Evaluation of Physical and Combustion Properties of *Boscia augustifolia* (A. Rich) for Heating Purposes

Ogunleye B.M [1], Aina K. S[2], Ilutoye I. R[1]

[1]*Department of Wood and Paper Technology, Federal College of Forestry, Ibadan, Nigeria*

[2]*Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, Ibadan, Nigeria*

***Abstract*-This study investigated physical and combustion properties of briquettes produced from *Boscia augustifolia* and starch. The starch powder employed as a binder was derived from processed cassava tuber. Physical parameters assessed in the study were: moisture content and density while combustion properties include: ash content, percentage fixed carbon, percentage volatile matter, and heating value. The results obtained from the assessment of the physical properties of briquettes produced from 2:1 of sawdust and starch showed the lowest mean moisture content of 27.95 % while solid wood recorded the highest density of 0.58 g/cm^3. For the combustion properties, it was observed that admixture of 2:1 of sawdust and starch produced briquette with the lowest ash content of 0.48%. The results also revealed that briquette produced from 2:1 sawdust and starch had the highest mean value percentage fixed carbon, 2:1 of sawdust and starch produced briquette with the highest heating value of 13032.14 Kcal/kg and relatively high volatile matter of 86.30 %. Based on the results obtained from this study, it is recommended that briquette should be produced from sawdust of *Boscia augustifolia* and starch mixed together at varying proportion for improved combustion properties due to its low moisture content, low ash content, high heating value and high percentage fixing carbon.**

***Keywords:* Sawdust, *Boscia augustifolia,* Briquette, Combustion, heating, starch**

I. INTRODUCTION

Fuel has always being an indispensable need for man to survive; people around the world need fuel for their daily activities, in preparing for their basic daily necessities like food and water, energy is greatly required. The use of fuelwood has being in existence for many years ago and it has being paramount to the globe. Mostly, people living in the developing countries rely on generation of energy to survive and this is done through fetching of fuelwood from the forests, this predominantly occurred in the northern parts of the Sahara and sub Sahara regions. It is recently, that attention has shifted from fuelwood to the use of liquefied gas and electricity for heating and cooking. However, as the interest and demands for the use of these new products are increasing, some people in the developing countries still strongly rely on fuelwood [7]. The reason is attributed to these following; free and easy accesses to the forest, poverty level, educational standard, availability and high cost of liquefied gas and kerosene. As the world population is growing, energy demand also increases, together with growing global consciousness about the scarcity of the earth's natural resources. Biomass consumption is nowadays the only source of energy for nearly 2.5 billion people living in rural areas of developing countries found in Asia, Africa and Latin America. The problems of acute energy scarcity and deficit in supply of kerosene and cooking gas in arid and semi-arid areas of developing countries have resulted in increase for fuelwood [7]. It was found that approximately 70 % of biomass energy is consumed in developing countries for traditional uses with very low efficiencies of 10 - 20 % while the volume of fuelwood demands by the people continues to increase annually [20] and [2]. The pattern of fuelwood consumption has been noted to be increase in Africa with the estimation of about 583 million people depending on fuelwood and charcoal for energy purposes [1]. The demand for fuelwood is increasing and is being projected to increase more by 20 million people within the next three decades [3].

Therefore, the negative implication of using fuelwood in the developing countries has resulted to adverse effect on forest ecosystems. The increase in the demand for fuelwood and charcoal has caused large percentage of the forestland is lost to indiscriminately felling of young trees for fuelwood [22]. [1] also reported that a transition to a sustainable energy system is urgently needed in the developing countries to solve the energy crisis in Africa. According to the previous report of [23], that 80 % of people living in the rural or semi-urban areas of Nigeria solely depend on fuel wood for their daily energy consumption and these accounts for about 37 % of the total energy demand for the country. [27] also reported that 90 % of the total wood demanded and sourced from the forest goes into fuelwood. Recently in Nigeria, it has been reported that the total fuelwood annually consumes is estimated to about 43 x 10^9 kg [1].

Therefore, in order to meet up with this challenge, Africa must raise-up to develop their technology resources based so as to cater for locally fetched fuelwood and charcoal. The rate of increase in demand for fuelwood and charcoal by the consumers is alarming and there is need for urgent attention in proffering solution to this problem. The needs for additional effort in building an alternative energy to meet the demand of the people are paramount and necessary; so as to be able to sustainable future needs. And to meet up with the demands, a new innovation product known as briquette and charcoal briquette needs to be developed, this technology involves the production of new innovation compressed wood based products derived from particles that are readily available and affordable [10]. Much has been done using wood dusts from different wood species, agro residues and paper for the production of briquettes. The wood scientists should also intensify efforts to investigate the properties of all available indigenous and exotic wood dust for the production of briquette and their suitability for heat generation.

