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Thermal and Mechanical Quality Analysis of Briquettes of Arabica Coffee and Rice Husk Composites as an Alternative Bio-fuel

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ABSTRACT

Coal remains a primary energy source for fuel and electricity generation; however, it is a major contributor to global carbon emissions. Therefore, researchers are exploring strategies to reduce coal usage in fuel briquettes. A promising alternative is biomass-based briquettes, which offer similar performance to traditional charcoal while being more sustainable. This study investigated the thermal and mechanical properties of briquettes made from rice husk (RH) and coffee husk (CH), focusing on how the particle sizes of the raw materials affect the heating value. RH and CH are rich in lignin, cellulose, and hemicellulose, which are crucial for briquette structure, whereas tapioca flour, used as a binder, provides amylose and amylopectin to enhance bonding. Carbonization was performed at 400 °C for 60 min. A 25:75 (wt/wt%) CH: RH blend was used and three mesh sizes (60, 80, and 100) were evaluated by thermal and mechanical characterizations. The briquettes were assessed on the basis of their calorific value, moisture content, shatter index, volatile matter, fixed carbon content, density, ash content, and combustion rate. The 149 µm (100 mesh) sample had the highest density (662.81 kg/m^3), moisture content (6.7%), volatile-matter content (7.07%), and burning rate (0.39 gr/min). In contrast, the 250 µm (60 mesh) sample had the highest ash content (5.01%) and the lowest fixed carbon content (82.04%) and shatter index (4.36%). These findings indicate that controlling the particle size of rice husk and coffee husk can improve the performance of biomass composite briquettes, highlighting their potential as a sustainable alternative to coal for domestic use and small-scale energy applications.

Keywords: rice husk, carbonization, briquettes, coffee husk, mesh

1. INTRODUCTION

Coal remains a primary energy source and is commonly utilized for fuel and electricity production [1]. The combustion of fuel coal emits substantial quantities of CO_2 and other pollutants, resulting in local air pollution and contributing to global atmospheric CO_2 [2,3]. To reduce these environmental impacts, researchers are exploring ways to minimize coal usage in briquettes by developing biomass-based briquettes offer comparable quality to traditional charcoal briquettes [4–8].

The quality, i.e., strength and durability, of briquettes is determined by the raw materials, material composition, particle size, level of compaction, and binder used during briquette molding [9,10]. Another method for improving briquette quality is to use additives to improve their physical, mechanical, and thermal properties [11]. The addition of biomass can enhance the calorific value per unit volume, improve particle size consistency, and boost overall quality [9].

Coffee husk (CH) and rice husk (RH) are currently underutilized biomass resources with the significant potential. CH is the dry outer shell of coffee cherries discarded during processing, while RH is the hard-protective layer removed from rice grains during milling. In particular, one hectare of coffee plantation can generate approximately 1.8 tons of CH waste. Currently, this byproduct is primarily used as an organic fertilizer without further processing to maximize its potential. CH is advantageous because of its high calorific value, substantial moisture content (75–80%), and low sulfur content. In their raw form, CH typically contains 2.2% moisture, 0.73% ash, 74.20% volatile matter, 25.07% fixed carbon, and is composed of 10.78% crude protein, 33.13% crude fiber, 24.67% lignin, and 20.22% cellulose [9].

RH is the outer shell of rice grains that is separated during the milling process. The West Java region of Indonesia has a harvested rice area of 1,587 hectares, yielding approximately 9.017 million tons of dry milled grain (GKG). After milling, approximately 20–30% of the rice weight (1.8–2.7 million tons) remains as waste RH [12]. The advantages of RH include its good biochemical and physicochemical properties, making it a suitable carbon source for fabricating activated carbon, adsorbents, supercapacitors, and electrodes [13]. RH typically contains 18–29% ash, 6.0–10.0% moisture, and 35.0–42.0% fixed carbon. It also comprises approximately 40% lignocellulose, 40% cellulose, and approximately 5% hemicellulose; the remaining components include mineral carbon in the form of silica and alkali elements [14]. RH is typically used as an organic fertilizer, animal feed, and substrate in a Fenton catalyst applications[15–19]. Hence, there is broad potential for using CH and RH wastes as alternative fuel sources. These materials are rich in cellulose and lignin, both of which are crucial components for briquettes[20].

