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Original Article

Production and characterisation of corn chaff briquette using cassava starch and gum Arabic as binders

OPEN ACCESS

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ABSTRACT

This study was undertaken to determine the production and characterisation of corn chaff briquettes using cassava starch and gum Arabic binder. The wet corn chaff was sun-dried to a moisture content of 12%; it was milled using a hammer miller and sieved using a 2 mm particle-size mesh screen for consistency purposes. The briquette samples were produced by separately mixing 60 g of corn chaff with starch and gum Arabic at binder levels 10, 15, and 20 g. The experiment was conducted to determine physical properties (density, moisture content, stability, and shatter index) and proximate analysis (volatile matter, ash content, fixed carbon, and calorific value). The data collected was analysed using Analysis of Variance (ANOVA) in a completely randomized design (CRD) at $p<0.05$. The results show that binder type and binder level significantly influenced the briquettes' moisture content, ash content, and calorific value. The highest density of 495.87 kg/m^3 was obtained at 20 g in starch-bonded briquettes. Similarly, starch-bonded briquettes at 10 g had the highest shatter index of 99.68%. On the other hand, gum arabic-bonded briquettes at 20 g had the lowest moisture content of 5.56% at 10 g binder level; the briquette recorded the lowest ash content, highest fixed carbon and calorific value of 1.36%, 85.11%, and 33.67 MJ/kg^1 respectively. Therefore, gum Arabic briquette proves to have a higher energy value than starch briquette, while in terms of binder level, 10 g proves better. However, corn chaff could be recommended as a good and acceptable feedstock to achieve sustainable energy.

KEYWORDS: *Ash content, Calorific value, Corn chaff, Moisture content.*

INTRODUCTION

Nigeria is a nation endowed with natural resources; for instance, in terms of agricultural resources, it has a land area of 98.3 million hectares, out of which 79 million hectares is arable land (Oladimeji *et al*., 2013). In the country, 60%–70% of the population are involved in agriculture and agricultural related activities contributing a large share of gross domestic product as recorded by Udolisa *et al*. (1994). These farming activities result in the production of various economic products from which many types of residues that are biomass materials containing enormous amount of energy are left as waste materials after harvest (Fapetu, 2000a). Jekayinfa and

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Omisakin (2005), found out that these agricultural residues are neither utilized nor properly managed in all developing countries including Nigeria but can be used to play a significant role in meeting energy demand.

Presently, agro wastes management practice in the country is that of burning or allowing them to decay on farm. Whichever approach causes environmental contamination and pollution aside from also resulting to enormous waste of resources. Burning of agricultural wastes on a farmland affects soil biodiversity, geomorphic process and volatilizes large amount of the nutrients in the soil including organic matter, while black carbon and particulate matters emitted into the atmosphere during the process is also worrisome (Onuegbu *et al.*, 2012).

With man, life is a continuous process of energy conversion and transformation. This emphasize that the accomplishment of civilization has largely been achieved through the increasingly efficient and extensive harnessing of various forms of energy to extend human capabilities and ingenuity (Fapetu, 2000b). Sustainable, suitable and affordable energy is required for human continuity in term of development and growth so, provision of adequate energy is essential to improve living standard. According to Fapetu (1994), in Nigeria about 51% of total energy consumption is estimated to be met from various biomass resources (i.e., agricultural residues, animal dung, forest waste, firewood). While corncob can be directly utilised as fuels, they are nevertheless not directly suitable apparently because of their bulkiness, uneven nature, and having low energy density; characteristics that make them difficult to handle, store, transport, and utilise in their raw form; hence, there is the need to subject them to conversion processes in order to mitigate these problems as suggested by Oladeji (2010).

One of the promising technology solutions to these problems is the application of briquetting technology. Wilaipon (2007), defined it as a densification process for improving the handling characteristics of raw materials and enhancing volumetric calorific value of the biomass. The technology which is termed densification enhances physical and combustion characteristics.

