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Production and characterization of biomass briquettes from *Bambusa bambos*

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Abstract
Known for its versatility and fast growth, bamboo is a perennial plant. Bamboo is noted for expanding rapidly; some types may do so by several feet in a single day. A prototype hydraulic piston briquette machine was used to process the bamboo samples, which were obtained from the Forest College and Research Institute Mettupalayam, India. The briquettes were made from *Bambusa bambos* and had various ratios of lantana camara and sawdust. Different combinations of briquettes made of *Bambusa bambos*' bamboo were measured for the physico-thermochemical examination. Based on the moisture content (5.13%), ash content (4.97%), volatile matter (73.19%), fixed carbon content (16.71%), bulk density (0.342 g cm^3), and gross calorific value (3913.5 kcal kg^{-1}), the current study deduces that the briquettes made with a combination of 50:25:25 of *Bambusa bambos*, lantana camara, and sawdust gave better performance.

Keywords: Briquettes, *Bamboosa bambos*, proximate analysis, saw dust, energy

1. Introduction

Briquettes are a type of compacted and compressed blocks made from various types of combustible materials. They are widely used as a source of fuel and energy in both industrial and domestic settings (Obi *et al.*, 2022) [1]. Briquettes offer several advantages over traditional fuels like firewood and coal, making them a popular and eco-friendly alternative. Due to their compact and dense structure, briquettes have a higher energy content compared to loose biomass materials, making them more efficient in terms of energy use and transportation. When compared to traditional fuels like coal and loose biomass, briquettes generally produce lower emissions of harmful pollutants like sulfur dioxide and carbon monoxide (Sharma *et al.*, 2015) [10] and are bulky in nature. However, previous studies have shown that agricultural residues, including biomass materials like rice husk, coffee husk, coconut husk, bagasse, groundnut shell, and cotton stalk, are useful in providing heat energy, despite the fact that they are challenging to store, handle, and even transport due to their low density, high bulkiness, and high moisture content. This indicates that briquetting is required to reduce their volume while maintaining a usable output. The process of compressing loose biomass material under pressure to create compact solid composites of various sizes is known as biomass briquetting (Bhoumick *et al.*, 2016) [11]. Because of their rapid growth, high cellulose and hemicellulose content, high calorific value, and low ash content, bamboo species have the potential to provide bioenergy (Liang *et al.*, 2023) [12] The hunt for new energy generation uses for bamboo crops and their residues is crucial given the growing potential of these species. With a compound annual growth rate (CAGR) of 8.2%, the worldwide bamboo market increased from $66.22 billion in 2022 to $71.63 billion in 2023, according to the Bamboo worldwide Market Report 2023. Since there is presently no research on the ideal approach to combine bamboo residues for briquette production, the objective of the current study is to assess the potential usage of *Bambusa bambos* for better briquette manufacturing.

2. Materials and Methods

2.1 Collection and Sorting of samples

The bamboo samples were collected from Timber nursery of Forest College and Research Institute Mettupalayam, Tamil Nadu (N 11.19' and E 77.56'). The culm age was determined based on morphological characteristics such as internodal length, the presence or absence of a culm sheath, nodal root rings, and the colour of the culm. Saw dust was collected from Ambiply plywood, Mettupalayam and *Lantana camara* was collected from Sathyamangalam Tiger Reserve.

2.2 Briquette manufacturing process

Bambusa bambos (Giant thorny bamboo) are known for their impressive height and substantial culm diameter (Wong *et al.,* 2004) [13]. 4 years old bamboo culms were selected to study the characteristics of bamboo- based biomass briquettes suitability. The weighed samples were taken with the ratio 50:25:25 and 40:30:30 for *Bambusa bambos*, saw dust and *Lantana camara* for two combinations and 100% *Bambusa bambos* for the other combination. For the creation of higher-quality briquettes, the optimal moisture level of the raw materials should be less than 15% (Dinesha *et al.,* 2019) [14]. Therefore, the selected raw materials were dried up for reducing moisture content by upto 15% with the help of an electrical seasoning kiln. Using a manual saw, the bamboo culms were divided into little pieces. With the use of a chipping machine, the cut bamboo pieces were further reduced in size into little chips. The chips are then pulverized into a fine powder using the pulverizing machine. Briquettes were created using the ground-up bamboo sample. For the other mixtures, sawdust and Lantana camara powder were added to the bamboo powder in the following ratios: 40:30:30, 50:25:25, and accordingly. The material was combined on the ground using a hoe and a shovel. All the briquette combinations were created using a pilot hydraulic piston briquette machine, which heated the briquettes to a temperature of 130 °C and compacted them under pressure of 60 MPa for the first 10 minutes and 110 MPa for the following 5 minutes (Krishnamoorthi *et al.,* 2023) [4]. The briquettes created by the machine must first be cooled down in order to prepare them for burning (Krishnamoorthi *et al.*, 2023) [4]. As a result, they cannot be used right away due to their high temperature. Once they have cooled, the briquettes can be kept dry and cool until they can be tested. The briquettes were roughly 100 cm long and 60 mm in diameter. In the current study, the physiochemical characteristics of the briquettes were examined.

