

Analysis of Biomass Briquettes Made from Rubber Seed Shells and Acacia Sawdust with Variation in Material Composition Percentage

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Abstract

Indonesia is reducing reliance on fossil fuels by expanding renewable energy, including biomass from rubber-plantation residues and acacia wood. This study evaluates briquettes made from rubber seed shell (RSS) and acacia sawdust (AWS) using 10% tapioca binder, a compaction pressure of 50 kgf cm⁻², and drying at 100 °C for 3 h. Three compositions (RSS:AWS, %wt) were tested: A (50:50), B (70:30), and C (80:20). The best performance was obtained for C (80:20), with moisture 7.40%, volatile matter 9.56%, ash 4.47%, fixed carbon 85.95%, HHV 6,716.88 cal g⁻¹ (28.10 MJ kg⁻¹), and burn rate 0.10 g min⁻¹. All compositions satisfied SNI 01-6235-2000 limits for HHV ($\geq 5,000$ cal g⁻¹), VM ($\leq 15\%$), and ash ($\leq 8\%$); the moisture criterion ($\leq 8\%$) was met by B and C. For context, SNI 1683:2021 (wood charcoal, not briquettes) imposes stricter thresholds; under these, C is closest to First-Quality ranges, while A and B fall short for several parameters. Overall, increasing the RSS (char) fraction produced briquettes with lower moisture and VM, higher fixed carbon and HHV, and steadier combustion suitable for household fuel.

Keywords: Renewable Energy, Biomass Briquettes, Rubber Seed Shell, Acacia Sawdust, SNI.

1. Introduction

Indonesia's rapid development is driving a sharp rise in energy demand. Today, the energy mix is still dominated by fossil fuels; coal, natural gas, and petroleum which are finite and carbon-intensive. To ensure long-term energy security and reduce emissions, Indonesia must accelerate the deployment of renewable energy. Prioritizing modern renewables, including sustainably sourced biomass, will provide cleaner, more environmentally friendly energy while gradually reducing dependence on fossil fuels [1]. Solid fuels produced from biomass are known as briquettes. Their use offers dual benefits: they help address organic-waste management by diverting residues from disposal, and they provide an affordable, lower-impact fuel that can reduce reliance on increasingly scarce fossil fuels. Typical feedstocks include agricultural and forestry residues such as husks, shells, sawdust, and prunings that still contain sufficient energy to be densified into a usable fuel. Because the primary particles are fine powders, briquettes require a binder to provide cohesion and mechanical strength. Common binders include starches (e.g., tapioca or corn starch), molasses, clay, or other biodegradable adhesives chosen for availability, cost, and combustion performance [2].

The development of alternative renewable fuel sources is an ongoing effort to address the biggest challenge facing humanity today, which is the availability of fuel energy. Fuel energy consumption is increasing along with economic and population growth. As non-renewable fossil fuels become scarcer and eventually depleted, the world will continue to rely on fossil fuels, especially petroleum. To maintain the availability of fuel in a sustainable manner, it is important to create renewable fuel energy sources [3]. Often called “phytomass” or resources that come from living things, biomass is also known as bioresource. Biomass does not need to be converted into charcoal to be used directly. However, using biomass directly is not as efficient as it could be. Using wood as fuel is one example, where less than 10% of the energy in the wood can be used. However, the amount of energy generated can be increased by using biomass to make charcoal. Burning wood only creates about 2300 cal/g of energy, but burning biochar can create up to 5000 cal/g of energy [4]. Briquettes are a solid fuel substitute derived from natural material. The high caloric content of biomass derived from livestock and agricultural waste makes it a promising raw material for briquetting. Biomass materials that can be used to make briquettes include livestock manure, wood waste, rice husks, straw, bagasse, coconut shells, palm shells, and municipal waste. According to research, livestock manure has a calorific value of about 4000 cal/g, while plant waste has a calorific value of about 6000 cal/g [5].

Thirty years is a long time for a rubber plant to live. Rubber originated in Brazil and is known by the Latin name *Hevea brasiliensis* [6]. The prospective development of rubber commodities in Lampung Province is shown by data from the Lampung Provincial Statistics Agency quoted from the Central Bureau of Statistics (2022). There were 175,384 hectares of land and 121,593 tons of production in 2022. Rubber seed shells have not been taken advantage of by farmers in this amount [7]. The strong structure of the rubber seed shell indicates that the rubber seed shell contains cellulose, hemicellulose, and lignin, among other substances. Rubber seed shell contains 48.64% cellulose, 33.54% lignin, 16.81% pentose, 1.25% ash content, 0.52% silica content.

