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Research Article

Quality Analysis of Biobriquettes Combination Ratio of Oil palm Frond and Water Hyacinth Waste with Durian Seed Flour Adhesive

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Abstract

This study investigates the production of biobriquettes from a mixture of oil palm frond waste and water hyacinth using durian seed flour as a sustainable adhesive. Biobriquettes were fabricated with varying mass ratios of oil palm frond to water hyacinth (25:75, 50:50, and 75:25) and adhesive concentrations (5%, 10%, 15%, and 20%). Durian seed flour was selected for its starch content, offering an eco-friendly alternative to conventional adhesive like tapioca flour without competing with food resources. Slow primary carbonization (pyrolysis) was employed as the fabrication method. The produced biobriquettes were analyzed for moisture content, ash content, volatile matter, fixed carbon, and calorific value. The optimal formulation was identified at a 75:25 ratio of oil palm frond to water hyacinth with 15% durian seed flour adhesive, yielding a moisture content of 5.91%, volatile matter of 13.97%, ash content of 3.05%, fixed carbon content of 77.07%, and a calorific value of 6,400.78 cal/g. These results demonstrate the potential of durian seed flour as an effective adhesive and highlight the feasibility of utilizing agricultural and invasive biomass wastes to produce high-quality, sustainable biobriquettes.

Keywords: biobriquette; carbonization; oil palm fronds; water hyacinth; durian seeds

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1. Introduction

Based on data from BPS (2023), Indonesia experiences an annual population growth rate of approximately 1.26%, resulting in an estimated increase of 3.4 million individuals per year [1]. This population growth contributes to a rising demand for energy, particularly petroleum and natural gas [2]. Fossil energy sources are becoming increasingly scarce, and their prices continue to rise. Consequently, there is a growing need to develop alternative renewable energy sources. Biomass is considered as a promising candidate due to its carbon-neutral characteristics and widespread availability [3]. Biomass is derived from organic materials, including wood, agricultural residues, and animal manure [4]. In Indonesia, one of the promising biomass sources is oil palm plantation waste, particularly oil palm fronds [5]. These fronds are characterized by high carbon content and similar cellulose and hemicellulose amounts compare to other softwoods but lower lignin content [6], along with calorific values ranging from 5,563 to 6,700 cal/g [7]. Similarly, water hyacinth is a potential co-material for biobriquette production due to its favorable carbon content and calorific value [8]. As an adhesive, durian seed flour is employed because of its physicochemical properties, which are comparable to those of tapioca flour, making it suitable for producing high-quality biobriquettes. Durian seed flour possesses a similar starch composition to tapioca flour, making it a viable alternative as an adhesive in biobriquette

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production. The amylose content in durian seed flour is 26.61%, closely aligning with the 20–27% range found in tapioca flour. Likewise, the amylopectin content in durian seed flour is 74.80%, compared to 83% in tapioca flour. Amylose contributes to the hardness of the adhesive, whereas amylopectin imparts adhesive properties [9]. Previous studies have utilized various adhesives, such as tapioca flour, jackfruit bark, and resin, in biobriquette production [10,11]. However, the application of durian seed flour as an adhesive remains underexplored. Durian seed flour exhibits similar starch characteristics to tapioca flour, particularly in amylose and amylopectin content, but is derived from organic waste, thus avoiding competition with food resources [12]. Therefore, this study aims to investigate the use of durian seed flour as a biobriquette binder and evaluate its performance in accordance with the Standar Nasional Indonesia (SNI) 1683:2021 standard.

This study aims to determine the highest calorific value of biobriquettes by investigating the effects of varying ratios of oil palm frond waste and water hyacinth, combined with different concentrations of durian seed flour as an adhesive. This research represents an innovative effort to utilize bioenergy as a sustainable alternative to reduce Indonesia's dependence on fossil fuels. The primary objective is to identify the ideal formulation that meets the quality criteria specified in the SNI 1683:2021 standard. To achieve this, the produced biobriquettes are analyzed for key parameters including moisture content, ash content, volatile matter, calorific value, and fixed carbon content, which collectively determine their overall quality and suitability for energy applications.

