JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(11), 299–308
https://doi.org/10.12911/22998993/208087
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.07.01
Accepted: 2025.08.01
Published: 2025.08.15

Toward sustainable energy: Fuel properties and combustion behavior of torrefied king grass at various briquetting pressures

Alchalil[1], Adi Setiawan[1,3*], Aldi Winaldy Lubis[1], Shafira Riskina[3], Abdul Rahman[1]

[1] Mechanical Engineering Department, Faculty of Engineering, Universitas Malikussaleh, Bukit Indah, 24352, Lhokseumawe, Indonesia
[2] Magister Program in Renewable Energy Engineering, Faculty of Engineering, Universitas Malikussaleh, Jalan Batam, Bukit Indah, 24352, Lhokseumawe, Indonesia
[3] Biomass and Hydrogen Technology (BiHYTECH) Research Centre, Universitas Malikussaleh, Jalan Batam, Bukit Indah, Lhokseumawe, Indonesia
* Corresponding author's e-mail: adis@unimal.ac.id

ABSTRACT

Most countries are facing a steady decline in conventional energy resources, prompting governments to prioritize the development of renewable alternatives. With its rich biodiversity, an agricultural country like Indonesia holds significant potential for biomass utilization – one promising feedstock being king grass (*Pennisetum purpureoides*). This study examines the physical and thermal characteristics of torrefied king grass bio-briquettes produced under varying briquetting pressures (100, 200, 300, 400, and 500 kg/cm²). Proximate analysis reveals that torrefaction enhances fuel quality by increasing fixed carbon content while reducing moisture and volatile matter. The calorific value, density, and dimensional stability of the briquettes improve with higher briquetting pressure, whereas brittleness declines, resulting in more durable and manageable briquettes. Combustion tests indicate that increased pressure leads to slower burn rates and extended combustion duration. Water boiling tests further show that although high-pressure briquettes require more time to reach boiling point, they maintain more stable combustion efficiency. Overall, the results underscore the viability of torrefied king grass bio-briquettes as a sustainable and efficient alternative energy source to help address Indonesia's growing energy demands.

Keywords: biomass, rate of combustion, king grass, torrefaction, briquetting pressure.

INTRODUCTION

Energy is one of the primary needs of human life, and currently, the demand is continuously increasing. However, the reserves of conventional, non-renewable fuels are gradually depleting. If this situation continues, future generations will face a shortage of fuel used for energy, which will eventually run out (Nawawi et al., 2018). One concrete solution that has been implemented by the government is setting a target for energy supply, as outlined in Government Regulation Number 79 of 2014 on the National Energy Policy, specifically in Article 9, letter F (peraturan pemerintah (PP) Nomor 79 Tahun 2014 Tentang Kebijakan Energi Nasional, 2014). The transition to renewable energy sources is an important global priority due to the environmental challenges posed by fossil fuel consumption, such as greenhouse gas emissions and the depletion of fossil fuel reserves.

Global concerns about greenhouse gas emissions and their impact on the environment remain unresolved issues. Although there are several greenhouse gas reduction technologies, such as high-efficiency conversion (efficient use of fossil fuels) and carbon capture and storage (pre- and post-combustion), these approaches are very expensive. The rising cost of fossil fuels and the urgency to address climate change through carbon dioxide (CO_2) reduction have sparked renewed interest in energy crop-based power generation. As a renewable resource, energy crops present a more sustainable option compared to heavy reliance on fossil fuels, with potential applications in producing biofuels, electricity, and thermal energy (Kung and Zhang, 2015).

Biomass from non-food crops is preferred due to its wide availability and its potential as a sustainable alternative energy source (Zhang et al., 2019). Biomass is considered a clean and renewable energy source because, during combustion, it releases an amount of CO_2 equivalent to what it absorbed during its growth. Neglected lignocellulosic materials, such as king grass (*Pennisetum Purpureoides*), exhibit high growth rates, adaptability to marginal lands, and minimal competition with food crops (Rifanida et al., 2023). King grass outcompetes weeds, requires little to no additional nutrients, and therefore has lower establishment costs. It can be harvested up to four times a year, with an energy output-to-input ratio of approximately 25:1, making it one of the most sustainable renewable energy sources (Hendarto and Setyaningrum, 2022).

Despite its potential, the direct use of king grass as fuel faces several challenges, including high moisture content, low energy density, and hydrophilic properties. These limitations can hinder its efficiency and stability during storage and combustion. To address these issues, thermochemical pretreatment methods such as torrefaction have been extensively studied. Torrefaction is a mild pyrolysis process conducted at temperatures between 200 and 300 °C under limited oxygen conditions. This process significantly enhances the fuel properties of biomass by reducing the oxygen-to-carbon ratio, increasing calorific value, and improving its hydrophobic characteristics (Yan et al., 2009). During this process, hemicellulose, cellulose, and lignin undergo partial decomposition, accompanied by the release of water and various volatile organic compounds. As a result, the biomass exhibits enhanced quality and more consistent characteristics. According to Chen et al., torrefaction has four main advantages: (1) increasing calorific value or energy density, (2) reducing moisture content, hydrogen-to-carbon (H/C) ratio, and oxygen-to-carbon (O/C) ratio, (3) enhancing water resistance, and (4) improving reactivity and grindability. Most torrefaction studies have focused on three key conditions to enhance torrefaction performance: biomass type, torrefaction temperature, and torrefaction duration. As mentioned earlier, biomass has low bulk density, making transportation and handling challenging. To address this drawback, densification (briquette) can be used to increase volumetric density and ensure a more uniform shape and size of the biomass (Alchalil et al., 2021).

