Rice Husk Derived Biomass Briquettes for Boilers: Ingredient-Based Product Quality Study

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ABSTRACT

This research investigates the feasibility of repurposing rice husk waste into sustainable biomass briquettes, addressing environmental and economic challenges associated with conventional biomass sources in Sri Lanka. The study involves a comprehensive analysis of rice husk utilization, focusing on three size fractions: original size, particles less than 5mm, and powder form. Rice husks less than 5mm was observed to have a composition of optimal fixed carbon content (11.63% ± 0.215), moisture content (10.53% ± 0.013), volatile matter (80.72% ± 0.005), and ash content (7.65% ± 0.004). The binding agents, namely starch, *dummala* tree resin, and wastepaper pulp, were used for briquette production. The optimal compositions for briquettes made with rice husk particles less than 5mm were determined as follows: rice husk with starch (1:6), rice husk with tree resin (1:7), and rice husk with wastepaper pulp (1:5). The calorific values of these optimum briquettes were found to be 15.446 MJ/kg for starch-based briquettes, 15.278 MJ/kg for paper pulp-based briquettes, and 15.323 MJ/kg for tree resin-based briquettes. In addition, briquettes made with an equal ratio (1:1) of binders showed calorific values of 14.175 MJ/kg for starch, 14.227 MJ/kg for paper pulp, and 15.275 MJ/kg for tree resin, with tree resin-based briquettes exhibiting the highest calorific value. In the product quality evaluation study carried out with these results, the proximate and ultimate analyses were conducted to characterize the briquettes and the thermogravimetric analysis (TGA) was conducted to characterize the rice husk and to examine the physical properties of the produced briquettes. The findings indicate that repurposing rice husk waste with various binding agents offers a sustainable solution for biomass fuel production. Accordingly, natural tree resin briquettes exhibited the highest density, compression ratio, and shatter resistance. These results suggest that utilizing natural tree resin can effectively address waste management challenges and create an environmentally friendly and economically viable industrial sector in Sri Lanka.

KEYWORDS: *Binding agents, Biomass briquettes, Calorific value, Waste management*

1 INTRODUCTION

Industrial biomass boilers play a crucial role in meeting the energy demands of production processes in Sri Lanka. With approximately 400 biomass boilers currently operational, the daily steam demand is satisfied by consuming around 3200 metric tons of biomass, predominantly sourced from well-grown trees, especially rubber wood (Arachchige and Sandupama, 2019). Reliance on conventional biomass, particularly in the form of trees, raises environmental concerns, contributing to the severe issue of deforestation in Sri Lanka (Nuwantha et al., 2022). In addressing these environmental challenges, the focus of this research on the exploration of an alternative biomass source – rice husk waste. Sri Lanka's extensive rice cultivation, covering 910,500 hectares and yielding approximately 3.2 million tons of rice annually, presents a significant opportunity for utilizing rice husks as a valuable raw material. The potential annual energy yield from rice husks alone could effectively meet the 246 days of steam demand in the country (Arachchige and Sandupama, 2019).

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Biomass, a widely consumed fuel source, poses sustainability challenges such as deforestation and resource depletion (Dinesha et al., 2019). This research acknowledges the existing environmental strain associated with biomass usage and aims to provide a transformative solution. The research endeavors to develop eco-friendly biomass briquettes as a sustainable alternative by focusing on waste utilization, specifically repurposing rice husk waste. Biomass residues available for manufacturing briquettes are mainly of two categories: crop-based waste residues and municipal-based waste residues. Crop base residues are unusable materials after the harvesting of useful crops. Rice husk belongs to this category (Dinesha et al., 2019). The significance of repurposing rice husk waste lies in not only addressing the critical issue of waste management but also reducing dependence on conventional biomass sources. This dual benefit contributes to environmental sustainability while mitigating strain on biomass resources. In Sri Lanka, biomass is a major fuel source, with abundant resources like agricultural waste (Perera et al., 2005). Despite this abundance, efficient utilization remains a challenge, leading to environmental pollution. By considering biomass waste, including rice husk, as alternative fuel sources, the aim is to elevate the value of these products beyond mere agricultural waste (Onochie et al., 2020).

Furthermore, the potential for utilizing biomass waste as an income source for rural residents and small-scale entrepreneurs is highlighted. This approach could offer substantial employment opportunities for youths, contributing to improved living standards for impoverished communities (Romallosa & Hornada, 2012). The research, therefore, not only aligns with responsible waste management but also presents a practical solution to reduce the environmental impact of biomass consumption, ultimately promoting a more sustainable industrial sector in Sri Lanka.

