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Combustion Properties of Briquettes Produced From Finger Millet Straws of Different Particle Sizes

Hesborn R Ayub, Dennis O Bichang'a, Janet J Kipsanai, Danvas A Kegesa and Beavon N Osumo

Abstract: The choice of agricultural residue briquette for domestic and industrial applications depends on its combustion characteristics. This paper reports the findings of densifying finger millet straws at room temperature without a binder at 25MPa compacting pressure. The finger millet straws were crashed using an electric hammer mill of circular sieve size openings to obtain particle sizes of 0.425, 0.600 and 1.18mm. Combustion-related properties such as percentage volatile matter, percentage ash content, percentage fixed carbon, moisture content, heating (or calorific) value of the briquettes were determined. Results indicated that different particle sizes produced briquettes of different properties. Density ranged between 0.43-0.76g/cm3; moisture content 9.5-11%; volatile matter 61.5-64%; fixed carbon 19-22%; ash content 6.6-7.5% and calorific value ranged between 4213-4662Kcal/kg for the three particle sizes of the four varieties under study. Assessment of burning characteristic showed that briquettes produced with particle size 0.425mm indicated the highest burning time of 6 minutes while briquettes with particle size 1.18mm had the highest burning rate of 4.6g/minute with low specific fuel consumption.

Keywords: finger millet straws; briquettes; particle size; proximate analysis, density, calorific value, combustion responses

Introduction

The increasing demand for clean, cheap and effective energy sources is the main driving force for exploitation of agricultural residues as a source of renewable energy. Agricultural residues such as finger millet straws are attractive sources of renewable fuel for domestic applications in developing countries as they are cheap compared to their non-renewable counterparts such as LPG, kerosene and other petroleum products. Globally, 140 billion metric tonnes of agricultural residues are generated after harvesting the main crops every year. The conversion of these enormous biomass materials into energy will solve the challenge of overdependence on energy from petroleum products which are characterized by high and unstable prices at 95-110 US dollar/barrel in the world markets [1].

The agricultural sector is very dominant in the Kenyan economy where it accounts for 24% of the total gross domestic product (GDP). Therefore, there are large quantities of agricultural residues available for conversion into energy for domestic use. However, these residues are under-utilized as a result of handling, transportation, storage and combustion characteristics associated with these residues [2]. The conversion of these residues will provide an environment-friendly form of energy that can be used for domestic purposes instead of firewood and charcoal produced in the traditional way hence saving forests and increasing forest cover [3].

The major agricultural residues in Kenya are maize husks, maize stalks, maize cobs, wheat straws, sorghum straws, millet straws, rice straws and husks; and sugarcane bagasse amongst others (table 1). In Kenya, finger millet is grown on approximately 65,000 ha and this is expected to increase as a result of promotion and research to mechanize finger millet cultivation [4,5]. 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].

It's evident that in Kenya, agriculture produces high rate of waste from the harvest of finger millet (table 1); leaving finger millet straws as agricultural waste. These waste when left unattended, can lead to land pollution (due to accumulation), environmental degradation and visual obstruction. To overcome this challenge, finger millet straw wastes should be converted into beneficial materials such as fuel exploitation as they are less expensive and environmental friendly. To achieve this, the determination of the combustion characteristics is crucial to evaluating the briquetting potential of any agricultural waste or biomass.

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This study, therefore, is aimed at evaluating the potentials of finger millet straws, of different sieve sizes for briquettes production.

Table 1: The relationship between Crop production, Residues generated and the Energy potentials in Kenya [8]

Crop residue	Crop production	Residue estimate (tonnes)	Heating Value(Mj/Kg)	Energy potential(GJ)
Maize stalks	3603338	7,206,676	12.5	90,083,450
Maize cobs	3603338	983,711.274	15.5	15,247,524.75
Maize husk	3603338	2,162,002.8	12	25,944,033.6
Wheat straw	441756	773,073	16.4	12,678,397.2
Millet straw	64023	112,040.25	12.39	1,388,178.698
Sorghum straw	126433	221,257.75	12.38	2,739,170.945
Cane bagasse	523652	151,859.08	13	1,974,168.04
Cane tops	523652	157,095.6	16.6	2,607,786.96
Cassava stalks	841196	1,472,093	17.5	25,761,627.5
Rice straw	64840	113,470	13.45	1,526,171.5
Rice husk	64840	1,7831	16	285,296
Coffee husk	23062	484,302	12.38	5,995,658.76
Barley	33035	57,811.25	19.2	1,109,976
Total		**13,913,223**		**187,341,439.9**

2.0 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 cleaned before putting another to avoid species contamination. Milled finger millet straws were sieved into three different sieve size openings of 0.425, 0.600 and 1.180mm respectively.