2. Experimental Method

2.1. Raw Materials and Equipment

The primary raw materials used in this study were oil palm fronds, water hyacinth from Danau Toba Island, durian seeds, and distilled water (H_2O). The equipment utilized for biobriquette production and analysis included Erlenmeyer flasks, beakers, measuring cups, stir bars, digital balance, bomb calorimeter (B-ONE Oxygen Bomb Calorimeter type BCM-20), sieves (mesh sizes 70, 100, and 140), thermometer, furnace (SAFTherm Laboratory Muffle Furnace type STM-3-12), tube clamps, oven, ball mill, porcelain cups, briquette molds, blender, and desiccator.

Table 1. SNI 1683:2021 for Quality Testing Biobriquette

Parameter	SNI Standard
Moisture content (%)	≤ 10
Ash content (%)	≤ 4
Fixed carbon (%)	≥ 77
Volatile content (%)	10 – 17
Calorific value (cal/g)	6,000 – 6,500

2.2. Experimental Design

The study involved varying the mass ratios of oil palm fronds to water hyacinth at 75:25, 50:50, and 25:75, alongside durian seed flour adhesive concentrations of 5%, 10%, 15%, and 20%. These variations aimed to determine the optimal formulation for producing high-quality biobriquettes.

2.3. Experimental Procedures

The manufacture of biobriquettes from oil palm frond waste and water hyacinth in this study involved several key stages, beginning with raw material preparation and culminating in the biobriquette molding process. Slow carbonization was employed as the primary thermal treatment method, optimized at 300 °C for oil palm fronds and 400 °C for water hyacinth. This approach was selected based on comparative evidence indicating that rapid carbonization tends to yield biobriquettes with higher ash content and lower fixed carbon levels [11]. Durian seed flour was prepared as a natural adhesive through a sequence of steps: durian seeds were peeled, cut into small pieces, and soaked in lime water for 24 hours to remove mucilage, followed by thorough washing. The soaked seeds were blended with distilled water at a 1:5 (w/w) ratio to form a slurry, which was filtered to separate the starch suspension. After settling for 24 hours, the clear supernatant was discarded, and the starch-rich sediment was sun-dried for 24 hours. The dried starch lumps were pulverized and passed through a 70-mesh sieve to obtain fine adhesive powder.

For biobriquette fabrication, dried and smoothened oil palm fronds were carbonized for 180 minutes at 300 °C, while water hyacinth was cleaned, sun-dried, and carbonized for 60 minutes at 400 °C. Both carbonized materials were ground and sieved through 100 and 140 mesh sieves to obtain fine charcoal powder. The powder was then mixed in varying ratios (25:75, 50:50, and 75:25) with durian seed adhesive at concentrations of 5%, 10%, 15%, and 20%. The resulting mixtures were molded using a hydraulic press at a compression pressure of 100 kg/cm^2. The molded biobriquettes were subsequently dried in an oven at 100 °C for 3 hours to remove residual moisture. This procedure was systematically repeated to evaluate the effects of different raw material ratios and adhesive concentrations on biobriquette quality.

3. Results and Discussion

3.1. Moisture Content Analysis

Moisture content analysis was conducted in accordance with the SNI 1683:2021 standard. Elevated moisture levels in biobriquettes negatively impact their quality, as a portion of the heating value is consumed to evaporate water, resulting in a lower flash point, slower combustion rate, and increased volume of flue gases [13]. The measured moisture content of biobriquettes produced from varying ratios of oil palm frond waste and water hyacinth, combined with different adhesive concentrations, is presented in Figure 1. As shown in Figure 1, the moisture content of the biobriquettes ranged from 5.28% to 6.94%. The highest moisture content was observed in the sample with a 25:75 ratio of oil palm frond waste to water hyacinth combined with 20% durian seed flour adhesive, while the lowest moisture content occurred in the 75:25 ratio with 5% adhesive concentration. All samples met the SNI 1683:2021 standard, which specifies a maximum moisture content of 10%. Compared to Saputra *et al.* [11], who utilized tapioca flour as an adhesive, the biobriquettes in this study exhibited lower moisture content, indicating that durian seed flour may contribute to moisture reduction and potentially enhance combustion efficiency. The increase in moisture content from 75:25 to 25:75 ratio correlates positively with a higher proportion of water hyacinth, which contains approximately 95,5% moisture content compare to oil palm fronds with only 10.10% in its fresh state [11,14]. High durian seed flour adhesive concentration resulted in higher moisture content, because water content in the adhesive infiltrating and binding within the pores of the charcoal matrix [15]. Elevated moisture content in biobriquettes can hinder ignition and reduce overall combustion performance [16]. For the lowest moisture content obtained was at ratio of 75:25 with the ideal adhesive concentration must below 20% to prevent rising of moisture content from water content that adhesive contain.