2.3 Characterization of briquette

2.3.1 Analysis of Physical and Chemical Parameters

Proximate analysis of bamboo-based briquettes was performed using ASTM standard practises (ASTM E871, ASTM D1102, ASTM E872, and ASTM D1762-84). This analysis comprises moisture content, ash content, volatile matter, and fixed carbon content.

2.3.1.1 Bulk density (kg m^{-3})

According to ASTM E-873-82, the bulk density of briquettes was measured. The following formula was used to calculate the bulk density,

$$\text{Bulk density (kg m} - 3) = \frac{(\text{W2} - \text{W1})}{\text{V}}$$

Where,
W_1 = Empty weight of the container (kg), W_2 = Weight of the container along with sample (kg) and V = Volume of the container (m^3).

2.3.1.2 Gross calorific value (kcal kg^{-1})

The gross calorific value of briquettes made from bamboo was determined using ASTM D2015-77. The calorific value of briquettes made from bamboo was calculated using the formula below.

$$\text{GCV (kcal kg}^{-1}) = \frac{(\text{T x W})\text{- (CVT+CVW)}}{\text{M}}$$

Where,
T = Final Temperature increase in Degree Celsius, W = Water equal in calories per degree Celsius, CVT = The thread's Calorific Value, CVW = Ignition wire's Calorific Value and M = Mass of the sample collected in the crucible (g).

2.4 Statistical analysis

The IBM Statistical Package for Social Science Data (SPSS) application was used to assess the results of the ANOVA analysis and the Scott-Knott test at a 95% level of significance.

3. Results and Discussion

3.1 Moisture content

According to several academics, briquettes should have a moisture content between 6% and 8%. Durability, heating value, density, storage, and transportation are all significantly impacted by moisture content (Karunanithy *et al.* (2012) [16], Brand *et al.* (2019) [8], Grover *et al.* (1996)) [9]. The briquettes' moisture content is a crucial factor since it directly impacts the energy equilibrium of the densification. The heat generation per mass unit increases as the moisture content decreases. (Vale *et al.,* 2000) [2] The moisture content in this investigation ranges from 5.13% to 7.52%. The current study's findings showed that the bamboo briquette (100%) had the highest moisture content (7.52%), followed by briquettes made with the ratio 40:30:30 (6.78%), and briquettes made with the ratio 50:25:25 was recorded minimum moisture content (5.87%). Overall, the study found that briquette moisture content decreased with the decreased bamboo concentration. The principal bamboo species were determined to be the same by Brand *et al.* (2019) [8] and Mulindwa *et al.* (2021) [6], who also reported that all the briquettes were within the optimal moisture content range and had moisture levels lower than 10%. Wang *et al.* (2012) [16] made a similar discovery; the bamboo-based briquette's measured moisture content was 6.45.

3.2 Ash content

Ash content is a measure of the sample's inert and non-combustible components. When it is high, it reduces the sample's calorific value or heating value, increases dust and pollution emissions, and typically affects the sample's briquette particle combustion volume (Mulindwa *et al*., 2021, Furtado *et al*., 2010) [6, 15]. Ash levels in *B. bambos* briquettes varied from 4.97% to 6.06%. When comparing the ash percentage of the bamboo-based briquettes, the briquettes manufactured with the ratio 40:30:30 had the greatest ash content (6.06%), followed by those made with the ratio Bamboo (100%) (5.47%), and those made with the ratio 50:25:25 had the lowest (4.97%). Overall, the study discovered that as bamboo concentration is responsible for the higher ash content in briquette. Krishnamoorthi *et al.* (2023)

[4] found the similar results in Bambusa tulda based briquettes, ash content ranged from 3.47% to 4.84%. Similar findings in four distinct bamboo-based briquettes were reported by Brand *et al.* (2019) [8], who found that Bambusa vulgaris-based briquettes had the highest ash percentage (2.49%).

3.3 Volatile matter
When briquettes are burned, a mixture of short- and long-chain hydrocarbons are released as gases that are either combustible or incombustible, or both, is volatile matter. The combustion efficiency of briquettes is greatly decreased by these gases. In briquettes made of bamboo, the volatile matter was measured at a range of 73.19% to 76.70%. The current investigation found that the bamboo (100%) briquettes had the highest volatile matter levels (76.70%), followed by the briquettes manufactured with the ratio 40:30:30 (75.98%), and the briquettes made with the ratio 50:25:25 (73.19%). Therefore, we can state that the concentration of bamboo in briquette can affect the amount of volatile matter of the briquette. The similar results was observed by Krishnamoorthi *et al.* (2023) [4] in *Bambusa tulda* based briquettes the range of volatile matter was in between 71.29% to 76.82%.