This research aims to assess the feasibility of utilizing rice husk waste to develop biomass briquettes with proper binding agents, providing a cost-effective and environmentally sustainable alternative for industrial biomass boilers in Sri Lanka. The research intends to identify suitable binding agents for creating efficient rice husk briquettes, with an emphasis on selecting proper binding agents. Additionally, it seeks to design and optimize the composition of rice husk briquettes to ensure high combustion efficiency and handling convenience.

2 MATERIALS AND METHODS

This section provides an overview of the materials utilized in the experiment and explains the scientific methodologies employed in the study.

2.1 Materials

Rice husks, sourced from a local rice mill, were transported to the laboratory in clean conditions to avoid contamination and stored in dry, ventilated, clearly labeled containers. Binding agents were chosen for their functional roles in briquette production and environmental sustainability: starch was obtained from a local flour mill where it is typically discarded as waste; wastepaper was sourced from the University of Sri Jayewardenepura, where it accumulates as a by-product of academic activities; and natural tree resin was collected from the *dummala* tree (*Shorea oblongifolia*), with the resin thickening upon contact with air and gathered from the trunk and branches.

2.2 Sample Preparation

A domestic electric grinder/blender was employed to crush the coarse particles of rice husk, and the pulverized particles were subsequently separated by using a 5mm mesh. Three binding agents were utilized in this study, including starch and paper pulp, commonly used in literature (Lubwama et al., 2022; Mckendry, 2002; Obi et al., 2022; Shyamalee et al., 2015; Tamilvanan, 2013) for comparison with tree resin. Figure 1 depicts the three binding agents after they have been prepared.

Starch: Wheat flour served as the starch in this investigation. The wheat flour was measured and mixed with water at a ratio of 50 ml of water per 10 grams of wheat flour. This mixture was then heated on a heating plate and boiled until the starch reached a gelatinous consistency. (Figure 1a) Subsequently, it was poured over the rice husk and thoroughly mixed.

Wastepaper Pulp: Paper was weighed based on the weight ratio of the sample used. For every 10 grams of paper, 100 ml of water was added. The mixture was left to soak until the paper softened in the water. Then, the softened paper was thoroughly mixed with water to achieve a homogeneous paper pulp mixture, which was later combined with the rice husk.

Natural Tree Resin: The resin obtained from '*dummala*' trees was fragmented into small pieces, and 20 grams of these pieces were mixed with 5 ml of vegetable oil. The mixture was then melted on a heating plate at 200 degrees Celsius to form the resin. (Figure 1c) Subsequently, the melted resin was poured over the rice husk and meticulously mixed to ensure uniform distribution. Rice husk and binding agents were combined in ratios starting from 1:1 onwards.

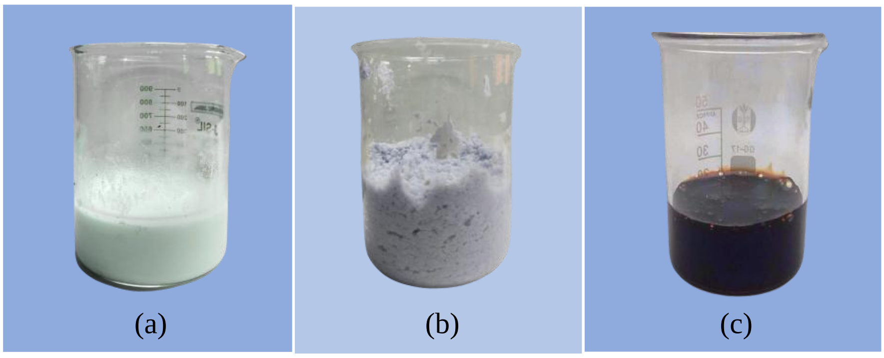

Figure 1. Photograph of (a) Starch (b) Paper pulp (c) Natural tree resin

2.3 Briquette Production

A small hand-operated machine was used in producing briquettes to apply pressure on the substrate. (Figure 2) The feed material was filled into the mould until it reached a height of 8 cm, after which it was compressed to 4 cm. Sample briquettes were manufactured at medium pressure and ambient temperature conditions. Subsequently, the produced briquettes were air-dried for one week. The resulting briquettes exhibited a cylindrical shape with a central hole, as depicted in Figure 3. According to (Danlami et al., 2023; Thabuot et al., 2015), incorporating a central hole in cylinder-shaped briquettes enhances combustion efficiency. This design feature promotes airflow, facilitating improved combustion and better air circulation underneath the briquette.

