Combustion Characteristics of Briquettes of Different Feed-Stock of Agricultural Wastes a Review

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ABSTRACT

Biomass utilization through briquette technology has been used extensively with a number of agricultural feedstocks. Despite having energy policies and implementation framework in some countries like Nigeria regarding biomass waste utilization, some agricultural wastes still remain unexploited nor characterized. This review paper embraced journals mainly from Google scholar published between 2006 and 2025, to establish properties and characteristics of various agricultural wastes and emerging trends. For the agricultural wastes characterized in this paper, the proximate analysis results showed, the average moisture content as 8.48 %, volatile matter 56.91 %, ash content 8.94 % and fixed carbon 24.42 %. These quantities were well within the recommended ranges, showing opportunities for utilization in briquette making. Limited amount of nitrogen and Sulphur content, that is below 1 % and 0.3 % respectively and absence of the same in some feedstocks was observed too. This encourages their utilization since nitrogen and Sulphur are the agents of pollution and being low, provides best substitutes for fossil fuels which have been main donors of the same to the environment. Carbon and hydrogen content averages for these feedstocks were 43.19 % and 5.94 % respectively. This having an influence on fuel combustion, the quantities portrayed, gives an assent for utilization of such feedstock for briquettes making. Average calorific value for briquettes from covered feedstocks was 18796.95 kJ/kg. Thermogravimetric analysis revealed high burning rates at high temperatures with increase in heating rate. Increase in amount of binder, negatively affect calorific values. Highly compacted briquettes result to low combustion rate, but good briquettes in terms of storage and transportation. More research needs to be carried out on other agricultural wastes to add to the available feedstock for briquettes. Further, there’s need to adopt modelling and artificial intelligence which is underutilized in characterization and study of properties of this agricultural biomass.

Key words: Briquettes, Feedstock, Proximate, Binder and Thermogravimetric

INTRODUCTION

Research in new developments concerning energy has reached advanced levels [1]. This is fueled by economic developments which majorly rely on energy [2]. Agricultural wastes, referred to as biomass has attracted greatest attention from researchers, first as an alternative energy resource facilitating reduction in deforestation and secondly as a better way of their disposal aiming to reduce environmental degradation [3],[4],[5]. Unlimited supply of agricultural wastes especially in countries where agriculture is the backbone and their limited amount of nitrogen and Sulphur has fueled dependency on them [6]. Research has also shown that developing countries have higher dependence on fuel from biomass as they are readily available, cheaper and very reliable [7]. This has led to decline in fossil fuels which is facing worldwide restriction as they are regarded agents of global warming [8] and their supply too is limited [9].

Biomass utilization technologies in the market include combustion (direct combustion, co-firing and co-generation), pyrolysis, gasification, liquefaction and densification (briquetting and pelleting), [6],[10]. Among these methods, densification that's briquetting has gained greater attention as can be witnessed from the numerous research. In briquette making, collection of feedstocks is done then dried, ground, sieved and compacted before cooling [11].

For best briquette results, combustion characteristics, which are determined by feedstock, need to be evaluated [12]. Elemental and proximate quantities differ among different biomass [13]; these are also affected by the ratio of the individual feedstock for the case of varied feedstocks [14]. The densities, thermal characteristics, available energies, compressive strength and index of durability change as specific amount of a strand in a briquette is changed [4], [8]. Heating value of single strand too is unique for different wastes [15].

Energy Policies

Energy policy framework plays a crucial role in ensuring support, proper utilization, tax reliefs, implementation of state-of-the-art technologies in briquetting, binder use and automation processes. These policies play a crucial role in ensuring that technologies adopted are economical and viable. European union policy (Fit for 55) package give priority to renewable energy resources such as biomass. This policy has ensured that there is reduced emissions and the wastes have been reused effectively. Other policies also aid in promoting briquette awareness, innovations regarding biomass use and market readiness [16].

Some other countries have put in place energy policies and implementation frameworks. These strategies are well defined for easy implementation. A country like Nigeria has supported some initiatives such as National Renewable Energy Policy (NREP) 2018, National Development Plan (NDP) 2020 and National Clean Cooking Policy Draft (NCCPD) 2023, which brought up the issue of having biomass briquettes utilized as a substitute for fossil fuels. These policies have emphasized on the need to have reliable energy solutions in place. This aims at ensuring unlimited clean energy supply hence combatting issues of climate change which has been as a result of overreliance of conventional energy resources such as fossil fuels [17].