3.2. Ash Content Analysis

Ash content testing was conducted based on the SNI 1683:2021 standard. Ash content refers to the residual inorganic matter remaining after the complete combustion of biobriquettes and associated thermal degradation reactions. Elevated ash levels are generally detrimental to biobriquette quality, primarily due to their negative impact on calorific value [13]. As the ash content increases, the energy output of the briquettes decreases, reducing their combustion efficiency and overall performance as a fuel. According to SNI 1683:2021, the maximum ash content in charcoal briquettes is limited to 4%. The ash content observed in biobriquettes, produced from varying ratios of oil palm frond waste and water hyacinth with different concentrations of durian seed flour adhesive, is illustrated in Figure 2. Based on the data presented in Figure 2, the ash content of the biobriquettes produced in this study ranged from 2.65% to 5.05%. The highest ash content (5.045%) was observed in the sample with a 25:75 ratio of oil palm fronds to water hyacinth and an adhesive concentration of 20%. Conversely, the lowest ash content (2.65%) was recorded at a 75:25 ratio with a 5% adhesive concentration. According to the SNI 1683:2021 standard, which stipulates a maximum ash content of 4% for charcoal

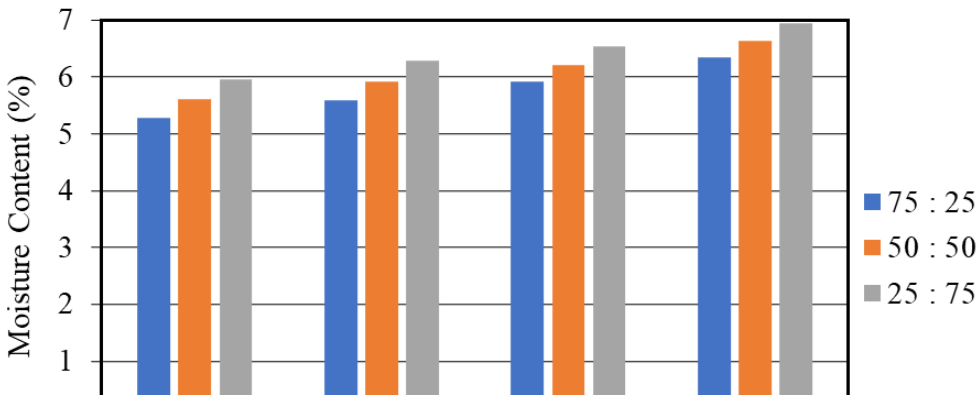

Figure 1. Effect of varying ratios of oil palm frond and water hyacinth waste combined with different concentrations of durian seed flour adhesive on the moisture content of biobriquettes.

briquettes, seven sample formulations in this study were found to be compliant. These included all adhesive concentrations (5%, 10%, 15%, and 20%) at a 75:25 ratio, yielding ash contents of 2.65%, 2.75%, 3.05%, and 3.28%, respectively, as well as the 50:50 ratio at 5%, 10%, and 15% adhesive concentrations, producing ash contents of 3.41%, 3.57%, and 3.85%, respectively.

