



The influence of adding lime on the physical and combustion properties of charcoal briquettes made from water hyacinth (*Eichhornia crassipes*)

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Abstract. Water hyacinth (*Eichhornia crassipes*) is an invasive aquatic macrophyte that disrupts many ecosystems and causes environmental and economic problems. To address its proliferation, the study explored its potential use in producing charcoal briquettes as a form of utilization and control. This study aimed to determine the effect of different lime types on the physical and combustion properties of water hyacinth charcoal briquettes. Four briquette formulations were prepared: F1 (no lime), F2 (with agricultural lime), F3 (with hydrated lime), and F4 (with quick lime). These were analyzed for density, durability, ash content, volatile matter, fixed carbon, burn duration, and burning rate. The highest density was observed in F1, while F2 achieved the greatest durability. Although no significant differences were found for most parameters, F3 and F4 showed the highest ash content. The longest burn duration occurred in F3, and the addition of lime generally reduced the burning rate. Overall, results indicate lime can improve certain properties of water hyacinth briquettes and may help reduce fuel consumption. Further studies are recommended to optimize formulation and performance for sustainable energy applications.

Key Words: density, durability, ash content, fixed carbon, burning rate.

Introduction. Water hyacinth is a free-floating, flowering aquatic plant native to South America and is recognized as one of the world's worst invasive weeds due to its rapid growth and efficient dispersal (Dersseh et al 2019; Cardenas-Cuadrado et al 2025). Its dense mats obstruct sunlight penetration, reduce dissolved oxygen, and degrade water quality, leading to biodiversity loss and ecosystem imbalance (Yang et al 2025). Beyond ecological impacts, heavy infestations disrupt navigation (Nguyen et al 2015), hinder fishing and irrigation activities (Enyew et al 2020; Ayana 2021), limit livelihood opportunities (Namitha et al 2024), and interfere with tourism and recreation (Degaga 2018).

The growing dependency on wood fuel has placed greater strain on forest resources, underscoring the need to explore alternative, non-woody biomass sources such as invasive aquatic plants (Raswat et al., 2024). Using water hyacinth briquettes presents an excellent alternative to traditional wood fuels; these briquettes offer a reliable and sustainable energy source. Its conversion into biofuel, particularly charcoal briquettes, offers dual benefits: mitigating invasive spread while providing an affordable alternative energy source amid declining fuelwood supply and rising fossil fuel prices (Rodrigues et al 2014). However, the performance of water hyacinth briquettes remains limited by suboptimal combustion and mechanical properties, which depend on factors such as fixed carbon, ash, and moisture contents (Nurba et al 2019; Jelonek et al 2020).

The study investigated the effect of incorporating different types of lime on the physical and combustion characteristics of the charcoal briquettes. Liming materials are available commercially in different variants, typically used for agricultural purposes. Among these are agricultural lime (CaCO_3), hydrated lime (Ca(OH)_2), and quicklime (CaO). Agricultural lime is produced by finely grinding limestone, while quicklime is obtained by

calcining limestone at high temperatures (Lubis et al 2021). Meanwhile, hydrated lime is produced by adding water to quicklime. These lime types also differ in terms of neutralizing power, with quicklime having the highest. Based on studies, lime could increase ash content, modify pore structure, improve mechanical durability, and lower burning rate (Jelonek et al 2020). Moreover, lime could considerably contribute to desulfurization (Altun et al 2006). However, studies on the application of lime in water hyacinth charcoal briquettes remain limited. Furthermore, different types of lime may affect the properties of briquettes differently.

Therefore, this study aimed to evaluate the influence of different lime types (agricultural lime, hydrated lime, and quicklime) on the physical and combustion properties of water hyacinth charcoal briquettes, to improve briquette performance for sustainable energy applications.

Material and Method

Collection and processing of raw materials. Water hyacinth was collected from different water bodies in Magalang, Pampanga. The raw materials were chopped and sun-dried for one week. After drying, the biomass was subjected to carbonization using a metal drum fitted with limited air entry. The carbonization process was carried out at a temperature range of 400-600°C for 1 hour (Maulina et al 2019). The resulting char was then cooled, ground, and sieved to obtain a uniform particle size.



Figure 1. A dense mat of water hyacinth in a waterway.