METHODOLOGY

In this review of combustion characteristics of briquettes of different feedstock of agricultural wastes, a structured methodology was adopted in selection of articles reviewed. The journal adopted were published between 2006 and 2025. These journals were mainly from Scopus, Google scholars and Science direct, focusing on briquetting, agricultural waste and combustion characteristics as the key words. The experimental results reviewed includes; proximate analysis (moisture content, volatile matter, ash content and fixed carbon), ultimate analysis (carbon, hydrogen, oxygen, sulphur and nitrogen contents), other results reviewed were calorific values, porosity, ignition time, combustion rate, thermal efficiency, binder properties, density and thermogravimetric analysis. The journal and articles adopted were those in English version.

Biomass Use and Challenges

In developed parts of the globe such as Europe, America and Asia, briquettes from biomass wastes are utilized in household heating and power generation, while in developing countries mainly from sub-Sahara, the use is limited to kitchen fuel [18].

Adoption of briquettes have been mired by a few challenges including, lack of awareness, high capital costs, poor supply (unreliability) and cultural beliefs. Other limiting factors include insufficient stakeholder involvement, high machine maintenance, lack of briquette making experts, withdrawal of briquette making project experts, poor technology involvement, inappropriate government based policies to drive biomass use and limited research on biomass briquettes [17], [19], [18].

RESULTS ANALYSIS

Proximate Analysis

This aims at evaluating the percentage composition of a given fuel in terms of Volatile Matter (VM), Fixed Carbon content (FC), Moisture content (MC) and Ash content (A) [20].

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Moisture content

Moisture content is said to be the percentage of water present in a given fuel [21]. The average moisture content of the selected agricultural waste in Fig. 1.1 above is 8.475%, with the highest being in corn cobs at 13.47 % and least in oil shale at 3.84. The majority have a moisture content of between 6% and 10 %. Moisture content in fuels has negative effect during utilization, storage and transportation [4], [22], [23]. It is preferred that for a given biomass fuel, the moisture content to range between 5 – 10 % [24] which is satisfied by the majority of the feedstock selected here.

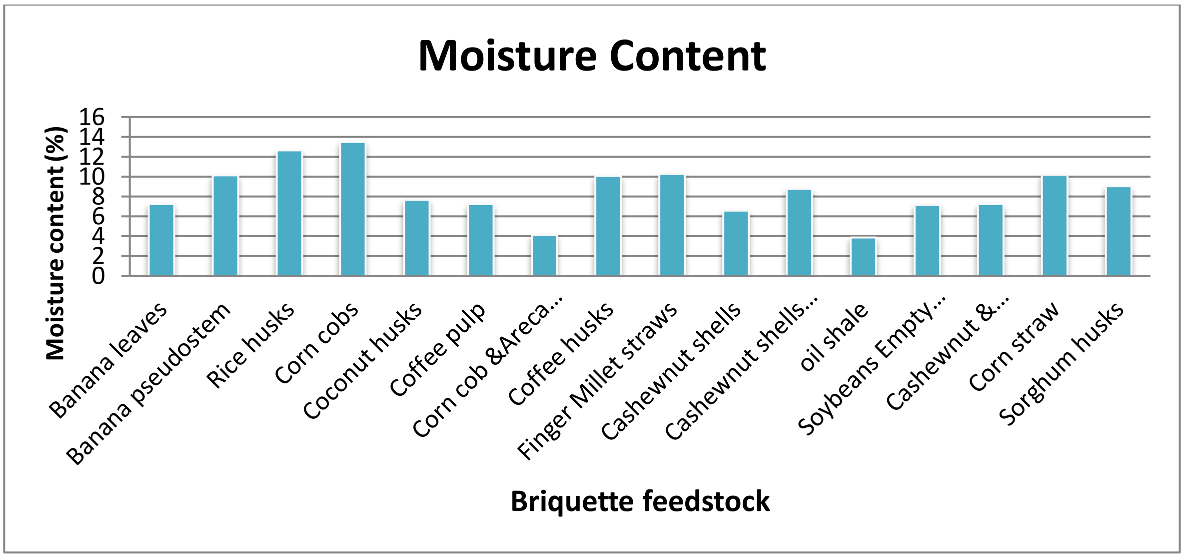

Fig. 1.1Graph of moisture content against selected feedstock for briquettes [4], [5], [25], [26], [27], [28], [29]