The results indicate that ash content increases with a decrease in the proportion of oil palm fronds and an increase in both water hyacinth and adhesive content. This trend is attributable to the higher inherent ash content of water hyacinths, which is approximately 12%, thus contributing more residual minerals upon combustion. Additionally, the use of durian seed flour as an adhesive contributes to ash formation due to its content of non-combustible inorganic materials [17]. Elevated ash content negatively impacts the calorific value and combustion quality of biobriquettes and may lead to slagging and crust formation. When compared to the study by Saputra *et al.* [11], which utilized tapioca flour as an adhesive, the ash content observed in the present research is lower. This suggests that the use of a slow carbonization method was effective in minimizing combustion residues and enhancing the overall quality of the biobriquettes [18]. From the data above, the most optimum ash content results are obtained from 75:25 ratio with adhesive concentration within 15%. For ratio of 25:75 and adhesive concentration above 15% result does not meet the SNI requirement.

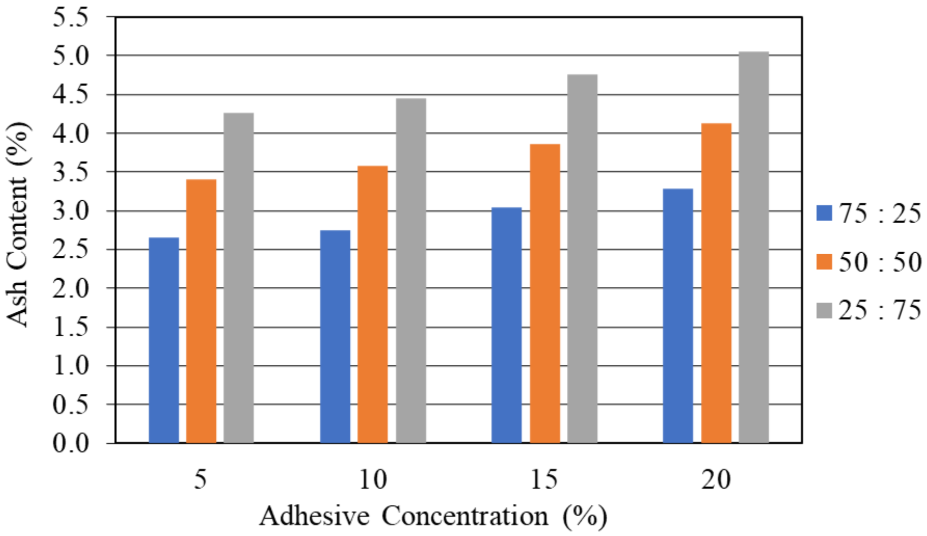

Figure 2. Effect of varying ratios of oil palm frond and water hyacinth waste combined with different concentrations of durian seed flour adhesive on the ash content of biobriquettes.

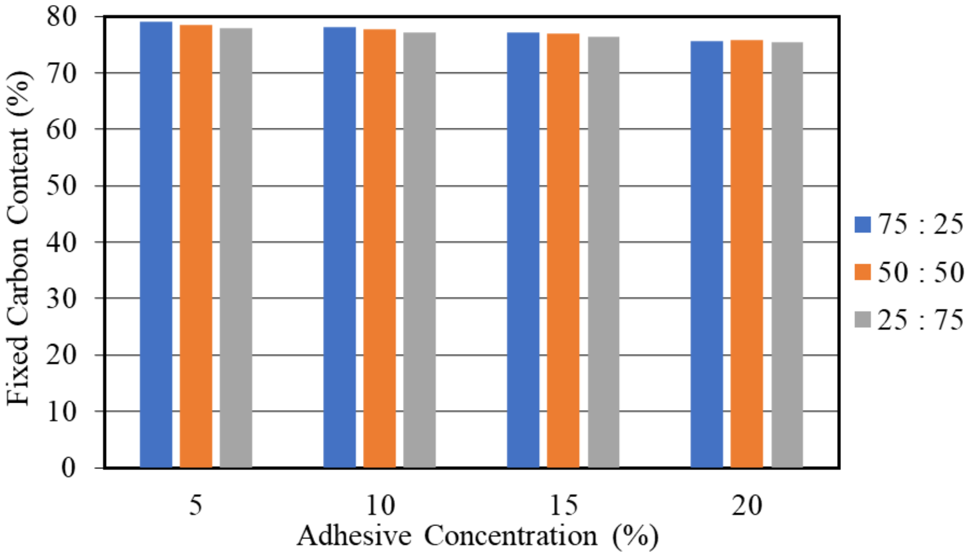

Figure 3. Effect of varying ratios of oil palm frond and water hyacinth waste combined with durian seed flour adhesive concentrations on fixed carbon content.