The main raw material used in Indonesia's pulp and paper industry today is acacia wood. It is a by-product of this industry. The chemical composition of acacia wood consists of 51.20% cellulose, 29.79% hemicellulose, 80.99% cellulose, and 24.89% lignin. Wood chips, pulp, paper, particleboard, and boxes can be made from acacia wood. In addition, its calorific value ranges from 4,800 to 4,900 kcal/kg, making it suitable for veneer, molding, and firewood. Karlinasari is the study of the anatomical and chemical aspects of wood as they relate to its acoustic qualities [8]. The biomass potential of Acacia plantations in Riau has been documented in regional and national sources. Authoritative datasets define above-ground biomass (AGB) as the oven-dry mass of stems, bark, branches and twigs (excluding roots), and regional studies in Pelalawan, Riau provide allometric equations for estimating stand biomass of *Acacia crassicarpa* by age class. For chemical composition, Acacia wood typically contains around 43.85% cellulose, 17.87% pentosans (hemicellulose proxy), and 24.89% lignin, consistent with Indonesian reports; thus, acacia sawdust is a feasible briquetting feedstock [9].

One of the supporting materials used during the briquetting process is adhesive. Both organic and inorganic materials can be used as adhesives. Adhesives are used during the briquette molding process to facilitate the procedure. In addition, the purpose of using adhesives is to unite several charcoal particles so that they are safe and resistant to breaking or damage. The quality of the briquettes made is also influenced by the adhesive used. Good briquettes also produce relatively less ash during combustion when organic adhesives are used. Adhesives of various types are often used, including rice flour, rice flour with glutinous rice flour, sago, clay, and tapioca starch [10].

Adhesives as well as raw materials are two major parts of the briquetting process, and both have an impact on the quality of the final product. Since tapioca has the maximum viscosity among rice flour, glutinous rice, and wheat flour, it is used as an adhesive. Tapioca is inexpensive, readily available, and has good adhesion when dried. Adhesives must be carefully controlled when used to make charcoal briquettes, as excessive use can reduce briquette quality and increase smoke production. Adhesives affect the density, strength, calorific value, moisture content, and ash content of charcoal briquettes. Compared to those with molasses-based adhesives, briquettes made with starch-based adhesives had higher density and ash content. However, the material strength and calorific value of the briquettes also decreased with the addition of starch-based adhesive [11].

Previous briquette studies have widely examined single feedstocks or binary mixes with generic binders, but there is limited evidence on (i) how rubber seed shell (RSS) synergizes with acacia sawdust (AWS) under a fixed starch binder fraction, and (ii) whether such mixes can simultaneously satisfy the

older SNI 01-6235-2000 and the newer SNI 1683-2021 quality thresholds. Moreover, many reports do not keep pressing pressure and drying schedule constant across compositions, which makes performance attribution to composition alone inconclusive.

This work isolates the effect of composition by fixing the processing route, tapioca binder at 10%, pressing at 50 kgf/cm², oven drying at 100 °C for 3 h and varying only RSS:AWS at 50:50, 70:30, and 80:20. We then benchmark moisture, volatile matter, ash, fixed carbon, calorific value, and burn rate directly against both SNI standards. The novelty lies in: (1) establishing the composition–property relationship for the RSS-AWS system under a controlled, industry-realistic route; and (2) identifying a composition window (notably 80:20) that approaches or meets the stricter SNI limits for key properties.

2. Material and Method

2.1 Research Parameters

Response variables were moisture content (%), volatile matter (%), ash content (%), fixed carbon (% by difference), higher heating value (cal/gram), and burn rate (g min⁻¹). The single process factor was the RSS:AWS mass composition with three levels: A = 50:50, B = 70:30, and C = 80:20. The tapioca binder was fixed at 10 wt% of total solids. Compaction pressure (50 kgf cm⁻²) and drying (100 °C for 3 h) were held constant for all runs. The study comprised two stages: (i) Briquette fabrication (Figure 1) and (ii) Briquette testing.