3.4 Fixed carbon content
How much char is still there after the volatile material has been eliminated can be inferred from the fixed carbon content. It provides a rough estimation of the fuel's thermal value and is pictured as the main source of heat during briquette burning (Mulindwa *et al.*, 2021) [6]. This experiment yielded a figure for fixed carbon that varied from 9.72% to 16.71%. In the present investigation, the briquettes created in the proportion 50:25:25 had the highest fixed carbon content (16.71%), followed by those manufactured in the proportion 40:30:30 (12.08%), and the briquettes made from bamboo (100%) had the lowest fixed carbon content (9.72%). The results were the same for Krishnamoorthi *et al.*, 2023 [4], and the range of fixed carbon content was 10.79% to 18.63%.

3.5 Bulk density
Bulk density is the fundamental and significant physical qualities that influence the briquettes' features, including their performance during storage, transit, and handling (Karunanithy *et al.*, 2012) [16]. Bulk density values for the briquettes manufactured from Bamboosa bambos in this investigation ranged from 0.255 g cm^{-3} to 0.342 g cm^{-3}. The present study's findings showed that the briquettes formed in the ratio of 50:25:25 had the highest bulk density (0.342 g cm^{-3}), followed by those manufactured in the ratio of 40:30:30 (0.275 g cm^{-3}), while the briquettes made in the ratio of 100% bamboo had the lowest bulk density (0.255 g cm^{-3}). Similar results were discovered by Krishnamoorthi *et al.* (2023) [4] in Bambusa tulda-based briquettes, with bulk densities ranging from 0.291 g cm-3 to 0.383 g cm^{-3}. Similar research was done by Vijayakumary *et al.* (2023) [3], who discovered that the bulk density of bamboo-based briquettes varied from 0.68 g cm-3 to 0.70 g cm^{-3}.

3.6 Calorific value
Calorific value, which is calculated by the full combustion of a particular quantity under constant pressure and under typical circumstances, is the amount of heat energy present in fuel. The calorific value of briquettes prepared from various combinations of *Bambusa bambos* ranged from 3658.2 kcal/g to 3913.5 kcal/g. The current study's findings showed that the briquettes made with the ratio 50:25:25 had the highest calorific value (3913.5 kcal/g), followed by those made with the ratio 40:30:30 (3725.4 kcal/g), and the briquettes made with 100% bamboo had the lowest calorific value (3658.2 kcal/g). The difference in results can be attributed to the briquette's density; a higher density indicates a higher calorific value. Similar results were reported by Krishnamoorthi *et al.* (2023) [4] using Bambusa tulda-based briquettes, and the calorific value varied from 3975.2 kcal kg1 to 4714.3 kcal kg1. Similar findings were made in bamboo-based briquettes by Vijayakumary *et al*. in 2023 [3]. The calorific value varied from 3949 kcal/kg to 4372 kcal/kg.

Table 1: Briquette combination

Parameters	Briquette combination		
	Bamboo species (100%)	**Bamboo species (50%) + *Lantana camara* (25%) + Sawdust (25%)**	**Bamboo species (40%) + *Lantana camara* (30%) + Sawdust (30%)**
Moisture content (%)	7.52	5.13	6.87
Ash content (%)	6.06	4.97	5.47
Volatile matter (%)	76.70	73.19	75.98
Fixed carbon content (%)	9.72	16.71	12.08
Bulk density (g cm^{-3})	0.255	0.342	0.275
Calorific value (kcal/gm)	3658.2	3913.5	3725.4

4. Conclusion
In comparison to many other potential bioenergy crops, bamboo is substantially more productive. Bamboo residues have a lower heating value than woody biomass. To find the ideal combination of bamboo, lantana camara, and sawdust, briquettes made from both sawdust and bamboo were tested for their qualities. With a 50:25:25 blend of sawdust, lantana camara, and bamboo, good quality briquettes with a bulk density of 0.342 g cm-3 and a calorific value of 3913.5 kCal/kg were produced. The optimized briquettes had volatile, fixed carbon, and ash contents of 73.19%, 16.71%, and 4.97%, respectively. The combustion rate of briquettes made from bamboo, sawdust, and lantana camara is comparable to that of coal, making them suitable for use in industrial, commercial, and domestic heating systems. These briquettes can be gasified to create producer gas, which has potential uses in the production of thermal and electric power.

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