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Briquettes from Finger Millet Straws at Room Temperature and Low Compacting Pressure without a Binder

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Abstract:- **This paper reports the findings of densifying finger millet straws at room temperature using low compacting pressure without a binder. The finger millet straws were crashed using an electric hammer mill of circular sieve size openings. The particle size for this study was 0.600mm. The proximate analysis results of milled finger millet straw particles showed a range of 9.5 to 11% moisture content; 61.5 to 64% volatile matter; 19 to 22% fixed carbon and 6.5 to 7.5 ash content for all finger millet straws. Briquettes were produced using a manual hydraulic press. Compacting pressure was varied at 15MPa, 25MPa and 35MPa. The results indicated that the density of finger millet briquettes ranged from 480 to 698kg/m^{3}and compressive pressure from 20.5-33MPa for all the four varieties of finger millet under study. These results indicate that briquettes with sufficient physical and mechanical characteristics could be produced from finger millet straws at room temperature without a binder. This could enhance the existing technology for densifying agricultural residues such as finger millet straws, especially in rural communities.**

Key words: Finger millet straws, briquettes, proximate analysis, density, compressive strength

1. INTRODUCTION

The majority of the Kenyan population majorly depends on wood fuel and charcoal while others use fossil fuels like Liquefied Petroleum Gas (LPG) for domestic purposes. Diesel and petroleum are used to power motor vehicles and generate electricity. However, these sources are non-renewable and their prices have lately been very unstable and high at 95-110 US dollar/barrel [1]. The solution to the current and future energy needs calls for diversification of energy sources. According to previous research findings, there should be a best match between energy production methods with the locally available natural resources [2].
In Kenya, finger millet is grown in approximately 65, 000 ha accounting for about 8% of all millet types grown in Kenya although it's expected to increase as a result of promotion and research to mechanize finger millet cultivation [3,4]. Apart from finger millet, agricultural crops such as maize, rice, sorghum wheat, coffee and sugarcane are grown in Kenya. This has generated large volumes of agricultural crop residues as represented in table 1.

Table 1: Quantity, Potential Heat and Power of Some Agricultural Residues in Kenya [5]

Agricultural residue	Quantity (000's tons)	Potential Heat Energy (TJ)	Potential Power (MW)
Maize cobs Maize Stalks	431.61 2,397.87	4, 862.44 33,562	154.19 1,064.24
Sorghum Straws	1.15	13.62	0.4323
Finger Millet Straws	0.68	8.057	0.256
Wheat Straws	119.5	1,409.90	44.71
Coffee Husks	134.76	1,597.17	50.65
Rice Straws Rice Husks	69.10 7.60	712.90 82.38	22.61 2.61
Cotton Stalks	3.04	29.30	0.93
Bagasse	3158.64	95.11.12	301.59
Totals	**6323.38**	**51767.21**	**1642.218**

Finger millet straws, being lignocellulosic biomass materials, have high composition of organic constituents and energy, therefore, can be considered as a potential source of renewable energy [6]. In its original form, finger millet straw structure is porous hence low bulk density making it difficult for use as domestic fuel due to storage, transport and handling problems. To overcome this challenge, biomass raw materials are compressed at high pressure a process known as densification. Densification of finger millet straws will lower volume hence higher bulk density, improve energy density and improved mechanical handling [7]. This can be achieved through: baling, palletizing and briquetting.

Briquetting is a form of densification that involves compression of biomass to eliminate inter and intra-particle voids by either using pure agricultural residues without a binder or with a binder or carbonized residues using a hydraulic, screw and mechanical piston press [8].

Production of fuel briquettes from finger millet straws has not been explored extensively in literature. Several studies [9, 10, 11, 12, 13, 14, 15] are mainly based on briquettes from other agricultural residues: maize cobs, maize stalks, rice straws, wheat straws, alfalfa straws, coconut husks and shells, coffee husks, cashew nut husks. Since finger millet straws have been recognized as potential source of renewable energy, the current study is based on production of finger millet briquettes at room temperatures without a binder.

2 MATERIALS AND METHODS

2.1 Materials and material preparation

Finger millet straws were obtained from Kenya Agricultural and Research Institute (KARI), Kakamega Station. Four varieties of finger millet: P-224, Gulu-E, U-15 and Okhale-1 were collected. The straws were milled in an electric hammer mill of circular sieve size openings; the hammer mill was finally cleansed before putting another to avoid species contamination. The particle size for this study was 0.600mm.