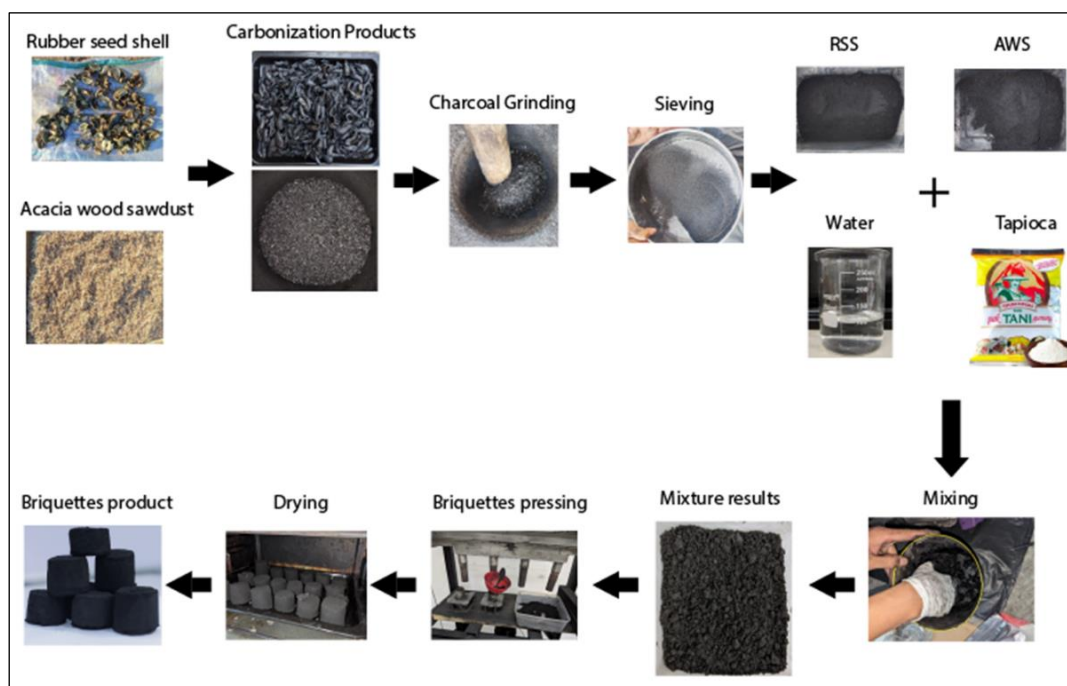


Figure 1. Process of Making Briquettes

The stages of making these briquettes are the first drying after collecting rubber seed shells and acacia sawdust, the next step is to dry the rubber seed shells for two days with a duration of six hours/day and acacia sawdust for one day for three hours to reduce the water content. The next step is carbonization, which is the process of burning in a closed container. For rubber seed shells, it is done for three hours and acacia sawdust for two hours [12]. Then the next step is to pulverize and sift through a 60-mesh sieve [13]. After sifting, the next step is mixing the ingredients with the adhesive. After mixing, enter 100 ml of water and stir until evenly distributed with the ratio of the mixture of materials and adhesives is 90:10. The mixture ratio between rubber seed shells and acacia sawdust is variation A 50%;50%; variation B 70%;30%, and variation C 80%;20%. After mixing, the sample was put into the mold and then pressed with a pressure of 50 kg/cm² [14]. The briquettes were molded then dried in an oven at 100°C and rested every 30 minutes during the drying process with a drying time of 3 hours [15]. After the briquettes are made, the next step is to carry out the testing process. This briquette testing consists of testing the water content using a Moisture Analyzer, testing the calorific value using a

Calorimeter Bomb, using a Furnace tool to test ash content, volatile matter, and carbon content. And testing the combustion rate using scales [16].

2.2 Data Processing and Analysis

Fixed carbon (FC, %) was calculated by difference (Eq.1):

$$FC (\%) = 100 - (\text{Moisture} + \text{Volatile Matter} + \text{Ash}) \quad (1)$$

Fixed carbon (FC) represents the carbon fraction remaining in the briquette after accounting for moisture, volatile matter, and ash. Combustion rate (g/min) was computed from mass loss during burning divided by burning time (Eq.2):

$$\text{Combustion rate} = \frac{m_0 - m_t}{t} \quad (2)$$

Standards: Moisture, volatile matter, ash, and fixed carbon followed the referenced standard methods; compliance was assessed against SNI 01-6235-2000 (charcoal briquettes). SNI 1683:2021 (wood charcoal) is reported for context only. HHV is reported in cal g⁻¹ and MJ kg⁻¹ using 1 cal g⁻¹ = 0.004184 MJ kg⁻¹.

2.3 Instruments and Specifications

The instruments and specifications of the measuring instruments used in this study are:

- Moisture analyzer/oven: Oxone OX-858; temperature setpoint 105 °C.
- Bomb calorimeter: PARR 1341CLEE; test duration about 20 min per sample.
- Muffle furnace: used for ash and volatile matter determinations per the referenced standards (temperatures and dwell times as specified by the methods).
- Analytical balance & timing: digital balance (readability ±0.01 g) for combustion-rate measurements; stopwatch Joyko SW-500.
- Hydraulic press: applied pressure 50 kgf cm⁻²; cylindrical mold Ø 34 mm × height 35 mm,
- Preparation tools & consumables: 60-mesh sieve; 10 wt% tapioca binder (relative to total solids); 100 mL added water per batch.
- Drying protocol: oven drying at 100 °C for 3 h, using staged drying with 30-min door-open cooling intervals.

3. Result and Discussion

This research aims to test and analyze biomass briquettes made from rubber seed shells and acacia sawdust, using tapioca starch as an adhesive with variations in the ratio of A (50%:50%), B (70%:30%), C (80%:20%) and 10% tapioca starch from the total mass of the briquette composition. Then 100 ml of water is added. Then pressed with a manual hydraulic press with a pressure of 50 kgf/cm². Then the briquettes were dried using an oven with a drying temperature of 100°C for 3 hours. Drying of the briquettes was carried out with the aim of reducing the moisture content contained in the briquettes. Figure 2 shows the results of briquettes with variations in material composition.