Several studies have investigated the effects of adjusting certain parameters on briquette quality. Nagarajan and Prakash reported a composite briquette made of sugarcane bagasse, RH, and corncobs, with the highest calorific value (27.07 MJ/kg) obtained for the 1:1:2 mixture[21]. Setters et al. characterized the solid and liquid fractions of CH briquettes and the effect of particle size using the pyrolysis method, but no improvement in the volatile-matter content[22]. Lubwama and Yiga examined the effect of the binder concentration on the quality of CH/RH composite briquettes; they showed that adding cassava flour as a binder results in high heating values[20]. Similarly, Saeed et al. studied the moisture content of RH briquettes and reported the highest calorific value (17.688 MJ/kg) at 14% water content[14]. Although several studies have focused on improving briquette quality by modifying factors such as the raw material ratio, binder type, and moisture content, there is a lack of research on the influence of the particle size on the performance of composite briquettes made from a mixture of multiple biomass types. Although Setters et al. analyzed the effects of particle size of a single biomass in a pyrolysis study[22], no studies have specifically examined the impact of variations in particle size on the properties of composite briquettes.

To address the aforementioned gap in the existing literature, this study investigated the effect of the particle sizes of Arabica CH and RH waste on the physical and thermal properties of composite briquettes. Three types of briquettes were prepared with CH and RH raw materials with different sieve sizes. A proximate analysis based on ASTM standards, physical properties, and burning capability was performed. The characteristics of the briquettes were compared to the standard quality of usable briquettes.

2. RESEARCH METHODOLOGY

2.1. Briquetting. Briquettes were prepared from CH waste and RH obtained from Pangalengan Bandung and Pebayuran Kab. Bekasi, West Java, Indonesia. Tapioca flour was used as the binder for the briquettes. CH and RH were sieved to obtain 100 mesh (<149 μm), 80 mesh (<177 μm), and 60 mesh (<250 μm) fractions. The composite briquettes contained 25% CH and 75% RH fractions (by weight).

The husk materials for the briquettes were dried using an oven at 100 °C for 60 min under air atmosphere operation. Then, the material was carbonized in a furnace at 400 °C for 60 min, with both heating and cooling rate set at 20°C/min. The carbonized samples were ground and sieved through 60, 80, and 100 mesh sieves. The sifted material was mixed with a binder derived from tapioca flour. The binder was made by mixing the tapioca flour and water. The mixture between the carbonized material and binder were then molded at a pressure of 4.4 tons using manual pressure for five minutes to form a briquette measuring 6 cm × 6,5 cm. The resulting briquette samples were dried in an oven at 100 °C for 60 min. The procedure for fabricating the composite briquettes is shown in Figure 1.

2.2. Characterization Methods.

2.2.1. Proximate testing. The moisture content was determined according to the ASTM 1959 standard. Density measurements were conducted according to the ASTM D 2395 standard by calculating the mass and volume of the briquettes using the tube method. The ash content was determined according to the ASTM 1959 standard by heating the samples in a furnace at 900 °C for 6 min. The fixed carbon content was defined as the carbon content of the briquettes after excluding volatile matter, ash, and moisture. The shatter index test was performed according to ASTM D 440, which involved measuring the initial mass of the briquettes and then dropping them from a height of 1.8 m to evaluate their durability.

