JOURNAL OF ECOLOGY AND CONSERVATION
2023, VOL. 1, ISSUE 1, pp. 13-19
https://doi.org/10.61577/jec.2023.100003

RESEAPRO JOURNALS

ORIGINAL ARTICLE

OPEN ACCESS

Performance evaluation of biomass briquettes from agro residue in India

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ABSTRACT

In the present scenario, millions of tons of agricultural residue are annually produced from crops and other resources such as trees and grass. This biomass is usually burnt in an open atmosphere, causing environmental pollution. On the other hand, India has a huge demand for renewable energy resources. The briquetting of these crop residues may solve both problems along with providing some extra income to the farmers. In the present study, briquettes of the dry leaf, paddy straw, and dry grass were produced using starch as a binder by using an indigenously developed screw extruder. The produced briquettes properties were characterized by proximate analysis and ultimate analysis, fuel properties such as calorific value, and pollution analysis. The biomass briquette produced from dry leaf (3990.33 ± 32.96 kcal/kg) showed better calorific values compared to paddy straw (3455.67 ± 66.12 kcal/kg) and dry grass (3528.33 ± 55.19 kcal/kg) briquettes which may be used for cooking and other heating application.

KEYWORDS

Biomass; Briquette; Agro-residue; Briquette characterization; Bio-Energy in India; Secondary income

ARTICLE HISTORY

Received 13 September 2023; Revised 29 September 2023; Accepted 12 October 2023

Introduction

A significant contributor to India's air pollution is the ineffective utilization of agricultural biomass, which is instead burned in an open environment to prepare fields for the next crop. Paddy and wheat crops account for the majority of India's annual production of agricultural residue, which totals about 560 million tons in gross terms. Theoretical excess is regarded as being one-third of the gross residue. The majority of this biomass comes from paddy (*Oryza sativa*), wheat (*Triticum aestivum*), sugarcane (*Saccharum officinarum*), maize (*Zea mays*), and cotton (*Gossypium spp.*) crop biomass, as shown in Figure 1. Apart from agricultural waste, an ample amount of biomass is generated from tree leaves and grass, which are abundantly available in residential complexes, institutions, offices, and villages. This biomass is not being utilized effectively, but rather burnt in the open environment, which is one of the major causes of air pollution in India. The raw biomass has low density, leading to high costs for transportation and storage, making it unsuitable as an efficient fuel source. The above-said problem can be overcome by the densification of biomass through briquetting/pelletizing technology. Biomass briquettes can be used for energy generation in different sectors, e.g., cooking, and thermal power plants. The potential utilization of biomass briquettes for energy generation will help to overcome various socio-economic challenges, i.e., stubble burning issue, and coal dependency of industries. It will further help farmers to have an additional source of income. Many researchers have been working in this area to make briquette/pellets from biomass using various technologies and performed characterization to recommend the potential uses of briquette/pellets.