Briquetting using this technology had been extensively studied (Ndiema *et al*., 2002). Lately, many studies had been conducted on the production of briquettes from unprocessed or raw agricultural residues. For instance, briquettes from rice straw and rice bran were feasible to be converted into solid biomass fuel using a hot-pressing temperature (Chou *et al.*, 2009). Eucalyptus wood and rice husk from Uruguay was used as an activated carbon briquette (Amaya *et al.,* 2007).

Corn (*Zea mays* L.) is one of the most produced foodstuffs in the world along with sugarcane. Corn Chaff (CC) are leftover product of corn mill industries. Popular among the CC is the chaff (dry, scaly coating of corn seeds with fragments of cotyledon and endosperm) which is the residue from milling corn seeds into powder. There is need to research into the use of CC for the production of briquettes as sustainable and alternative source of energy.

MATERIALS AND METHODS

Sample collection and Preparation

Corn chaff (CC) was collected from Feedmill, Ijokodo, Ibadan, Oyo state. The wet sample was air dried for a period of 2 weeks and sieved using a 2mm particle size mesh screen for the purpose of consistency. Cassava starch was purchased for the purpose of this research while gum arabic (Grade C) was gotten as the remnant from *Acacia senegal* product. It was mixed at different composition to give a total of 30 samples.

Binder preparation

Using gum arabic and cassava starch as a binder, 100ml of water was boiled at 98°C for 28 mins and mixed with each binder (10, 15, and 20g) to form a gelatin paste (Chungcharoen and Srisang, 2020). 60g each of the corn chaff was thoroughly mixed with the prepared binder paste at ratios 1:6, 1:4 and 1:3 (10, 15, and 20g respectively).

Production of Briquettes

The mixture was hand fed into a 5-ton hydraulic jack briquetting machine. The machine is equipped with twelve cylindrical molds with a dimension of 80cm (heights) x 6.5 cm (diameter) welded together in a single frame. A pressure of 10 kg/cm^2 was applied for the mixture compaction to form briquette (Sotannde *et al.*, 2010a). The briquette molds are designed to produce twelve briquettes per batch. For the sawdust and wheat offal, each production batch was duplicated three (3) times. The produced briquettes were allowed to set for a day before placing in the oven to dry at 90°C.

Briquette Characterisation

The physical and combustion characteristics of the briquettes were determined using ASTM standard procedures: Density-ASTM Standard D 2395-17 (2017), Moisture content-ASTM D2444-16 (2016), Shatter index-ASTM D440-86 (2002), Dimensional stability in accordance with the method adopted by Olorunisola, (2007). Other parameters are volatile matter-ASTM Standard D 3175-20 (2018), ash content- ASTM Standard D3174-12 (2018), fixed carbon-ASTM Standard D 3172-

13 (2021) and calorific value-ASTM Standard D 5865- 19 (2013).

Experimental Design and Statistical Data Analysis

A 2 x 3 factorial experiment with 5 replications and a completely randomized design (CRD) was used to determine the material's physical, and calorific properties. This yielded a total of 30 samples. The performance of the briquettes and the means of their various attributes were compared using Analysis of Variance (ANOVA) to identify any significant differences. All significance tests in this study were conducted at 95% confidence level ($p< 0.05$).

RESULTS AND DISCUSSION

Physical Properties of Briquette

Density

The result of density of briquette as shown in Figure 1 is an indication that briquettes produced using starch binder at 20% binder level had highest density of 495.87kg/m^3 while density was lowest (415.15kg/m^3) in gum arabic bonded at 10% binder level. However, Table 1 shows the ANOVA. The highest compressed density of 1437 kg/m^3 was obtained for briquettes made of cassava as binder at 30%. The density in this study falls within the range of 729 and 1437kg/m^3 recorded by Aransiola *et al.*, 2019. These results agree with the findings of previous authors (Chirchir *et al*., 2013) who observed that briquette density is dependent on both the binder type and quantity.