Figure 2. Hand-operated briquette machine

Figure 3. Holey cylindrical briquettes

2.4 Raw Material Analysis

The raw material analysis in this section involved evaluating the rice husk samples to determine their suitability for biomass briquette production.

2.4.1 Thermogravimetric Analysis (TGA) of the Rice Husk

The thermal behaviour of rice husk was investigated using TGA conducted on a simultaneous thermal analyser model STA 449F3. The TGA analyses were performed over a temperature range of 25 to 420°C, with a heating rate of 10°C/min, under both oxidizing (O_2) and inert (N_2) atmospheres. Gas flow rates of 30 mL/min were maintained for both O_2 and N_2 environments. Each rice husk sample utilized for the TGA analysis was prepared with a mass of 10 mg. This experimental setup allowed for a comprehensive examination of rice husk's thermal degradation and decomposition characteristics under varying atmospheric conditions, providing valuable insights into its thermal stability and behaviour in different environments.

2.4.2 Drying Curve Analysis of the Rice Husk

The drying curve analysis was conducted to characterize the moisture removal process of the rice husk samples. First, the samples were weighed to determine their initial moisture content. Subsequently, the samples were dried at a controlled temperature using a drying oven. The weights of the samples were recorded at regular intervals (0, 30, 60, 90, 120, 150, and 180 minutes) over time to track changes in the moisture content. The drying curve was then constructed based on the recorded data points to visualize the moisture removal rate and the drying progression. This analysis provided valuable insights into the kinetics of moisture removal and the effectiveness of the drying process in reducing the moisture content of the rice husk samples.

2.5 Proximate Analysis of the Briquettes

The proximate analysis, a standardized procedure providing insight into the fuel's bulk components, was conducted to determine the average percentage of volatile matter content, ash content, moisture content, and fixed carbon content of the briquettes obtained from four replicates. The procedures outlined in ASTM standard D5373-02 (2003) were adopted to obtain the following parameters (Efomah & Gbabo, 2015).

2.5.1 Percentage Moisture Content

The percentage moisture content (PMC) of the briquette samples was determined by initially weighing 2g of the sample (E) and subsequently subjecting it to oven drying at 105°C until the mass of the sample reached a constant value. The weight change (ΔD) after 60 minutes of drying was then utilized to calculate the sample's PMC using the following equation 1:

$$PMC = \frac{\Delta D}{E} \times 100\% \quad (1)$$

2.5.2 Percentage Volatile Matter

The briquette samples' volatile matter percentage (PVM) was determined using a muffle furnace. Initially, 2g of each sample was pulverized in a crucible and then placed in the muffle furnace until a constant weight was achieved. Subsequently, the briquettes were subjected to the furnace at a temperature of 550°C for 10 minutes and then weighed after cooling in a desiccator. The PVM was calculated using the equation 2:

$$PVM = \frac{A-B}{A} \times 100\% \quad (2)$$

Where A represents the weight of the oven-dried sample, and B represents the weight of the sample after being subjected to the furnace at 550°C for 10 minutes.

2.5.3 Percentage Ash Content

The briquette samples' percentage ash content (PAC) was determined using a furnace set at a temperature of 550°C. Initially, 2g of each briquette sample was heated in the furnace for 4 hours. After the heating process, the samples were allowed to cool in a desiccator, and the weight of the resulting ash (C) was obtained. The PAC was then calculated using the equation 3:

$$PAM = \frac{C}{A} \times 100\% \quad (3)$$

Where C represents the weight of the ash obtained after heating the sample, and A represents the initial weight of the briquette sample.

2.5.4 Percentage Fixed Carbon

The percentage fixed carbon (PFC) of the briquette samples was computed using the equation 4:

$$PFC = 100\% - (PAC + PVM) \quad (4)$$

2.6 Ultimate Analysis of the Briquettes

The elemental composition of the briquettes was estimated based on the proximate analysis using the equations 5-7 derived by (Obi et al., 2017):

$$C = 0.637PFC + 0.455PVM \quad (5)$$

$$H = 0.052PFC + 0.062PVM \quad (6)$$

$$O = 0.304PFC + 0.476PVM \quad (7)$$

These equations allowed for the estimation of the carbon (C), hydrogen (H), and oxygen (O) content of the briquettes, providing valuable insights into their elemental composition and potential energy yield.

2.7 Physical Characteristics Determination

Several types of briquettes were fabricated using various ratios of raw materials and binding agents, starting from a 1:1 ratio and onwards. The selection of briquettes with optimal ratios was determined based on their shatter resistance.