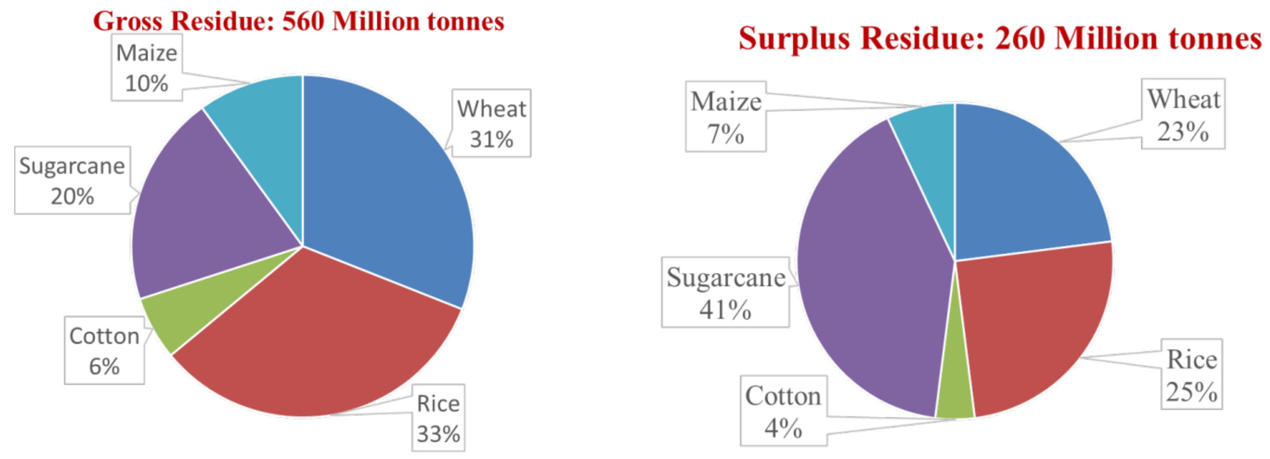

Figure 1. Gross and surplus availability of biomass residue from crops.

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Various biomass has been used to produce briquettes, such as coffee husk, sawdust, khat waste, and dry grass as biomass. Kebede et al. used paper pulp and clay soil as sawdust with paper pulp binder, which has better fuel properties and is recommended for use as an alternative fuel [1]. Deshannavar et al. conducted a study on briquettes made from rice husk and carbonized rice husk, with starch and bentonite clay as binders [2]. They found that the briquettes' bulk density and compressive strength increased with the binder percentage, up to 6%, then decreased [2]. Karunanithy et al. made briquettes from various biomass materials and tested particle size, density, porosity, etc [3]. They discovered that cotton stalk briquettes had the highest bulk density and corn stover and pigeon pea grass had the highest (96.6%) and lowest (61%) durability, respectively. Zhang and Guo researched the impact of pressure, temperature, moisture content, and particle size on the physical properties of *C. korshinskii* Kom briquettes [4]. They found that particle size was the main factor affecting the properties, followed by moisture content and temperature.

The pressure was of marginal importance. Falemara et al. examined the physical and burning characteristics of briquettes made from agricultural waste materials (groundnut shells and corn cobs), wood debris (*Anogeissus leiocarpus*), and a blend of these materials with starch levels of 15%, 20%, and 25% (used as a binding agent) [5].

They evaluated the briquettes' density, volatile matter, ash content, fixed carbon, and heat of combustion. They discovered that the briquettes made from a combination of *A. leiocarpus* and groundnut shells with 25% starch showed superior density and combustion qualities, making them an eco-friendly energy source. Onuegbu et al. investigated the comparison of ignition time and water boiling performance between coal briquettes mixed with elephant grass (*Pennisetum purpurem*) and spear grass (*Imperata cylindrica*) [6]. The briquettes were made by blending different amounts of plant material and coal in ratios ranging from 0:100 to 100:0, with cassava starch serving as a binding agent and calcium carbonate ($Ca\ (OH)_2$) acting as a sulfur-reducing agent. They found that the ignition time decreased as the amount of plant material increased, with coal blends containing elephant grass performing better. The properties improved steadily with an increase in biomass concentration up to 50%. Rahman et al. used bagasse briquettes made with starch and molasses as binders for clove leaf distillation with a heat value of 28.996MJ/kg and 27.019MJ/kg, respectively [7]. The results indicate that the heat value of the briquettes affects the quality of clove leaf oil. The most of literature on briquettes has studied the wood type of biomass and their fuel properties. Whereas, a few kinds of literature were found reporting briquettes from different leaves and agro-based waste biomass such as dry leaf, paddy straw, and dry grass.

In this study, attempts have been made to produce the briquette using an indigenously developed electric-operated screw-type briquette machine. The abundantly available biomass, such as dry leaf, paddy straw, and dry grass, was selected to make briquette by using starch (wheat flour) as a binder in a 5:1 ratio. The produced briquettes were characterized by physiochemical and fuel characteristics.