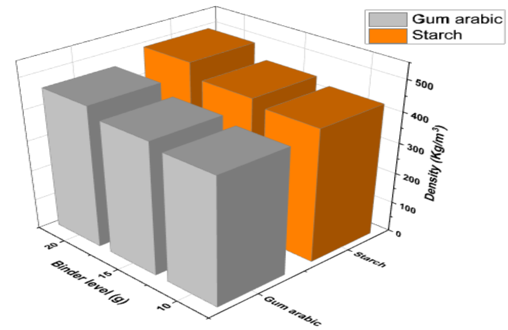


Figure 1. Density of Briquettes Base on Binder type and Binder level

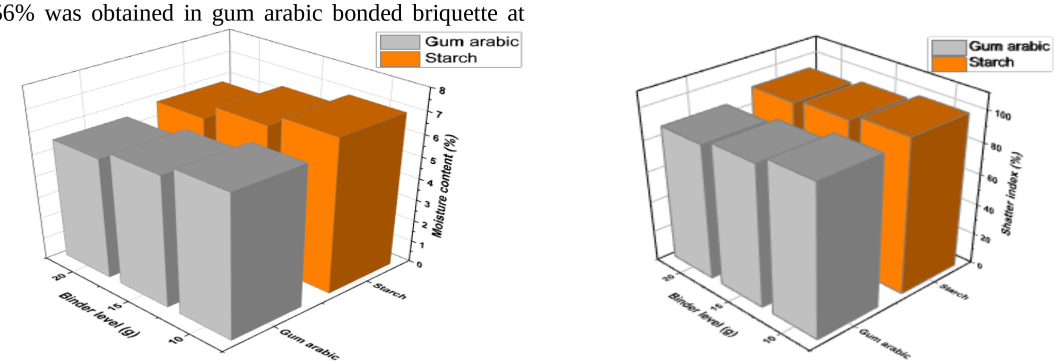
Table 1. P-values of Density, Moisture content, Porosity and Shatter index of briquettes

Source of Variation	Df	Density	Moisture content	Shatter index	Volatile matter	Ash content	Fixed carbon	Calorific value
Binder type	1	0.6468^{ns}	0.0026*	0.7989^{ns}	0.4932^{ns}	0.0000*	0.8425^{ns}	0.0000*
Binder level	2	0.0003*	0.0000*	0.4572^{ns}	0.4633^{ns}	0.0005*	0.2928^{ns}	0.0004*
Binder type*Binder level	2	0.1426^{ns}	0.0670^{ns}	0.7193^{ns}	0.0449*	0.0000*	0.0269*	0.0000*
Error	24							
Total	29							

*= Significant ($P<0.05$), ns= not significant ($p>0.05$), Df = Degree of freedom

Moisture content

Moisture content of briquette in Figure 2a, shows that starch bonded briquette had highest moisture content of 7.06% at 10% binder level and lowest moisture content of 5.56% was obtained in gum arabic bonded briquette at 20% binder level. Table 1 shows the Analysis of variance. The feedstock's moisture level can have a substantial effect on how well it burns (Eke *et al*., 2020). According to Carnaje *et al.* 2018, briquettes with a moisture level of more than 10% become brittle when burned.



A B

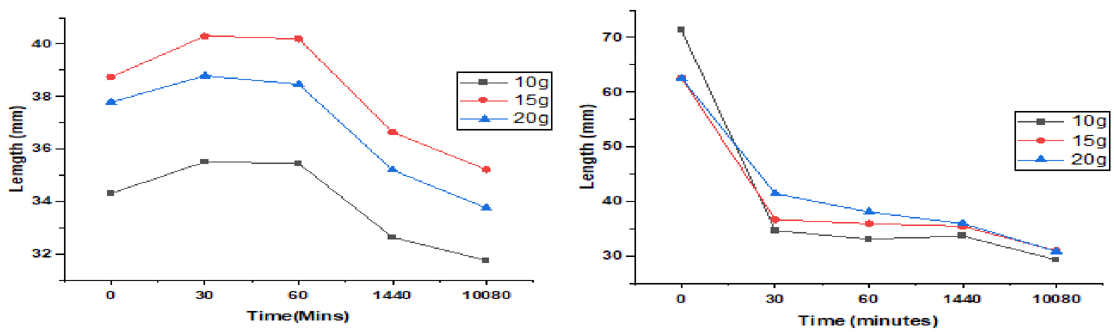
Figure 2. A-Moisture content and B-Shatter index of Briquettes Based on Binder type and Binder level