2.7.1 Shatter Resistance of the Briquettes

Shatter resistance testing was conducted to evaluate the durability of the briquettes. This involved subjecting each briquette to drop tests, wherein the briquette was lifted to a height of 2 meters and then released to fall freely onto a paper placed on a concrete floor. The weight of the briquette before and after the drop was measured, and the weight ratio after dropping was recorded. Shatter resistance was calculated using the following equations 8-9:

$$Percentage\ weight\ loss\% = \frac{W1-W2}{W1} \times 100\% \tag{8}$$

$$Shatter\ resistance\% = 100 - Percentage\ weight\ loss \tag{9}$$

The variables W1 and W2 represent the weights of the briquette before and after shattering, respectively, measured in grams.

2.7.2 Density and Compression Ratio Determination

The loose bulk density (BD) of the rice husk was determined according to the method described by (Igbo, 2016), while the density of the briquettes was calculated by measuring the mass and volume of the briquettes and using equations 10-11:

$$BD = \frac{mass\ of\ rice\ husk}{volume\ of\ rice\ husk} \tag{10}$$

$$Density = \frac{mass\ of\ briquette}{volume\ of\ briquette} \tag{11}$$

The mass was obtained using a digital weighing scale, while the volume was calculated by taking the dimensions of the cylindrical briquettes (radius and height). The volume of the formed briquette was obtained by applying the formula for the volume of a cylinder ($\pi h\ (r_1^2 - r_2^2)$). The compression ratio of briquettes for all the raw material combinations was determined using equation 12:

$$Compression\ ratio = \frac{density\ of\ briquette}{density\ of\ raw\ material} \tag{12}$$

2.8 Combustion Analysis

The combustion analysis involved evaluating various parameters such as ignition time, burning rate, and calorific value of the briquettes.

2.8.1 Calorific Value Determination

Aspen Plus software was utilized to determine the calorific value of biomass briquettes. Since these briquettes lack a fixed chemical formula due to varying compositions based on raw materials, they were introduced as non-conventional inlet streams in Aspen Plus. Proximate and ultimate analysis data, obtained from laboratory analysis, were provided as input parameters, allowing the software to calculate the calorific value accurately.

A new simulation was created in Aspen Plus, where biomass was defined as a non-conventional component by selecting 'NC Solid'. The proximate analysis data included moisture content, volatile matter, ash content, and fixed carbon, while the ultimate analysis data included elemental composition percentages for carbon (C), hydrogen (H), and oxygen (O). These values were inputted into the software. The 'IDEAL' property method was chosen to ensure an accurate representation of biomass behavior during combustion. A heater block was added to the process flow diagram to simulate the combustion process, configured with appropriate temperature and pressure settings corresponding to typical biomass combustion conditions.

The calculation was executed, and Aspen Plus used the input data to develop the reaction mechanism for biomass combustion. Upon completion, the calorific value was retrieved from the output results, successfully determining the calorific value of the biomass briquettes using Aspen Plus. A heater block was added to the process flow diagram to simulate the combustion process as shown in Figure 4.

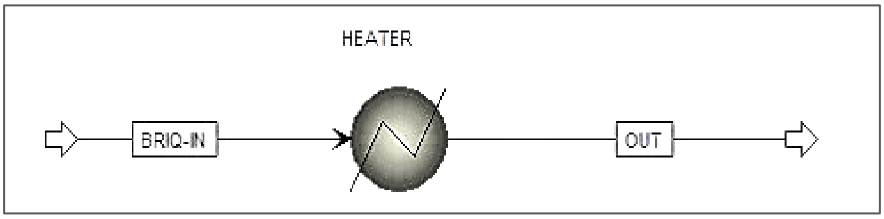

Figure 4. Operating conditions of the heater in Aspen plus software design

2.8.2 Determination of Ignition Time and Burning Rate

The ignition time of the produced briquettes was determined simultaneously with the burning rate experiment. A weight of 50 g of the briquette sample was placed on the stand and ignited using a candle. The stopwatch was started once the candle was ignited, and the ignition time was recorded.

The burning rate of the produced briquettes was determined using a handmade insulated stand. A weight of 50 g of the briquette sample was placed on the stand and ignited. The stopwatch was started once the sample began to burn. After the briquette sample was completely burned, the weight of the remains was measured. The weight loss at a specific time was calculated using Equation 13.

$$Burning\ rate \ = \frac{W3-W4}{T} \tag{13}$$

In the equation, (W3) represents the initial weight of the briquette sample in grams, (W4) denotes the final weight of the fuel after burning in grams, and (T) signifies the total burning time in minutes.

