retrieved from http://dx.doi.org/10.29356/jmcs.v68i3.2032

ISSN: 2716-3865 (Print), 2721-1290 (Online)

Gori, M., Bergfeldt, B., Reichelt, J., & Sirini, P. (2013). Effect of natural ageing on volume stability of MSW and wood waste incineration residues. *Waste Management, 33*(4), 850–857. https://doi.org/10.1016/j.wasman.2012.12.005

Herwanda, A. E. (2016). Kajian proses pemurnian minyak biji bintaro (Cerbera Manghas L) sebagai bahan bakar nabati. IPB University. Retrieved from http://repository.ipb.ac.id/handle/123456789/51164

Imanningsih, N. (2012). Profil gelatinisasi beberapa formulasi tepung-tepungan untuk pendugaan sifat pemasakan. *Penelitian Gizi dan Makanan, 35*(1), 13–22. https://doi.org/10.22435/pgm.v35i1.3079.13-22

Jacob, G., Hasan, H., & Winarno, A. (2021). Karakteristik campuran batubara dengan arang gergaji kayu meranti dalam pembuatan briket batubara di kota Samarinda, Kalimantan Timur. *Jurnal Teknologi Mineral FT UNMUL, 9*(1), 27–32.

Lutfi, M., Syahbana, & Gunomo. (2013). Rancang bangun dan uji kinerja tungku biomassa dengan bahan bakar kayu. *Journal of Chemical Information and Model, 53*(9), 1689–1699.

Musdja, M. Y., Chadidjah, & Djajanegara, I. (2019). Antibacterial activity of dichloromethane and ethyl acetate extracts of bintaro leaf (Cerbera manghas, linn) against Staphylococcus aureus and Escherichia coli. *International Journal of Current Research, 11*(1), 398–402. https://doi.org/10.24941/ijcr.33901.01.2019

Mustamu, S., & Pattiruhu, G. (2018). Pembuatan biopelet dari kayu putih dengan penambahan gondorukem sebagai bahan bakar alternatif. *Jurnal Hutan Pulau-Pulau Kecil, 2*(1), 91–100. https://doi.org/10.30598/jhppk.2018.2.1.91

Nosek, R., Holubcik, M., & Jandacka, J. (2016). The impact of bark content of wood biomass on biofuel properties. *BioResources, 11*(1), 44–53. https://doi.org/10.15376/biores.11.1.44-53

Rudolfsson, M. (2016). Characterization and densification of carbonized lignocellulosic biomass.

Sharma, M. K., Priyank, G., & Sharma, N. (2015). Biomass Briquette Production: A propagation of non-convention technology and future of pollution free thermal energy sources. *American Journal of Engineering Research (AJER), 4*(02), 44–50.

Ståhl, M., & Berghel, J. (2011). Energy efficient pilot-scale production of wood fuel pellets made from a raw material mix including sawdust and rapeseed cake. *Biomass and Bioenergy, 35*(12), 4849–4854. https://doi.org/10.1016/j.biombioe.2011.10.003

Sukarta, I. N., & Ayuni, P. S. (2016). Analisis proksimat dan nilai kalor pada pellet biosolid yang dikombinasikan dengan biomassa limbah bambu. *Jurnal Sains dan Teknologi, 5*(1), 752–761. https://doi.org/10.23887/jst-undiksha.v5i1.8278

Sutrisno, S., Rahmi, R., Marlinda, L., Al Muttaqii, M., Afrila, C. D., Fasmawi, Y., & Evrianti, Y. (2022). A Mass Ratio of Hierarchical H-ZSM5 And Fatty Acid Methyl Ester of Cerbera Manghas Oil and The Effect on The Hydrocarbon Liquid Product Composition. *IPTEK The Journal for Technology and Science*, *33*(3), 190-200. https://doi.org/10.12962/j20882033.v33i3.14200

Suwaedi, O. (2018). Pemanfaatan limbah serbuk gergaji sebagai bahan dasar pembuatan briket. *Biosel: Biologi dan Pendidikan Biologi*, *7*(2), 204. https://doi.org/10.33477/bs.v7i2.656

Syarief, A., Nugraha, A., & Ramadhan, M. N. (2021). Variasi komposisi dan jenis perekat terhadap sifat fisik dan karakteristik pembakaran briket limbah arang kayu alaban. *Prosiding Seminar Nasional Limbah B3,* 6(April), 1–12.

ISSN: 2716-3865 (Print), 2721-1290 (Online)