Previous studies have highlighted that torrefaction can improve the physical and mechanical properties of biomass, making it more suitable as a solid fuel. Oyebode and Ogunsuyi (2021) conducted a pretreatment on *Alstonia Congensis* wood biomass through torrefaction at varying temperatures of 200, 250, and 300 °C for 45 minutes, which enhanced its friability and hydrophobic properties. Kethobile et al. (2020) discussed the effect of torrefaction temperature (200, 250, 275, and 300 °C) on *Jatropha curcas* biomass, showing that increasing torrefaction temperature generally reduces moisture and volatile matter. However, it increases fixed carbon, ash content, and energy density. Luo et al. reported that torrefaction can enhance the hydrophobic properties and calorific value of agricultural residues. Rifanida et al. (2023) examined the effect of torrefaction temperature variation on the physical and mechanical properties of king grass briquettes, showing that calorific value and fixed carbon increased with higher torrefaction temperatures. In terms of mechanical properties, torrefaction was found to improve friability, density, and size stability.

Based on the review of the studies above, it was found that the utilization of king grass remains limited, particularly as a fuel source. So far, no studies have been published on the effect of briquetting pressure at 100, 200, 300, 400, and 500 kg/cm² on the physical and mechanical properties of king grass briquettes as an alternative fuel.

METHODOLOGY

Preparation of king grass

King grass is collected from the Lhokseumawe region, Aceh. It is chopped into pieces of approximately 5–10 cm, then washed and soaked in ladeng water at a ratio of 1:5 for one hour. During the soaking process, the grass is stirred every minute to ensure even immersion. This soaking step is performed to remove dirt and soil attached to the grass. After soaking, the king grass is drained and dried under sunlight for one week. The dried king grass appears as shown in Figure 1.

Figure 1. (a) King grass plant; (b) Dried king grass biomass

Torrefaction process and briquette dough preparation

The dried king grass is then placed into a retort kiln drum (Alchalil et al., 2025) for the torrefaction process. The torrefaction of king grass is conducted at a temperature range of 270–290 °C. Approximately seven kilograms of dried king grass are loaded into the torrefaction reactor and sealed. After the torrefaction process is completed, the solid product is cooled under inert conditions to prevent ignition upon contact with air.

The solid product, in the form of biochar, is then ground and sieved until it passes through a 20-mesh screen. The finely ground material is then mixed with a tapioca binder at a concentration of 5% wt. The mixing process is carried out manually and stirred for 10 minutes until a homogeneous dough is obtained. The mixture is then placed into a briquette mould (as shown in Figure 2) and subjected to pressures of 100, 200, 300, 400, and 500 kg/cm², with a holding time of approximately three minutes. The resulting briquettes are then dried under sunlight for two to three days.

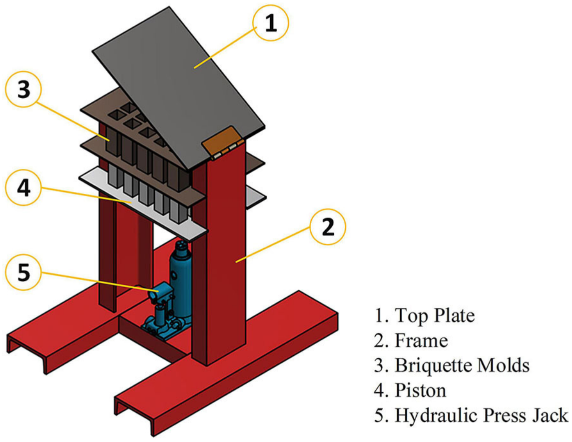

Figure 2. Briquetting press machine

Characterization

The King grass samples in this study consisted of five types: BKG, which is a non-torrefied King grass briquette; BKGT-100, a torrefied King grass briquette at a pressure of 100 kg/cm²; BKGT-200, a torrefied King grass briquette at a pressure of 200 kg/cm²; BKGT-300, a torrefied King grass briquette at a pressure of 300 kg/cm²; BKGT-400, a torrefied King grass briquette at a pressure of 400 kg/cm²; and BKGT-500, a torrefied King grass briquette at a pressure of 500 kg/cm². All prepared samples were then subjected to characterization of their chemical, physical, mechanical, and thermal properties. These included proximate analysis, apparent density, calorific value, drop test, direct combustion test, and water boiling test using a biomass stove. Proximate analysis was conducted to determine the moisture content, volatile matter, fixed carbon, and ash content by SNI-01-6235-2000 (SNI, 2000). Apparent density was determined based on the external volume of the briquette by measuring its different sides using a micrometer to obtain the outer volume, which was then divided by the total weight of the sample after drying.