Shatter Index

In Figure 2b, shows that starch bonded briquette at 10g binder level has a highest mean shatter index of 99.68% compared to 97.03% obtained in gum arabic. The P-value in Table 1 shows that both binder type and binder level had no significant effects on the shatter index. According to Borowski *et al*, (2017) the shatter index of briquettes should be at least 90%. Ujjinappa and Sreepathi, 2018 stated that the higher the value of the shatter index, the better the quality of briquette. The shatter index decreased with increase in binder level.

Dimensional Stability

Result of dimensional stability in Figure 3a and b shows that all the gum arabic bonded briquettes produced at 10, 15 and 20g binder level shows more stability with time than starch bonded briquettes. This is because it tends to be more linear with minimal expansion, it gave a nearly straight line after 30mins of production. The diameter and height of the briquettes were measured immediately after production, after intervals of time according to Jiao *et al* 2020. Also, Kaliyan *et al*., 2009 reported that dimensional stability was mainly dependent on feed stock moisture, binder type and compression pressure.



A B

Figure 3. Compares the Stability of Briquette Bonded with A-Starch and B-Gum Arabic

Combustion Properties of Briquette

Volatile Matter

Figure 4a shows that percentage volatile matter of the briquette increased with increase in binder level. Though the highest volatile matter (19.1%) was obtained in starch bonded briquettes at 20g binder level. While the least percentage volatile matter (13.3%) was obtained at 10g binder level in gum arabic bonded briquette. The result in Table 1 is the Analysis of variance. These results reveal that volatile matter increased as binder concentrations increased and reduced as binder concentrations decreased. According to Helwani *et al.*, 2020, the volatile matter concentration of the generated briquettes is 19.73 and 17.23%, respectively, which is similar to the results obtained in this study.

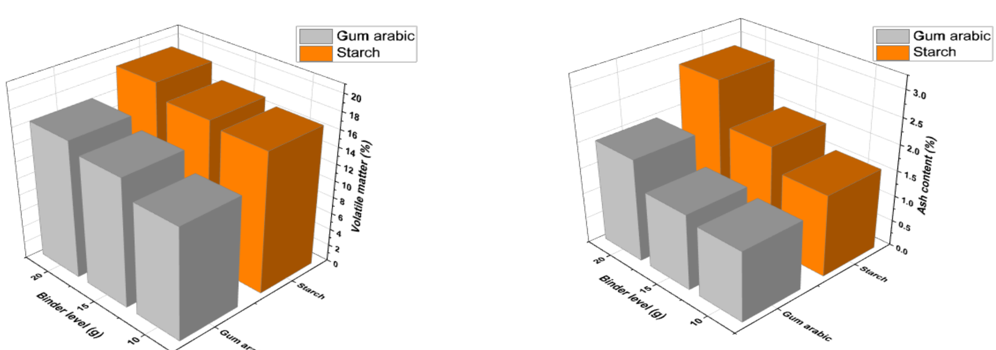


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Figure 4. A-Volatile matter and B-Ash content of Briquettes Based on Binder type and Binder level