The quality of fuel (biomass) is inversely proportional to moisture content [26], this to a large extent influences rate of burning of such biomass as some heat is used to dry the fuel before burning commences [21]. Basing argument on moisture content alone therefore implies that rice husks and corn cobs are poorest feedstock of the one selected here in making briquettes. Ignition is likely to be fastest in oil shale and corn cob & areca peel due to low moisture content [30].

Volatile matter

Volatile matter is ideally the amount of hydrogen, carbon and oxygen in a fuel [21]. Corn cob, Rice straw& nahar seed cake and banana leaves & nahar seed cake had highest volatile matter (ranging between 85.51 % and 86.53 %), while coffee husks, oil shale and corn cob and areca peel had the least (ranging between 12.6 % and 16.4 %) as can be seen from Fig. 1.2. The average for this feedstock's volatile matter was 56.905%.

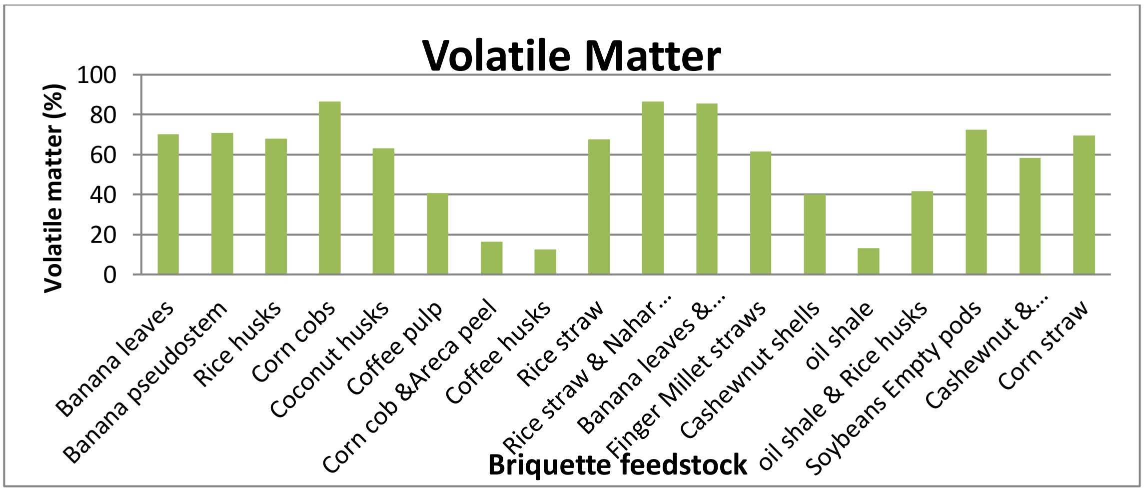

Fig. 1.2 Graph of Volatile Matter against selected feedstock for briquettes [4], [5], [25], [26], [27], [28], [29]

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This paper contradicts with Moore and Johnson's research [19] that amount of volatile in most biomass ranges between 70% and 80%, as most of the feedstock portrayed percentage volatile matter below this range. During utilization, the emissions noticed are directly proportional to percentage of volatile matter of such fuel [20], for this selected feedstock, corn cob, rice straw& nahar seed cake and banana leaves & nahar seed cake will have highest emissions with an advantage of quick ignition, a long flame time and high rate of fuel burn [26].

Ash Content

Ash can is defined as that component of fuel which does not get combusted [21].

Corn cob, corn cob & areca peel, cashew nut shells and sorghum husk had the least ash content (below 5 %), while rice husks, rice straw, soybean empty pods and oil shale & rice husks registered highest ash content (above 15%) with the latter registering 48.51%, as shown in Fig. 1.3, such a high value. This implies poor quality of briquettes from this feedstock [31].

With exception of oil shale & rice husks, the average percentage ash content of these agricultural wastes was 8.942%, this was well within 0.6 % and 9.8 % meant for commercial purposes [32].