3.3. Fixed Carbon Content Analysis

Fixed carbon content testing was conducted in accordance with the SNI 1683:2021 standard. Fixed carbon represents the fraction of carbon remaining in the material after the removal of moisture, volatile matter, and ash through combustion. It serves as an important parameter in assessing the quality of activated carbon, as it reflects the amount of pure combustible carbon available in the material [19]. Determining the fixed carbon content provides insights into the energy potential and combustion stability of biobriquettes. The fixed carbon content of biobriquettes produced from varying ratios of oil palm frond and water hyacinth waste, combined with different concentrations of durian seed flour adhesive, is presented in Figure 3. Based on Figure 3, the fixed carbon content of the biobriquettes produced in this study ranges from 75.44% to 79.15%. The highest fixed carbon content was observed in the sample with a 75:25 ratio of oil palm frond waste to water hyacinth and a durian seed flour adhesive concentration of 5%. Conversely, the lowest fixed carbon content was found in the sample with a 25:75 ratio and an adhesive concentration of 20%. According to the SNI 1683:2021 standard for charcoal briquettes, the minimum acceptable fixed carbon content is 77%. In this study, eight formulations met or exceeded this threshold: a 75:25 ratio with adhesive concentrations of 5%, 10%, and 15%, yielding fixed carbon contents of 79.15%, 78.16%, and 77.07%, respectively; a 50:50 ratio with adhesive concentrations of 5%, 10%, and 15%, yielding 78.52%, 77.82%, and 77.01%; and a 25:75 ratio with adhesive concentrations of 5% and 10%, yielding 77.91% and 77.14%, respectively.

Compared to the study conducted by Balong *et al.* [20], the fixed carbon content in the present research was higher, indicating that the selected combination of raw materials and the application of the slow carbonization method effectively enhanced biobriquette quality. The increase in oil palm frond mass and reduction in durian seed flour adhesive concentration were found to positively correlate with higher fixed carbon content. This is attributed to the fact that increasing adhesive levels reduces the proportion of carbon-rich material in the formulation, consequently lowering the fixed carbon content [21]. Furthermore, the optimization of the carbonization process contributed significantly to achieving higher levels of fixed carbon in the biobriquettes. In this study, only 8 variables satisfied the SNI requirement of minimum fixed carbon content with the highest fixed carbon content was obtained at 75:25 oil palm frond waste to water hyacinth ratio with 5% adhesive.

3.4. Volatile Matter Content Analysis

Volatile matter content testing in this study was conducted in accordance with SNI 1683:2021. Volatile matter refers to the compounds released as vapor, excluding moisture, during the thermal decomposition of biomass. An increase in volatile matter content generally reduces the adsorption capacity of charcoal for liquids and gases, thus affecting its overall performance and quality [22]. According to SNI 1683:2021 standards for charcoal briquettes, the acceptable range for volatile matter content is 10% to 17%. In this research, biobriquettes were produced from varying ratios of oil palm frond waste and water hyacinth, combined with different concentrations of durian seed flour adhesive. The resulting volatile matter contents from these formulations are presented in Figure 4. Based on the Figure 4, the volatile matter content of the biobriquettes produced in this study ranged from 11.87% to 14.69%. The highest volatile matter content was

