Journal of Agriculture Science & Technology JAGST 23 (1) 2024, 78-93

ORIGINAL RESEARCH ARTICLE

Energy Characteristics of *Prosopis Juliflora* with Binary Combination of Maize Cobs and Bagasse Agricultural Waste on Briquette Production

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ABSTRACT

Cooking energy accounts for a significant part of the daily household energy needs in developing countries. The study aimed to investigate the use of *Prosopis juliflora* as a feedstock for briquette production and evaluate the influence of a binary combination of maize cobs and bagasse on the characteristics of the briquettes. Binary combination ratios were done at 25% and 50% of the total sample weights. Laboratory bench testing evaluated the physicochemical characteristics of *Prosopis juliflora* and its binary combinations to establish both proximate and ultimate elemental composition. Experimental analysis results showed that using *Prosopis juliflora* in its pure form for briquette production achieved moisture content of 5.59$\pm$0.09%; volatile matter of 77.49$\pm$1.98%; ash content of 3.12$\pm$0.16%; fixed carbon of 19.39$\pm$1.82% and calorific value of 18.99$\pm$0.21 MJ/kg; for ultimate analysis it achieved, 46.26% carbon, 5.75 % hydrogen, 0.27% nitrogen and 0.44% Sulphur; which are all within desirable range for briquette production; revealing that even without combinations of other feedstock, *Prosopis juliflora* is sufficient as an energy crop. The experiment went further to establish the impact of binary combinations of bagasse and maize cobs at 25% and 50 % of its sample on the energy characteristics of *Prosopis juliflora*. It was found that adding the binary combinations to *Prosopis juliflora* on briquette production increased its calorific value; it also increased carbon and hydrogen percentage compositions which play a key role in attaining high calorific values in a biomass fuel. Results obtained were 19.27$\pm$0.05 MJ/kg at 25% of maize cobs; 19.73$\pm$0.05 MJ/kg at 50% maize cobs; 19.07$\pm$0.07 MJ/kg at 25% of bagasse and 19.14$\pm$0.07 MJ/kg at 50% of bagasse, which were all higher than 18.99$\pm$0.21 MJ/kg that of using *Prosopis juliflora* in its pure form. This showed that bagasse and maize cobs combination to *Prosopis juliflora* at binary levels increased calorific value of the resulting briquette fuels. In finding out the desirable binary combination with better energy characteristics, the experimental analysis showed that the binary combination of 50% *Prosopis juliflora* and 50% Maize cobs is a better desirable fuel choice for briquette production. This combination had a high calorific value of 19.73$\pm$0.05 MJ/kg compared to other binary combinations under this study; making it the ideal binary combination fuel.

Keywords: proximate analysis, ultimate analysis, Briquettes, *Prosopis juliflora*, maize cobs, bagasse

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

1.0 Introduction

Briquette production is one of the pathways of generating efficient fuel from biomass materials. According to Marreiro and Junior (2021), briquette production involves the densification of raw materials into fuel forms that can transform biomass into usable energy. Briquette production is associated with achievement of denser fuel, improved physical and energy properties which enhances homogeneous combustion. Briquette production is then seen as a process of biomass densification that serves to improve physical and chemical properties of biomass hence more efficient energy source (Omwenga, 2021). According to Araújo et al. (2022), a briquette refers to the a biomass that is combustible and that has been compressed for use as fuel. Various feedstocks can be used in the production of briquettes which include but not limited to agricultural residues, forestry waste, and municipal waste and energy crops (Okwara et al., 2022). In Kenya briquette usage has been hindered by several constraints; the availability of efficient and sustainable feedstock, efficient technology and consistency of briquette availability. These constraints have made Kenyan households and industries to continue depending on both charcoal and firewood for their energy needs. In Kenya, 90% of the energy utilized in rural households for cooking and heating is mainly in form of firewood, while more than 80% of urban households use charcoal(Ndegwa et al., 2022). Majority of Kenyan industries too continue to utilize woody biomass in powering their boilers. The use of non-clean energy sources are associated with challenges of air pollution and deforestation aspects while being deemed unsustainable (Kiprop et al., 2021). Previous attempts at solving the problem associated with energy for cooking and heating in Kenya has had limited success as a result of inadequate scientific knowledge on the current level and utilization of modern cooking energy sources among households. The present study seeks to provide a solution by looking into biomass and specifically briquette production as a renewable alternative to reducing if not to eradicate the use of firewood and charcoal in our homesteads and industries.