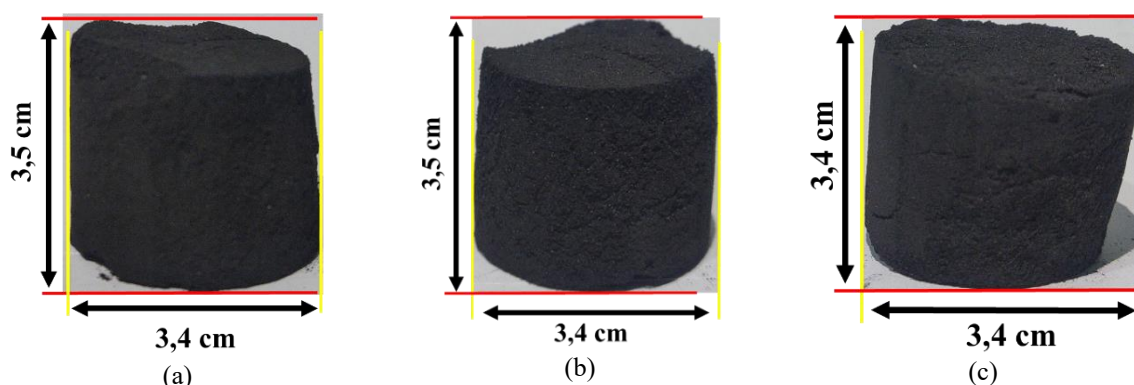


Figure 2. Briquettes of Rubber Seed Shells and Acacia Sawdust with Varying Percentages of Material Composition: a) Sample variation A (50%:50%), b) Sample variation B (70%:30%), c) Sample variation C (80%:20%)

Figure 2 shows the results of making briquettes made from rubber seed shells and acacia sawdust. Figure 2a is the result of making briquettes with variation A (RSS 50%: AWS 50%). The briquette variation has a smoother surface, this is related to the composition of materials between rubber seed shells and acacia sawdust in a ratio of 50%: 50%. Briquettes with variation A have carbon loss, which is related to the composition of acacia sawdust charcoal with a lighter mass than rubber seed shell charcoal. Figure 2b is a briquette with variation B with a percentage composition of materials namely RSS 70%: AWS 30%. Briquettes with variation B have a surface shape that is not smooth, this is due to the composition of rubber seed shell charcoal which has a heavier mass even though it is given the same pressing treatment (50 kgf/cm²). Briquettes with variation B have less charcoal loss than briquettes with variation A, because briquettes with variation B have a higher percentage of rubber seed shell charcoal (RSS 70%: AWS 30%), which causes the binding force of the tapioca adhesive to be quite strong. Figure 2c is a briquette with variation C with a percentage composition of materials namely RSS 80%: AWS 20%. Briquettes with more rubber seed shell material composition cause the shape of the briquette surface to have a little crack on the surface of the briquette. Briquettes with variation C tend to be more resistant if dropped at a height of ± 1 meter with the condition of the briquette being lit [17]. Briquettes that have gone through the drying process can be tested. Tests include moisture content testing, calorific value testing, ash content testing, volatile matter testing, carbon content testing, and combustion rate testing.

3.1 Moisture Content

To determine the water contained in charcoal briquettes, we measured moisture content using a moisture analyzer. Three sample variations (A, B, and C) with different material ratios were prepared; each briquette was ground to a fine charcoal powder to facilitate consistent measurements, then weighed prior to analysis. The procedure reported the briquette's moisture content as well as the test duration and temperature. The findings are presented in Figure 3.

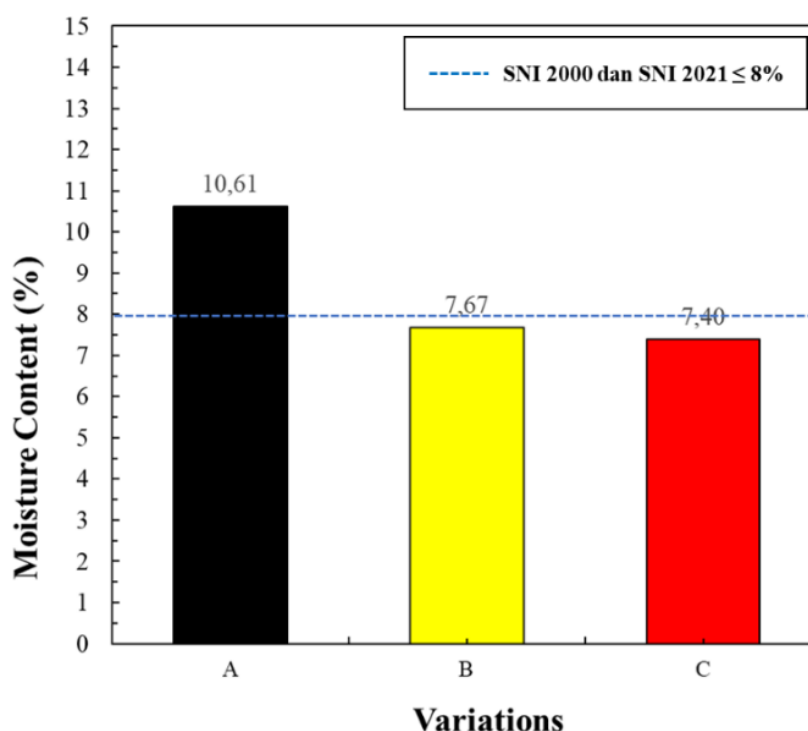


Figure 3. Variation in Percentage Materials Against Moisture Content

Figure 3 shows the moisture content of rubber seed shell–acacia sawdust briquettes, with the highest value for A and lower values for B and C. Moisture decreases as the RSS fraction increases: C (80:20) shows 7.40%, B (70:30) 7.67%, whereas A (50:50) is highest at 10.61% ($C < B < A$). Under identical pressing (50 kgf cm⁻²) and drying (100 °C, 3 h), higher char fraction generally retains less water; B and C satisfy the SNI 01-6235-2000 moisture limit ($\leq 8\%$), while A does not. This reduction in moisture for C is consistent with its improved combustion behavior reported elsewhere in the results,