Materials and Methods

Pretreatment of biomass

The biomass of Paddy straw, dry grass (*Cynodon dactylon*), and dry leaves (*Shorea robusta*) were selected as these are abundantly available across the country and considered as waste which is occasionally burnt in the open environment, causing environmental issues. The mentioned biomass materials were used in this study for briquetting, which can be utilized effectively for cooking and other heating applications. For briquetting, the biomass of Paddy straw, dry grass, and dry leaves were collected from the experimental farm and lawn area of the Central Mechanical Engineering Research Institute, Durgapur, West Bengal campus, respectively. The collected biomass was inspected for impurities such as stone, plastic, and metals and removed manually. After the removal of these impurities, the raw materials were sundried for three days to reduce the moisture of biomass suitable for the shredding application. If the biomass moisture is greater than 15%, further sun drying is required for shredding [1]. The moisture of the shredded biomass was measured and found as 14.2%, 13.9%, and 14.8% for paddy straw, dry grass, and dry leaves, respectively [8]. The dried biomass was shredded into 2-4mm particle size by using an electric-operated impact-type biomass shredder. Next, the shredded biomass was mixed with binder in a ratio of 5:1, where starch-containing biomass (Wheat flour) was used as a binder. The three briquette samples were prepared, namely paddy straw and wheat flour (PS:WF), dry leaves and Wheat flour (DL:WF), and dry grass and wheat flour (DG:WF) containing moisture of 20.5%, 21.3% and 19.4%, respectively.

Production of briquette

An indigenously developed electric motor-operated screw extruder was used for the production of biomass briquette. The shredder and extruder were designed and fabricated such that they can be accommodated in a single machine that takes power from a single electric motor. The biomass samples were fed into the briquette extruder manually through a feeding hopper. The screw extruder type briquette machine was used to make the briquette with different combinations of biomass and with and without binding material. Paddy straw, dry leaves, and dry grass were fed into the screw extruder without a binder but could not succeed in briquette formation. The starch binder was mixed in various proportions ranging from 10:1 ratio to 3:1 ratio but briquette formation was done for 5:1, 4:1, and 3:1 biomass to binder ratio. The characterization of briquette with a 5:1 biomass-to-binder ratio is done in this study. These mixtures were used to produce solid cylindrical shaped biomass briquettes of 30mm diameter from the machine, which were further cut into 200mm length pieces. The detailed briquette production is given in Figure 2 These briquettes were further sun-dried for 15 days. The prepared briquettes were characterized by their physio-chemical and fuel properties.

Characterization of briquette

The produced biomass briquette samples were characterized for physical properties such as bulk density and porosity, proximate analysis (moisture content, volatile matter, fixed

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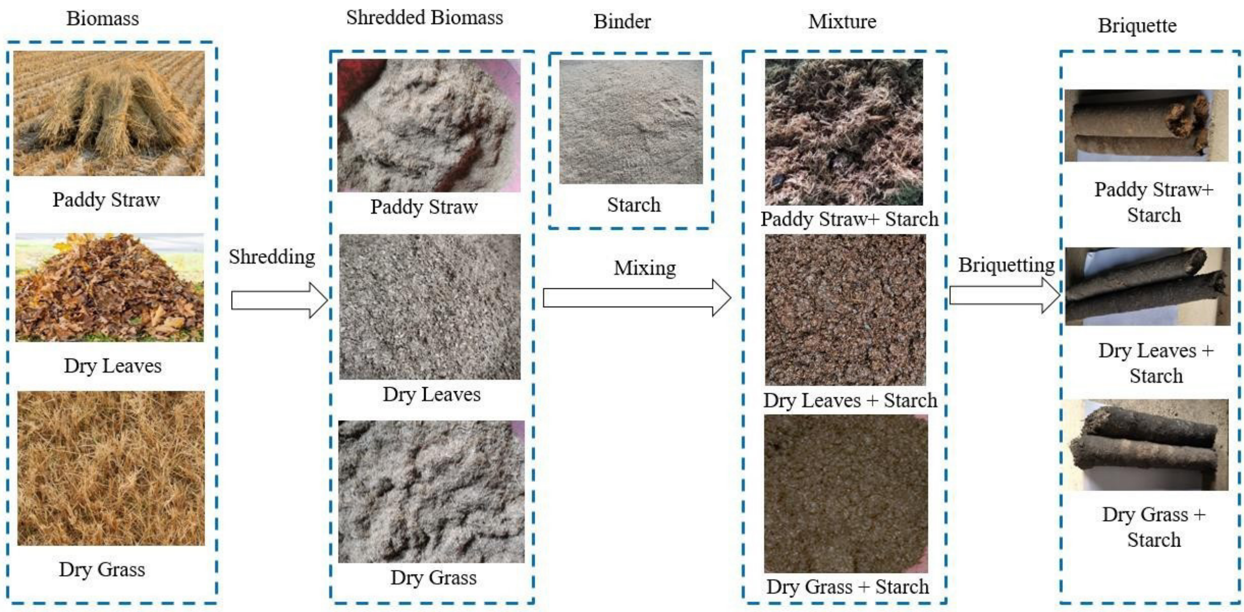