Therefore, this study aims to investigate the suitability of *Boscia angustifolia* for heat generation, the properties such the physical and combustion are also determined. *Boscia angustifolia* is very widespread wood specie found in Nigeria and other countries like southern Mauritania, Senegal and Gambia eastward to Somalia and southward to northern South Africa. It's comprises of about 20 family species which occurs in semi-arid regions of main land of Africa, Madagascar and Arabia where the demand for fuelwood are high.

II. MATERIALS AND METHODS

Location of study

The research activity such as production and laboratory experiment was carried out at the Department of Forest Products Development and Utilization, Forestry Research Institutes of Nigeria, Jericho Ibadan.

Method of sample preparation

The particle of *Boscia augustifolia* was obtained using hammer mill machine available at the workshop of Wood and Paper Department, Federal College of Forestry Jericho Ibadan. The particle was sundried to reduce the moisture content and sieved thoroughly with wire mesh of dimensional size of 0.1µm to obtain fined powder. Plant adhesive derived from the tuber of Cassava was employed for binder. The processed cassava mash was dried to cake and milled into powder. The powdered cassava was thoroughly mixed with 30 ml of cold water at 26 ^{0}C room temp to soluble which was later mixed in 250 ml of water at 100 ^{0}C of boiling pt and stirred constantly and steadily for 20 minutes to form adhesive stock known as starch. The wood powder was thoroughly hand mixed at two mixing ratio of 3:1 and 2:1 (wood and starch) weight to weight basis. The mixture was fed into a cylindrical mould of volume 734.64 cm^3 with the height of 12 cm and compressed under the pressure of 75 Pascal. The briquette samples of volume 146.94 cm^3 at the height of 4 cm were produced, removed and air dried for 3 days before taken to the oven dried at 65 ^{0}C. The total numbers of 18 briquette samples were produced for laboratory analysis tests. The properties such as physical and combustion properties such as moisture content, density, percentage ash content, percentage volatile matter, percentage fixed carbon and heat values were determined on both the solid wood and the briquettes.

Properties determination

The physical and combustion properties of briquette samples were carried out in these following procedures;

1. Moisture content was done in accordance with [6], the samples was weighed and placed in a laboratory oven at a temperature of 103 ± 2 ^{0}C and weighed at interval of 2 hrs until constant weight was achieved.

   $$MC = \frac{W1-W2}{W2} \times 100$$

   Where MC = Moisture Content; W_1 = Initial weight before oven drying and W_2 = Final weight after oven drying

2. The density of the samples was determined by the ratio of the mass of each briquette to its volume of each sample

   $$Density = \frac{mass\ of\ briquette}{volume\ of\ briquette}$$

3. The Percentage Ash Content was determined by placing 2g of oven dried briquette sample in a furnace at 550 ^{o} C for 4hrs and weight after cooling.

   $$Percentage\ Ash\ Content = \frac{D}{B} \times 100$$

   Where D = weight of ash and B = Original weight of sample

4. Percentage Volatile Matter (PVM) was determined by placing 2g of grinded briquette sample in a crucible in the oven to obtain constant weight after cooling. The Briquette sample was now kept in the furnace at temperature of 550 ^{0}C for 10 minutes and weighed after cooling. Then the PVM was determined using the formula below:

   $$Percentage\ Volatile\ Matter = \frac{B-C}{B} \times 100$$

   Where B = Weight of dried samples of briquette and C = Weight of briquette sample after 10 minutes in furnace at 550 ^{0}C.

5. Percentage Fixed Carbon: 100 – (% V + % A)

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

6. Heating Value: HV = 2.326 (147.6 C + 144 V) $^{kj}/_{kg}$ .s

   Where C = Percentage Fixed carbon and V = Percentage Volatile Matter.

Experimental design

The experimental briquette samples were produced at different ratio as treatments. The treatments include a briquettes at different ratio of 2:1 and 3:1 (wood: starch); and solid wood (as control). The statistical methods adopted for this study were Complete Randomize Design (CRD) at 5 %

level of probability, descriptive statistic and bar chart. The Social Package for Social Science (SPSS) version 20.0 software was used to run the analysis and the results are presented under results.