as lower moisture generally facilitates ignition and more stable burning [18]. Briquette moisture content decreases as the fraction of carbonized material (e.g., rubber seed shell/biochar) increases, mixtures dominated by raw rice husk retain more moisture. This trend aligns with studies on rice-husk briquettes showing that carbonization lowers retained moisture and volatile matter while increasing fixed carbon and HHV [19]. Moisture content in biomass briquettes generally falls as the fraction of carbonized material (e.g., rice-husk or rubber seed-shell char) increases, because carbonization drives off bound water and other volatiles; mixes dominated by raw biomass tend to retain more moisture. This trend is widely reported in the literature on carbonization/torrefaction and fixed-bed briquette combustion [20].

3.2 Calorific Value Testing

The importance of calorific value in the manufacture of briquettes is because briquettes must undergo a combustion process to determine the amount of heat generated. Calorific value is a primary quality indicator for briquettes because it determines the useful heat released during combustion. We measured HHV using a bomb calorimeter (20 min per sample) [21]. In this test there are 3 variations in the percentage of material composition including variations A, B, and C.

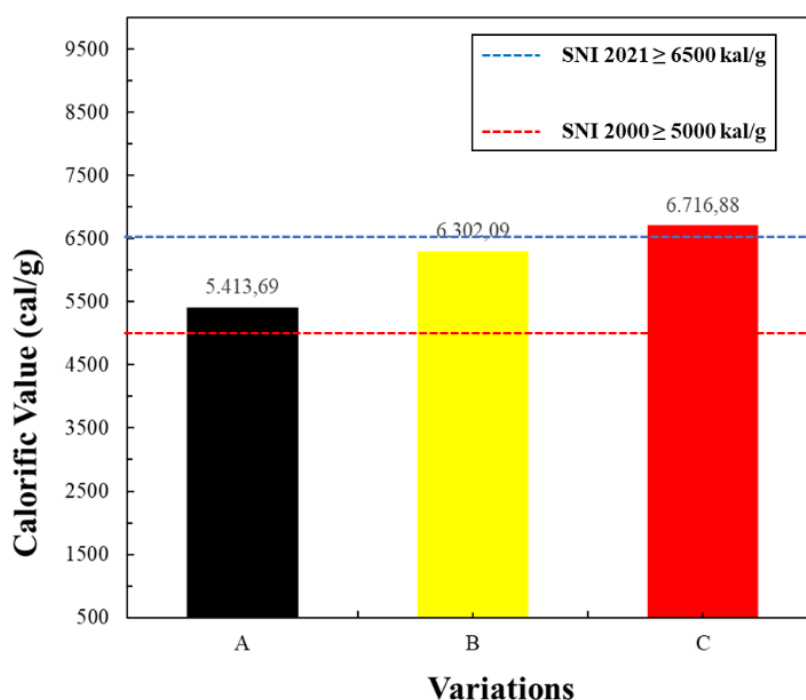


Figure 4. Variation in Percentage Materials Against Calorific Value

Figure 4 shows that the briquettes made from rubber seed shells and acacia sawdust had an increase in calorific value at each variation in the percentage of ingredients. Calorific value increases with RSS fraction: A = 5413.69 cal g⁻¹, B = 6302.09 cal g⁻¹, C = 6716.88 cal g⁻¹. All compositions meet SNI 01-6235-2000 (HHV ≥ 5000 cal g⁻¹). Against SNI 1683:2021 First Quality (wood charcoal), only C reaches the HHV threshold (≥ 6500 cal g⁻¹); A and B do not appropriate since SNI 1683 targets charcoal, not briquettes [22]. As well as other comparison standards using SNI 1683-2021 first quality, the minimum calorific value of briquettes is ≥ 6500 cal/g [23]. So, it can be concluded that briquettes with rubber seed shells and acacia sawdust variations A, B, and C meet SNI 01-6235-2000 standards, while in SNI 1683-2021 variations A and B do not meet SNI standards. Meanwhile, variation C has met the SNI 1683-2021 standard. Consistent with findings in Deshannavar et al. [19], carbonizing rice husk lowers volatile matter and increases fixed carbon and the higher heating value (HHV). Therefore, mixtures with a higher fraction of biochar/carbonized rice husk tend to produce higher HHV than mixtures dominated by raw rice husk. This provides a mechanistic basis for the increase in HHV as the proportion of carbonized material rises [19]. The higher the composition of rubber seed shell material, the moisture content in the briquette will decrease, which has an impact on the calorific value of the briquette [24]. This is like in the author's research, which creates the lowest calorific value in variation A and the highest calorific value in variation C. When referring to SNI 01-6235-2000, the minimum