Production of charcoal briquettes. The carbonized material was mixed with the cassava flour as a binder (5.0 g) and lime (5%). Four (4) formulations were prepared based on the types of lime used (F1 – no lime added; F2 – with agricultural lime; F3 - with hydrated lime; and F4 - with quick lime). The components were thoroughly mixed with a small amount of water until a homogenous paste was obtained. The resulting mixtures were then molded into uniform cylindrical briquettes with a diameter of 5 cm and a height of 8 cm using a hydraulic press under a compaction pressure of 5-10 MPa. The produced briquettes were air-dried for 3-5 days before being subjected to further testing.



Figure 2. Drying of charcoal briquettes.

Characterization of charcoal briquette. The density of the briquette was determined by measuring its mass using a digital weighing scale and its volume using the water displacement method, after which the density was calculated by dividing mass by volume (Marganingrum & Estiaty 2019). The durability of the briquette was assessed using the shatter index test as described by Tanui et al (2018). The combustion characteristics, including ignition time, burning duration, and burning rate, were evaluated by conducting a combustion test using 62.83 g of briquette samples. The ignition time was recorded as the period required for the briquette to ignite, while the burning duration was the total time taken for the briquette to burn completely from ignition to final consumption. The burning rate was calculated using the formula proposed by Nasrudin et al (2021). After combustion, the residual ash was collected and weighed. The moisture content of the briquette was determined by oven-drying a sample at 103°C for 1 hour, following the method of Aransiola et al (2019). The ash content was analyzed by placing a known mass of sample in a crucible and heating it in a muffle furnace at 750 °C for 5 hours (Sukarta et al 2023). After heating, the residue was cooled in a desiccator and weighed. The ash content was then computed as the ratio of the residue weight to the initial weight of the briquette. By dividing the quantity of residue by the initial weight of the briquette, the ash content was determined. The volatile matter was determined by heating a weighed sample in a furnace at a temperature of 750°C for 7 minutes, following the procedure outlined by Lestari et al (2017).

Data treatment and analysis. The data were consolidated and subjected to descriptive and inferential statistics. Significant differences among charcoal briquette formulations were determined using one-way analysis of variance (ANOVA) at a 0.05 level of significance, followed by the least significant difference (LSD) test to compare treatment means. All analyses were done using the Statistical Tool for Agricultural Research (STAR) of the International Rice Research Institute (IRRI).

Results and Discussion. The results indicate several observable trends and relationships among the briquette formulations (Table 1).

Table 1
Physical properties of water hyacinth briquettes with different lime types

Attributes	Charcoal briquette			
	F1	F2	F3	F4
Density (g cm ⁻³)	0.113	0.111	0.102	0.108
Durability index (%)	98.76	100.00	99.10	98.76
Moisture content (%)	8.87	6.15	8.00	6.16
Ash content (%)	17.21 ^a	20.00 ^b	22.53 ^c	22.53 ^c
Volatile matter (%)	34.79 ^b	40.00 ^a	34.47 ^b	38.04 ^a
Fixed carbon (%)	39.13 ^a	33.85 ^b	35.00 ^b	33.27 ^b
Burn duration (min)	23.04 ^b	30.25 ^a	27.89 ^a	27.07 ^a
Burning rate (g min ⁻¹)	2.73 ^b	2.08 ^a	2.25 ^a	2.32 ^a

The mean difference was statistically significant ($p < 0.05$); F1-No lime; F2- With agricultural lime; F3 – With hydrated lime; F4 – With quick lime.