Figure 2. Biomass briquette production.

carbon, and ash content), and ultimate analysis (carbon, hydrogen, nitrogen, sulphur, oxygen), fuel properties such as calorific value and pollution analysis. The detailed methodology of the characterization techniques followed is mentioned below:

Bulk density (g/cc)

The bulk density of the samples is measured by the geometric method [2]. The diameter and length of the briquette samples were measured after cutting both ends of the briquettes to have a smooth surface with a Vernier caliper. The volume of the briquette samples was calculated by using the formula of cylinder volume and then bulk density was calculated after weighing the briquette sample by using equation 1.

$$\text{Bulk Density} = \frac{\text{Mass of briquette}}{\text{Volume of briquette}} \quad (1)$$

Porosity (%)

The porosity of the briquette, expressed as a ratio of voids to total volume and ranging from zero to one, is calculated using its true density and bulk density. It indicates the amount of empty space within the briquette. The porosity of the briquette was calculated by using equation 2. The durability of the briquette depends on this parameter.

$$\text{Porosity} = 1 - \frac{\text{Bulk Density}}{\text{True Density}} \quad (2)$$

The moisture content of briquette (db%)

The moisture content of the briquette was determined by taking 100g samples of each briquette in a container and dried inside an oven at a temperature (105 ± 2) °C for 24 hr till the mass of the sample became constant [8]. The moisture content of the briquette is calculated by using equation 3.

$$M_{db} = \frac{m_2 - m_1}{m_3 - m_1} \times 100 \quad (3)$$

Where, M_{db}= Moisture content on a dry basis (%), m_1= Container weight (g), m_2= Container+Sample weight before heating (g), and m_3= Container + Sample weight after heating (g).

Volatile matter of briquette (VM, dry basis%)

$$VM_{(db\%)} = \frac{m_4 - m_3}{m_4} \times 100 \quad (4)$$

Where, m_4= Weight of the sample after drying, m_3= Weight of the sample before drying.

The ash content of the briquette is measured and calculated by using equation 5 [9].

$$Ash\ (\%) = \frac{m_7 - m_8}{m_6 - m_5} \times 100 \quad (5)$$

Where, m_5= Weight of the container, m_6= Weight of the container+sample, m_7 =Weight of the container+ash, m_8= Weight of the container after removal of ash.

Percentage of fixed carbon (%)

The percentage of fixed carbon is calculated and calculated by using Equation 6 [9].

$$Fixed\ carbon\ (\%) = 100 - M_{db} + VM + Ash \quad (6)$$

Measurement of carbon and hydrogen (%)

The carbon and hydrogen content of the biomass briquette sample were calculated [10]. The biomass briquette samples were crushed to a particle size of less than 2mm and dried at 105-110 °C in a hot air oven to remove any moisture. The dried samples were combusted in an oxygen-rich environment. The heat generated by the combustion reaction was measured and used to calculate the amount of carbon and hydrogen present in the sample by using equation 7 and 8, respectively.

$$\text{Carbon content (wt\%)} = \frac{12 \times (\text{sample mass} - \text{ash mass})}{\text{sample mass}} \quad (7)$$

$$\text{Hydrogen content (wt\%)} = \frac{2 \times \text{sample mass} - 32 \times (\text{sample mass} - \text{ash mass})}{\text{sample mass}} \quad (8)$$

Measurement of Nitrogen (%)

The nitrogen percentage of biomass briquette was measured by using the Kjeldahl method [11]. In this process, the nitrogen sample was converted into ammonium sulfate, followed by titration with a standard acid solution to determine the amount of nitrogen present. The percentage of nitrogen by mass is calculated by using equation 9.