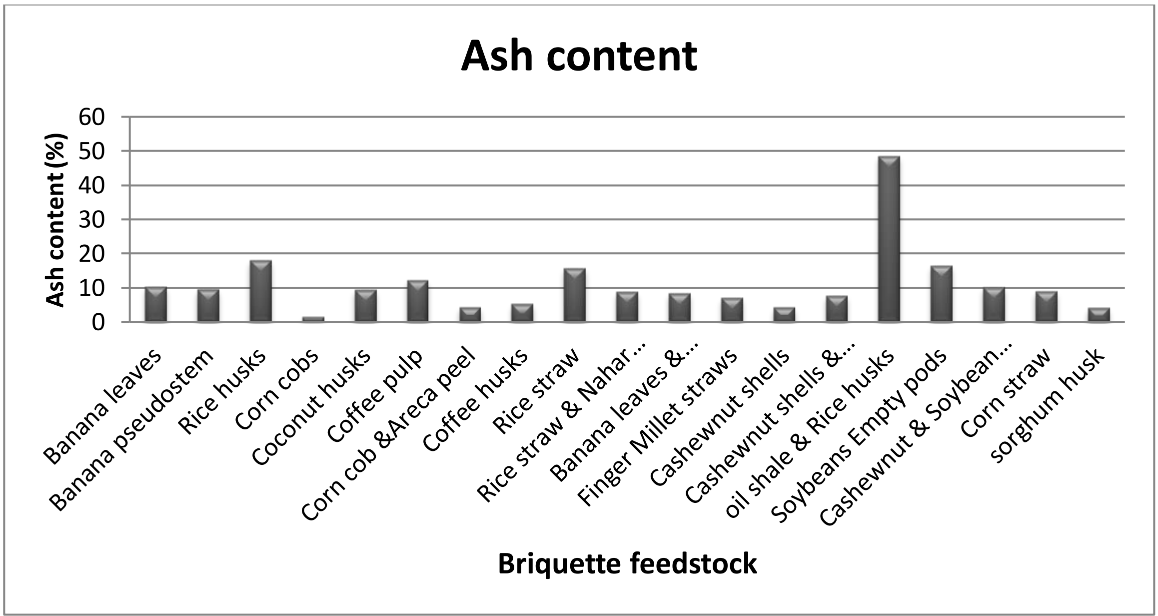

Fig. 1.3 Graph of percentage ash content against selected feedstock for briquettes [4], [5], [25], [26], [27], [28], [29]

Due to high ash content, clogging in combustion chamber, reduced rate of burning and environmental degradation as a result of emitted dust is expected in briquettes from rice husks, rice straw, soybean empty pods and oil shale & rice husks feedstock [26]. Sunard [21] also argues that fuels with high ash content to large extent have low amount carbon hence retarded burning as the entry of oxygen to the combustion chamber is hindered.

Fixed carbon content

Fixed carbon is in form of solid and has a direct influence to the heating value of fuels [15], [27]. The fixed carbon is available after the removal of volatile matter, and is as a result of lignocellulose content, which determines the quality of char [26], [27] and [28].

From Fig. 1.4, highest fixed carbon was in coffee husk and corn cob & areca peel (81 % and 75.3 % respectively), hence higher burning time for this fuel [15].