Density and durability. The highest density occurred in F1, suggesting that this formulation produced the most compact briquette. However, the highest durability was found in F2, implying that despite not being the densest product, F2 briquettes exhibited the greatest resistance to breakage or abrasion. The lack of significant differences ($p > 0.05$) across formulations suggests that the addition of lime did not markedly alter these physical properties. Density is an important physical property, particularly during transport and handling. The density of charcoal briquettes is affected by the size and uniformity of materials used in the production (Nurba et al 2019). Lime particles are fine and lightweight, and thus did not affect the packing efficiency or reduce the void spaces within the briquette during compaction. According to a previous undertaking, the density of charcoal briquettes should not be more than 0.8 g cm⁻² (Pinate & Dangphontong 2018). In comparison with the present formulations, the values obtained are relatively low. Also, the values are lower than those of briquettes made from water hyacinth in previous studies (Oroka & Akhihero 2013; Okia et al 2016; Suttibak & Loengbudnark 2018). Lower density offers an advantage as it allows faster ignition and heating. The durability of a briquette refers to its ability to withstand mechanical handling. As observed, all formulations have comparable durability, indicating that inclusion of different liming materials will not negatively affect the durability of the product. For charcoal briquettes made from biomass, the ideal durability is considered $\geq 95\%$ (Kpalo et al 2020). In comparison with the present finding, the formulations met the standard. Charcoal briquettes produced from previous studies reported varying durability indices, such as those made from water hyacinth and cow dung mixture (85.3 to 92.7%) (Oroka & Akhihero 2013). Higher durability is an important aspect of charcoal briquettes, suggesting that it can withstand the vigor of transportation, handling, and storage (Onyango et al 2020).

Moisture content. The moisture content of a charcoal briquette is the amount of water present in the material that is lost during drying. According to Pramadhana et al (2018), the lower the moisture content, the higher the quality of the briquette. As revealed in this study, lime has no significant effect on the moisture content of briquettes, regardless of its type. Briquettes using hydrated lime require a higher water percentage ($\sim 15\%$) to develop sufficient mechanical strength (Pascoal et al 2022). Lower water addition (0-10%) leads to brittle briquettes that crumble easily. In a composite of water hyacinth, charcoal dust, and cow dung, equilibrium moisture content ranged from 8.5% to 15.2% under ambient conditions ($\sim 29^\circ\text{C}$, 58% RH) (Okia et al 2016). Meanwhile, a study on water hyacinth and cow dung blends reported moisture content at 5.81% for one optimal blend, and 5.32% for water hyacinth and sawdust blends (Bandara & Kowshayini 2018). Based on studies, the ideal moisture content of a charcoal briquette falls within the range of 8-12%. Tumuluru

et al (2015) cited that 8-10% moisture yields crack-free, dense briquettes; moisture below 5% creates brittle briquettes with fines during handling.

Ash content. In terms of combustion characteristics, F3 and F4 showed the highest ash content, indicating greater residual material after burning. Ash is an incombustible component of a charcoal briquette. This study revealed that the addition of lime will increase the ash content of the briquette. This result is in agreement with the review of Obi et al (2022) that lime could provide strong bonding and stability, but may also lead to high ash content and lower calorific value. This effect was associated with the incombustible nature of the material. During combustion, lime does not oxidize to release energy (Altun et al 2006); instead, it remains as mineral residue, thereby diluting the proportion of combustible carbon. The ash content of the briquettes produced in this study varied from that made in previous studies. Recently, Widodo et al (2025) reported an ash content of 3.93% for water hyacinth bio-briquettes. Torrefied water hyacinth charcoal briquettes at 200°C showed 17.65% ash (Aris & Amani 2025). A composite of 52:75 water hyacinth and groundnut shell briquette exhibits a low ash content of 3.73% (Rezania et al 2016). Although the values obtained did not fall within the standard range based on ISO 17225 of 3.3-11% (Inegbedion 2022), the increase in ash extends the burn duration and reduces the burning rate of the briquette. According to Mencarelli et al (2025), the increase in ash content due to the addition of fillers accumulates and acts as a barrier on the briquette surface, impeding oxygen flow, which slows combustion and reduces thermal output.

Volatile matter. F2 and F4 had similar volatile matter levels but differed significantly from F1 and F3, suggesting that the presence of lime influenced the release of volatile components during combustion. The volatile matter is used to measure the amount of smoke produced by burning a charcoal briquette (Pramadhana et al 2018). The result of this study showed higher volatile matter in all formulations compared with the Japanese and American standards of 15-30% (Sunardi et al 2019). It indicates that the carbonization of dried water hyacinth is not sufficient. Moreover, variation across briquette formulations could be attributed to the uneven distribution of carbonized materials. Although there is still no direct study on the changes of volatile matter from adding lime, the percentage tends to drop as the fraction of ash increases. It was known that lime increases ash, as it is not combustible. Pramadhana et al (2018) reported a range of 25-32% for water hyacinth charcoal briquettes using tapioca gel binder and 25-37% using PVAc adhesive at different temperatures for carbonization.