2.2.2. Burning rate. The burning rate was examined by measuring the change in briquette mass during combustion. The initial briquette mass before burning was recorded as m_0. To maintain the burning process, a portable fan was used to blow air over the briquettes from a distance of approximately 15–20 cm. An observation period of $t = 5$ min was used, after which the remaining mass m_1 was recorded. The burning rate was then calculated using Equation 1:

$$Burning\ Rate = \frac{m_0 - m_1}{t} \tag{1}$$

3. RESULTS AND DISCUSSION

The density of briquette is influenced by the size and distribution of charcoal particles within the briquette and plays a crucial role in determining how long briquettes burn and how fast they combust. Generally, briquettes with a higher density exhibit a higher combustion rate, whereas those with a lower density burn less vigorously[23]. Figure 2 (a) shows the densities of briquettes made with different particle sizes of CH and RH. The particle size significantly influences briquette density, with the highest density of 662.81 kg/m^3 obtained for the smallest particle size (<149 μm) and the lowest density of 570.44 kg/m^3 obtained for the largest particle size (<250 μm). The briquette density increases with decreasing particle size because finer particles enable the formation of a more compact structure during molding, which reduces the number of internal voids and limits oxygen diffusion.

The moisture content of the composite CH:RH briquettes meets the quality standards set for briquettes. According to SNI 01-6235-2000, the acceptable moisture content for briquette production is less than 8%. Lower moisture levels help reducing energy consumption, and moisture plays a crucial role in combustion because a high moisture content decreases the calorific value of the briquette. Figure 2 (b) shows that the moisture content tends to increase as the particle size decreases, because larger particles absorb less water than smaller particles for the same mass of material[24].

The volatile-matter content characterizes the mass lost during combustion. Lower volatile-matter levels are preferable for high-quality briquettes to avoid excessive smoke production[25]. Figure 2 (c) shows similar volatile-matter contents for all briquettes produced using different particle sizes. The content is 6.58% for the 250 μm sample, which decreases to 6.12% for the 180 μm sample, and then increases to 7.07% for the 149 μm