The mechanical properties of the briquettes was evaluated using a drop test based on the ASTM D440-86 standard. This assessment aimed to determine the durability of the briquettes when dropped from a height of 1.8 meters onto a hard, flat surface. The briquettes' mass was recorded before and after the test using a digital scale with a precision of 0.001 grams (D440-86, 2002).

Thermal testing was conducted using the Koehler K88990 bomb-type calorimeter to analyze the calorific value of the King grass briquettes. The direct combustion test was carried out following the method proposed by Quirino (Quirino and Brito, 1991), in which 50 g of King grass briquettes were placed in the combustion chamber and ignited using 20 g of ethanol. The blower was turned on after the bio-briquette started burning, and temperature data were recorded using a thermocouple connected to a laptop. The mass was measured using a digital scale, also connected to the laptop. The schematic of the combustion test apparatus is shown in Figure 3.

The water boiling test using a biomass stove was conducted to directly evaluate the performance of the produced briquettes in terms of boiling time. A total of 500 g of King grass briquettes was placed into the fuel chamber, with a small amount of ethanol added for initial ignition. A pot containing 1 L of water (Hadi et al., n.d.) was then placed on top of the biomass stove. The setup of the biomass stove for the water boiling test is shown in Figure 4.

RESULTS AND DISCUSSION

Physical properties of king grass briquettes

The torrefaction process of king grass was carried out at temperatures not exceeding 300 °C. The temperature inside the retort kiln drum was controlled to remain within the torrefaction range. The drum temperature increased up to 290 °C, and the torrefaction process at this temperature required up to 180 minutes (approximately 3 hours) for one cycle. Maintaining a stable temperature below 300 °C had a positive impact on fuel efficiency. In one torrefaction cycle, 4 liters of used oil were consumed as fuel.

Table 1 shown the results of the proximate analysis of King grass briquettes. The non-torrefied King grass briquette (BKG) contained a higher amount of volatile matter compared to fixed carbon. After the torrefaction process, the fixed carbon content increased significantly, while the volatile matter decreased. Setter et al. (2020a) reported that The fixed carbon content in lignocellulosic biomass is closely linked to its lignin concentration, which contributes positively to the fuel's calorific value. Calorific value is a crucial parameter in determining fuel quality. The higher the calorific value, the better the fuel quality. Therefore, an increase in calorific value is often considered a key indicator in evaluating the performance of biomass briquettes (Setter et al., 2020b). The following is a comparison of the proximate analysis results of King grass briquettes before and after torrefaction.