Fixed carbon. Fixed carbon remained consistent across formulations, showing that this parameter was not affected by the incorporation of lime, regardless of type. The fixed carbon content of a briquette refers to the remaining material after all volatile compounds and moisture have been driven off during pyrolysis, and is commonly associated with the smoke produced during the combustion process (Anis et al 2024). Fixed carbon acts as the primary heat generator during burning and is inversely proportional to volatile matter (Akowuah et al 2012). As reviewed previously, the fixed carbon of most water hyacinth charcoal briquettes is in the range of 14-26%, depending on the treatment. Carnaje et al (2018) observed that the fixed carbon of the briquette increases as the ratio of molasses to water hyacinth increases. A sample analyzed by Munjeri et al (2016) showed a fixed carbon of 20.7%. A study in Zimbabwe revealed 21.9% fixed carbon. Meanwhile, a higher percentage was reported by Murakami & Sato (2024) in using different mixing ratios of binders and organic matter. However, these values, including those obtained from this study, did not fall within the range that is commonly used for cooking and small-scale heating (55-70%) (Yirijor & Bere 2024). Widodo et al (2025) reported an exceptionally high fixed carbon of 78.57% for carbonized water hyacinth with binder. Based on the present finding, the fixed carbon content of briquettes treated with lime is significantly lower than that of non-treated ones. According to Yirijor & Bere (2024), lime does not contribute carbon but decreases its percentage due to the increase in ash. Lime is primarily added to fix sulfur and deodorize the briquette, not for carbon retention (Wu et al 2025). Also, it would likely reduce calorific quality (Pascoal et al 2022).

Burn duration and burning rate. For combustion performance, F2 recorded the longest burn duration, although this was statistically similar to F3 and F4. This trend indicates that F2 tended to burn more slowly, which may relate to its higher durability. The burning rate followed a similar pattern, reinforcing the relationship between burn duration and combustion efficiency among the formulations. The burn duration of charcoal briquettes refers to the time from ignition to the point where it is fully consumed or ceases to emit useful heat, which is critical in determining its cooking efficiency and quality (Ademiluyi & Mepba 2013). Whereas the burning rate is expressed by the mass of material burned over time. In the context of this study, the material formed a thermally stable residue on the surface of the charcoal that effectively inhibits combustion by blocking oxygen exchange and preventing re-ignition. By contrast, coal briquettes applied with hydrated lime or agricultural lime as desulfurizing agents showed different effects on combustion performance (Singh et al 2005). Comparing the burning duration of water hyacinth charcoal briquettes to the previous study, Riyadi et al (2016) reported a range of 14.52 to 35.18 minutes for the mixture of water hyacinth, coconut shell, and bagasse. When it comes to burning rate, the result is closer to or within the range obtained in previous studies dealing with different binders, particle sizes, compaction pressures, and pre-treatment methods. A range of 1.63 to 2.25 was reported by Davies & Davies (2013) using phytoplankton scum as a binder. A study conducted revealed a burning rate ranging from 0.92 to 2.66 g min⁻¹, depending on the particle size, binder ratio, and compaction pressure (Davies et al 2019). Meanwhile, after torrefaction (thermal treatment) at 300°C., Aris & Amani (2025) found a significantly slower burning rate of 0.085 g min⁻¹, with a burn duration of about 47 minutes.

Conclusions. Lime addition improved the combustion efficiency of water hyacinth briquettes by prolonging burn duration and lowering consumption rate. However, increased ash and reduced fixed carbon indicate the need for optimization of binder ratio and carbonization temperature to achieve a higher calorific value. Future studies should explore varying lime concentrations and alternative binders to minimize ash formation while maintaining structural integrity. Additionally, investigating the effects of controlled carbonization conditions on the physicochemical properties and energy performance of the briquettes could further enhance fuel quality.

Conflict of interest. The authors declare that there is no conflict of interest.

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Received: 07 July 2025. Accepted: 29 October 2025. Published online: 21 March 2026.

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How to cite this article:

Javier R. B. R., Cunanan R. A., Mendoza D. M., Baysa R. P., 2026 The influence of adding lime on the physical and combustion properties of charcoal briquette made from water hyacinth (*Eichhornia crassipes*). *AACL Bioflux* 19(2):517-525.