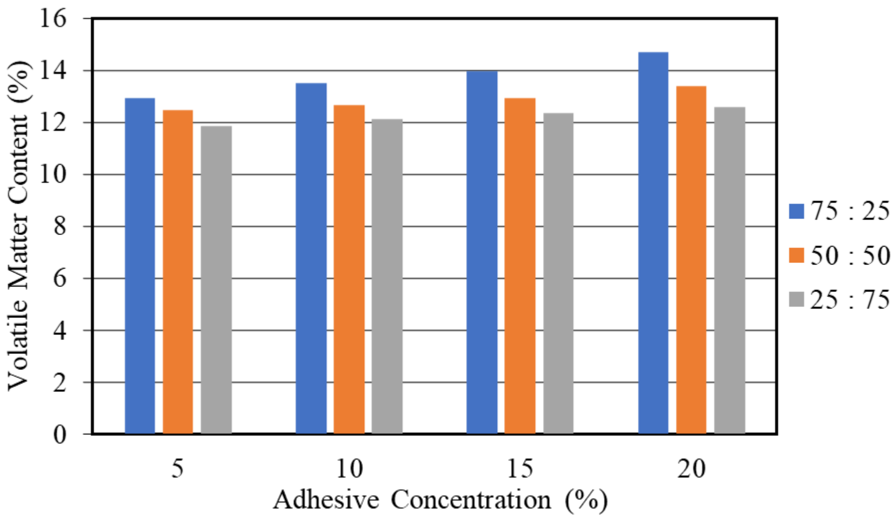

Figure 4. Effect of oil palm frond and water hyacinth waste ratio combined with durian seed flour adhesive content on the volatile matter content of biobriquettes.

recorded in the sample with a 75:25 ratio of oil palm frond waste to water hyacinth and an adhesive content of 20%, while the lowest was observed in the 25:75 ratio with 5% adhesive content. All biobriquette samples met the requirements set by SNI 1683:2021, which specifies an acceptable volatile matter range of 10–17%.

Compared to the findings of Balong *et al.* [20], the volatile matter levels in this study were lower, indicating that the biobriquettes produced are more thermally stable and exhibit improved combustion efficiency. The data also suggests that volatile matter content tends to increase with a higher proportion of oil palm frond waste and elevated levels of durian seed flour adhesive. This trend is likely due to the decomposition of organic compounds during heating, which involves the breaking of molecular bonds between atoms such as oxygen, nitrogen, and hydrogen. The volatilization of gases such as CO, CO_2, CH_4, and H_2 from the charcoal contributes to this effect. Additionally, the adhesive component plays a significant role; as its concentration increases, the quantity of volatile compounds released during combustion also rises [23], due to the thermal degradation of organic constituents in the durian seed flour. High volatile matter content is associated with increased smoke production during combustion, which can negatively impact air quality and combustion cleanliness [24]. The result above shown that the ideal composition for volatile content was 25:75 ratio and adhesive concentration within 15% because volatile content rise significantly at 20% adhesive.

3.5. Calorific Value Analysis

The determination of calorific value is a critical parameter in assessing the quality of biobriquettes as a fuel source, as it directly reflects the energy content released during combustion. A higher calorific value indicates superior fuel quality, as it correlates with greater heat output per unit mass [13]. In this study, calorific value was measured under constant volume conditions, where the heat released from the combustion of a biobriquette sample was used to increase the temperature of a known quantity of water. The calorific value was then calculated based on the resulting temperature change.

According to the Indonesian National Standard (SNI) 1683:2021, a high-quality charcoal briquette should possess a calorific value ranging from 6,000 to 6,500 cal/g. The calorific values of biobriquettes produced using different ratios of oil palm frond waste and water hyacinth, along with varying concentrations of durian seed flour adhesive, are presented in Figure 5. This evaluation serves as a key indicator of the fuel performance and efficiency of the produced biobriquettes. Based on Figure 5, the calorific values of the biobriquettes produced in this study range from 5,012.84 cal/g to 6,400.78 cal/g. The highest calorific value was observed in the sample with a 75:25 ratio of oil palm frond waste to water hyacinth and an adhesive content of 15%. Conversely, the lowest calorific value was recorded for the 25:75 ratio with 5% adhesive. According to SNI 1683:2021, the acceptable range for calorific values in charcoal briquettes is 6,000–6,500 cal/g. In this study, seven sample variations met or closely approached this standard, specifically in ratio of 75:25 at adhesive concentrations of 10%, 15%, 20%, with calorific