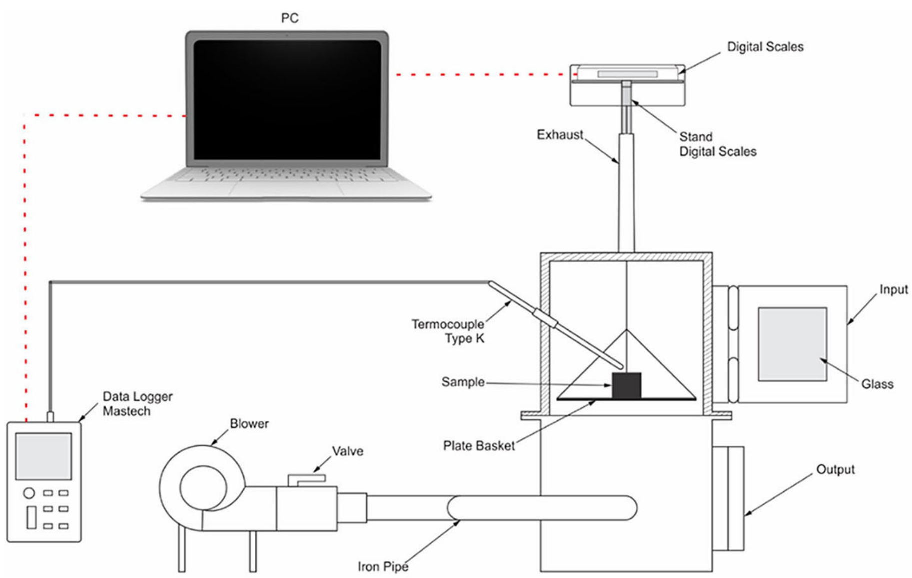

Figure 3. Setup of the combustion test apparatus

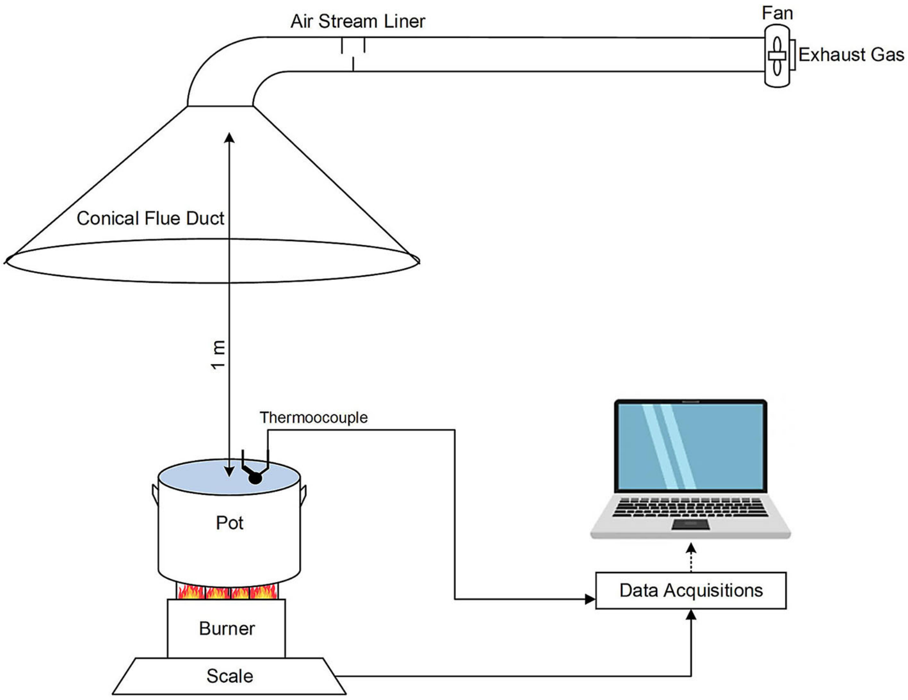

Figure 4. Biomass stove setup for water boiling test

Moisture content decreases as torrefaction pressure increases. This reduction occurs due to the decomposition of light organic compounds and the release of bound water within the biomass. Higher pressure leads to greater material compression, reducing porosity and lowering water absorption capacity. The decrease in moisture content directly contributes to an increase in calorific value, as the energy previously used to evaporate water can now be fully allocated for fuel combustion (Poddar et al., 2014). A study conducted by Lai et al. (2024) on wood pellets found that reducing moisture content from 10% to 5% improved combustion efficiency and resulted in lower emissions compared to fuels with high moisture content .

Ash content tends to remain stable, with the highest value observed in the non-torrefied sample (BKG). After the torrefaction process, the ash content slightly decreases, but at higher pressures (300–500 kg/cm²), a slight increase is observed. This may be due to changes in mineral composition or contamination during the compression process. Studies on briquettes made from agricultural waste, such as rice husks and corn cobs, have shown that higher ash content often reduces combustion efficiency and increases the need for cleaning combustion residues (Primadita et al., 2020).

The volatile matter content decreases drastically at low pressure (BKGT-100) and slightly increases at higher pressures (BKGT-400 and BKGT-500). Conversely, the fixed carbon content

Table 1. Physical properties analysis results of king grass briquettes

Parameters	Sample ID					
	BKG	BKGT-100	BKGT-200	BKGT-300	BKGT-400	BKGT-500
Proximate analysis						
Moisture content (%)	9.51	6.756	5.471	3.209	2.950	2.852
Ash content (%)	15.65	12.186	11.282	11.006	11.678	11.045
Volatile matter (%)	75.11	48.888	59.554	38.841	40.573	43.240
Fixed carbon (%)	4.76	32.178	23.697	42.863	44.849	46.944
Size stability (%)	98.15	30.21	45.52	59.62	69.25	82.66
Friability (%)	2.84	69.79	54.48	40.38	30.75	17.34
Apparent density (g/ml)	0.472	0.369	0.378	0.387	0.403	0.403
Caloric value (cal/g)	3739	5230	5335	5290	5309	5118

increases significantly, especially at 500 kg/cm², reaching the highest value of 46.94%. A study on torrefied palm kernel shell (PKS) found that increasing the fixed carbon content to 50% contributed to improved combustion efficiency and a reduction in greenhouse gas emissions compared to conventional fuels (Lee et al., 2013).

Size stability improves with increasing torrefaction pressure, while brittleness decreases. Briquettes with higher size stability are more resistant to impact and storage conditions. Similar findings were reported in a study on bamboo residue briquettes, which showed that increasing pressure during briquette production enhances mechanical durability and extends the product's shelf life (Hernandez-Mena et al., 2014).

Density increased from 0.369 g/mL (BKGT-100) to 0.403 g/mL (BKGT-500), indicating that the material became more compact. Briquettes with higher density exhibit more efficient combustion as energy is stored in a smaller volume. A similar trend was observed in a study on bamboo residue briquettes, where increasing density improved combustion performance. Research has shown that increasing density from 0.369 g/mL to 0.45 g/mL enhances fuel efficiency and extends burning time. Additionally, higher density reduces porosity, leading to more stable combustion and improved energy output (Wulandari et al., 2020).

The calorific value increased significantly after torrefaction, reflecting the higher fixed carbon content and lower moisture content. This is consistent with studies on coffee waste briquettes, which have shown that the calorific value increases with higher fixed carbon content (Kamga et al., 2024). The analysis results indicate that increasing the pressure during the torrefaction process can enhance the quality of King grass briquettes, as evidenced by higher fixed carbon content and lower moisture levels. This improvement contributes to a higher density and calorific value, as well as reduced moisture content and porosity, leading to better combustion efficiency. Similar findings have been observed in studies on biomass briquettes made from coffee waste and bamboo residue. The competitive thermal properties of King grass briquettes make them a promising candidate for sustainable alternative fuel sources.