3 RESULTS AND DISCUSSION

In this section, the findings of the experiments conducted and their implications are examined and discussed.

3.1.1 Proximate and Ultimate Analysis of the Raw Material

The Table 1 summarizes the key findings from the proximate and ultimate analysis of the rice husk:

Table 1. Proximate and ultimate analysis of the rice husk

Rice husk type	Moisture (%)	Volatile Matter (%)	Ash (%)	Fixed Carbon (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)
Original size	10.97	85.89	6.49	7.62	43.93	5.72	43.20
<5 mm	10.53	80.72	7.65	11.63	44.14	5.61	41.96
Powder	9.32	73.13	9.53	17.33	44.32	5.44	40.08

Although the fixed carbon value was highest in powder form, practical considerations were taken into account. When 40g of the powder form is crushed for 5 minutes, only 16g of usable powder is obtained, with approximately 60% being removed as waste. In contrast, rice husk particles less than 5mm can be processed more efficiently, with 100% of the material being usable within the same 5-minute timeframe.

The proximate and ultimate analyses of rice husk particles that are each less than 5mm reveals promising characteristics for biomass briquette production. Compared to the original size, the <5mm particles show a slight decrease in moisture content, suggesting improved suitability for processing. Despite a reduction in volatile matter compared to the original size, it remains higher than the powdered form, indicating favourable combustion properties. The ash content remains consistent across different particle sizes. Notably, the fixed carbon content significantly increases in <5mm particles, enhancing the briquettes' energy density and combustion efficiency. This underscores the potential of <5mm rice husk particles as an effective raw material for biomass briquette production despite challenges in grinding.

3.1.2 TGA of the Raw Material

The TGA of rice husks under a nitrogen (N_2) atmosphere reveals distinct weight loss regions corresponding to different stages of decomposition (Figure 5). From 28.73°C to 173.99°C, a minor weight loss of 7.116% is observed, likely attributed to removing moisture and volatile organic compounds in the sample. Subsequently, between 173.99°C and 349.30°C, a significant weight loss of 26.583% is recorded, indicative of the thermal degradation of organic components within the rice husk. This decomposition process peaks around 349.30°C, with the highest weight loss rate. Beyond 349.30°C, up to 394.85°C, a further weight loss of 7.276% is observed, likely representing the decomposition of residual organic matter and char formation. These findings align with typical biomass decomposition profiles and provide insights into the thermal behaviour of rice husks under an inert N_2 atmosphere.

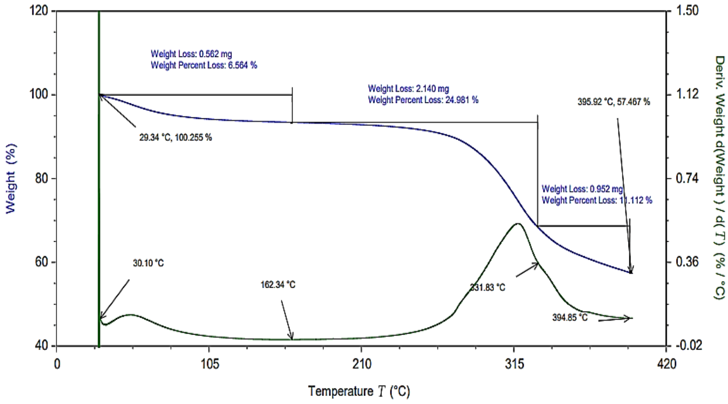

Figure 5. The TGA of rice husks under a nitrogen (N_2) atmosphere

In contrast with the N_2 atmosphere, the TGA analysis of rice husks under an oxygen (O_2) atmosphere exhibits similar decomposition patterns but with some notable differences (Figure 6). The initial weight loss observed between 30.10°C and 162.34°C amounts to 6.564%, indicating the removal of moisture and volatile organic compounds. The subsequent decomposition stage, spanning from 162.34°C to 331.83°C, results in a significant weight loss of 24.981%, reflective of the thermal breakdown of organic constituents. Unlike under N_2, the decomposition process under O_2 may involve additional oxidative reactions, contributing to a more pronounced weight loss. Beyond 331.83°C, up to 394.85°C, the weight loss decreases slightly to 11.112%, possibly due to the combustion of char and remaining organic matter. These observations highlight the surrounding atmosphere's influence on a rice husk's thermal degradation behaviour, with oxygen facilitating more extensive decomposition through oxidative pathways.