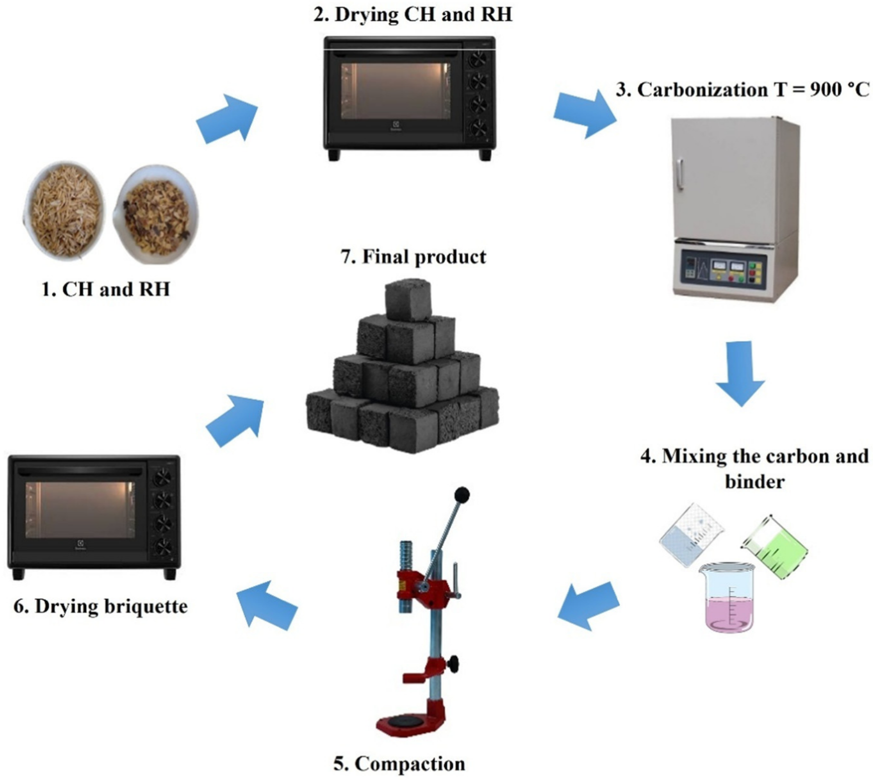

Figure 1. Schematic of the process for fabricating CH:RH composite briquettes

sample. Elevated volatile matter levels are often linked to inefficient carbonization resulting from an insufficient carbonization temperature and/or time. Specifically, higher temperatures and longer carbonization times typically remove more volatile matter, reducing the residual content in the briquettes [25,26]. Smaller particle sizes tend to exhibit enhanced reactivity due to their higher surface area, promoting faster reactions, but they can also intensify secondary reactions and alter volatile components, particularly in composite briquettes [27]. These effects may explain the lower volatile-matter content measured for the 177 μm sample.

Ash in solid fuel refers to the mineral residue that remains after combustion and cannot be burned [28]. Ash primarily consists of minerals containing silicon, calcium, magnesium, and phosphorus. Among these, the silica content has the most significant impact on the ash value and negatively affects the calorific value of briquettes, thereby reducing their quality [29]. Figure 2 (d) shows that the ash content in the briquettes decreases slightly with decreasing particle size. These findings are consistent with those reported by Bhattarai et al. [30]; they showed that larger particles were more difficult to compact and had weaker bonds, enhancing oxygen flow, leading to more complete combustion and a lower ash content. In addition, the ash content depends on the silica content of the raw materials. The addition of tapioca flour binder can also affect the ash content [31] because the binder contains inorganic components that increase the ash content of the briquettes.

Figure 2 (e) shows the fixed carbon contents for the briquette prepared with different particle sizes of CH and RH. The highest fixed carbon percentage (82.57%) was observed at a particle size of 177 μm. Briquettes with lower volatile matter, ash, and moisture contents tend to have a higher fixed carbon content as low levels of the former components indicate efficient carbonization, resulting in a greater proportion of stable carbon remaining in the briquette. A higher fixed carbon content generally enhances the energy density and combustion efficiency of briquettes, making them more effective fuel sources. Thus, controlling these parameters during briquette production is essential for optimizing the fixed carbon content and overall fuel quality [32].

The shatter index is used to assess the mechanical strength and robustness of briquettes by examining their ability to withstand impacts. In this test, the briquettes were dropped from a height of 1.8 m, and the extent of fragmentation or the number of fragments resulting from the drop was measured to gauge their durability. Figure 2 (f) presents the shatter indexes for the briquettes prepared with different particle sizes of CH and RH. The sample prepared with 250 μm particles has the lowest shatter index, with fewer particles lost during the test. These results suggest that the 250 μm briquette has better durability (higher quality) than the other samples.

The burning rate describes the amount of briquette mass consumed over a specific period during combustion. Burning rate tests were conducted using the briquettes prepared with different feedstock particle sizes to assess the efficiency of the briquettes as a fuel source, and the results are shown in Figure 2 (g). The sample with the smallest particle size (149 μm) shows the highest burning rate of 0.39 g/min. This is because increasing the particle size decreases the rate of briquette burning and ash formation. Similarly, when the briquette particle size is small, the combustion rate increases.