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$$\text{Nitrogen (wt\%)} = \frac{1.4N(V_1 - V_2)}{m} \quad (9)$$

Where, N= Normality of standard sulfuric acid; V_1= Volume (ml) of standard sulphuric acid used in the test; V_2= Volume (ml) of standard sulphuric acid used in the blank; m= mass (g) of the sample taken for the test.

Measurement of Sulphur (wt %)

The Sulphur content of the biomass briquette was measured through calorimetric combustion of the biomass briquette sample using equation 10 [12].

$$\text{Sulphur(wt\%)} = \frac{13.74(A - B + 0.0080)}{W} \quad (10)$$

Where, A= Weight (g) barium sulfate found in determination; B= Weight (g) barium sulfate found in blank determination; W= Weight (g) of biomass sample.

Determination of calorific value (cal/g)

The calorific value of biomass briquettes was determined using a bomb calorimeter [13]. The sample of briquettes was crushed into less than 2mm particle size and mixed thoroughly. The mixed samples were put into the sample holder which was placed inside a combustion vessel. The calorific value of three samples was taken in triplicate.

Statistical analysis

The statistical analysis of the biomass briquette characterization is done using a python program. The analysis of variance (ANOVA) was performed to check the significant difference between the means of biomass briquettes with a significant level $\alpha = 0.05$.

Results and Discussion

The produced biomass briquettes from dry leaf, paddy straw, and dry grass with starch binder were characterized for proximate (bulk density, porosity, moisture content, ash content, volatile matter, and fixed carbon), ultimate analysis (carbon, nitrogen moisture content, ash content, sulphur, and oxygen content) and fuel properties (calorific value). The statistical analysis was done using Python (version 3.9). The results for all these parameters are reported in this section. The outcome of the One-way ANOVA analysis with a significant level $\alpha = 0.05$ of biomass briquette is given in Tables 1 and 2.

Table 1. Proximate analysis of biomass briquettes.

Biomass	Density (g/cc) Mean ± SD	Porosity (%) Mean ± SD	Moisture Content (%w/w) Mean ± SD	Ash Content (%w/w) Mean ± SD	Volatile Matter (%w/w) Mean ± SD	Fixed Carbon (%w/w) Mean ± SD
Dry Leaf+Starch	0.94 ± 0.036	43.3 ± 0.458	9.397 ± 0.626	15.507 ± 0.671	60.197 ± 1.704	14.9 ± 1.805
Paddy Straw+Starch	1.043 ± 0.02	42.267 ± 0.643	9.193 ± 0.161	28.967 ± 0.62	52.893 ± 0.74	8.947 ± 0.558
Dry Grass+Starch	1.087 ± 0.022	36.933 ± 1.007	7.583 ± 0.595	22.32 ± 1.01	61.503 ± 1.002	8.593 ± 0.57
p-value	0.00143	9E-05	0.008843	2E-06	0.0003	0.00082

Table 2. Ultimate analysis of biomass briquettes.

Biomass	Moisture Content (%w/w) Mean ± SD	Ash Content (%w/w) Mean ± SD	Carbon (%w/w) Mean ± SD	Hydrogen (%w/w) Mean ± SD	Nitrogen (%w/w) Mean ± SD	Sulphur (%w/w) Mean ± SD	Oxygen (%w/w) Mean ± SD
Dry Leaf+Starch	9.397 ± 0.626	15.507 ± 0.671	44.263 ± 0.602	3.577 ± 0.335	1.16 ± 0.044	0.523 ± 0.091	25.573 ± 0.926
Paddy Straw+Starch	9.193 ± 0.161	28.967 ± 0.62	40.37 ± 0.871	2.34 ± 0.171	0.48 ± 0.089	0.083 ± 0.021	18.567 ± 1.183
Dry Grass+Starch	7.583 ± 0.595	22.32 ± 1.01	50.523 ± 0.717	2.193 ± 0.261	0.48 ± 0.05	0.06 ± 0.02	16.84 ± 0.666
p-value	0.008843	0.000002	0.000008	0.001255	0.000017	0.000077	0.000066