2.2 Briquetting Process

A cylindrical mould measuring 55.3mm internal diameter and 52.5mm height was used in fabricating the briquettes. Forty-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 (plate 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 25MPa compacting pressure with the dwelling time of each press maintained at 10 seconds.

2.3 Laboratory analysis

The produced briquettes were taken to the Material Science Laboratory, Mechanical and Production Department, Moi University where the combustion characteristics: ash content, calorific value, volatile matter and fixed carbon were determined

2.3.1 Proximate analysis

Proximate analysis was performed to determine the following combustion related properties: ash content, percentage fixed carbon, percentage volatile matter and calorific/heating values of the produced briquettes.

2.3.1.1 Determination of Percentage Ash Content

The ash content of specimen was determined according to [9]. 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:

$$\text{Percentage ash content, } \% = \frac{Y}{Z} \text{x}100, \qquad (1)$$

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

Plate 1: Briquetting process (A-Directing the piston; B, C &D- extruding briquette from the die)

2.3.1.2 Determination of Volatile Matter

The percentage volatile matter was calculated according to [10]. The samples were placed in a crucible in an inert state under a 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:

Volatile Matter, % = $\frac{B-C}{A}$ x 100, (2)

where A, B and C 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.

2.3.1.3 Determination of Percentage Fixed Carbon

This was calculated by subtracting the sum of percentage volatile matters and percentage ash content from 100%

Percentage Fixed Carbon = 100 – (%V + %A), (3)

Where %V = Percentage Volatile Matter and %A = Percentage Ash Content

2.3.1.4 Determination of moisture content

On oven-dry basis, the moisture content of the milled finger millet straws was determined in accordance with [11]. 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:

Moisture content, % = $\frac{M_1 - M_c}{M_o}$ x 100, (4)

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

2.3.2 Heating Value

This was determined using a ballistic bomb calorimeter using benzoic acid of known calorific value of 6.32Kcal/g. The benzoic galvanometer deflection reading value was compared with the deflection readings for the samples. Mass of benzoic acid used = 1.0g; Benzoic galvanometer reading = 7.05 and the galvanometer deflection reading= 5.00

Known calorific value of Benzoic acid = 6.32kcal/kg

For Okhale-1, Calorific value for 1.0g of benzoic acid is, $= \frac{5.00}{7.05} * 6.32 = 4.4823\frac{Kcal}{g}$ = 4482.3 Kcal/kg,

Similar procedure was repeated for other species under study and the results presented.

2.3.3 Determination of Briquette Density

The diameter and height of briquette were measured using a vernier caliper gauge; and the mathematical formula of a cylinder was used to calculate their volumes. 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:

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

2.3.4 Combustion Responses

The combustion responses in terms of burning time and rate of the briquette samples were determined as highlighted by [12]. This was done by igniting an oven-dried briquette sample over a Bunsen burner in the laboratory environment until the fire extinguishes and recording the burning time ad rate. This will determine how long the individual briquette will burn before restocking when they are used for cooking and heating.

3.0 Results and Discussion

3.1 Proximate analysis

The proximate analysis (fixed carbon, volatile matter, moisture content and ash content) of milled finger millet straw is presented in figure 1.