Combustion rate properties of king grass briquettes

The combustion rate test was conducted to evaluate the burning characteristics of the briquettes. This test involved igniting the briquette with 20 g of ethanol and measuring the burning rate using a stopwatch while monitoring the reduction in mass over time. The results of the combustion rate test are presented in Table 2 and illustrated in Figures 5 and 6.

Table 2 indicates that the longest combustion rate was observed in the BKGT-500 sample, with a combustion rate of 0.300 g/min, while the fastest combustion rate was recorded for the BKGT-100 and BKGT-200 samples at 0.362 g/min. The BKGT-500 sample had the longest combustion time of 163 minutes, whereas the fastest combustion was observed in the BKGT-100 and BKGT-200 samples at 0.362 g/min with a burning time of 135 minutes. This can be attributed to several factors, including higher density values and lower friability. Increased briquetting pressure results in higher biomass particle compaction, reducing porosity and making the briquettes more resistant to breakage, which in turn slows down the combustion rate and prolongs the burning duration.

The analysis results indicate that increasing the torrefaction pressure enhances the quality of King grass briquettes. This is evident from the higher fixed carbon content, increased density, and calorific value, as well as the reduction in moisture content and friability. The longest burning rate was observed in the BKGT-500 sample, with a combustion rate of 0.300 g/min, whereas the fastest burning rate was recorded in the BKGT-100 sample at 0.362 g/min. The decrease in the burning rate at higher compression pressures can be attributed to the increased density

Table 2. Results of combustion rate test

Samples	Initial sample mass (g)	Final sample mass (g)	Burning time (min)	Combustion rate (g/min)
BKGT-100	50.19	9.18	121	0.362
BKGT-200	50.11	9.18	121	0.362
BKGT-300	50.17	9.30	123	0.359
BKGT-400	52.61	9.17	136	0.344
BKGT-500	54.04	9.05	163	0.300

and reduced friability of the briquettes. Higher briquetting pressure leads to more compacted biomass particles, minimizing the air pockets within the structure.

Since the combustion reaction requires oxygen, a lower friability means reduced airflow, leading to a slower burning rate. Consequently, briquettes produced under higher compression take longer to burn, but they offer improved energy efficiency due to enhanced density and a higher fixed carbon content. Additionally, previous studies on biomass briquettes, such as those from coffee waste, have shown that an increase in fixed carbon content directly correlates with higher calorific value, further supporting the conclusion that torrefaction pressure plays a crucial role in enhancing the fuel quality of King grass briquettes.

Figure 5 displays the relationship between weight loss and time observed during briquette combustion tests. In general, the plots show a decreasing trend, indicating the burning process took place steadily. As the combustion time increases, the remaining mass decreases, signifying the conversion of biomass into gas. This trend was consistently observed across all samples, confirming the progressive combustion of the briquettes over time, with the outer layers burning first before heat penetrates deeper into the material.

The BKGT-100 sample experienced a faster mass loss compared to the other briquettes, indicating that briquettes with lower briquetting pressure tend to burn more quickly. This is due to their lower density and higher volatile matter content, which accelerate the combustion reaction (Faisal et al., 2018). As a result, the BKGT-100 briquette exhibits a faster burning rate but with a larger and less stable flame. On the other hand, the BKGT-200 to BKGT-400 samples exhibited a slower combustion rate compared to BKGT-100. This suggests that increasing briquetting pressure enhances density, which in turn reduces the combustion rate. The higher density limits oxygen diffusion into the briquette structure, slowing down the combustion process (Rayes, 2018). Among all samples, BKGT-500 showed the slowest mass loss rate, indicating that briquettes compressed under higher pressure burn in a more controlled and efficient manner. This is attributed to their higher fixed carbon content and lower volatile matter, which make them more resistant to rapid combustion (Winaya and Susila, 2010). Figure 6 illustrates the relationship between combustion temperature and burning time for different types of torrefied King grass briquettes.

All samples exhibited the characteristic combustion pattern of biomass, consisting of an initial heating phase (ignition phase), an intensive combustion phase (flaming combustion phase), and a cooling phase (char oxidation phase). The sharp temperature rise at the beginning of combustion indicates that the fuel ignites rapidly upon exposure to a heat source. The peak temperature is reached within approximately 60–90 seconds before gradually decreasing as the readily combustible material is consumed.

