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Performance Evaluation of the Physical and Combustion Properties of Briquettes Produced from Agro-Wastes and Wood Residues

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Abstract: This study investigated the physical and combustion properties of briquettes produced from agricultural wastes (groundnut shells and corn cobs), wood residues (*Anogeissus leiocarpus*) and admixtures of the particles at 15%, 20% and 25% starch levels (binder). A 6 x 3 factorial experiments in a Completely Randomized Design (CRD) was adopted for the study. The briquettes produced were analyzed for density, volatile matter, ash content, fixed carbon and specific heat of combustion. The result revealed that the density ranged from 0.44g/cm^3 to 0.53g/cm^3, while briquettes produced from groundnut shells had the highest (0.53g/cm^3) significant mean density. Mean volatile matter and ash content of the briquettes ranged from 24.35% to 34.95% and 3.37% to 4.91%. *A. leiocarpus* and corn cobs particles had the lowest and highest ash content respectively. The briquette fixed carbon and specific heat of combustion ranged from 61.68% to 68.97% and 7362kca/kg to 8222kca/kg respectively. Briquette produced from *A. leiocarpus* particles had the highest specific heat of combustion. In general, briquettes produced from *A. leiocarpus* particles and admixture of groundnut shell and *A. leiocarpus* particles at 25% starch level had better quality in terms of density and combustion properties and thus suitable as environmentally friendly alternative energy source.

Keywords: Biomass; Briquette; Combustion; Density; Energy source

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1. Introduction

An estimated 3 billion people in our current estimated 7.63 billion people in the world [1, 2] rely upon wood, kerosene, biomass and coal for domestic cooking. This led to rapid deforestation and loss of more than 3% of the world's forests on an annual basis. The use of wood is increasing on daily basis especially in the less technologically developed countries of the world [3]. With deforestation becoming a major problem in many parts of the developing world, there is increased scarcity of fuelwood for household cooking. Increase in the energy demand and use in Nigeria due to rapid growth in population and industry has raised concerns about the economic and environmental impacts of power generation based on national energy sources. Kerosene and gas are the major cooking fuel [4].

Environmental and ecological problems are the major issues of concern associated with exploitation of these fuels. Another major challenge with these fuels is their unsustainability and projected depletion over the years. The use of fuel wood in the large scale without replenishing poses serious environmental consequences in many countries. Also population increase in countries like Nigeria places more demands on energy to light and heat homes, to cook food, to drive transport, and communication devices and provide power for industries [5].

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This situation therefore, calls for an alternative means of supplementing the acute demand of wood for fuel energy. One of such alternative means is the use of biomass for briquette production through densification and manufacture of carbonized or uncarbonised processes [6]. Biomass in the form of wood and agricultural wastes constitute one of the third largest alternative source of primary energy in the world aside from coal and oil [7].

The large quantities of agricultural residues produced in Nigeria can play a significant role in meeting her energy demand. However, the abundant quantities of agricultural wastes and forest residues are neither managed effectively, nor utilized efficiently in all developing countries. The common practice is to burn these residues or they are left to decompose [8]. This burning itself contributes to atmospheric pollution, but more than that; the burning or decomposition is a waste of available energy [9]. Recycling of these biomass helps to ameliorate the accumulation of greenhouse gases [10] and can be renewably converted into liquid, solid or gas states [11]. Briquetting provides a value addition, sustainable and efficient utilization of the biomass residues [12].

The natural environment cannot continue to provide cooking fuel for the ever increasing population. An alternative and sustainable fuel energy source becomes imperative. The focus of this study is to examine the qualities (physical and combustion properties) of briquettes produced from agricultural wastes (groundnut shells and corn cobs), wood residues (*Anogeissus leiocarpus*) and admixtures of the particles.

2. Materials and Method

2.1. Study Site

The experiment was carried out in Federal College of Forestry Jos, Plateau State Nigeria. Jos is located in Northern Guinea savanna is situated between latitudes 80 and 30′ and 100 10 N and longitude 80 20′ and 90 30′E.

2.2. Materials for the briquette production

The materials used for the briquette production include agricultural waste from groundnut shell and corn cobs; and sawdust of *Anogeissus leiocarpus* (Plate 1a). The choice of the agricultural wastes was based on the relative abundance of the groundnut and corn crops in the northern parts which are annual crops. The *A. leiocarpus* was chosen also based on its relative abundance in the timber market.

2.3. Sample Preparation Procedures

Wood samples (planks) of *A. leiocarpus* species was obtained from the timber market at Katako. The wood samples were processed and converted into sawdust using circular saw machine. The agricultural wastes (groundnut shells and corn cobs) were sourced from surrounding farms and pulverized into small particles. The particles were pre-treated in hot water at 100^{0}C for 30 minutes to remove extractives that may inhibits the binding ability of the particles and cassava starch. They were thereafter sundried for 7 days so as to reduce the moisture content (Plate 1a & 1b). The particles were sieved using 80μm wire mesh, so as to reduce the particles size into fine particles [13].

The starch binder at different levels of 15%, 20% and 25% [14, 15] was prepared with 250ml boiled water, stirred and mixed with measured (Plate 1d) grams of separate particles singly and combined (at a mixing proportion of 50:50). The homogenously mixed stock was poured into the fabricated briquette moulder (Plate 1e) and compressed using hydraulic jack (Plate 1f). The briquettes were then removed and air dried for 30days. Proximate analysis was thereafter carried out for properties investigation.