This study investigates *Prosopis juliflora* has a potential feedstock on briquette production. *Prosopis juliflora* is an invasive plant with high coppicing rate and low demand on its farming input; therefore making it an excellent candidate in providing a continuous and efficient supply of feedstock. Secondly, the study utilized *Prosopis juliflora* with binary combination of maize cobs and sugarcane bagasse which will not only add value to the invasive plant but provide a useful means to dispose the agricultural waste. Riyadi et al. (2019) noted that the sugarcane bagasse and maize cobs are by-product in the sugar and maize industry and they treated as an industrial wastes; hence making them suitable candidates to be used in the production of briquettes as an energy source; thus adding value and contribute to their disposal.

There are several characteristics of the briquettes that determine their suitability and efficiency as energy sources. These characteristics include; calorific value, moisture content, volatile matter, ash content, fixed carbon, and the ultimate composition in a briquette fuel (Urbanovicov et al., 2021). Understanding proximate and ultimate analysis of a biomass fuel is important to be able to categorize a good quality fuel from a low quality one (Urbanovicov et al., 2021). According to Nurek et al. (2021) the moisture content of the plant materials during the agglomeration period of plant materials has a bearing on the quality of the final briquette

ISSN 1561-7645 (online)
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products. With a view of enhancing the durability and density, the agglomeration of the plant materials should be undertaken at 8%-12% of the moisture content (Nurek et al., 2021). According to Akowuah et al. (2019), volatile matter has an influence on the thermal properties of the solid fuels such as briquettes. Biomass components of briquettes often have high volatile matter of about 70% or more. This leads to high reactivity and high combustion levels. In this context, Variani (2021) recorded that high volatile matter leads to ease of ignition and high combustion rate. According to Sarakikya (2020), it is expected of biomass fuels to have volatile matter in the ranges of 70% to 80%; this leads to rapid burning and helps in combustion. The ash content has impact on the use of briquettes due to the clinkering and fouling effect in the combustion chambers. Ullah et al. (2021) explained the impacts on the efficiency of the briquettes through lowering of heating efficacy leading to slagging effect. Ash content below 10% is desirable in most utilities (Sarakikya, 2020). The fixed carbon in biomass material comprises of the elemental carbon plus any other carbonaceous residue formed during combustion process (Gemeda, 2019). A high fixed carbon percentage is associated with higher eating values. However, fixed carbon content gives information of the amount of char formation in the thermochemical conversion process (Nurek et al., 2021). Calorific value is one of the most important parameter in determining the quality of briquette fuel (Anatasya et al. 2019).

According to Deng et al. (2020), calorific value is dependent on the total amount of matter that is combustible. It refers to the maximum amount of heat released on the combustion of a unit mass of briquette to completion. Ultimate analysis involves the determination of chemical elements present in a compound. For this study this involved finding out the percentage composition by weight of Carbon, Hydrogen, Nitrogen and Sulphur. A high Carbon and Hydrogen content in a biomass fuel is an excellent characteristic since it directly translates to high calorific value. This is due to the reason that between carbon and hydrogen, exists a high-energy bonds that releases and increased amount of energy during combustion (TgAzhar, 2020). Nitrogen has no calorific value significance in a biomass fuel; in addition to that, Nitrogen oxide (NO_x) has negative impacts to environment; therefore, low nitrogen content in a biomass fuel is a good characteristic. Low sulphur content in biomass fuel is a desirable characteristic as it leads to low emission of SO_2. SO_2 readily dissolves with water and brings about sulphuric acid; this has corrosive effect to the combustion chambers; also, Sulphur oxides are also responsible releasing significant amount of particulate matter and causing acidic rain (Kunle et al., 2021; TgAzhar, 2020).