The initial heating phase (ignition phase), as shown in Figure 6, indicates that the temperature begins to rise rapidly within the first 20–40 seconds, signifying that the fuel has

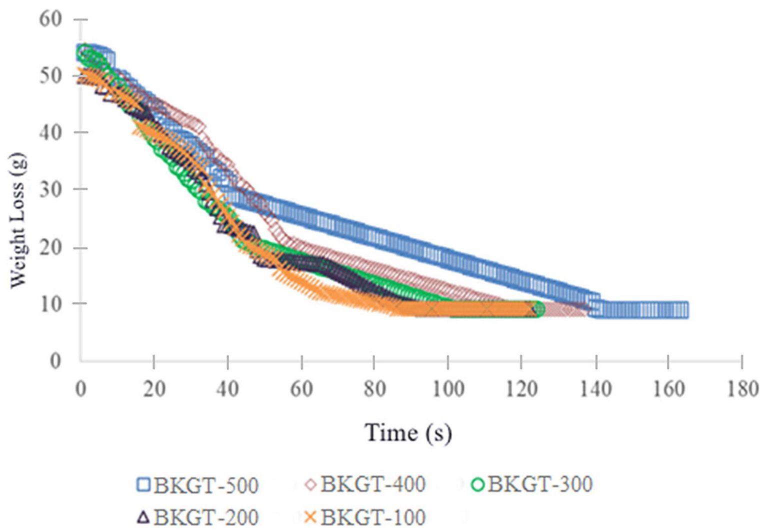

Figure 5. Weight loss as a function of time of torrefied king grass briquettes combustion

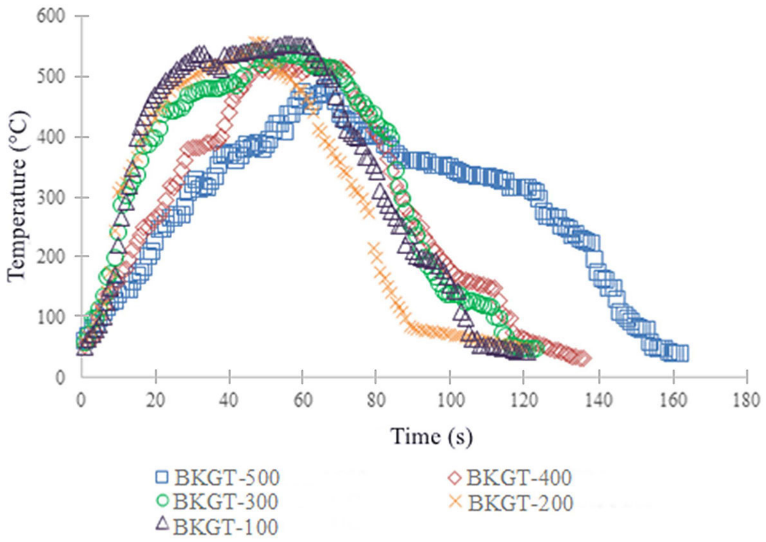

Figure 6. Combustion temperature as a function of time of torrefied king grass briquettes

started to combust and heat energy is being generated. This corresponds to Figure 5, where a slight mass reduction occurs due to moisture loss and the initial evaporation of volatile matter. Briquettes with higher compaction pressure (BKGT-500) exhibit a slower temperature increase compared to BKGT-100 and BKGT-200, as their higher density and lower volatile matter content restrict immediate air penetration into the briquette's pores.

The intensive combustion phase (flaming combustion phase), as shown in Figure 6, indicates that the temperature peaks within 60–100 seconds, depending on the type of briquette. In Figure 5, a significant mass reduction is observed, indicating that the fuel in the briquette is undergoing rapid combustion, primarily due to the evaporation and burning of volatile matter as well as the conversion of carbon into gas. BKGT-100 and BKGT-200 reach peak temperatures more quickly than BKGT-500, as the higher volatile matter content in low-compaction briquettes makes the fuel more flammable. As a result, BKGT-500 has a longer combustion phase, with more stable energy release and a more gradual mass reduction.

The char oxidation phase, as shown in Figure 6, begins after the temperature reaches its peak and starts to decline due to the depletion of volatile compounds and the formation of char. As a result, the mass reduction (Figure 5) slows down after the intensive combustion phase, as only fixed carbon remains for combustion. BKGT-500 exhibits a more gradual mass reduction compared to BKGT-100 and BKGT-200, indicating that briquettes with higher compaction pressure contain more fixed carbon, which burns more slowly but produces a longer-lasting flame.

Analysis of water boiling test using bio-briquettes as fuel

The water boiling test is a standard method for assessing the thermal efficiency of solid fuels, such as bio-briquettes. Based on the provided data, the time required to boil 1 L of water using each type of briquette is shown in Table 3.

These results indicate that as the briquetting pressure increases, the time required to boil water also increases. This phenomenon can be explained by several key factors, particularly the effect of briquetting pressure on combustion efficiency and the thermal efficiency of bio-briquettes in a biomass stove. Briquettes with higher briquetting pressure have greater density, meaning they contain fewer pores. This results in a lower combustion rate because the amount of oxygen entering the fuel material is more restricted. Consequently, although combustion becomes more efficient in the long run, the amount of heat generated in a short period is lower compared to briquettes with lower pressure. This explains why BKGT-500 takes longer (25 minutes) to boil water compared to BKGT-100, which requires only 18 minutes. This finding is consistent with Adam et al. (2024), which states that increasing briquetting pressure enhances

Table 3. Water boiling test

Samples	Boiling time (min)
BKGT-100	18
BKGT-300	23
BKGT-500	25

briquette density, thereby reducing the combustion rate but improving overall energy efficiency.