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Bulk density of biomass briquette

The bulk density of biomass is a significant metric that influences transportation, storage efficiency, transportation and storage equipment design, and the conversion process [3]. The statistical analysis showed that there was a significant difference in the bulk density of the briquettes produced from dry leaf, paddy straw, and dry grass ($p<0.05$) (Table 1). The mean bulk density ranges from (0.94 ± 0.036) g/cc for the dry leaf to (1.087 ± 0.022) g/cc for dry grass briquettes (Figure 3). The briquettes made from dry leaves had lower bulk density compared to paddy straw and dry grass briquettes Table 1. The bulk density of briquettes depends on various parameters such as particle size distribution, chemical composition, true density, moisture content, and applied axial pressure during production [14].

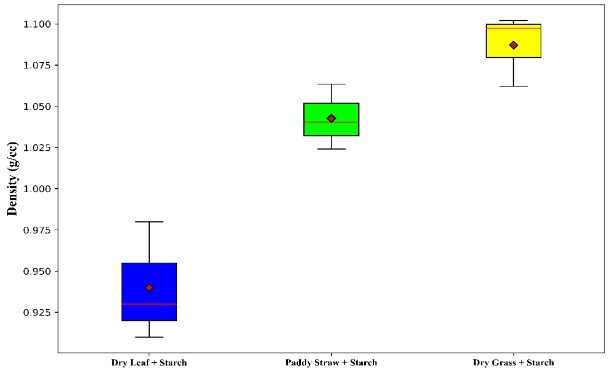

Figure 3. Effect of biomass briquettes on bulk density.

Porosity of biomass briquette

The porosity of the briquette is the available void space in the given size of the briquette. The storage and transportation of biomass briquettes are impacted by their porosity [3]. The statistical analysis showed that there was a significant difference in the porosity of briquettes produced from different biomass taken in this study ($p<0.05$) as shown in Table 1. The porosity ranges from (36.933 ± 1.007) % for dry grass to (43.3 ± 0.458) % for dry leaf briquette, as shown in Figure 4. The briquette made from dry grass has lower porosity than paddy straw and dry leaf briquette. The porosity is dependent on the bulk density of the briquette and it increases with a decrease in the bulk density.

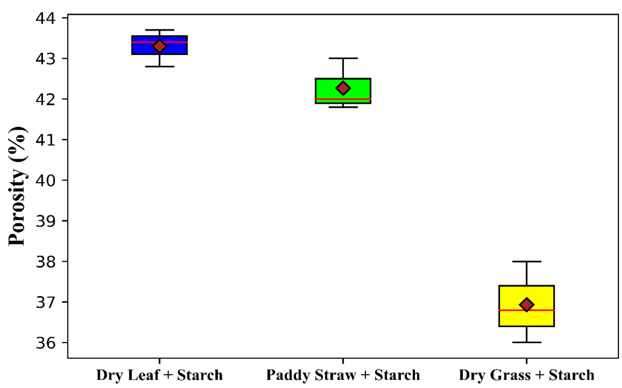

Figure 4. Effect of biomass briquettes on porosity.

The moisture content of biomass briquette

The statistical analysis showed that there was a significant difference in the moisture content of briquettes produced from dry leaves, paddy straw, and dry grass ($p<0.05$) (Table 1). The moisture content Ranges from (7.583 ± 0.595) % for dry grass to (9.397 ± 0.626) % for dry leaf briquette, as shown in Figure 5. The briquette made from dry grass has lower moisture content than paddy straw and dry leaf briquette. The moisture content of the dry grass briquette had a lower value compared to the recommended moisture content (8-10%) of biomass briquette. The moisture content of the paddy straw and dry leaf briquettes was within the recommended moisture content values. The moisture content of the briquette influences the burning quality of the briquette.