2.2 Proximate analysis

2.2.1 Moisture content

On oven-dry basis, the moisture content of the milled finger millet straws was determined in accordance with [16]. Five samples of each variety of finger millet each weighing 20g were weighed and placed in an oven at a temperature of 107^{0}C and recorded the final weight. The moisture content of the specimen was determined as:

$$\text{Moisture content, \%} = \frac{M_1 - M_o}{M_o} \text{x } 100, \quad (1)$$

where M_1 and M_o were masses (g) of the test samples before drying and after oven drying respectively.

2.2.2 Volatile matter

The samples after moisture content determination were used to calculate the percentage of volatile matter according to [17]. The samples were placed in an inert state under nitrogen flask followed by heating in a furnace at a temperature of 350^{0}C for 10 min. The crucible was removed from the furnace and cooled in the desiccator until it reached the room temperature and weighed. The Percentage of volatile matter of the sample was determined as:

$$\text{Volatile Matter, \%} = \frac{Y - Z}{X} \text{ x } 100, \quad (2)$$

where x, y and z are initial weight of sample (20g), final weight of sample after cooling process (heating temperature at 107^{0}C till the mass remained constant and final weight of sample after cooling process (heating temperature at 350^{0}C for 10 minutes) respectively.

2.2.3 Ash content

The ash content of specimen was determined according to [18]. This involved furnace heating at a temperature of 550^{0}C for 3 hours, followed by cooling and weighing. The ash content was determined as:

$$\text{Ash content, \%} = \frac{r}{x} \text{ x}100, \quad (3)$$

Where x and r represent initial weight of sample (20g) and final weight of sample after cooling (heating temperature at 550^{0}C for 3 hours) respectively.

2.2.4 Fixed carbon

The amount of fixed carbon in milled finger millet straws was determined as:

$$\text{Fixed Carbon, \%} = 100\% - [\text{Moisture Content, \%} + \text{Volatile Matter, \%} + \text{Ash Content, \%}] \quad (4)$$

2.3 Briquetting Process

A cylindrical mould measuring 55.3mm internal diameter and 52.5mm height was used in fabricating the briquettes. Fouty-two grams of each finger millet variety was weighed and filled into the mould. Using a manual hydraulic press with a gauge and piston, the biomass materials without a binder were compressed to form briquettes (fig. 1). To allow escape of trapped air, a clearance of about 0.1mm was provided for between the piston and the inner wall of the mould. The specimens were then pressed at predetermined compacting pressure of 15, 25 and 35MPa with the dwelling time of each press maintained at 10 seconds.

Figure 1: fabricated finger millet briquettes

2.4 Physical and Mechanical properties of briquettes

2.4.1 Density

The diameter and height of a briquette were measured using a vernier caliper gauge; and calculating its volume using a mathematical formula of a cylinder. Using a mechanical weighing balance, the mass of a briquette was determined, for accurate reading, there were four replicates of each sample. With volume and mass of the briquettes, its density was determined as:

$$\text{Density } (g/cm^3) = \frac{mass\ (g)}{volume\ (cm3)}, \qquad (5)$$

2.4.2 Compressive strength

The compressive strength of briquettes was determined according to [19] on Instron universal strength testing machine with a load cell capacity of 100kN and 0.305mm/min crosshead speed. A specimen of the briquette to be tested was placed vertically on the horizontal metal plate of the machine followed by load application at a constant speed of 0.305mm/min until the briquette failed by cracking.

3. RESULTS AND DISCUSSION

3.1 Proximate analysis

The proximate analysis (moisture content, fixed carbon, volatile matter and ash content) of milled finger millet straws is presented in figure 2.