2.0 Methodology

2.1 Research design

The series of steps followed to achieve briquette production are as shown in Figure 1:

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

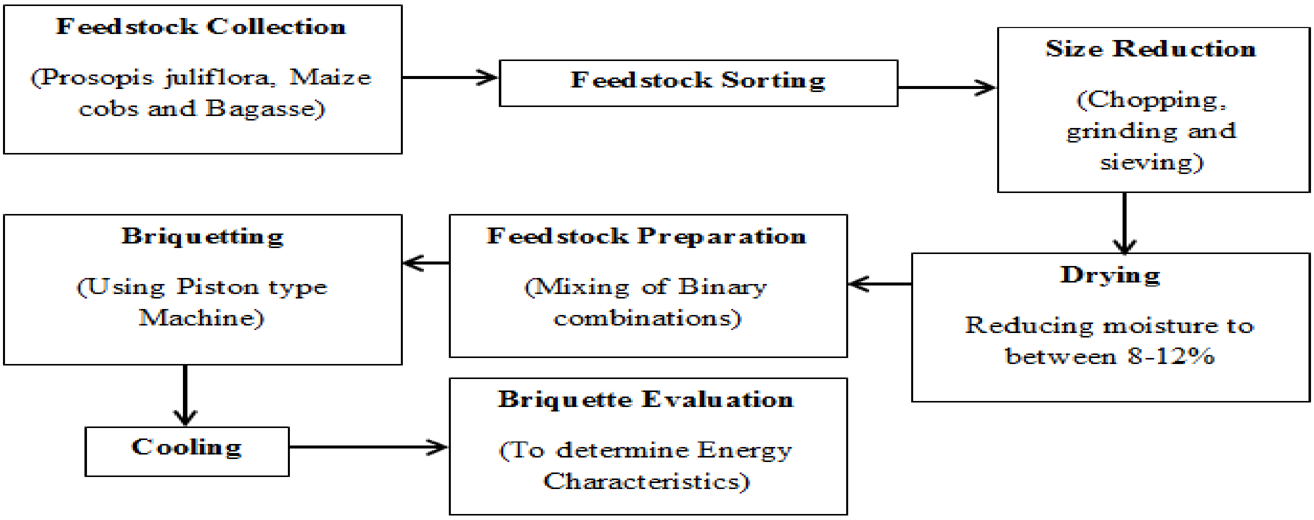

Figure 1: Briquetting Process Flowchart

2.2 Study area

The feedstock materials were picked from Baringo, Kisumu and Trans Nzoia counties. *Prosopis juliflora* was sourced from Baringo County where the shrub is abundant in nature. Sugarcane bagasse was sourced from Muhoroni Sugar Company located in Kisumu County. While the maize cobs were sourced from the Maize growing areas of Kitale region. The feedstocks were sorted to remove leaves and small branches on the *Prosopis juliflora* logs. Unwanted alien materials such as plastics and small pieces of metals were also removed from bagasse and maize cobs to attain purity of feedstock. Feedstocks were taken through chopping, grinding and sieving to attain uniform sizes of 2 mm in length which is required to produce briquettes. Furniture saw was used to mill *Prosopis juliflora* logs into sawdust averaging 2 mm particles. Maize cobs and bagasse was taken through a grinding machine which is fitted with an abrasive wheel that resized the maize cobs and bagasse to 2 mm particles. The feedstock containing high moisture contents than stipulated for briquetting underwent sun-drying process. All the three feedstock at this point had high moisture content of above 12%; there were subjected to sun drying for three days to reduce moisture to between 8-12% which is the acceptable limits suitable for briquette production; moisture content measurements were done using Bentake G. moisture meter .

2.3 Binary combination

Binary combinations levels were done at 25% and 50% for both bagasse and maize cobs with respect to *Prosopis juliflora* as shown in Table 1. Orhevba et al. (2019) indicated that 25% and 50% binary combinations of two various biomass fuels is ideal since it gives results that can be extrapolated to predict other multiple percentage combinations; this is in tandem with Romallosa (2020) who did use binary combination of 25% and 50% of paper waste to sawdust weighted sample on briquette production. Further, 25% and 50% binary combinations levels for biomass fuels on briquette production have been explored successfully by various scholars which include Shams (2019) and Sanwal et al. (2020).