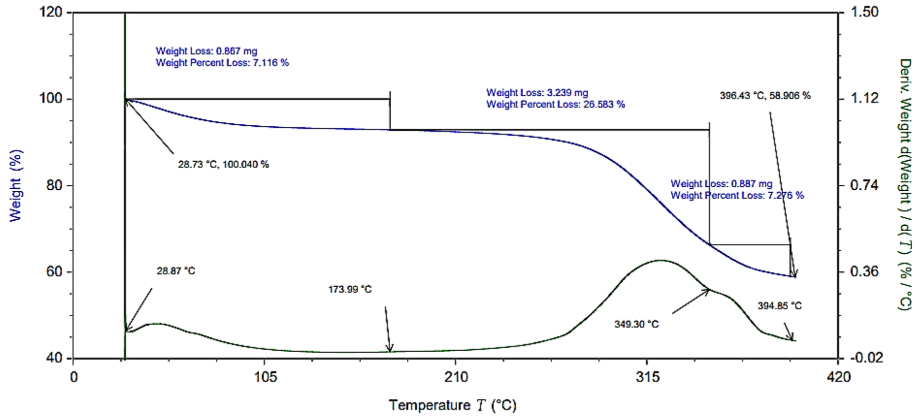

Figure 6. The TGA analysis of rice husks under an oxygen (O_2) atmosphere

3.1.3 Drying Curve Analysis of the Rice Husk

The drying curve analysis for the rice husk, as depicted in Figure 7, provides detailed insights into the weight reduction of the samples over a period of 200 minutes. Initially, the samples weighed approximately 4.50 grams. As the drying process commenced, there was a rapid decline in weight, indicating significant moisture loss during the initial stages. Accordingly, at the 120-minute mark, the weight of the samples reached a stable point of 4.16 grams. The overall moisture content of the samples was thus determined to be 7.15%.This stability level indicates that the majority of the easily removable moisture had evaporated by this time, and the drying process had reached a phase where the rate of weight loss significantly slowed down. This stable point is crucial as it represents a transition in the drying kinetics, from rapid moisture loss to a more gradual drying process where bound moisture is removed.

As the drying progresses past the 120-minute mark, the rate of weight loss decreases, which is reflected by the gradual flattening of the curve. This change indicates that the remaining moisture content is bound within the structure of the biomass and requires more energy and time to be removed. The final weight stabilizes around 4.16 grams, showing that most of the moisture content has been eliminated by the end of the drying period.

The moisture content of 7.15% in the samples is a critical parameter, especially for biomass briquettes used as a fuel source. Lower moisture content in biomass is found to enhance its calorific value, making it more efficient for combustion.

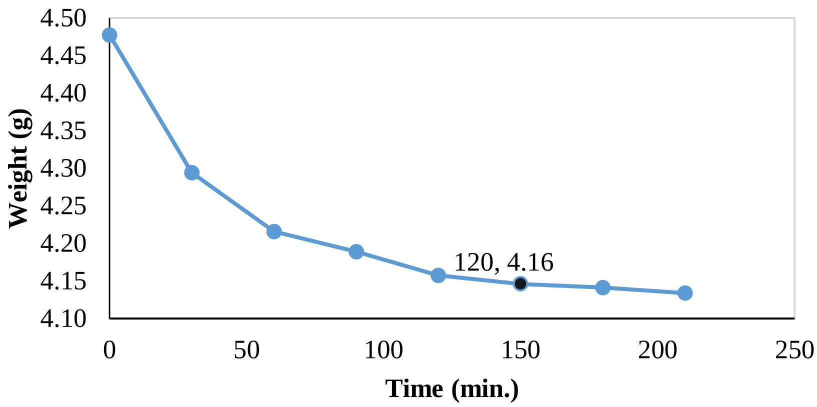

Figure 7. Drying curve analysis of the rice husk

3.1.4 Physical Properties of the Briquettes

Briquettes were produced using different ratios, with optimal compositions determined as follows: Rice Husk with Starch (1:6), Rice Husk with tree resin (1:7), and Rice Husk with Wastepaper Pulp (1:5). The most resilient composition was selected based on shatter resistance. Refer to Figure 8 below for further details.

The physical properties of rice husk briquettes prepared with different binders are presented in Table 2. The density of the briquettes is a key indicator of their potential performance as a fuel source. Tree resin briquettes exhibited the highest density at 834.00 kg/m³, suggesting a more compact and energy-dense product. This high density is accompanied by the highest compression ratio of 7.13, indicating that tree resin is the most effective binder in terms of producing tightly packed briquettes. In contrast, paper pulp briquettes had a density of 551.24 kg/m³ and a compression ratio of 4.71, representing a moderate level of compaction and durability. Starch briquettes, with the lowest density of 504.20 kg/m³ and a compression ratio of 4.31, are the least dense and compact, potentially impacting their efficiency and stability during handling and combustion.