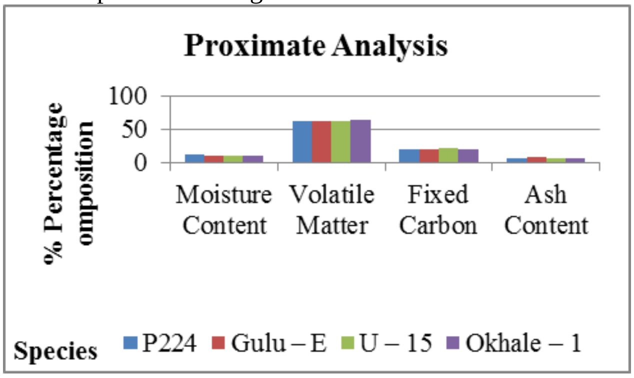
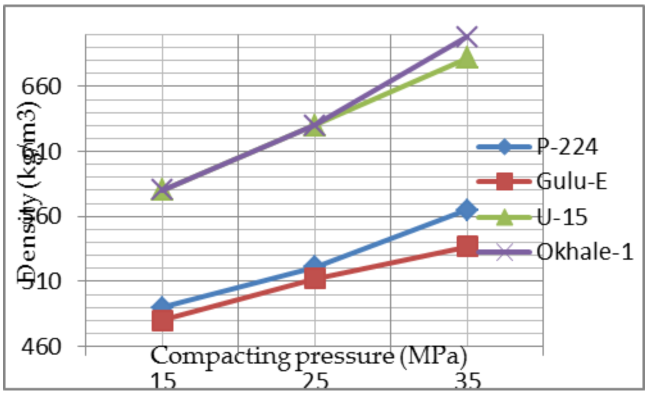


Figure 2: proximate analysis of milled finger millet straws

On average, the moisture content was between a minimum of 9.5% for Okhale-1 and U-15; and maximum of 11% for P224 and Gulu-E. This was within the acceptable ranges of 8-12% reported in literature [10]. The volatile matter was between a minimum of 61.5% for Gulu-E and maximum of 64% for Okhale-1. U–15 had a high fixed carbon of 22% while P224 had the lowest of 19%. This shows a low content of fixed carbon which is a common characteristic for biomass residues [9]. Gulu-E had a high ash content of 7.5% while Okhale recorded low value of 6.5%.

3.2 Density

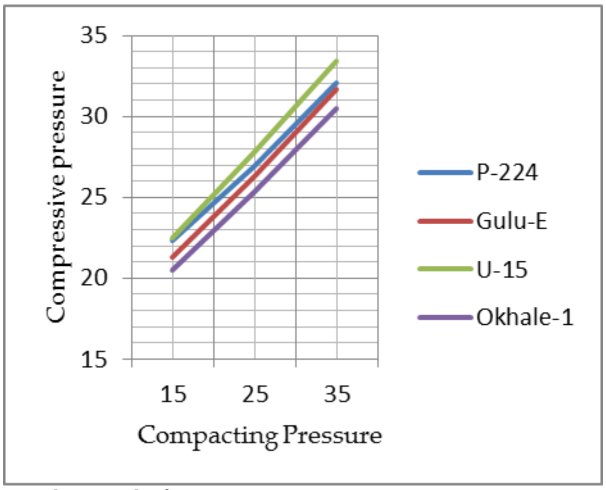
The density of briquettes produced from finger millet straws is presented in graph 1. For the three compacting pressures, Okhale-1 species had the highest density while Gulu-E had the lowest. The density of the briquettes obtained from the four finger millet varieties used in this study could be considered adequate as they fall within the recommended density values of briquettes made using hydraulic press. From literature, the density of briquettes produced using a hydraulic press falls between 300 and 600kg/m^3[20, 21].



Graph 1: Graph of density against compaction pressure for all finger millet varieties

3.3 Compressive strength

Table 2 shows the results of compressive strength of finger millet briquettes. The result indicates that for all compacting pressure levels, Okhale-1 had the lowest while U-15 had the highest compressive strength (graph 2). This implies that finger millet straws are reasonably adequate for handling and can be used as fuel for domestic purposes since their compressive strength is more than 19.6N/mm^2 recommended in literature [22].



Graph 2: Graph of compressive pressure against compaction pressure for all finger millet varieties

CONCLUSION

This study examined the characteristics of briquettes produced from finger millet straws without a binder at room temperature and low compacting pressure. From the study, it can be concluded that:

1. The proximate analysis of milled finger millet straws showed a high volatile matter of 60% with low moisture and ash content (below 20%). This

indicates that finger millet straws is a potential source of renewable energy;

2. On densification, finger millet straws were compacted at pressures of 15MPa, 25MPa and 35MPa to form briquettes. These briquettes were tested for density and found to be strong with the ability to be transported and stored for a period of over six months without detoriating; and
3. The physical characteristics such as density and compressive strength of finger millet straws were evaluated and all variety had comparably high compressive strength and density.

This study therefore, reveals that finger millet straws, like most agricultural residues can be used as a source of renewable energy thereby minimizing overdependence on fossil fuels which are characterized by non-renewability, pollution, high and fluctuating prices in the world markets.

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