ISSN 1561-7645 (online)
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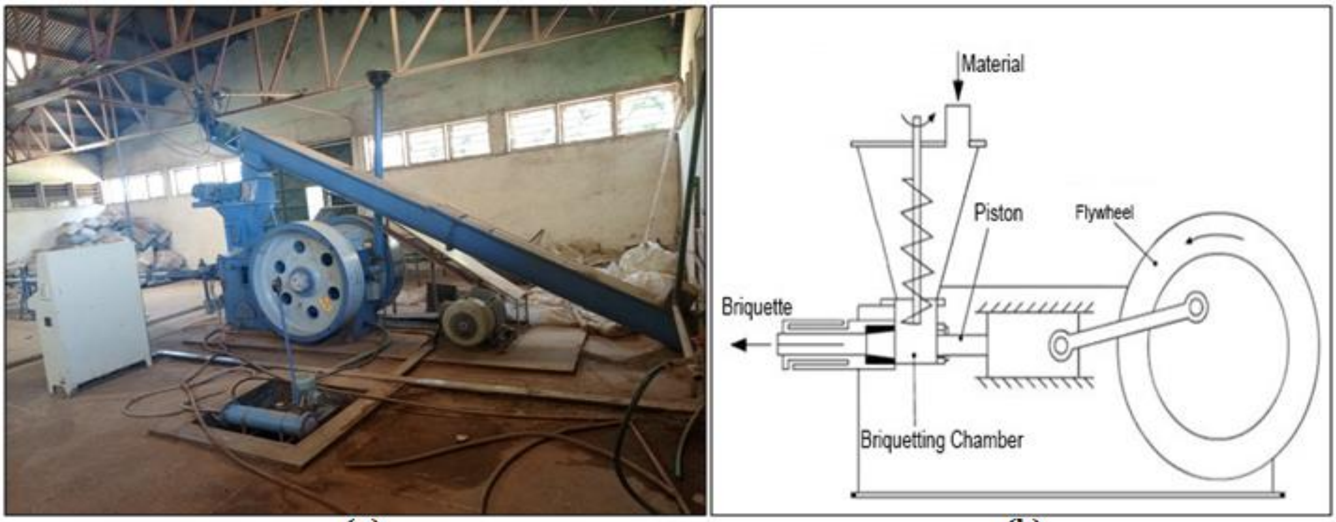
Table 1: Binary combinations

Biomass Material	Binary combination ratios	Sample % of Binary combination of Maize cobs and Bagasse
Prosopis Juliflora	1	0
Prosopis Juliflora + Maize cobs	3:1	25
Prosopis Juliflora + Maize cobs	1:1	50
Prosopis Juliflora + Bagasse	3:1	25
Prosopis Juliflora + Bagasse	1:1	50

2.4 Briquette production

Briquetting process was carried out using a piston-type briquetting machine accessed at Njoro Ecoline Company located in Nakuru County. Figure 2 Shows the piston type industrial briquetting machine at Ecoline Nakuru briquetting company which utilizes the rotary power of a heavy mechanical flywheel to reciprocate the plunger (piston) and the plunger drives the ram to reciprocate in the forming sleeve to generate a pressing force above 100 MPa which causes lignin to melt and agglomerate the material into briquette; hence there was no binders needed for this study During the briquetting process, the biomass materials were fed into the machine, which compressed them using a hydraulic piston. The high pressure generated by the machine resulted in a compaction process that formed the raw materials into solid briquettes. The resulting briquettes were of high quality, with a consistent size of 90 mm in diameter. The use of a piston-type briquetting machine at high pressure proved to be an effective method of pressing the biomass materials into solid briquettes. After the briquettes were produced and cooled to room temperature, all five samples illustrated in Table 1, were analyzed in a laboratory set up to find out their physicochemical characteristics.



(a) (b)

Figure 2: (a) Piston-type briquetting machine and (b) Piston-type machine diagram

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

2.5 Research Instruments

2.5.1 Muffle furnace

Figure 3, shows the Ceramic fibre Faithful Model SGS which was used to determine moisture content, volatile matter and ash content of the biomass briquette samples. It is equipped with a variable temperature controller that is used to set desired temperatures; for this study 105 ^{o}C was set for percentage moisture content and 550 ^{o}C was set for determining percentage volatile matter and ash content.

Figure 0: Ceramic fibre Faithful Model SGS Muffle furnace

2.5.2 Analytical balance

Figure 4 is the Precisa 310M type of analytical balance that was used to measure samples placed in crucibles to determine the weight of the biomass samples of briquettes before and after the Muffle furnace tests; the analytical balance had an accuracy of 0.1 mg.

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ISSN 1561-7645 (online)
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Figure 4: Precisa 310M analytical balance measuring briquette sample in a crucible

2.5.3 Desiccator

Figure 5 is the desiccator that was used to cool the samples after the muffle furnace tests, and to maintain a dry environment for the samples before and after testing against atmospheric humidity. It contained desiccants which absorbs moisture and maintains a dry environment for the samples.