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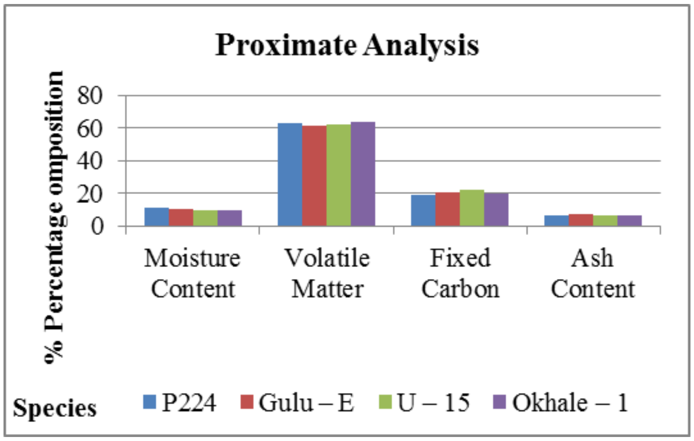

Figure 1: proximate analysis of milled finger millet straws

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. 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 [13]. Gulu-E had a high ash content of 7.5% while Okhale recorded low value of 6.5%.

3.2 Heating value/ calorific value

The heating value of milled finger millet was calculated and presented in figure 2

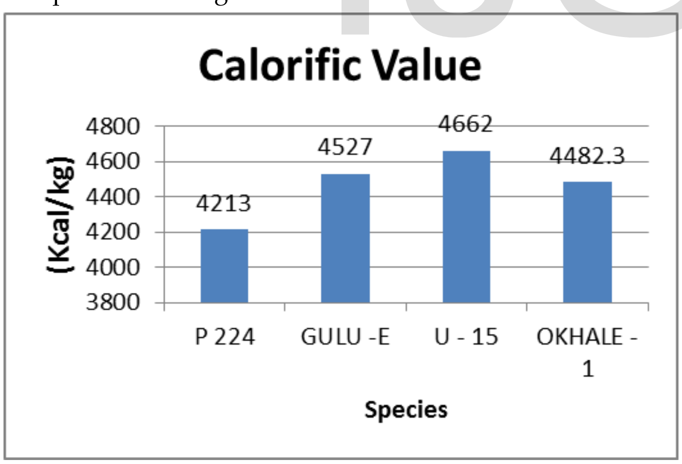

Fig. 2: Calorific values of four species of finger millet straws

U-15 had the highest heating value followed by Gulu-E then Okhale-1 and lastly P224. This is because U-15 has a high fixed carbon and relatively low moisture and ash content with moderate volatiles than all four species as obtained in the proximate analysis. The calorific values for four species were between 4213-4662Kcal/kg. This is within the ranges of other biomass, for instance, the calorific value of wheat is 4060 Kcal/Kg; bagasse 3996kcal/kg; Rice 3678 Kcal/Kg; and Wood 4538 Kcal/Kg [14].

3.3 Density

The different particles produced different briquette properties. This indicates that particle size has effects on briquette properties. Densities of the produced briquettes ranged from 0.43-0.76g/cm^3.

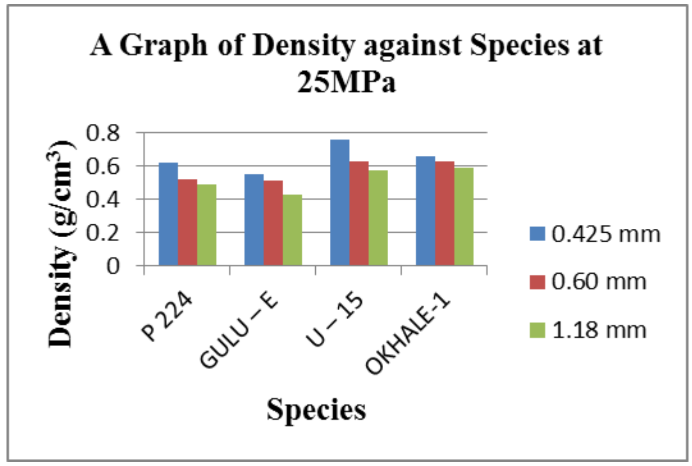

Fig. 3: Effect of Species to Density at 25MPa

For all briquettes, density reduced with increase in particles size with 0.425mm having the highest density and 1.180mm particles showing lowest densities. U-15 species showed the highest density while Gulu-E had the lowest density (fig. 3).

3.4 Combustion responses

3.4.1 Burning Time against Species of different particle sizes

Briquettes were burned and a graph was plotted to show the relationship between the burning time and the four species of finger millet of different particle sizes at 25MPa compacting pressure (figure 4).