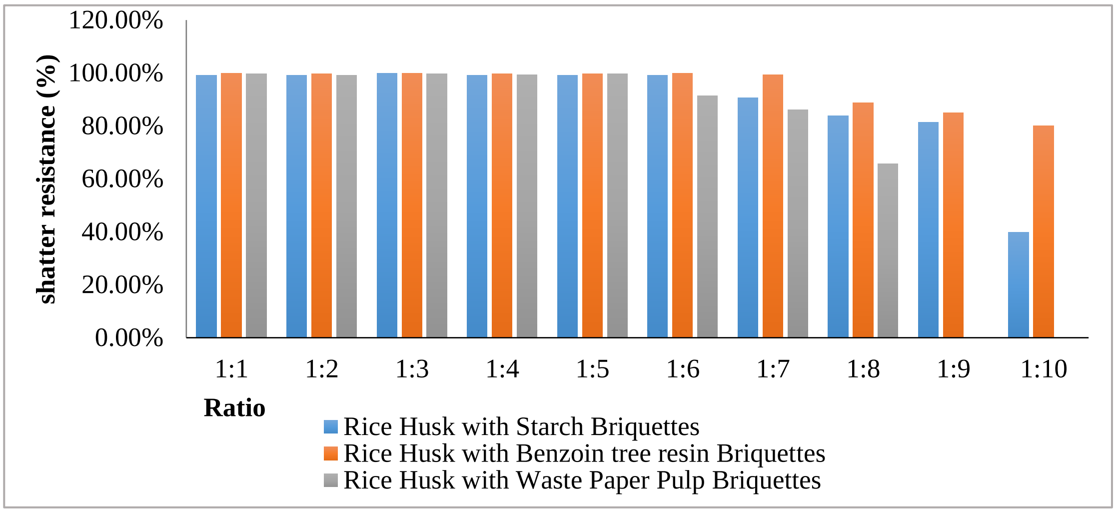

Figure 8. Shatter resistance of the briquettes with different binding agents

Although the volume of the briquettes is fairly consistent across all samples, ranging from 6.606×10^{-5} to 6.389×10^{-5} m^3, there is a notable difference in mass, with tree resin briquettes being the heaviest at 0.053 kg, followed by paper pulp at 0.036 kg and starch at 0.033 kg. This variation in mass directly contributes to the differences in density and compression ratios observed among the briquettes.

In terms of physical appearance, all briquettes share a shade of brown, indicating that the binder type does not significantly alter the visual aspect of the product. However, the texture varies, with starch and tree resin briquettes having a rough texture, while paper pulp briquettes are smooth. This difference in texture could influence the handling and mechanical properties of the briquettes, potentially affecting their usability in different applications.

The findings from this analysis suggest that tree resin briquettes, with their higher density and compression ratio, are more suitable for applications that require high energy output and prolonged combustion duration. Paper pulp briquettes, offering a balance between density and ease of handling, could serve as a versatile option for various energy needs. Starch briquettes, being less dense, may burn more quickly and be appropriate for situations where rapid energy release is desired.

Table 2. Physical properties of the rice husk briquettes

Parameters	**Starch**	**Paper pulp**	**Tree resin**
Height of briquette (m)	0.0425	0.0416	0.0411
Hole diameter (m)	0.0120	0.0120	0.0120
Outer diameter (m)	0.0450	0.0450	0.0450
Volume (m^3)	6.606×10^{-5}	6.466×10^{-5}	6.389×10^{-5}
Mass (kg)	0.0333	0.0357	0.0533
Density (kg/m^3)	504.20	551.24	834.00
Compression ratio	4.31	4.71	7.13
Colour	Brown	Brown	Brown
Texture	Rough	Smooth	Rough

3.1.5 Proximate Analysis of the briquettes

The proximate analysis of rice husk briquettes with different binding agents is summarized in the table 3 below:

Table 3. Proximate analysis of rice husk briquettes

Briquettes type	Moisture Content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon Value (%)
Starch	9.18	76.36	16.20	7.44
Waste paper pulp	7.45	84.32	14.63	1.05
Natural tree resin	5.77	89.18	7.11	3.70

The results indicate variations in the proximate composition of the briquettes depending on the type of binding agent used. Starch-based briquettes have a higher moisture and ash content than those made with wastepaper and tree resin. Conversely, tree resin-based briquettes exhibit the lowest moisture content and highest fixed carbon value. These findings suggest that the choice of binding agent significantly influences the characteristics of the briquettes, potentially impacting their combustion properties and overall performance in various applications.