Figure 5: Desiccator containing desiccant

ISSN 1561-7645 (online)
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2.5.4 Bomb calorimeter

Figure 6 shows e2K combustion calorimeter which was used to measure the calorific values for the respective briquettes samples. The e2K bomb calorimeter had a bomb which was filled with the sample and oxygen, and was then ignited. The heat released during the combustion of the sample was measured and electronically displayed; and this provided an indication of the energy content of the sample.

Figure 6: e2K Combustion Calorimeter

2.5.5 Porcelain markers

Figure 7 shows the graphite porcelain marker which was used to label the biomass samples placed in porcelain crucibles during testing. This ensured that the samples were easily identifiable during the testing process.

Figure 7: Graphite porcelain marker

2.5.6 Crucibles

Figure 8 is the porcelain crucible that was used to hold the briquette samples during and after experimental testing. Porcelain crucibles are heat-resistant containers that can withstand high temperatures in a Muffle furnace.

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

Figure 8: Porcelain Crucibles

The use of these apparatus in the laboratory testing procedures ensured the accuracy and precision of the measurements obtained. The Muffle furnace and the Bomb calorimeter are specialized pieces of equipment designed for high-temperature heating and calorific value measurements, respectively. The analytical balance, desiccator, porcelain markers and crucibles are standard laboratory equipment used for sample preparation and handling. The combination of these apparatus, alongside the adapted testing procedures, ensured that accurate and reliable measurements were obtained for the various characteristics of the biomass sample briquettes.

2.6 Data collection and analysis

Data was obtained by experimentally determining the *Prosopis juliflora* and its binary combination briquettes energy characteristics. The parameters to be measured were the percentage moisture content, volatile mater, ash content, fixed carbon and the briquettes calorific values to determine their proximate analysis; for ultimate analysis, elemental carbon, hydrogen, nitrogen and sulphur was also measured.

2.6.1 Moisture content (%MC) calculations

The moisture content was determined by measuring 2 g of sample briquette matter into a crucible and labelled (*W1*). The content was dried in a Muffle furnace at 105 ^{o}C for 2 hours to obtain dry weight which was labelled (*W2*). The crucible and its content were removed from the oven and allowed to cool to room temperature and reweighed. The percentage moisture content was calculated using Equation 1:

$$\%Moisture\ Content = \frac{(W1-W2)}{W2} \times (100) \qquad 1.$$

with W1 and *W2* being the weight samples before and after drying, respectively.

2.6.2 Volatile matter (%VM) Calculations

Percentage volatile matter was determined by keeping the 2 g of briquette material in crucible with dry weight (*W2*) in the Muffle furnace for 10 minutes at 550 ^{o}C to obtain weight (*W3*) after

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ISSN 1561-7645 (online)
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which the volatile matter in it have escaped. The percentage of Volatile Matter was calculated using Equation 2:

$$\%Volatile\ Matter = \frac{(W2-W3)}{W2} \times (100) \qquad 2.$$

where W3 is weight sample after burning for 10 minutes under 550 ^{o}C

2.6.3 Ash content (%Ash) calculations

Ash content was determined by putting measured (*W3*) in the crucible and put in the Muffle furnace at 550 ^{o}C for 4 hours. The sample was then cooled in desiccator and weighed after reaching room temperature as *W4*. The percentage Ash Content was calculated using Equation 3:

$$\%Ash\ Content = \frac{W4}{W2} \times (100) \qquad 3.$$

where W4 is the weight of ash.

2.6.4 Fixed carbon (%Fc)

Percentage fixed carbon was calculated by subtracting the sum of % Volatile matter and % Ash content from 100% as shown by Equation 4:

$$\%FC = 100\% - (\%VM + \%Ash\ Content) \qquad 4.$$

2.6.5 Calorific value

E2K Oxygen Bomb Calorimeter machine was used to measure the calorific values. This was done by inserting 0.5 g of every respective sample into a small capsule located within the dry type bomb which had oxygen filled up to 25 atmospheres of pressure. The setup had "dry" static jacket encompassing of isothermal method which has no water inside the calorimeter. An aluminium sleeve that is an integral part of the vessel, replaces the bucket. The sleeve transfers the heat from the combustion process rapidly and evenly around the outside shell of the vessel. The temperature sensors are located between the combustion vessel and the sleeve. The temperature rise of the vessel was measured to determine the net calorific value (which is the most considered parameter during heating and cooking) of each sample.