calorific value of a briquette is ≥ 5000 cal/g [22]. As well as other comparison standards using SNI 1683-2021 first quality, the minimum calorific value of briquettes is ≥ 6500 cal/g [23]. So, it can be concluded that the briquettes with rubber seed shells and acacia sawdust variations A, B, and C meet the SNI 01-6235-2000 standard, while in SNI 1683-2021 variations A and B do not meet the SNI standard. Meanwhile, variation C has met the SNI 1683-2021 standard.

3.3 Ash Content

Low ash content is one of the factors that affect the quality of briquettes, because briquettes with high ash content will form deposits in the form of impurities or crusts and show that the material in the briquette cannot be burned out [25].

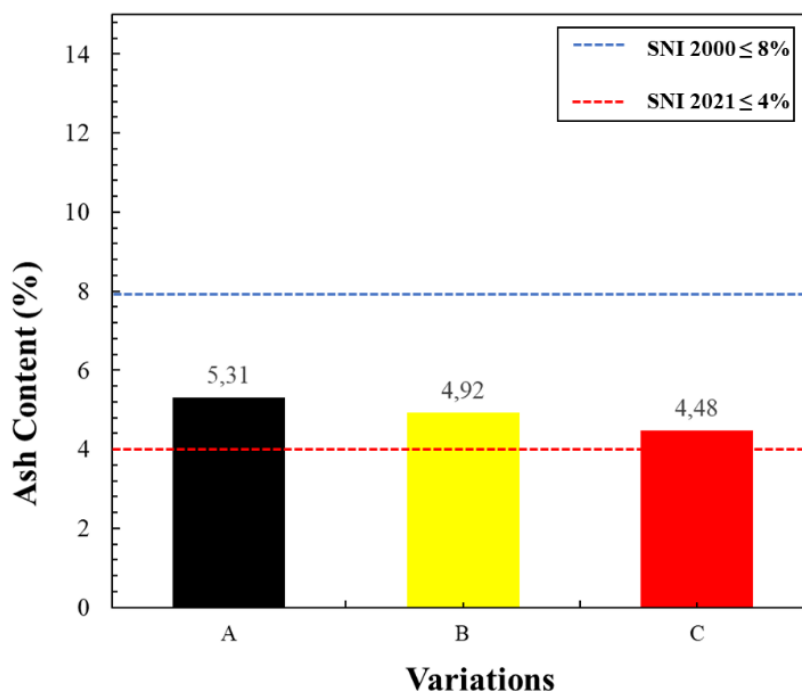


Figure 5. Variation in Percentage Materials Against Ash Content

Figure 5 shows that the ash content of rubber seed shell briquettes and acacia sawdust is quite low. Ash contents are A = 5.31%, B = 4.92%, C = 4.47%. All compositions meet SNI 01-6235-2000 (ash $\leq 8\%$). Against SNI 1683:2021 First-Quality (ash $\leq 4\%$), none fully qualify, with C (4.47%) being closest. Discussion focuses on SNI 01-6235-2000 for briquettes; SNI 1683 is cited for context only. [22]. So, the variation of briquettes made from rubber seed shells and acacia sawdust has met these standards. However, if you review SNI 1683-2021, it states that the ash content of briquettes is not more than 4% [23]. So, it can be concluded that briquettes made from rubber seed shells and acacia sawdust with variations in the percentage of material composition, namely A, B, and C do not meet these standards, namely for the three variations having sequential ash content of 5.30%, 4.92%, 4.47%. In reference to SNI 01-6235-2000, ash content should be $\leq 8\%$; all three compositions (A = 5.31%, B = 4.92%, C = 4.47%) meet this requirement. In SNI 1683-2021 (First Quality), the limit is $\leq 4\%$; therefore none of the compositions fully meet the First-Quality threshold, although C (4.47%) is closest to the limit.

3.4 Volatile Matter

If a briquette is heated in a closed room at a temperature of $\pm 950^\circ\text{C}$, a vaporized substance or volatile matter is formed. Volatile matter consists of combustible gases, such as methane (CH_4) and carbon monoxide (CO), and non-combustible gases, such as carbon dioxide (CO_2) and water (H_2O).

Figure 6 shows volatile matter (VM) decreasing as the proportion of rubber seed shell (RSS/biochar) increases: A = 14.06%, B lies between A and C, and C = 9.56%. All three compositions satisfy SNI 01-6235-2000 for wood-charcoal briquettes (VM $\leq 15\%$). Note that SNI 1683:2021 applies to wood charcoal (not briquettes) and uses different classification thresholds, so it is not directly

comparable to briquette data; use SNI 01-6235-2000 for compliance checks on briquettes. The observed trend in Figure 6 higher raw rice-husk fraction (lower biochar ratio) gives higher VM is consistent with Kipngetich's fixed-bed study on rice-husk briquettes, which reports greater devolatilization and higher VM when the biochar share is reduced [26].