The proximate analysis results of rice husk briquettes with different binding agents align with findings from previous studies. For instance, the moisture content of tree resin-based briquettes (5.77%) in our study is lower than similar briquettes reported by (Harcourt et al., 2018), indicating better moisture removal during production. Additionally, the ash content of starch-based briquettes (16.20%) matches closely with the findings of (Efomah & Gbabo, 2015), who observed a similar ash content of 16.10% in starch and rice husk briquettes. These comparisons underscore the consistency of these results with existing literature, validating the reliability and relevance of our study in biomass briquette production.

3.1.6 Ultimate analysis of the Briquettes

Below are the results of the ultimate analysis of rice husk briquettes with different binding agents:

Table 4. Ultimate analysis of rice husk briquettes

Briquettes type	Carbon (%)	Hydrogen (%)	Oxygen (%)
Starch	39.48	5.12	38.61
Wastepaper pulp	39.04	5.28	40.46
Tree resin	42.94	5.72	43.58

These results indicate variations in the elemental composition of the briquettes depending on the binding agent used. Notably, briquettes made with tree resin exhibit higher carbon content than those made with starch and wastepaper. This suggests that tree resin may increase carbonization during briquette production. Conversely, waste paper-based briquettes demonstrate higher oxygen content, indicating a higher proportion of oxygen-containing functional groups in the briquette matrix. These findings offer insights into the elemental composition of rice husk briquettes and highlight the influence of different binding agents on their chemical properties.

3.1.7 Combustion Analysis

The combustion analysis of rice husk briquettes with different binding agents reveals variations in ignition time, burning time, burning rate, and calorific value. Tree resin-based briquettes ignited the quickest at 30 seconds, while paper pulp-based briquettes burned the fastest in 933 seconds, with a high burning rate of 0.122 kg/hr. Despite these differences, all briquettes showed similar calorific values ranging from 15.28 to 15.45 MJ/kg, indicating consistent energy content per unit mass. These findings provide valuable insights into optimizing the performance of rice husk briquettes in practical applications.

The consistency of our study's calorific values, ranging from 15.28 to 15.45 MJ/kg, with those reported by (Efomah & Gbabo, 2015) at 15.175 MJ/kg underscores the reliability and accuracy of our findings. This alignment with previous literature enhances confidence in our results and underscores the relevance of our study in biomass energy research.

Table 5. Combustion analysis of rice husk briquettes

Briquette type	**Ignition time (s)**	**Burning time (s)**	**Burning Rate(kg/hr)**	**Calorific Value (MJ/kg)**
Starch	44	1522	0.061	15.446
Paper pulp	61	933	0.122	15.278
Tree resin	30	2512	0.068	15.323

Additionally, the calorific values of the briquettes made with an equal ratio (1:1) of the three binding agents were also analysed. The results show the following values:

- Starch-based briquettes: 14.175 MJ/Kg
- Paper-based briquettes: 14.227 MJ/Kg
- Tree resin-based briquettes: 15.275 MJ/Kg

The findings reveal that the Tree resin-based briquettes, even with a 1:1 ratio, maintain a high calorific value, comparable to the optimum ratio briquettes. This suggests that tree resin is a highly effective binding agent for enhancing the energy content of briquettes.

4 CONCLUSION

This research has demonstrated the feasibility of converting rice husk waste into sustainable biomass briquettes, providing an environmentally friendly and economically viable alternative to traditional biomass fuels in Sri Lanka. By analysing various rice husk sizes, the study identified that husks less than 5mm exhibit optimal properties, including fixed carbon content, moisture content, volatile matter, and ash content. Among the binding agents tested - starch, tree resin, and wastepaper pulp, *dummala* tree resin emerged as the most effective, producing the most resilient briquettes with a density of 834 kg/m³ and a compression ratio of 7.13. The calorific value analysis further confirmed the energy efficiency of these briquettes, with a calorific value of 15.275 MJ/kg, making them a promising substitute for conventional biomass sources. Despite these achievements, the research encountered several limitations. The study was confined to three binding agents, and there may be other potential agents that could offer better performance or cost-efficiency. The research was conducted on a laboratory scale, and scaling up the production process might present unforeseen challenges. The long-term durability and storage stability of the briquettes were not extensively tested, which could affect their practicality for large-scale use. Furthermore, the environmental impact of sourcing and processing binding agents, particularly *dummala* tree resin, was not fully explored.

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