2.6.6 Ultimate analysis

Sample weights of 2 g were weighed for every binary combination and put into a small capsule. The sample was then placed into the CHNS/O Flash 2000 analyzer. The analyzer is electronically controlled and is equipped with an auto sampler that drops each sample sequentially into a 900 ^{o}C furnace. A small volume of oxygen was introduced to the burner to aid burning the sample and converts the weighted sample into elemental gases. The instrument operates with the basic principle of combusting the sample in a pure oxygen atmosphere, and the resultant gases are automatically measured. Separation column and thermal conductivity detector equipped with

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

the analyzer was used to determine the element concentrations and the digital device gives out the elemental sample gases composition readings.

3.0 Results and discussion

The study aimed to evaluate the energy characteristics of *Prosopis juliflora* in combination with agricultural wastes of maize cobs and bagasse for briquette production. The specific objectives were to determine the energy characteristics of *Prosopis juliflora* and its binary combinations, examine the influence of the binary combinations on energy characteristics of *Prosopis juliflora* briquettes, and finally to determine the desirable binary combination for briquette production.

3.1 Proximate analysis results

Table 2; illustrates the summary laboratory results for proximate analysis done for *Prosopis juliflora* and its binary combinations of bagasse and maize cobs agricultural waste.

Table 2: Summary experimental results

	MOISTURECONTENT	VOLATILE MATTER	ASH CONTENT	FIXED CARBON	CALORIFIC VALUE
	%MC	%VM	%AC	%FC	MJ/kg
P. juliflora 100%	5.59±0.09	77.49±1.98	3.12±0.16	19.39±1.82	18.99±0.21
P. juliflora 50% & MAIZE COBS 50%	5.87±0.02	75.65±1.21	3.24±0.21	21.11±1.42	19.73±0.05
P. juliflora 75% &MAIZE COBS 25%	5.82±0.02	78.46±0.37	2.34±0.01	19.21±0.37	19.27±0.05
P. juliflora 50% & BAGASSE 50%	5.90±0.05	78.05±0.14	4.06±0.08	17.89±0.22	19.14±0.07
P. juliflora 75% & BAGASSE 25%	5.27±0.07	77.81±0.68	2.93±0.29	19.27±0.99	19.07±0.07

The moisture content of biomass fuel is a crucial factor in determining its combustion efficiency and heat output. In this regard, the moisture content of five different biomass fuel combinations were analysed, namely *Prosopis juliflora* 100%, *Prosopis juliflora* 50% & Maize cobs 50%, *Prosopis juliflora* 75% & Maize cobs 25%, *Prosopis juliflora* 50% & Bagasse 50%, and *Prosopis juliflora* 75% & Bagasse 25%.

The moisture content (%MC) of each combination was as follows: *Prosopis juliflora* 100% had a moisture content of 5.59±0.09%; *Prosopis juliflora* 50% & Maize cobs 50% had a moisture content of 5.87±0.02%; *Prosopis juliflora* 75% & Maize cobs 25% had a moisture content of 5.82±0.02%; *Prosopis juliflora* 50% & Bagasse 50% had a moisture content of 5.90±0.05%; and *Prosopis juliflora* 75% & Bagasse 25% had the lowest moisture content of 5.27±0.07%. Comparing the moisture content of the different binary combinations, it is evident that *Prosopis juliflora* 50% & Bagasse 50% had the highest moisture content, while *Prosopis juliflora* 75% & Bagasse 25% had the lowest. The moisture content of *Prosopis juliflora* 100%, *Prosopis juliflora* 50% & Maize cobs 50%, and *Prosopis juliflora* 75% & Maize cobs 25% fell in between these two extremes. It is worth noting that higher moisture content in the fuel can lead to incomplete

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

combustion, resulting in reduced heat output and increased emission of pollutants. Therefore, the combination of *Prosopis juliflora* 75% & Bagasse 25% can be considered a better fuel option compared to *Prosopis juliflora* 50% & Bagasse 50% due to its lower moisture content. However, it is important to evaluate other factors such as volatile matter, ash content, fixed carbon, and calorific value before making a final decision on the best fuel combination.