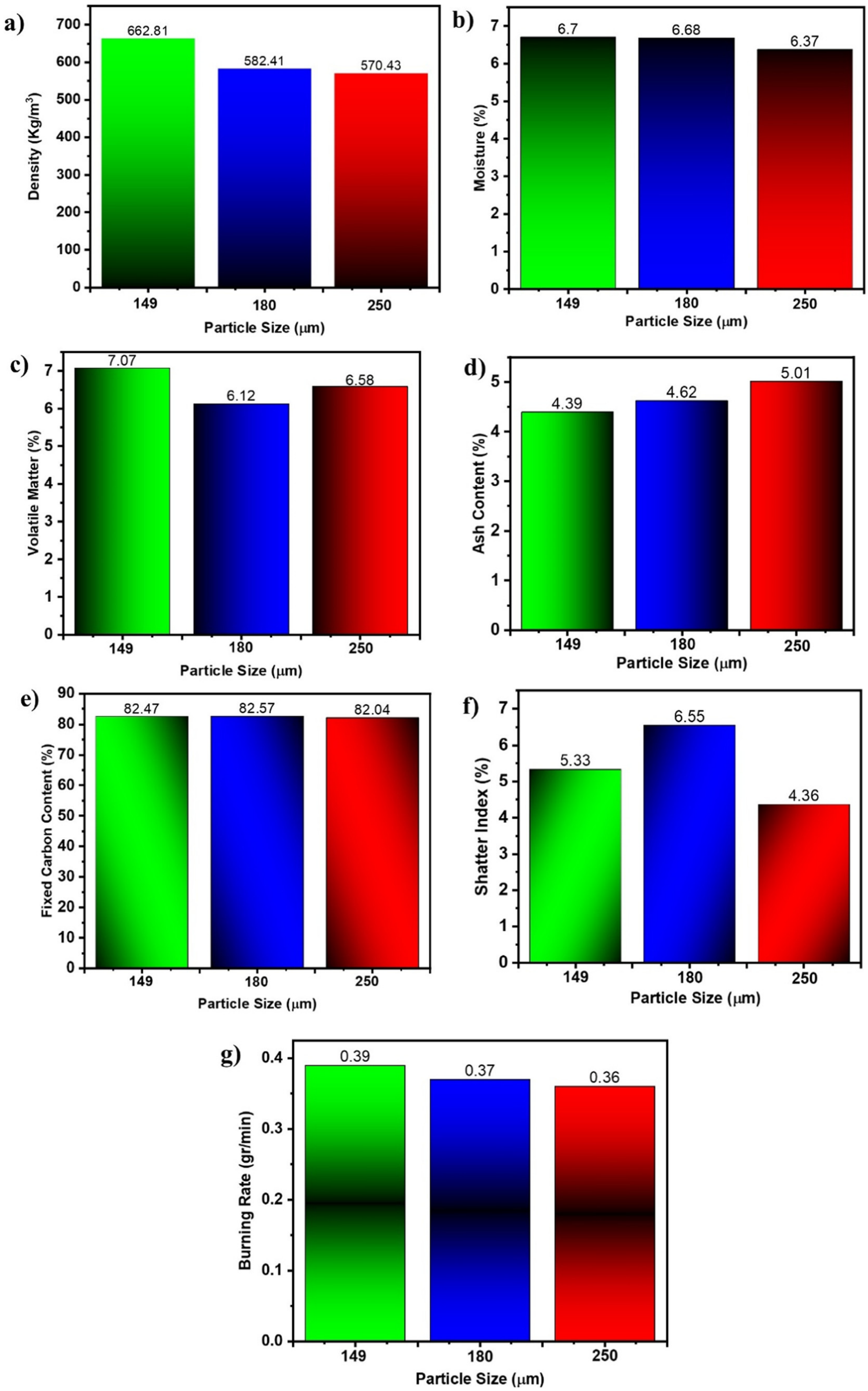

Figure 2. Effect of the particle size on the (a) density, (b) moisture content, (c) volatile-matter content, (d) ash content, (e) fixed carbon content, (f) shatter index, and (g) burning rate

4. CONCLUSIONS

This study demonstrated the potential of utilizing CH and RH biomass to produce sustainable and eco-friendly charcoal briquettes as a viable alternative fuel to coal. A comprehensive evaluation of briquettes prepared with different biomass particle sizes showed that the particle size significantly influences the physical and thermal properties of the briquettes. The briquette prepared with the smallest particles (149 µm) yielded the highest density (662.81 kg/m^3) and burning rate (0.39 g/min), while meeting moisture content standards (<8%). The highest fixed carbon content (82.57%) was observed for the 180 µm briquettes, indicating a good balance between compaction and carbonization. Although smaller particles enhanced the density and burning rate, they slightly increased the moisture and volatile matter content. Conversely, the ash content decreased with smaller particle sizes, indicating higher fuel quality. Overall, the composite briquettes made from 149 µm CH and RH showed the highest density, moisture content, volatile matter content, and burning rate. In contrast, the 250 µm sample had the highest ash content, along with the lowest fixed carbon content and shatter index. Future studies incorporating visual analyses, such as SEM, element analysis, and rheological testing, are recommended to further verify the influence of the particle size on the composition and rheological properties of briquettes.