Ash content

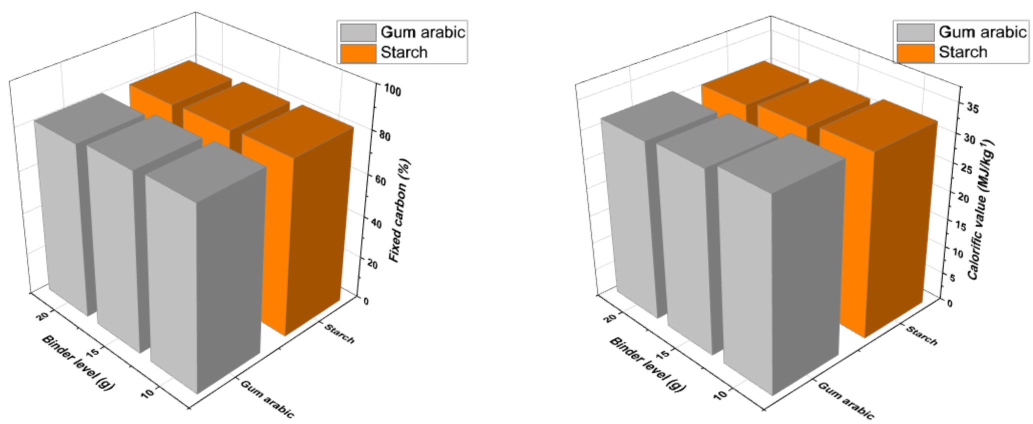
The least percentage ash content was obtained in gum arabic bonded briquette 1.36% at 10g binder level. While the highest was obtained in starch bonded briquette 2.84% (Figure 6). Analysis of variance is presented in Table 1. DIN 51731 recommended a minimum value of ash content for briquettes to be 0.7%. While according to the ISO standard (ISO 17225-7. 2014), the recommended maximum and minimum ash content value are ≤10% and ≤6% respectively. However, Guusu *et al*. (2021), provided a justification for the maximum ash values obtained that the biomass and binder materials used for the experiment has different attributes and process conditions.

Fixed carbon

Percentage fixed carbon of the briquette in Figure 5a shows that gum arabic briquette bonded at 10g binder level had the highest fixed carbon of 85.11% while starch briquette was high at 10g binder level with percentage fixed carbon of 82.71%. Percentage fixed carbon contents decreased with increase in binder concentration in both gum arabic and starch bonded briquette. It is expected that fixed carbon of briquettes can range between ≥90% and as low as 5% from oil palm briquettes (Onukak *et al*., 2017) which are tropical trees. There is no strictly defined appropriate percentage of fixed carbon under any criterion. This is so that the values may be determined, which depends on the quantities of ash and volatile materials. The high fixed carbon content and smokeless flame are anticipated to increase the briquettes' heating value and burning time.

Calorific value

Figure 8, shows that calorific value of gum arabic bonded briquette was slightly higher (33.674MJ/kg^{1}) at 10g binder level compared to starch bonded briquette (32.507MJ/kg^{1}) at 10g binder level. Both binder type and binder level significantly influenced the calorific value of the briquette (Table 2). The fuel ratio (i.e. the ratio of fixed carbon to volatile matter content) was analyzed to further justify the quality of the briquettes produced (Nhuchhen and Afzal, 2017). These values are greater than minimum requirement of ≥14.5 MJ/kg (ISO, 2014). The observation in this study, was in good agreement with the report of Onuegbu *et al* (2012) experiment conducted on elephant grass and *imperata cylindrica* with a blend of coal.



A B

Figure 5. A-Fixed carbon B-Calorific value of Briquettes Based on Binder type and Binder level

CONCLUSION AND RECOMMENDATION

This study concluded that fuel briquettes produced from corn chaff using the 2 different binders (starch and gum arabic) at different binder proportion met the minimal criteria for briquettes as cooking fuel. Gum arabic briquette proves to have higher energy value than starch briquette. In terms of binder level, 10g happens to perform better in physical and combustion properties than other binder levels. However, it could be recommended that corn chaff has great opportunities to achieve sustainable energy.

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Authors Contributions

Authors AGT and ABB managed data collection, interpretation of data, writing of manuscript, material support, and review of manuscripts and wrote the first draft of the manuscript. Authors AIT and OMO managed the literature searches. Author AAR, and ORI managed the development of methodology, while AOO and AEA managed data analysis, and the development of the model. All authors read and approved the final manuscript.

Ethical Statement

Not applicable.

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