The combination of 100% *Prosopis juliflora* has a volatile matter content of 77.49±1.98%. When 50% maize cobs are added to 50% *Prosopis juliflora*, the volatile matter content decreases slightly to 75.65±1.21%. However, when the proportion of *Prosopis juliflora* is increased to 75% and maize cobs reduced to 25%, the volatile matter content increases to 78.46±0.37%. Similarly, it is observed that when 50% bagasse is added to 50% *Prosopis juliflora,* the volatile matter content increases to 78.05±0.14%. But when the proportion of *Prosopis juliflora* is increased to 75% and bagasse reduced to 25%, the volatile matter content decreases slightly to 77.81±0.68%. Overall, the combination of 75% *Prosopis juliflora* and 25% maize cobs had the highest volatile matter content (78.46±0.37%), while the combination of 50% maize cobs and 50% *Prosopis juliflora* had the lowest volatile matter content (75.65±1.21%). The other combinations have intermediate volatile matter contents.

The combination of 100% *Prosopis juliflora* had an ash content of 3.12±0.16%. When 50% maize cobs are mixed with 50% *Prosopis juliflora*, the ash content increases slightly to 3.24±0.21%. However, when the proportion of *Prosopis juliflora* is increased to 75% and maize cobs reduced to 25%, the ash content decreases significantly to 2.34±0.01%.

Further, when 50% bagasse is added to 50% *Prosopis juliflora*, the ash content increases further to 4.06±0.08%. But when the proportion of *Prosopis juliflora* is increased to 75% and bagasse reduced to 25%, the ash content decreases to 2.93±0.29%. In comparison, the combination of 50% bagasse and 50% *Prosopis juliflora* had the highest ash content (4.06±0.08%), while the combination of 75% maize cobs and 25% *Prosopis juliflora* had the lowest ash content (2.34±0.01%). The other combinations had intermediate ash contents. In summary, the ash content of the mixtures is highly dependent on the proportions of the different types of biomass and the intrinsic inorganic matter found in that feedstock. It is observed that mixtures with higher proportions of *Prosopis juliflora* tend to have lower ash content, while mixtures with higher proportions of maize cobs or bagasse tend to have higher ash content.

The combination of 100% *Prosopis juliflora* had a fixed carbon content of 19.39±1.82%; when 50% maize cobs are added to 50% *Prosopis juliflora*, the fixed carbon content increases to 21.11±1.42%. However, when the proportion of *Prosopis juliflora* is increased to 75% and maize cobs reduced to 25%, the fixed carbon content decreases to 19.21±0.37%. Similarly, it was evident that when 50% bagasse is added to 50% *Prosopis juliflora*, the fixed carbon content decreases to 17.89±0.22%. But when the proportion of *Prosopis juliflora* is increased to 75% and bagasse reduced to 25%, the fixed carbon content increases slightly to 19.27±0.99%. In comparison, the combination of 50% maize cobs and 50% *Prosopis juliflora* had the highest fixed carbon content (21.11±1.42%), while the combination of 50% bagasse and 50% *Prosopis*

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

juliflora had the lowest fixed carbon content (17.89±0.22%). The other combinations achieved intermediate fixed carbon contents. Overall, the proportion of maize cobs in the mixtures appears to have a greater impact on the fixed carbon content, with higher proportions resulting in increased fixed carbon. However, the proportion of *Prosopis juliflora* and bagasse also had a moderate effect on the fixed percentage carbon content.

The combination of 100% *Prosopis juliflora* had a calorific value of 18.99±0.21MJ/kg. When 50% maize cobs are added to 50% *Prosopis juliflora*, the calorific value increases to 19.73±0.05MJ/kg. However, when the proportion of *Prosopis juliflora* is increased to 75% and maize cobs reduced to 25%, the calorific value decreases to 19.27±0.05MJ/kg. Similarly, it was observed that when 50% bagasse (sugarcane residue) is added to 50% *Prosopis juliflora*, the calorific value decreases to 19.143 MJ/kg. But when the proportion of *Prosopis juliflora* is increased to 75% and bagasse reduced to 25%, the calorific value decreases further to 19.14±0.07MJ/kg. In comparison, the combination of 50% maize cobs and 50% *Prosopis juliflora* had the highest calorific value (19.73±0.05MJ/kg), while pure *Prosopis juliflora* had the lowest calorific value (18.99±0.21MJ/kg). The other combinations achieved intermediate calorific values. Overall, the proportion of maize cobs in the mixtures appears to have the greatest impact on the calorific value, with higher proportions resulting in higher calorific values. However, the proportion of *Prosopis juliflora* and bagasse also had a moderate effect on the calorific value of *Prosopis juliflora* briquettes. It is worth noting that while the differences in calorific value between the combinations are relatively small, they can be important when considering the suitability of the different mixtures for different applications.