III. RESULT AND DISCUSSION

Table 1: Mean effects of treatments on properties of briquettes and solid wood product

Variables *(Wood:Starch)*	Combustion properties				Physical properties	
	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Values (kcal/kg)	Density (g/cm^3)	Moisture Content (%)
3:1	4.38^a	86.30^a	9.33^b	12913.31^a	0.38^c	29.13^b
2:1	0.48^c	85.45^a	14.07^a	13032.14^a	0.42^b	27.95^b
Solid Wood	3.25^b	83.23^a	13.53^a	12686.35^a	0.58^a	36.93^a

Means in the same column having the same superscripts are not significantly different ($p \geq 0.05$)

Physical Properties

The mean values obtained for density and moisture content of briquette compared with the wood are presented in Table 1. The values obtained for the briquettes and wood ranges from 0.38 g/cm^3 to 0.58 g/cm^3 and 29.13 to 36.93 for density and moisture content (Table 1). These values obtained for density and moisture content from briquettes agree with previous results recommended for standard briquette made from lignocellulosic materials [12] and [25]. As illustrated in fig. 1, it was observed that briquette made from 2:1 inclusion of sawdust had the lowest mean moisture content value of 27.95, that of 3:1 had 29.13 and solid wood had the highest mean moisture content value of 36.93. It has been noted that moisture content is a very important property that greatly affect the burning characteristics of the briquettes [26]. It has also been reported that moisture content of biomass should be as low as 21.00 to obtain a good combustion of briquettes [14]. The low moisture content found in biomass also helps in their storage (preventing rot and decomposition). As also illustrated in fig. 2, it was observed that the mean density for briquette made at 3:1of sawdust inclusion had the value of 0.38 g/cm^3 , that of 2:1 of sawdust inclusion had the value of 0.42 g/cm^3 and that of solid wood had the value of 0.58 g/cm^3. The density found in this study had the same trend with the findings for briquettes produced from wheat flour and waste paper studied by [17] and [19]. The study showed that the lower the percentage of binder in the mixture, the lower the density of the briquette product. It was observed that decline in density of briquette with increase in filler content could also be attributed to the relationship roles of adhesive to sawdust in briquette production [4]. However, the higher the density of the briquette produced, the higher the quantity of heat emission releases per unit mass and this has effect on the burning efficiency of the briquette [4]. The value of moisture content and density found in wood was higher than the briquettes, hence when compared with the wood, it found to be having higher heating value than the briquettes (Table 1). The outcome of the results of analysis of variance conducted for physical properties are presented in Table 2. As presented in Table 2, there was significant difference among the treatments at 5 % level of probability. The levels of significance among the treatments mean values are represented in Table 1 alongside with alphabetical letters.