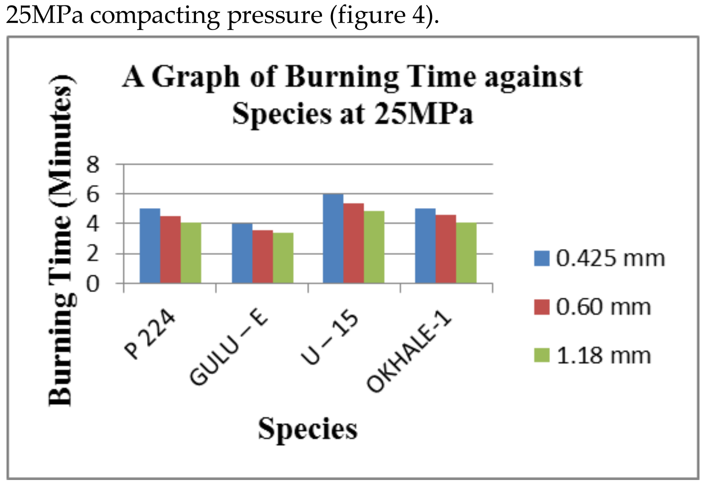

Fig. 4: A Graph of Burning Time against Species at 25MPa

U-15 had the highest burning time while Gulu-E showed the lowest for all the three particle sizes. This observation in burning time can be attributed to high density of U-15 species compared to other species under study.

3.4.2 Burning Rate against species of different particle sizes

The relationship between burning rate and finger millet species of different particle sizes was also analyzed by plotting graphs of burning rate against species (figure 5).

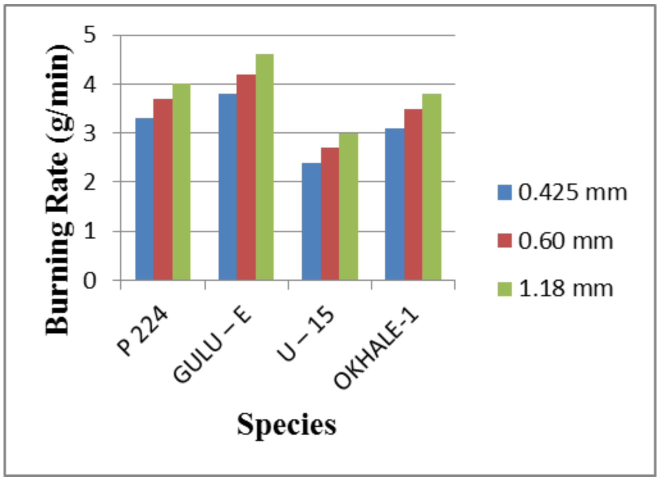

Fig. 5: A Graph of Burning Rate against Species at 25MPa

Gulu-E showed the highest burning rate followed by P224 and U-15 had the lowest burning rate, this could be due to high carbon content in U-15 as compared to other finger species. For all species under study, the burning rate increased with increase in particle size.

3.4.3 Specific fuel against Species of different particle sizes

The relationship between the specific fuel consumption and finger millet species of different particle sizes was also analysed figure 6.

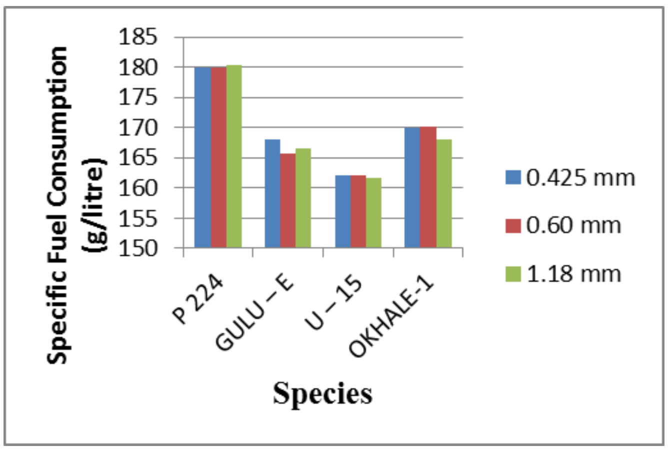

Fig. 6: A Graph of Specific Fuel Consumption against Species

The specific fuel consumption increases from U-15, Gulu-E, Okhale-1 and P224 respectively for the three particle sizes. This behavior in specifi c fuel consumption is inversely proportion to their calorific values (U-15 has high calorific value and P224 has the lowest). Therefore, the higher the calorific value, the lesser the specific fuel consumption and vice versa.