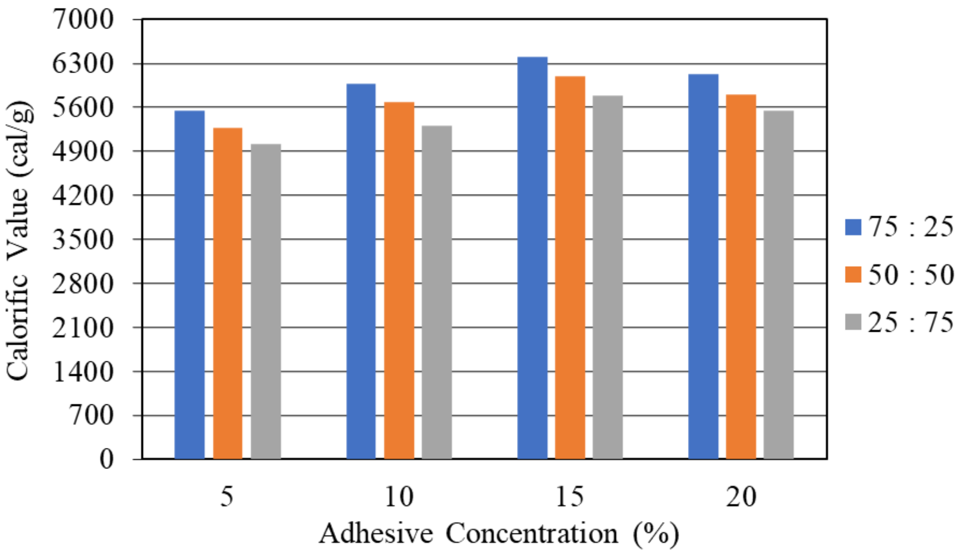

Figure 5. Influence of oil palm frond and water hyacinth waste ratios combined with durian seed flour adhesive content on the calorific value of biobriquettes.

values of 5,974.34 cal/g, 6,400.78 cal/g, 6,138.15 cal/g and ratio of 50:50 at adhesive concentrations of 10%, 15%, 20% with calorific values of 5,689.86 cal/g, 6,101.83 cal/g, 5,813.36 cal/g. Additionally, a 25:75 ratio with 15% adhesive yielded a calorific value of 5,790.41 cal/g.

Compared to previous studies by Saputra *et al.* [11] and Balong *et al.* [20] the biobriquettes in this research exhibited higher calorific values, indicating enhanced combustion efficiency. The calorific value increased with higher proportions of oil palm frond waste and adhesive content, up to an optimal adhesive concentration. This trend is attributed to the inherently higher calorific value of oil palm fronds (5,863 cal/g) compared to water hyacinth (approximately 4,049 cal/g). Furthermore, the adhesive content influenced calorific performance, with values rising from 5% to 15% adhesive but declining at 20%. This calorific value is similar to Pranaya *et al.* [10] studies using resin for adhesive which also got the best calorific value at 15% and declining from 20%, so it can be concluded that 15% adhesive with the composition of 75:25 ratio are optimal for maximizing calorific output in this formulation [10].

From all of the biobriquette parameter analysis, the most important parameter was calorific values. Calorific value determines the amount of energy that biobriquette contained as a fuel. High calorific value also extend the duration of biobriquettes burning time [18]. While the other parameters, such as moisture content, ash content, fixed carbon content, and volatile content, compliment the physique characteristic like the ignition time, amount of smoke, and residue of the biobriquettes.

To highlight the advantages of the biobriquettes developed in this study, a comparative analysis of key performance parameters was conducted against those reported in previous studies. The evaluated parameters include moisture content, ash content, fixed carbon content, volatile matter content, and calorific value. This comparison provides insight into the effectiveness of the raw material combination oil palm frond and water hyacinth and the use of durian seed flour as an adhesive. Data from this study are assessed alongside results from earlier research employing different feedstocks and adhesive materials, enabling a comprehensive evaluation of biobriquette quality and performance. The comparative data are summarized in Table 2.