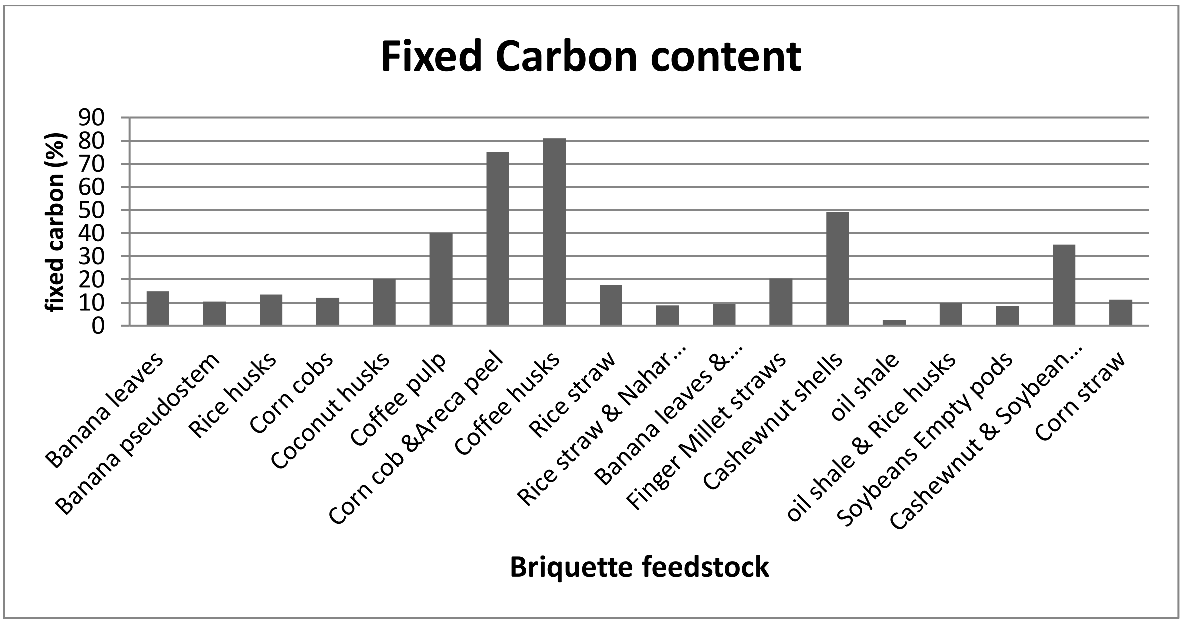

Fig. 1.4 Graph of percentage fixed carbon content against selected feedstock for briquettes [4], [5], [25], [26], [27], [28], [29]

The average percentage fixed carbon content was 24.42, implying average calorific value. However, oil shale, soybeans empty pods, rice straw & nahar seed cake and banana leaves & nahar seed cake showed low percentage fixed carbon (below 10 %), this indicating likelihood of very low heating value [15].

Elemental analysis

For all the selected four feedstock as shown in Fig. 1.5, the carbon content is relatively high, with corn cob being highest (45.41 %) and banana pseudo-stem least (37.69 %). Hydrogen content was highest (6.2 %) in banana leaves and least (5.58 %) in banana pseudo-stem. Carbon and hydrogen influence combustion of fuel [13], hence this displayed good fuel sources.