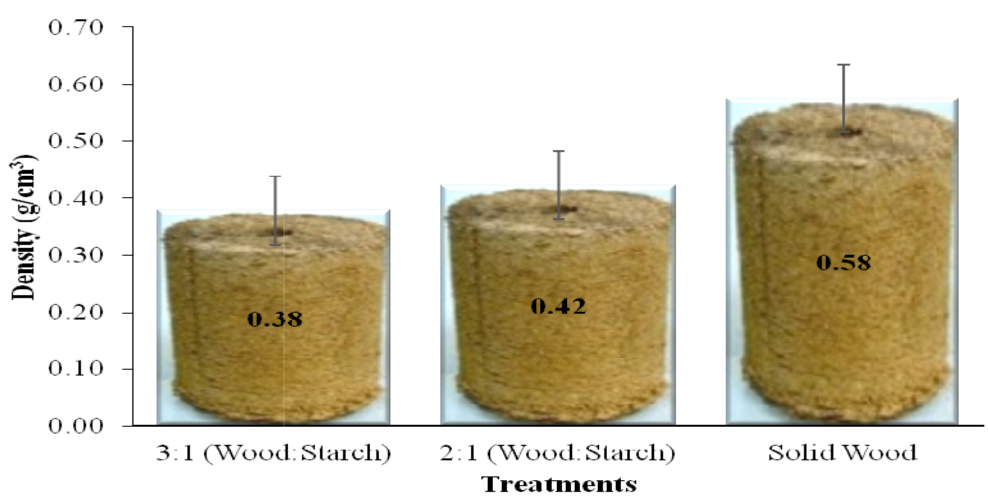

Fig. 1: Effect of ratio on density of the briquettes

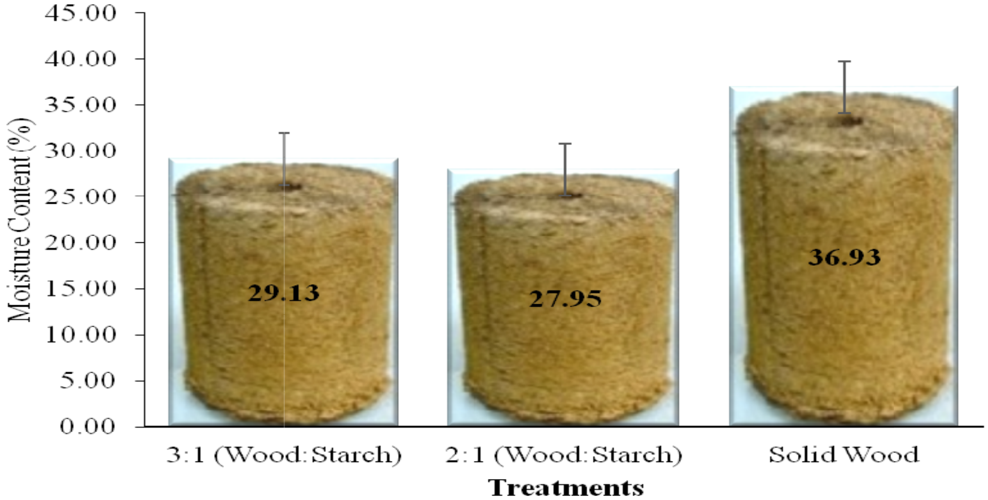

Fig. 2: Effect of ratio on moisture content of the briquettes

Table 2: Analysis of variance for physical properties of the briquettes

Physical properties	Source of variance	Sum of squares	df	Mean squares	F	Sig.
Density	Treatment	0.09	2	0.04	857.17	0.000*
	Error	0.00	9	0.00		
	Total	0.09	11			
Moisture content	Treatment	190.36	2	95.18	6.73	0.016*
	Error	127.23	9	14.14		
	Total	317.59	11			

*significant at $p \leq 0.05$

IV. COMBUSTION PROPERTIES

The outcome of results obtained for percentage ash content, percentage volatile matter, percentage fixed carbon and heating values are also presented in Table 1. The mean values ranges from 4.38 to 3.25 %, 86.30 to 83.23 %, 9.33 to13.53 % and 12913.31 and 12686.35 Kcal/kg for percentage ash content, percentage volatile matter, percentage fixed carbon and heating values respectively. As illustrated in fig. 3, wood samples (control) of *Boscia augustifolia* had the highest value of percentage ash content followed by the briquettes made from the combination of 3:1 and 2:1(sawdust: starch). It was observed that as the proportion of sawdust is reducing, the percentage ash content also reduces and this could be attributed to the proportion of starch content present in the briquette composition. This observation agrees with the report of findings for briquettes made from the sawdust of different hardwood species with different organic binders [16], [18] and [13]. The findings in this study also corresponded with the results presented for briquettes made from dust of corn cobs [11], [8]. [5], in his findings also reported that the lower the ash content found in briquette, then the higher the heating values. The ash content in briquettes causes increase in combustion thereby increases the rate of flammability and the ruminant left over which is in the form of ash lower the heating value of briquettes [15].

The heating value is the standard measure for the energy content of a fuel. It is defined as the amount of heat evolved when a unit weight of fuel is completely burnt. As illustrated in fig. 5, it was observed that briquette made from ratio 2:1had the highest value of 13032.14 Kcal/kg followed by briquette made from ratio 3:1 with the value of 12913.31 Kcal/kg, these values were higher to the heating vales obtained for wood of 12686.35 Kcal/ kg. The values obtained in this study are lower to the values of 20.18 and 19.32 MJ/kg obtained in previous findings by [19], the author also witnessed similar trend that the decrease in heating value increase with respect to the increase in the proportion of sawdust to starch. Additionally, the percentage volatile matter derived from the briquette was related to the heating values but decrease according to the proportions. The percentage volatile matter value was very high in briquette of 2:1 with 86.30 %, followed by 3:1 with 85.45 % and wood with 83.23 % respectively (Fig. 4). This observation agrees with the findings from previous study of [24]. The flammability of briquette could be attributed to the level of volatile matter; report shows that the higher the volatile matter the better the heating value for the briquette [16]. [21] also established that briquette with low volatile matter do resulted to low ignition while high volatile matter always lead to high flame. However, the percentage fixed carbon derived from the briquettes is illustrated in fig. 5; the percentage fixed carbon indicates the proportion of char that remains after the devolitization phase of the materials [11]. It was observed that there was decrease in the percentage fixed carbon content of the briquette as the proportion of sawdust increases. The sample of briquette made from ratio 2:1 had the highest percentage of char with 4.07 % followed by 9.33 % from ratio 3:1while the value derived from wood was 13.53 % (Fig. 5).