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REFERENCES

(1) Li, Q. The view of technological innovation in coal industry under the vision of carbon neutralization. *Int. J. Coal Sci. Technol.* **8**, 1197–1207 (2021).

(2) Kumar, J. A., Kumar, K. V., Petchimuthu, M., Iyahraja, S. & Kumar, D. V. Comparative analysis of briquettes obtained from biomass and charcoal. *Mater. Today Proc.* **45**, 857–861 (2021).

(3) Cheng, F. *et al.* Eliminating environmental impact of coal mining wastes and coal processing by-products by high temperature oxy-fuel CFB combustion for clean power Generation: A review. *Fuel* **373**, 132341 (2024).

(4) Narzary, A., Brahma, J. & Das, A. K. Utilization of waste rice straw for charcoal briquette production using three different binder. *Clean. Energy Syst.* **5**, 100072 (2023).

(5) Espuelas, S., Marcelino, S., Echeverría, A. M., del Castillo, J. M. & Seco, A. Low energy spent coffee grounds briquetting with organic binders for biomass fuel manufacturing. *Fuel* **278**, 118310 (2020).

(6) Lukas, A. G., Lombok, J. Z. & Anom, I. D. K. Briquettes made with mixtures of salak seed (Salacca zalacca) charcoal and coconut shell charcoal and the potential as an alternative Energy Source. *Int. J. Appl. Eng. Res.* **13**, 10588–10592 (2018).

(7) Wirabuana, A. D. & Alwi, R. S. Influence of starch binders composition on properties of biomomass briquettes from Durian peel (Durio kutejensis Becc). *AIP Conf. Proc.* **2349**, (2021).

(8) Wang, C., Zhang, S., Wu, S., Sun, M. & Lyu, J. Multi-purpose production with valorization of wood vinegar and briquette fuels from wood sawdust by hydrothermal process. *Fuel* **282**, 118775 (2020).

(9) Harsono, S. S., Fauzi, M., Koekoeh, R. & Wibowo, K. Biomass Stove with Low Carbon Monoxide Emission Fueled by Solid Fuel Coffee-Husk Biopellet. (2022).

(10) Khan, A. U. *et al.* Evaluating Coal–Jatropha curcas Composite Briquettes as Sustainable Fuel Alternatives. *Int. J. Energy Res.* **2025**, 8847392 (2025).

(11) Setter, C. & Oliveira, T. J. P. Evaluation of the physical-mechanical and energy properties of coffee husk briquettes with kraft lignin during slow pyrolysis. *Renew. Energy* **189**, 1007–1019 (2022).

(12) Badan Pusat Statistik. Luas Panen, Produksi, dan Produktivitas Padi Menurut Provinsi 2018, 2019, 2021. *Luas Panen, Produksi, dan Produktivitas Padi Menurut Provinsi 2018, 2019, 2021* (2021).

(13) Anggraeni, S., Girsang, G. C. S., Nandiyanto, A. B. D. & Bilad, M. R. Effects of particle size and composition of sawdust/carbon from rice husk on the briquette performance. *J. Eng. Sci. Technol.* **16**, 2298–2311 (2021).

(14) Saeed, A. A. H. *et al.* Moisture content impact on properties of briquette produced from rice husk waste. *Sustain.* **13**, (2021).

(15) Vadiveloo, J., Nurfariza, B. & Fadel, J. G. Nutritional improvement of rice husks. *Anim. Feed Sci. Technol.* **151**, 299–305 (2009).

(16) Dere, I. *et al.* Preparation of slow-release fertilizer derived from rice husk silica, hydroxypropyl methylcellulose, polyvinyl alcohol and paper composite coated urea. *Heliyon* **11**, e42036 (2025).