Based on the comparison with previous studies, the results of this research demonstrate that durian seed flour, an organic waste material, serves as an effective adhesive alternative for biobriquette production. Compared to adhesives such as tapioca flour, durian seed flour contributes to higher fixed carbon content and lower ash content in the briquettes. Additionally, water hyacinth—an invasive aquatic weed—can be effectively utilized as a raw material when combined with oil palm frond waste, which possesses a high calorific value. This combination results in biobriquette characteristics that comply with SNI 1683:2021 standards. Furthermore, the application of the slow carbonization method in this study significantly reduced the moisture and volatile matter content of the raw materials [25], thereby enhancing the combustion efficiency as reflected in the increased calorific value.

The optimal formulation identified in this study consists of a raw material ratio of 75:25 (oil palm fronds to water hyacinth) and an adhesive concentration of 15%, yielding the highest calorific value of 6,400.78 cal/g. This finding suggests a promising pathway for the valorization of agricultural and organic waste, such as durian seeds and water hyacinth, by combining them with high-carbon biomass like oil palm fronds to produce high-quality biobriquettes. Such biobriquettes not only meet national standards but also have the potential for commercial application.

4. Conclusion

This study demonstrates the successful production of biobriquettes using a combination of oil palm frond waste and water hyacinth, with durian seed flour serving as a novel adhesive. The resulting biobriquettes exhibited favorable characteristics, with moisture content ranging from 5.28% to 6.94%, ash content from 2.66% to 5.05%, fixed carbon content from 75.44% to 79.15%, volatile matter content from 11.87% to

Table 2. Comparative biobriquettes characteristics with previous research.

Parameter	SNI Standard	This Study	Tapioca flour [11]	Water hyacinth [20]	Resin [10]
Moisture Content (%)	≤ 10	5,28 - 6,94	0 – 8.56	11.85 – 12.65	7.37 – 8.16
Ash Content (%)	≤ 4	2,65 - 5,05	6.84 – 7.48	17.95 – 18.55	7.60 – 9.62
Fixed Carbon Content (%)	≥ 77	75,44 - 79,15	47.64 – 52.10	18.20 – 18.75	-
Volatile Matter (%)	10 – 17	11,87 - 14,69	36.96 – 40.42	50.65 – 51.40	8.50 – 19.00
Calorific Value (cal/g)	6,000 – 6,500	5,012.84 – 6,400.78	5,361 – 5,863	3,725.07 – 4,240.28	5,392.50 – 5,003.00

14.69%, and calorific values between 5,012.84 cal/g and 6,400.78 cal/g. The optimal formulation—identified as a 75:25 ratio of oil palm frond to water hyacinth with 15% durian seed flour adhesive—produced biobriquettes obtained the highest calorific value among all experiment variables and other properties that most closely meet the Indonesian National Standard (SNI 1683:2021). This composition yielded a moisture content of 5.92%, volatile matter of 13.97%, ash content of 3.05%, fixed carbon of 77.07%, and the highest calorific value of 6,400.78 cal/g.

Compared to previous studies utilizing conventional adhesives such as tapioca flour, durian seed flour resulted in biobriquettes with higher fixed carbon and lower ash content, indicating improved fuel quality. The use of water hyacinth—an invasive aquatic species—in combination with high-calorific biomass such as oil palm fronds also contributed to enhanced performance, demonstrating the feasibility of converting problematic or waste materials into a valuable energy resource. Furthermore, the application of a slow carbonization method effectively reduced the moisture and volatile matter content of the raw materials, thereby improving the combustion efficiency and overall quality of the biobriquettes. These findings not only validate the potential of durian seed flour as a sustainable adhesive but also highlight a promising route for the utilization of agricultural and invasive biomass wastes in the production of environmentally friendly and economically viable solid biofuels.

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CRedit Author Statement

Author Contributions: Mersi Suriani Sinaga: Supervision, Funding acquisition; Rondang Tambun: Project administration; M. Tjung: Conceptualization, Methodology, Resources, Writing - Review and Editing, Visualization; D.O. Sitinjak: Conceptualization, Validation, Investigation, Formal analysis, Writing - Original Draft. All authors have read and agreed to the published version of the manuscript.

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