The outcome of the result of analysis of variance conducted is presented in Table 3. As presented, it shows that there are significant difference among the treatments for only percentage ash content and percentage fixed carbon at 5 % level of probability while no significant difference exist in heating value and percentage volatile matter. This significantly implies that the briquettes samples were significantly different from each other in terms of ash content and percentage fixed carbon.

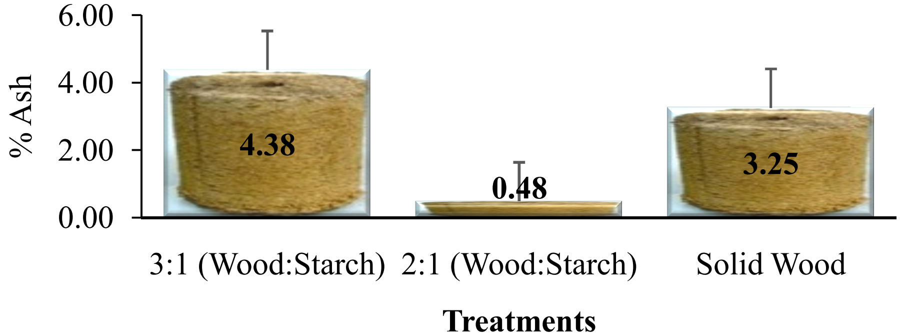

Fig. 3: Effect of ratio on percentage ash content of the briquettes

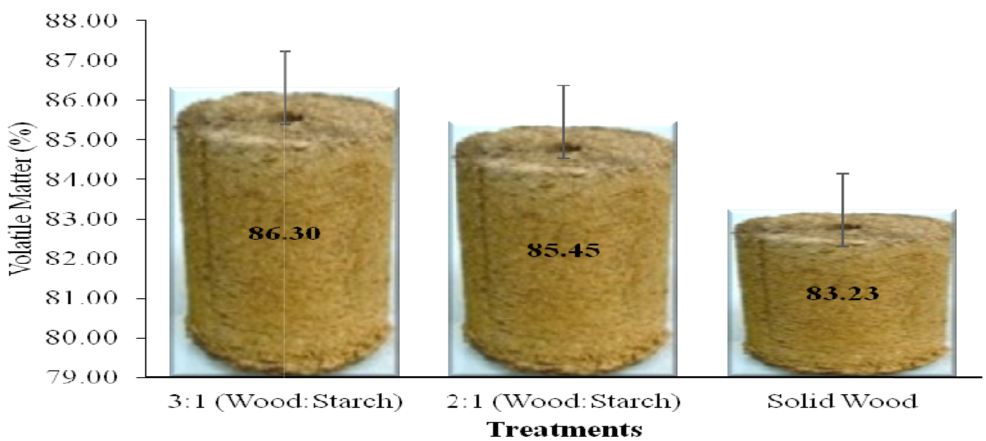

Fig. 4: Effect of ratio on percentage volatile matter of the briquettes

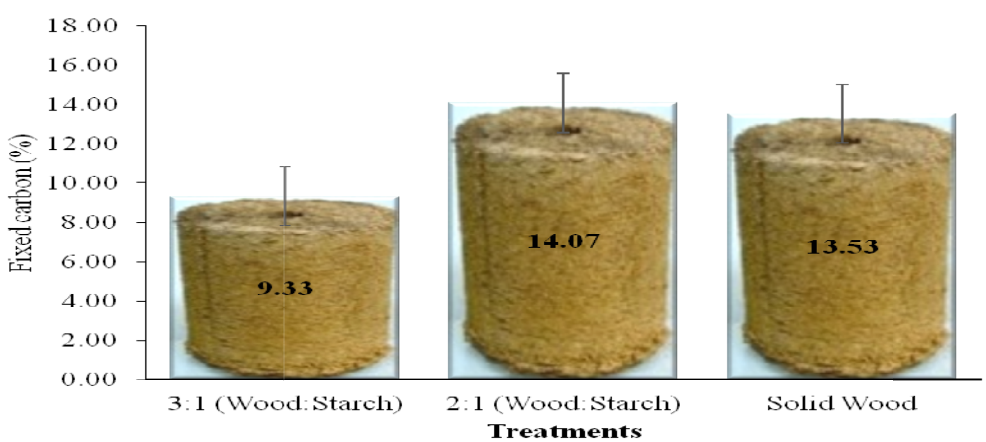

Fig. 5: Effect of ratio on percentage fixed carbon of the briquettes

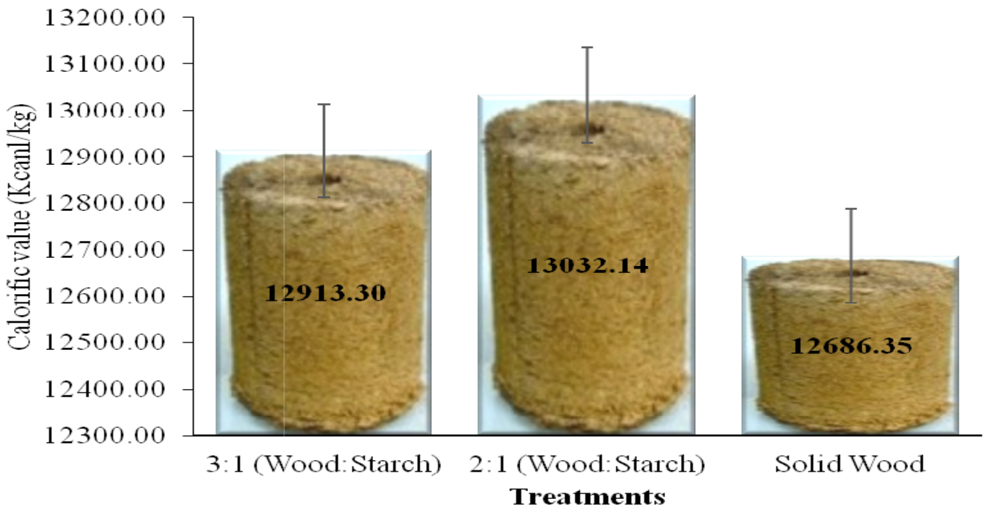

Fig. 6: Effect of ratio on calorific value of the briquettes

Table 3: Analysis of variance for combustion properties of the briquettes

Combustion properties	Source of variance	Sum of squares	df	Mean squares	F	Sig.
Heating value	Treatment	246930.92	2	123465.46	2.70	0.121^{ns}
	Error	412195.77	9	45799.53		
	Total	659126.69	11			
Percentage Ash Content	Treatment	32.15	2	16.07	2314.52	0.000*
	Error	0.06	9	0.01		
	Total	32.21	11			
Percentage Volatile Matter	Treatment	20.17	2	10.09	1.88	0.207^{ns}
	Error	48.17	9	5.35		
	Total	68.34	11			
Percentage Fixed Carbon	Treatment	53.94	2	26.97	5.06	0.034*
	Error	47.96	9	5.33		
	Total	101.90	11			

*represents significant at $p \leq 0.05$

V. CONCLUSION