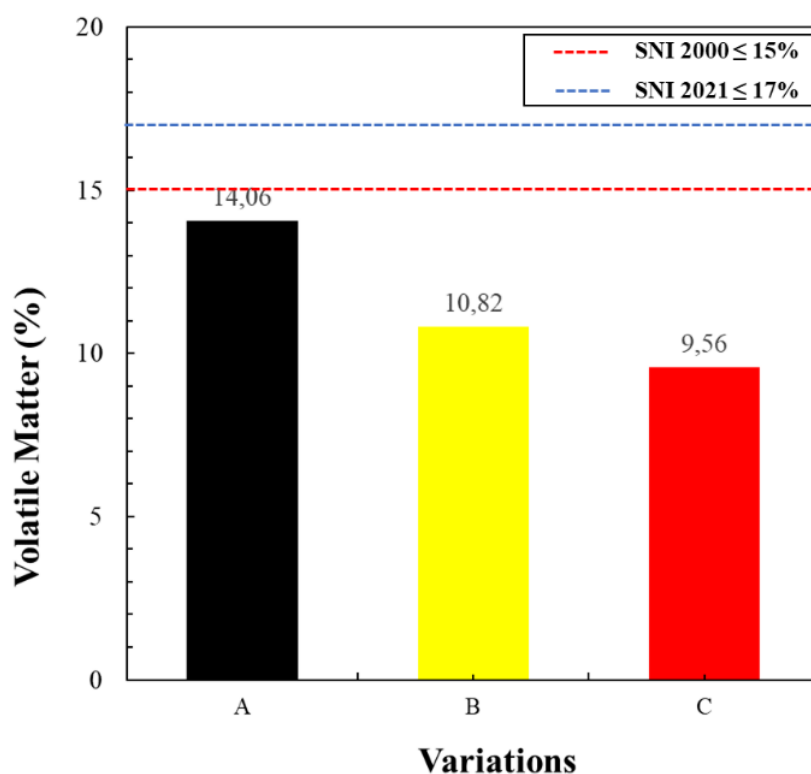


Figure 6. Variation in Percentage Materials Against Volatile Matter

3.5 Carbon Content

The fraction of carbon (C) bound in the briquette, together with the fraction of ash, water and volatile matter, is called the bound carbon content. Higher levels of bound carbon affect the quality of the fuel, with higher bound carbon content improving the quality of the briquettes, and higher bound carbon content leading to higher calorific values [27].

Fixed carbon (FC) increases with the RSS fraction: A = 80.62%, B = 84.25%, C = 85.95% (Figure 7). All compositions satisfy SNI 1683:2021 First-Quality FC $\geq 79\%$ (noting that SNI 1683 governs wood charcoal, while SNI 01-6235-2000 applies to briquettes). The increase in FC with RSS is consistent with the higher lignin content reported for rubber seed shells relative to acacia wood, which favors greater carbon residue after devolatilization. Syahrul et.al [28] conducted research using calorific value testing parameters with the composition of candlenut shell material and corn cob, the highest calorific value was obtained in variation C (65%: 25%), namely 5065 kal/g, while the lowest calorific value was in variation E (45%: 45%), namely 3316 kal/g. In the research conducted by Syahrul et.al [28], the calorific value of the briquette variation is influenced by the carbon content of the material and the carbon content is influenced by the composition of lignin in each material. This statement is related to the research organized by the author, where the highest carbon content is in variation C (85.9569%) with a higher composition of rubber seed shells and the lowest carbon content in composition A (80.6297%). The test results are like the high lignin content in rubber seed shell material of 33.54%, while acacia sawdust has a lignin content of 24.89% [9].