3.2 Ultimate analysis results

Table 3 shows the elemental measure composition of Carbon, hydrogen, nitrogen, sulphur and oxygen from the respective samples of *Prosopis juliflora* and its binary combination briquettes.

Table 3: Ultimate analysis

	Composition (%)				
	Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen
P. juliflora 100%	46.26±0.70	5.75±0.14	0.27±0.03	0.44±0.05	43.88±0.54
P. juliflora 50% & MAIZE COBS 50%	48.90±0.11	6.18±0.24	0.20±0.02	0.12±0.00	41.50±0.45
P. juliflora 75% &MAIZE COBS 25%	46.90±0.03	5.73±0.03	0.21±0.01	0.23±0.01	43.75±0.66
P. juliflora 50% & BAGASSE 50%	46.89±0.33	4.91±0.22	0.21±0.02	0.21±0.03	44.69±0.77
P. juliflora 75% & BAGASSE 25%	46.24±0.40	4.99±0.17	0.20±0.02	0.30±0.01	41.05±0.84

Ultimate analysis results as seen in Table 3 revealed that *Prosopis juliflora* 100% briquettes and its binary combination of bagasse and maize cobs at 25% and 50% respectively had reasonably high carbon and hydrogen content which is associated with high calorific values; this is due to the high energy bonds which releases an increased amount of heat energy during combustion. The results also show considerably low contents of nitrogen and sulphur which is usually

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

undesirable due to their negative impacts to both biomass fuel calorific values and environment. Oxygen available in the sample mixtures are within expected ranges of 40%-50% which when combusted combine with hydrogen and get to be less than they really are. However, *P. juliflora* 50% & MAIZE COBS 50% binary combination briquette sample, comparatively stands out as a better biomass fuel combination briquettes than the other mixtures; this is due to its high carbon and hydrogen contents at 48.90% and 6.18% respectively. The combination also has a relatively low Nitrogen and Sulphur standing at 0.20% and 0.12% respectively.

4.0 Conclusions

This paper provides information on the physicochemical characteristics of briquettes from *Prosopis juliflora* and its binary combinations with maize cobs and bagasse. *Prosopis juliflora* was characterized as a feedstock for briquettes production through proximate and ultimate analyses to evaluate the influence of binary combination of maize cobs and bagasse feedstocks. *Prosopis juliflora* 100% briquettes achieved moisture content of 5.59$\pm$0.09%; volatile matter of 77.49$\pm$1.98%; ash content of 3.12$\pm$0.16% and fixed carbon of 19.39$\pm$1.82%; for ultimate analysis the briquettes achieved, 46.26$\pm$0.70% carbon, 5.75$\pm$0.14% hydrogen, 0.27$\pm$0.03% nitrogen and 0.44$\pm$0.05% Sulphur. The briquettes also attained calorific value of 18.99$\pm$0.21 MJ/kg which is significant amount of energy enough for domestic and industrial use. Binary combinations of bagasse and maize cobs had positive influence to the *Prosopis juliflora* feedstock by increasing its calorific value. As a result, *Prosopis juliflora* 50% and Maize cobs 50% binary combination briquettes were comparatively the desirable binary combination considered for briquette production since it had comparatively increased amount of heating value; *Prosopis juliflora* 50% and Maize cobs 50% binary combination briquettes attained a higher calorific value of 19.73$\pm$0.05 MJ/kg with a significant fixed carbon of 21.11$\pm$1.42%, coupled with these desirable proximate parameters exhibited by the fuel, it also achieved carbon and hydrogen percentages of 48.90$\pm$0.11% and 6.18$\pm$0.24%, respectively which are characterized by their high-energy bonds that releases and increased amount of energy during combustion. *Prosopis juliflora* and maize cobs as feedstock for bioenergy production is a breakthrough in clean energy development in Kenya and providing a sustainable solution on managing the invasive Prosopis juliflora plus disposing agricultural waste on a more economical manner.

4.1 Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request

5.0 Acknowledgement

5.1 Funding

None

ISSN 1561-7645 (online)
doi: 10.4314/jagst.v24i1.5

5.2 General acknowledgement
None.

5.3 Conflict of interest
None.

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