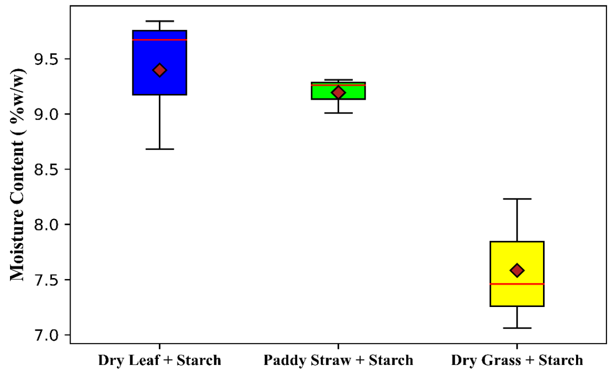

Figure 5. Effect of biomass briquettes on moisture content.

The ash content of biomass briquette

The statistical analysis showed that there was a significant difference in the ash content of briquettes produced from different biomass taken in this study ($p<0.05$) (Table 1). The ash content ranges from (15.507 ± 0.671) % for dry leaf briquette to (28.967 ± 0.62) % for paddy straw briquette as shown in Figure 6. The ash content was lower in dry leaf briquette compared to dry grass and paddy straw. The ash content of the briquette depends on the type of biomass and burning technique of the briquette [1].

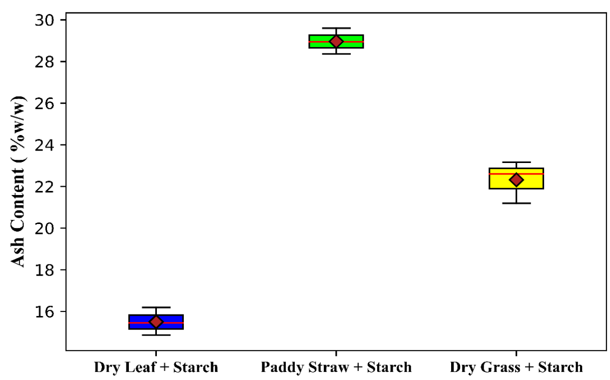

Figure 6. Effect of biomass briquettes on ash content.

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Volatile matter of biomass briquette

The statistical analysis showed that there was a significant difference in the volatile matter of briquettes produced from different biomass taken in this study (p<0.05) (Table 1). The paddy straw briquette has the lowest mean volatile matter (52.893 ± 0.74) %, and dry grass had the highest volatile matter (61.503 ± 1.002) % in this study, as shown in Figure 7.

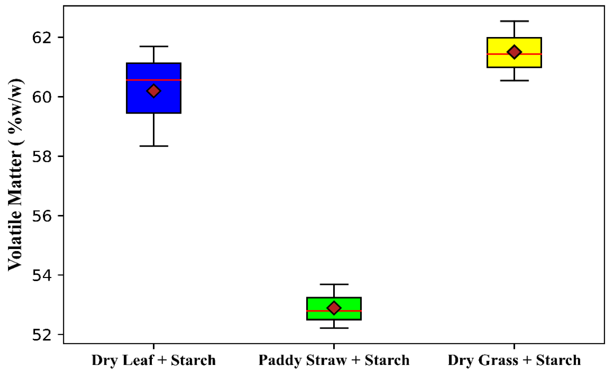

Figure 7. Effect of biomass briquettes on volatile matter.

Fixed carbon of biomass briquette

The statistical analysis showed that there was a significant difference in the fixed carbon of briquettes produced from different biomass taken in this study (p<0.05) (Table 1). The fixed carbon of tested briquettes ranges from (8.593 ± 0.57) % for dry grass to (14.9 ± 1.805) % for dry leaves, as shown in Figure 8. The dry leaf briquettes had the highest fixed carbon compared to paddy straw and dry grass briquettes.