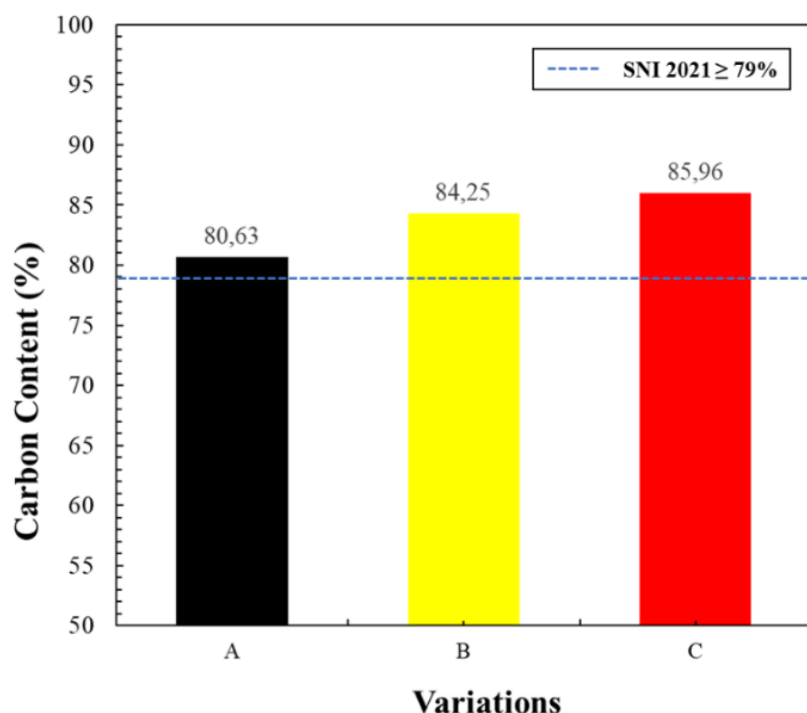


Figure 7. Variation in Percentage Materials Against Carbon Content

3.6 Combustion Rate

Variation A shows the highest rate at $0.1250 \text{ g min}^{-1}$ with a burn time of 88 min; B burns at $0.1146 \text{ g min}^{-1}$ for 96 min; and C exhibits the slowest rate at $0.1028 \text{ g min}^{-1}$ with the longest burn time of 107 min (1 h 47 min) as shows in Figure 8.

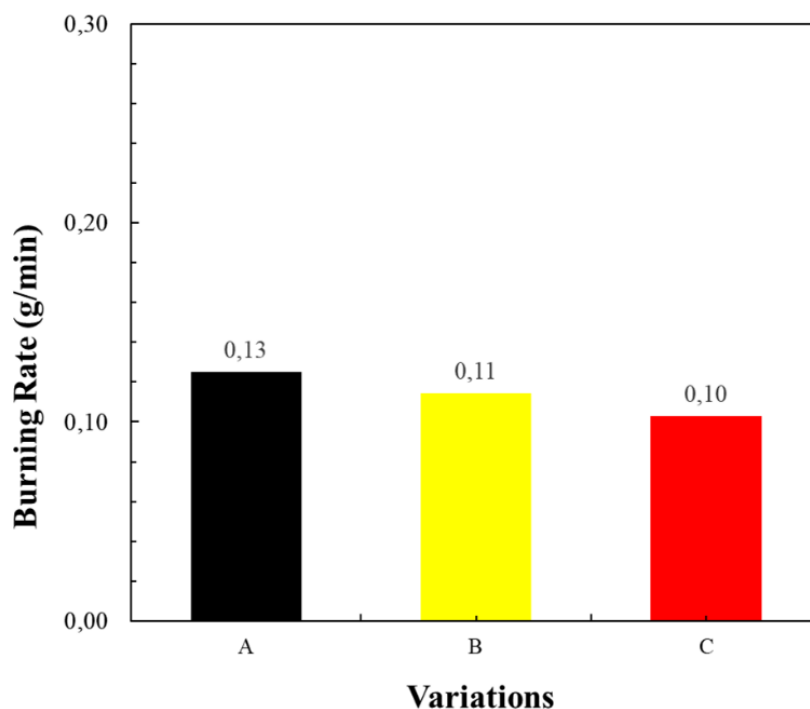


Figure 8. Variation in Percentage Materials Against Combustion Rate

In short, C burns more slowly and for longer, whereas A burns faster for a shorter duration. The lower combustion rate observed for C is consistent with its higher fixed carbon and lower volatile matter, which reduce rapid devolatilization and promote steadier flames. A higher fraction of char (RSS)

typically also means lower moisture, further slowing the burn and extending total combustion time. Practically, C is better suited to cooking applications that require stable, long-lasting heat, while A is more appropriate when quick heat-up is desired but shorter endurance is acceptable. Note that combustion rate can also be influenced by particle size, binder content/type, and airflow during testing; keeping these conditions constant or reporting them clearly strengthens reproducibility [26].

4. Conclusion

Increasing the fraction of rubber seed shell (RSS) char in RSS–acacia sawdust briquettes consistently improves performance: moisture and volatile matter (VM) decrease, while fixed carbon (FC) and higher heating value (HHV) increase. Among the three formulations, C (RSS 80% : Acacia 20%) performed best with moisture 7.40%, VM 9.56%, ash 4.47%, FC 85.95%, HHV 6,716.88 cal g⁻¹, and a burn rate 0.10 g min⁻¹ (slower, steadier combustion). B (70:30) ranked intermediate (moisture 7.67%; HHV 6,302.09 cal g⁻¹), while A (50:50) was the least favorable (moisture 10.61%; HHV 5,413.69 cal g⁻¹). With respect to standards, all compositions meet SNI 01-6235-2000 for HHV ($\geq 5,000$ cal g⁻¹), VM ($\leq 15\%$), and ash ($\leq 8\%$). For moisture ($\leq 8\%$), B and C comply, whereas A does not. Note that SNI 1683:2021 applies to wood charcoal (not briquettes); under those stricter thresholds, C is the closest to First-Quality criteria, while A and B remain below several limits. Overall, increasing the RSS (char) fraction is an effective strategy to produce briquettes with lower moisture and VM, higher FC and HHV, and more stable combustion, which are desirable for household fuel applications.

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