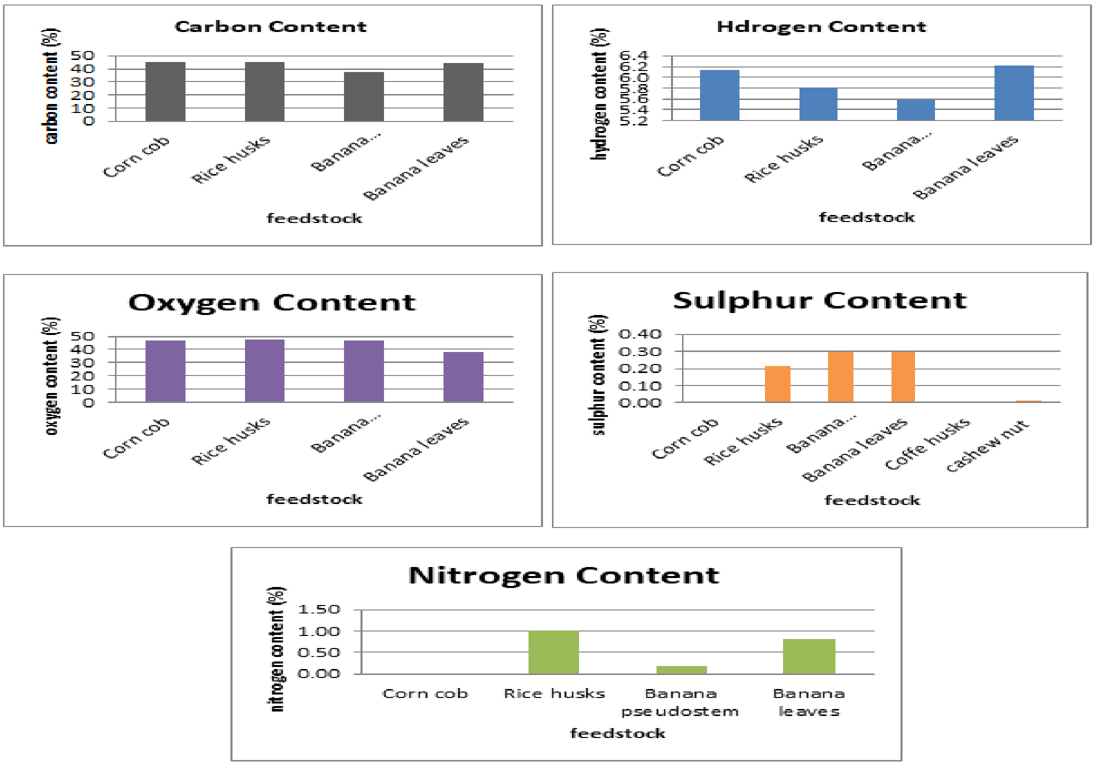

Fig. 1.5 Graph of percentage elements content against selected feedstock for briquettes [4], [27], [28].

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Nitrogen and Sulphur of insignificant quantities and nil in some feedstock was recorded. This was an indication of a good feedstock for briquettes since Sulphur and nitrogen lead environmental degradation [13].

Briquette Fuel Energy

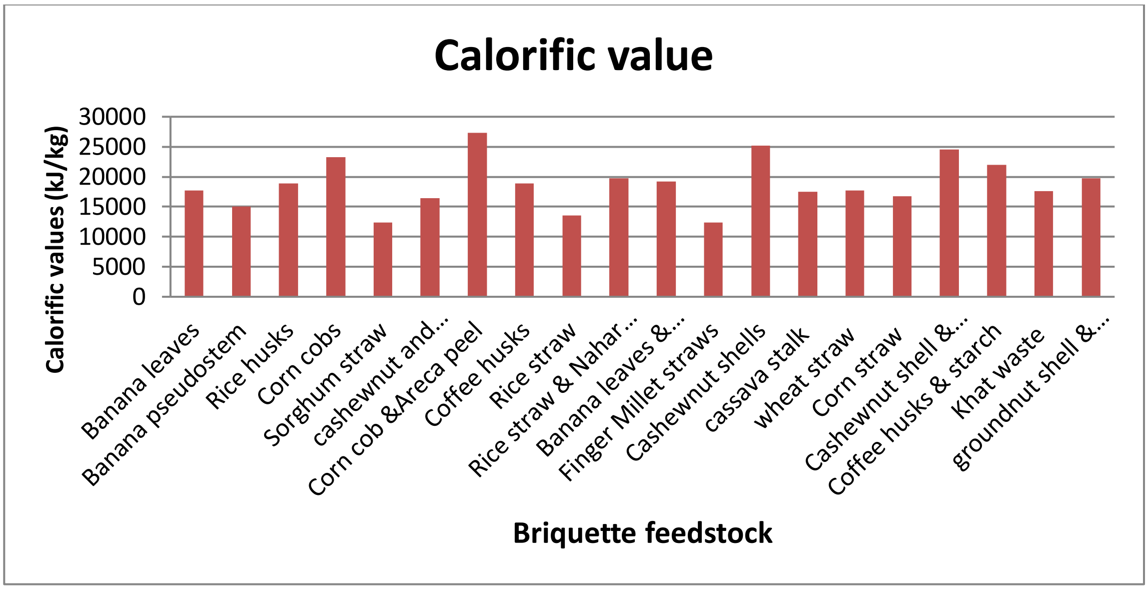

Fig. 1.6 Graph of calorific values against selected feedstock for briquettes [4], [5], [25], [26], [27], [28], [29]

Calorific value refers to energy contained in a given fuel [5] [21], and regarded as key element of any fuel [33]. Proximate analysis contents have a direct influence on the fuels' calorific values. As discussed earlier, the higher the ash content, moisture content and volatile matter, the lower the heating value. The amount of bonded carbon has a positive influence on heating value of a fuel, meaning the best fuel has highest amount of bonded carbon [34].

Corn cob & areca peel, cashew nut shells, cashew nut shells & soybean empty pods, corn cob and coffee husks & starch have relatively higher calorific values (above 22000 kJ/kg) for the selected briquette feedstock, they therefore presumed to have a long burning time [35]. This meets the SNI standards for biomass pegged at 20920 kJ/kg or more [21]. Finger millet straw, sorghum straws and rice straws have least calorific values (below 14000 kJ/kg). This likely to be given least attention since fuels with low calorific values are discouraged as large amount of that fuel will be required for a specific job [29].