The maximum temperature reached by briquettes with higher pressure tends to be lower during the initial combustion phase because the fuel burns more slowly and steadily. However, briquettes with lower pressure burn faster and generate higher heat in a shorter period, allowing water to boil more quickly. This is consistent with Yang et al. (2022), which discusses how density changes due to briquetting pressure affect combustion characteristics and heat transfer efficiency.

The biomass stove used in the water boiling test has several variables that influence heating efficiency, including stove design, air distribution, and the fixed carbon content in the briquettes. A well-designed stove allows heat to be more concentrated beneath the water pot. If the airflow in the stove is not optimal, combustion may become inefficient. The higher the fixed carbon content, the longer the burning time, but it also increases overall energy efficiency. Based on this test, we can conclude that briquettes with lower pressure are more suitable for applications requiring quick heat, while briquettes with higher pressure are ideal for long-term, stable combustion.

CONCLUSIONS

This study demonstrates that increasing briquetting pressure has a significant impact on the physical, mechanical, and thermal properties of King grass bio-briquettes. Higher pressures lead to greater fixed carbon content, density, and dimensional stability, while reducing moisture content and friability. Although the burning rate decreases with pressure, this results in longer and more stable combustion. Water boiling test results also show improved thermal efficiency at higher pressures, despite longer boiling times. Overall, the enhanced physical and mechanical properties suggest that torrefied King grass bio-briquettes hold strong potential as a sustainable alternative fuel source.

Acknowledgments

The Institute for Research and Community Service/ Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM), Universitas Malikussaleh under contract no. 228.UN45/KP/2024 dated 19 April 2024, sub-contract no. 37/PPK-2/SWKII/AL.04.2024 tanggal 02 Mei 2024.

REFERENCES

1. Adam, R., Yiyang, D., Kruggel-Emden, H., Zeng, T., Lenz, V. (2024). Influence of pressure and retention time on briquette volume and raw density during biomass densification with an industrial stamp briquetting machine. *Renewable Energy*, *229*, 120773. https://doi.org/10.1016/j.renene.2024.120773
2. Alchalil, Setiawan, A., Faisal, Rifanida, Lubis, A. W. (2025). Effect of pre-washing and torrefaction processes on the physical and thermal properties of bio-briquettes produced from king grass (Pennisetum Purpuroides). *International Conference on Mechanical Engineering and Emerging Technologies (ICOMEET2023)*, 1–7. https://doi.org/10.1063/5.0243237
3. Alchalil, Setiawan, A., Juwaini, Nur, T. Bin. (2021). Effect of Densification Pressure on Physical and Combustion Properties of Binderless Briquettes Made from Rice-Husk and Coffee-Pulp BT - *Proceedings of the 2nd International Conference on Experimental and Computational Mechanics in Engineering: ICECME 20* (Akhyar (ed.); 1–8). Springer Singapore. https://doi.org/10.1007/978-981-16-0736-3_1
4. D440-86, A. (2002). *Standard Test Method of Drop Shatter Test for Coal*. https://doi.org/10.1520/D0440-86R02
5. Faisal, Setiawan, A., Wusnah, Khairil, Luthfi. (2018). Effective height of chimney for biomass cook stove simulated by computational fluid dynamics. *IOP Conference Series: Materials Science and Engineering*, *308*(1). https://doi.org/10.1088/1757-899X/308/1/012043
6. Hadi, R. R., Imam, A., Shidiq, A., Ayu, S., Genyai, N., Pertiwi, G. K. (n.d.). *Pembuatan biobriket dari limbah dedaunan*. 698–703.
7. Hendarto, E., Setyaningrum, A. (2022). Production and king grass nutritional quality number of sources of nitrogen fertilizer. *HighTech and Innovation Journal*, *3*(3), 252–266. https://doi.org/10.28991/HIJ-2022-03-03-02
8. Hernandez-Mena, L. E., Pecora, A. A. B., Beraldo, A. L. (2014). Slow pyrolysis of bamboo biomass: Analysis of biochar properties. *Chemical Engineering Transactions*, *37*, 115–120. https://doi.org/10.3303/CET1437020