Conclusion

This study examined the combustion characteristics of briquettes produced from finger millet straws of different particle sizes. 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 are potential sources of renewable energy;
2. The density of the briquettes reduced with increase in particle size; for the three particle size, the density range was 0.43-0.76g/cm^3;
3. Finger millet briquettes showed higher calorific value 4213-4662Kcal/kg. This is comparable with those of common agricultural residues such as rice, wheat, bagasse and wood; and
4. On combustion, the burning time increased with decrease in particle size while the burning rate increased with increase in particle size. The specific consumption and calorific value were inversely proportional.

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References

[1]. Jekayinfa, S.O. and Scholz V. Potential Availability of Energetically Usable Crop Residues in Nigeria Energy Sources, Part A, Vol. 31, 2009, 687-697.

[2]. Matiru V., Forest Cover and Forest Reserve Cover in Kenya Policy and Practises, Oxford Press, Nairobi, Kenya, 2007.

[3]. Ministry of Energy, Economic Survey, Nairobi: Government Printer, Kenya, 2008.

[4]. Salasya B., Oduori C., Ambitsi N., Onyango E., Oucho P. &Lumuli J. The Status of Finger Millet Production in Western Kenya. African Crop Science Conference Proceedings, *9*, 2009, pp. 719-723.

[5]. Oduori C.O.A., Tongoona P., Derera J. and Odongo O.M. "Breeding Investigations of Finger Millet with Emphasis on Blast Disease and Striga Resistance in Western Kenya. *A Ph.D. thesis submitted to the University of KwaZulu-Natal,* 2008.

[6]. OECD/IEA: Sustainable production of second-generation biofuels, potential and perspectives in major economies and developing countries. Information paper, Paris (2010).

[7]. Bhattacharya, SC, Sett, S, Shrestha, RM: State of the art for biomass densification. Energy Sources 11, 1989, 161–182.

[8]. Stephen K. K., Alex M. M., Zachary O. S., and Ambrose K. K., A Study on Agricultural Residues as a Substitute to Fire Wood in Kenya: a Review on Major Crops, Journal of Energy Technologies and Policy, ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online) Vol.4, No.9, 2014.

[9]. ASTM International: Standard test method for compressive strength of wood. ASTM Standard D2166-85, West Conshohocken (2008).

[10]. ASTM E872-82(2013), Standard Test Method for Volatile Matter in the Analysis of Particulate Wood Fuels, ASTM International, West Conshohocken, PA, 2013, www.astm.org

[11]. ASTM D4442-15, Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials, ASTM International, West Conshohocken, PA, 2015, www.astm.org.

[12]. Musa, N.A. "Comparative Fuel Characterization of Rice Husk and Groundnut Shell Briquettes". *NJRED*l, 6(4), 2007, 23-27.

[13]. Omwando, T. A., Investigating the Combustion Behaviour of Selected Agricultural Residues Available in Kenya in a Fluidized Bed Combustor. Unpublished Master's Thesis Moi University, Eldoret, 2006.

[14]. Stahl Henrich E., Gehrmann H.J., Vodegel S. and Koch M., Definition of a Standard Biomass. RENEW–Renewable fuels for advanced power trains Karlsruhe, Germany, 2006.

Author Details

Hesborn R Ayub
Teaching Assistant
Department of Industrial and Energy Engineering
Egerton University

Dennis O Bichang'a
MSc. Student
Department of Manufacturing, Industrial & Textile Engineering
Moi University
ondiekidenis@gmail.com (correspondence)

Janet J Kipsanai
Graduate Assistant
Department of Mechanical and Production Engineering
Moi University

Danvas A Kegesa
MSc. Student
Department of Mechanical and Production Engineering
Moi University

Beavon N Osumo
MSc. Student
Department of Mechanical and Production Engineering
Moi University