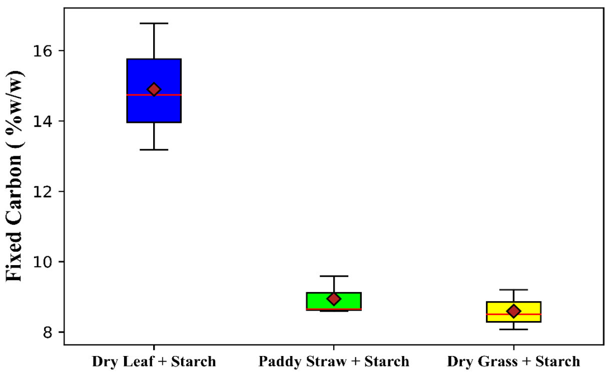

Figure 8. Effect of biomass briquettes on fixed carbon.

Calorific value of biomass briquette

The statistical analysis showed that there was a significant difference in the calorific value of briquettes produced from different biomass taken in this study (p<0.05) (Table 1). The paddy straw briquettes had the lowest calorific value (3455.667 ± 66.124) Kcal/kg and dry leaf briquettes had the highest calorific value (3990.333 ± 32.96) Kcal/kg in this study as shown in Figure 9. The briquettes from the dry leaf with this calorific value can be used for cooking purposes however, alternative binding material or a combination of other biomass may be used in briquettes from paddy straw and dry grass to have better calorific value to use for alternative energy generation.

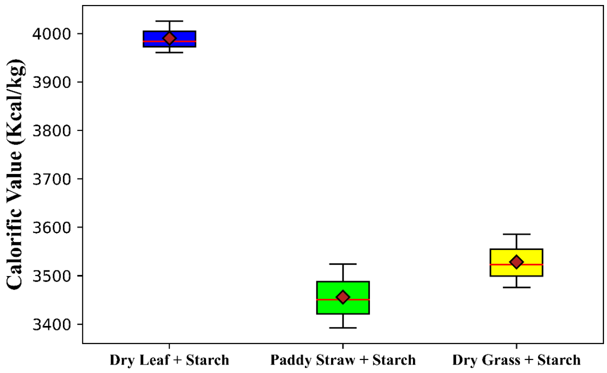

Figure 9. Effect of biomass briquettes on calorific value.

Ultimate analysis of briquette

The ultimate analysis of the produced briquettes from dry leaf, paddy straw, and dry grass is shown in Table 2. The statistical analysis showed that there was a significant difference in carbon, nitrogen, hydrogen, sulphur, and oxygen content of the briquettes produced from dry leaves, paddy straw, and dry grass. The carbon content ranges from (40.37 ± 0.871) % for paddy straw briquette to (50.523 ± 0.717) % for dry grass briquette. The hydrogen content ranges from (2.193 ± 0.261) % for dry grass briquette to (3.577 ± 0.335) % for dry leaf briquette. The nitrogen content ranges from (0.48 ± 0.05) % for dry grass briquette to (1.16 ± 0.044) % for dry leaf briquette. The sulfur content ranges from (0.06 ± 0.02) % for dry grass briquette to (0.523 ± 19 0.091) % for dry leaf briquette. The oxygen content ranges from (16.84 ± 0.666) % for dry grass briquette to (25.573 ± 0.926) % for dry leaf briquette (Table 2).

Conclusions

In this study, the briquettes were made from dry leaf, paddy straw, and dry grass as biomass and starch (wheat flour) as a binder using a screw extruder-type briquette machine. These briquettes were tested for physical, proximate, ultimate analysis, and fuel properties and showed varying results on these parameters. The study found that briquettes made from dry leaves had the highest calorific value, fixed carbon, porosity, and sulfur content, and the lowest bulk density and ash content compared to paddy straw and dry grass. However, the briquettes produced from paddy straw showed lowest calorific value, volatile matter, and highest ash content. The dry grass briquettes had lowest fixed carbon, sulfur content, moisture content and porosity and highest volatile matter. From these observations, it can be concluded that briquettes can be made from agro waste biomass having adequate fuel properties. Further extensive research is required to establish the briquettes for cooking and other heating applications as an alternative where LPG, firewood, or coal is used as a fuel.

Acknowledgment

Authors acknowledge the analytical facilities of CSIR-CMERI Durgapur and funding agenesis through OLP-233212.

Disclosure statement

No potential conflict of interest was reported by the authors.

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