Sawdust of various wood species are generated in large quantity at wood processing mills as municipal waste and often disposed indiscriminately by burning which also contribute to global warning. Incessant fetching of fuelwood from the forest for heat energy purpose has made the forest to be vulnerable for destruction, in an attempt to reduce this activity, the sawdust generated during wood processing are compacted to produce artificial fuelwood called briquette. Thus, this study successfully produced briquettes from the admixture of binder and sawdust of *Boscia augustifolia* at two mixing proportions (2:1 and 3:1). The briquettes were compared in combustion properties with the solid wood. The briquettes made from 2:1 had the highest density and lowest moisture content, which makes it to be more stable and durable for storage. Similarly, briquette made at 2:1 also had the highest heating value; lowest ash content and highest percentage fixed carbon that support high combustion properties for heating energy purposes. The heating values obtained from the briquettes made from the two levels of ratio were higher and can be sufficiently provide enough heat energy for cooking that is more important to the rural dwellers. Based on the results from this study, it can be concluded that the briquettes made from the two mixing ratio fulfills the maximum requirement of calorific value for making commercial briquette (>17500 kJ/kg), as stated by DIN 51731.

VI. RECOMMENDATION

According to the report of [9] that says that the higher the fixed carbon content the better the briquette for heating potential, the corresponding energy released is usually high. Based on this fact; briquette made from 2:1 (wood: starch) had higher energy value compared to 3:1 and *Boscia augustifolia* fuelwood. It can therefore be recommended for domestic heating and cooking.

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