(17) Selvarajh, G. *et al.* Enriched rice husk biochar superior to commercial biochar in ameliorating ammonia loss from urea fertilizer and improving plant uptake. *Heliyon* **10**, e32080 (2024).

(18) de Oliveira Simas, A. L. *et al.* Production of Phytase, protease and xylanase by aspergillus niveus with Rice Husk as a Carbon source and

application of the enzymes in animal feed. *Waste and Biomass Valorization* **15**, 3939–3951 (2024).

(19) Chu, J.-H., Kang, J.-K., Park, S.-J. & Lee, C.-G. Enhanced sonocatalytic degradation of bisphenol A with a magnetically recoverable biochar composite using rice husk and rice bran as substrate. *J. Environ. Chem. Eng.* **9**, 105284 (2021).

(20) Lubwama, M. & Yiga, V. A. Characteristics of briquettes developed from rice and coffee husks for domestic cooking applications in Uganda. *Renew. Energy* **118**, 43–55 (2018).

(21) Nagarajan, J. & Prakash, L. Preparation and characterization of biomass briquettes using sugarcane bagasse, corncob and rice husk. *Mater. Today Proc.* **47**, 4194–4198 (2021).

(22) Setter, C. *et al.* Slow pyrolysis of coffee husk briquettes: Characterization of the solid and liquid fractions. *Fuel* **261**, (2020).

(23) Aliah, H. *et al.* Physical properties of briquettes composite from coffee husks (Coffea arabica L) and corncob (Zea mays) for alternative fuel. AIP Conf. Proc. 2646, 60004 (2023).

(24) Abineno, J. C., Dethan, J. J. S., Bunga, F. J. H. & Bunga, E. Z. H. Characterization and performance analysis of Kesambi branch biomass briquettes: A study on particle size effects. *J. Ecol. Eng.* **26**, (2025).

(25) Inegbedion, F. Estimation of the moisture content, volatile matter, ash content, fixed carbon and calorific values of saw dust briquettes. *MANAS J. Eng.* **10**, 17–20 (2022).

(26) Gündüz, F., Akbulut, Y., Koyunoğlu, C., Önal, Y. & Karaca, H. Obtaining the best temperature parameters for co-carbonization of lignite (yatağan)-biomass (peach seed shell) by structural characterization. *Heliyon* **8**, e10636 (2022).

(27) Zhong, S., Baitalow, F. & Meyer, B. Experimental investigation on fragmentation initiation of mm-sized coal particles in a drop-tube furnace. *Fuel* **234**, 473–481 (2018).

(28) Staničić, I., Brorsson, J., Hellman, A., Rydén, M. & Mattisson, T. Thermodynamic analysis on the fate of ash elements in chemical looping combustion of solid fuels – Manganese-Based oxygen carriers. *Fuel* **369**, 131676 (2024).

(29) Liu, Y. *et al.* Ash chemistry in chemical looping process for biomass valorization: A review. *Chem. Eng. J.* **478**, 147429 (2023).

(30) Bhattarai, P., Sapkota, R. & Ghimire, R. M. Effects of Binder and Charcoal Particle Size on the Physical and Thermal Properties of Beehive Briquettes. *Proc. IOE Grad. Conf.* **1**, 57–63 (2016).

(31) Yuliah, Y., Kartawidjaja, M., Suryaningsih, S. & Ulfi, K. Fabrication and characterization of rice husk and coconut shell charcoal based bio-briquettes as alternative energy source. in *IOP Conference Series: Earth and Environmental Science* **65**, (2017).

(32) Jahiding, M., Ngkoimani, L.O., Erzam, S.H., Ratnawati, W.O., & Maymanah, S. Pengembangan briket hybrid berbasis sekam padi dan batubara muda (brown coal) sebagai bahan bakar alternatif. Jurnal Aplikasi Fisika, 7(1), 12–21 (2011).