From Fig 1.6, the average calorific value for the above feedstock is 18796.95 kJ/kg which is slightly below the recommended threshold (19150 kJ/kg) for biomass briquettes' calorific values to be relied upon as energy resource supplement [27].

Briquette porosity

Porosity of briquette is defined as the ratio of the mass gained by the briquette to the new mass after it has been completely submerged in water for a given period of time [5]. This is also an important factor in briquettes as it determines their storage and caution during transportation.

Mathematically, porosity can be represented as;

$$\rho = \frac{M_f - M_i}{M_f}$$

Where:

ρ = porosity

M_f = final mass

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M_i = initial mass

Ignition time and combustion rate

In briquettes, ignition time is the duration taken between introduction of spark to ignite a given briquette to the time the fire in that briquette stabilizes, while combustion rate refers to the time it takes exhaust a given fuel [5]. Burning rate also decreased with increase in compaction pressure of briquettes from biomass waste [15], [36]

Thermal efficiency (η)

Mathematically, thermal efficiency is given as: $\eta = \frac{M_w\, C_w\, (T_f - T_i) + M_e L}{M_f\, H_f}$

Where:

η = Thermal efficiency

M_w= Mass of water (kg)

C_w = Specific heat capacity of water (kJ/kg K)

T_f = Final temperature of water

T_i = Initial water temperature (K)

M_e = Mass of evaporated water (kg)

L = Latent heat of vaporization (kJ/kg K)

M_f = Mass of fuel burnt (kg)

H_f = Calorific value of the fuel (kJ/kg) [5].

From above formula therefore, we divide the heat consumed by water with heat supplied from the biomass fuel. Briquette from cashew nut shells showed efficiency of 18.01% of the heat and an average of 11.90 g/min burn rate [5].

Binder, bonding property and density

Type of binder and its concentration influence physical characteristics of biomass [37]. Calorific heating value is inversely proportional to the amount of binder material (the higher the amount of binder material, the lower the calorific value) [15]. Bonding property of biomass fuel improves with decrease in particle sizes and increase in compaction pressure reduces the void in the fuel hence increasing compressive strength [12]. When the briquettes are well compacted, the volume reduces, hence density increase, in turn, the briquettes occupy a small space. This facilitates easy storage and transportation [12], [37].

Thermogravimetric analysis

Thermogravimetric for banana leaves showed decline in percentage mass at different temperatures. Minimum loss was loss between 0 °C and 250 °C, this probably due to moisture loss, after which there was a sharp drop between 250 °C and 350 °C, at these temperatures, the volatiles are being released. For the temperatures between 350 °C and 900 °C there was almost insignificant drop, complete char combustion [28]. It was also noted that, use of a higher heating rate results to maximum burning rate at higher temperature [3].

CONCLUSION

The proximate analysis showed a large variation among the components, that is moisture content 4.1 % and 13.47 %, volatile matter 12.6% and 86.53%, ash content 1.4 % and 48.51 %, fixed carbon 2.48 and 81%. Despite the great difference, most of the quantities in each feedstock were within the recommended ranges.

Carbon and hydrogen from elemental analysis were ranging between 37.69 % and 45.2 % for carbon and 5.58 % and 6.23 % for hydrogen. This being the preferred component for combustion in fuels and their quantities being relatively within required range, therefore show that agricultural waste is a hub for energy resource.

Sulphur and nitrogen were quite low and missing in some. Sulphur was below 0.3 %, while nitrogen below 1 %. This is desirable since their absence makes this feedstock suitable for utilization since their release during combustion leads to environmental degradation.

Calorific values range between 12390 kJ/kg and 27313 kJ/kg. These calorific values were quite encouraging for utilization of this feedstock. More research needs to be carried out on other agricultural wastes to add to the available feedstock for briquettes. There is also need to refocus on integration of mathematical models such as Buckingham π theorem, artificial intelligence and machine learning which remains glaringly underutilized in the study of these agricultural wastes as an energy resource. These models will provide a cheaper and effective way of prediction and optimizing the properties and energy output. Once validated with field and laboratory experiments, they will offer a guiding policy and a sustainable way of utilizing these biomass wastes.

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