9. Peraturan Pemerintah (PP) Nomor 79 Tahun 2014 tentang Kebijakan Energi Nasional, Pub. L. No. Nomor 79 Tahun 2024, Peraturan Pemerintah (PP) 1 (2014).
10. Kamga, P. L. W., Vitoussia, T., Bissoue, A. N., Nguimbous, E. N., Dieudjio, D. N., Bot, B. V., Njeugna, E. (2024). Physical and energetic characteristics of pellets produced from Movingui sawdust, corn spathes, and coconut shells. *Energy Reports*, *11*, 1291–1301. https://doi.org/10.1016/j.egyr.2024.01.006
11. Kethobile, E., Ketlogetswe, C., Gandure, J. (2020). Torrefaction of non - oil *Jatropha curcas* L. (Jatropha) biomass for solid fuel. *Heliyon*, *6*(12), e05657. https://doi.org/10.1016/j.heliyon.2020.e05657
12. Kung, C. C., Zhang, N. (2015). Renewable energy from pyrolysis using crops and agricultural residuals: An economic and environmental evaluation. *Energy*, *90*, 1532–1544. https://doi.org/10.1016/j.energy.2015.06.114
13. Lai, Y., Liu, X., Davies, M., Fisk, C., Holliday, M., King, D., Zhang, Y., Willmott, J. (2024). Characterisation of wood combustion and emission under varying moisture contents using multiple imaging techniques. *Fuel*, *373*, 132397. https://doi.org/https://doi.org/10.1016/j.fuel.2024.132397
14. Lee, Y., Park, J., Ryu, C., Gang, K. S., Yang, W., Park, Y. K., Jung, J., Hyun, S. (2013). Comparison of biochar properties from biomass residues produced by slow pyrolysis at 500 °C. *Bioresource Technology*, *148*, 196–201. https://doi.org/10.1016/j.biortech.2013.08.135
15. Nawawi, D. S., Carolina, A., Saskia, T., Darmawan, D., Gusvina, S. L., Wistara, N. J., Sari, R. K., Syafii, W. (2018). Karakteristik kimia biomassa untuk energi. *Ilmu Teknologi Kayu Tropis*, *16*(1), 45–51.
16. Oyebode, W. A., Ogunsuyi, H. O. (2021). Impact of torrefaction process temperature on the energy content and chemical composition of stool tree (Alstonia congenisis Engl) woody biomass. *Current Research in Green and Sustainable Chemistry*, *4*(May), 100115. https://doi.org/10.1016/j.crgsc.2021.100115
17. Poddar, S., Kamruzzaman, M., Sujan, S. M. A., Hossain, M., Jamal, M. S., Gafur, M. A., Khanam, M. (2014). Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties: Higher heating value. *Fuel*, *131*, 43–48. https://doi.org/10.1016/j.fuel.2014.04.061
18. Primadita, D. S., Kumara, I. N. S., Ariastina, W. G. (2020). A review on biomass for electricity generation in Indonesia. *Journal of Electrical, Electronics and Informatics*, *4*(1), 1. https://doi.org/10.24843/jeei.2020.v04.i01.p01
19. Quirino, W. F., Brito, J. O. (1991). Características e índice de combustão de briguetes de carvão vegetal. *LPF - Série Técnica N° 13*, 19.
20. Rayes, W. Y. A. (2018). Pengaruh dosis pupuk nitrogen terhadap pertumbuhan dan produksi rumput gajah mini (*Pennisetum purpureum* cv.Mott) pada usia pemotongan 60 hari. In *Fakultas Peternakan Universitas Mataram*.
21. Rifanida, Riskina, S., Setiawan, A., Abubakar, Alchalil. (2023). The effect of varying torrefaction temperature on the physical and mechanical properties of briquettes made from king grass. *Jurnal Polimesin*, *21*(1), 1–5.
22. Setter, C., Borges, F. A., Cardoso, C. R., Mendes, R. F., Oliveira, T. J. P. (2020a). Energy quality of pellets produced from coffee residue: Characterization of the products obtained via slow pyrolysis. *Industrial Crops and Products*, *154*, 112731. https://doi.org/10.1016/j.indcrop.2020.112731
23. Setter, C., Sanchez Costa, K. L., Pires de Oliveira, T. J., Farinassi Mendes, R. (2020b). The effects of kraft lignin on the physicomechanical quality of briquettes produced with sugarcane bagasse and on the characteristics of the bio-oil obtained via slow pyrolysis. *Fuel Processing Technology*, *210*(April), 106561. https://doi.org/10.1016/j.fuproc.2020.106561
24. SNI. (2000). *Briket Arang Kayu Standar Nasional 01-6235-2000*.
25. Suprapta Winaya, I., Darma Susila, I. (2010). Co-firing sistem fludized bed berbahan bakar batubara dan ampas tebu. *Jurnal Energi Dan Manufaktur*, *4*(2).
26. Wulandari, W., Jahsy, N. A., Tandias, A. H., Rizkiana, J., Rubani, I. S., Saputera, W. H., Sasongko, D. (2020). Torrefaction of rubberwood waste: The effects of particle size, temperature & residence time. *Journal of Engineering and Technological Sciences*, *52*(2), 137–152. https://doi.org/10.5614/j.eng.technol.sci.2020.52.2.1
27. Yan, W., Acharjee, T. C., Coronella, C. J., Vásquez, V. R. (2009). Thermal pretreatment of lignocellulosic biomass. *Environmental Progress & Sustainable Energy*, *28*(3), 435–440. https://doi.org/10.1002/ep.10385
28. Yang, W., Lv, L., Han, Y., Li, Y., Liu, H., Zhu, Y., Zhang, W., Yang, H. (2022). Effect of densification on biomass combustion and particulate matter emission characteristics. *Atmosphere*, *13*(10), 1582. https://doi.org/10.3390/atmos13101582
29. Zhang, C. T., Zhang, L., Li, Q., Wang, Y., Liu, Q., Wei, T., Dong, D., Salavati, S., Gholizadeh, M., Hu, X. (2019). Catalytic pyrolysis of poplar wood over transition metal oxides: Correlation of catalytic behaviors with physiochemical properties of the oxides. *Biomass and Bioenergy*, *124*(February), 125–141. https://doi.org/10.1016/j.biombioe.2019.03.017