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2.4. Experimental Design

The experimental design for the study was 6 x 3 factorial experiments in a Completely Randomized Design (CRD). The factors consist of six (6) particle types (*A. leiocarpus* sawdust only (T1), groundnut shell only (T2), corn cobs only (T3), *A. leiocarpus* sawdust (T4) + Groundnut shell, *A. leiocarpus* sawdust + Corn Cobs treatment combination (T5) and *A. leiocarpus* sawdust + Groundnut shell + Corn Cobs treatment combination (T6) and three starch levels (15%, 20% and 25% starch levels). This gave18 treatment combination replicated four times (Plates 2a, 2a, 3a-3f).

(a) (b) (c) (d) (e) (f)

Plate 1. Materials used for the production of the briquette and production process. (a) Particle types and starch; (b) Pre-treatment in hot water (100^{0}C); (c) Drying of the particles; (d) Weighing of the materials (particle and starch); (e) Fabricated briquette hydraulic moulder; (f) Compression, hydraulic pressing and moulding of the briquette.

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Plate 2. (a) Briquettes produced based on particle types; (b) Briquettes produced based on particle types and starch levels

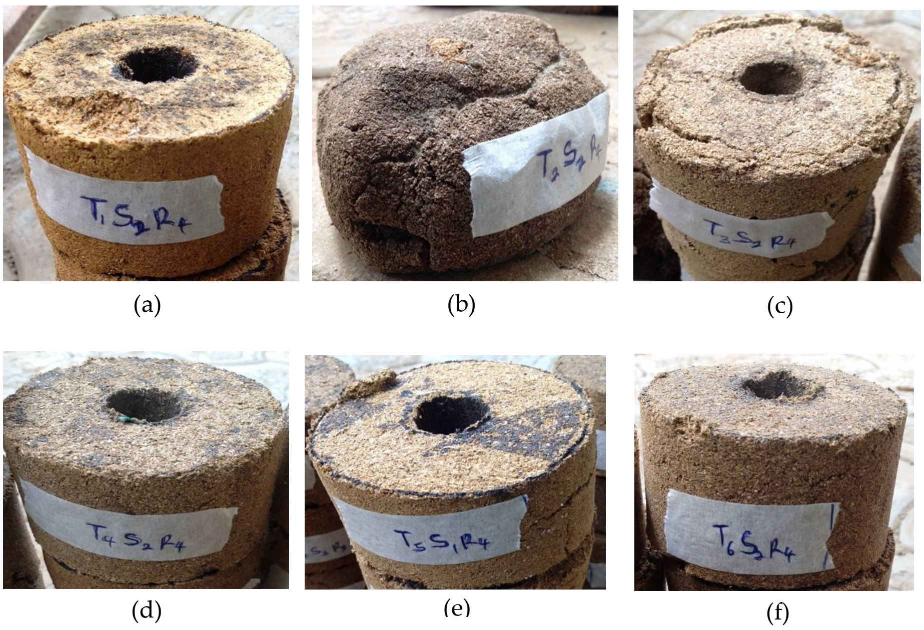

Plate 3. Briquettes produced from different particle types. (a) *Anogenssus leiocarpus* briquette (T1); (b) Groundnut Shell briquette (T2); (c) Corn Cobs briquette (T3); (d) Admixture of T1 + T2 briquette; (e) Admixture of T1 + T3 briquette; (f) Admixture of T1 + T2 + T3 briquette.

2.5. Variables Assessed

The following parameters were determined on each of the sample briquettes [14, 16].

- Relaxed density: The relaxed density was determined according to the weight and the volume of each briquette block which depends on its shape. The volume (V=πr2h) was be based on direct

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measurement of radius and height (m) and the weight (g) using digital weigh balance. The density of each briquette sample was calculated using the formula in equation 1;

$$Density\left(\frac{g}{cm^3}\right) = \frac{Mass\ (g)}{Volume\ (cm)^3} \quad \text{.................................Equation 1}$$

- Volatile matter (%Vm): The percentage volatile matter was determined by placing the crucible containing the oven dry weight (w2) in the furnace for 10 minute at 550^0C to obtain weight (w3) after which the volatile matter in it must have escaped. The percentage volatile matter (%Vm) was calculated using the formula as shown in equation 2;

$$Volatile\ matter\ (\%) = \frac{\text{(Dry weight (w2) – weight of sample (w3) after 10min.in the furnace at } 500^0\text{C}}{\text{Oven dry weight (w2)}}$$

$$\text{....................Equation 2}$$

- Ash content (%Ash): 2g of oven dry pulverized briquette was placed in a crucible (w2). The crucible was placed in the furnace for 4 hours at 55^0C to obtain the ash weight (w4). Percentage ash content was calculated using equation 3;

$$Ash\ Contentn\ (\%) = \frac{\text{weight of Ash (w4)}}{\text{Dry weight (w2)}} \quad \text{.................Equation 3}$$

- Fixed carbon (%FC): The percentage fixed carbon was calculated by subtracting the sum of percentage volatile matter and percentage ash content from 100% (Equation 4).

$$Fixed\ Carbon\ (\%) = 100\% - (\%Vm + \%Ash) \quad \text{........Equation 4}$$

- Specific Heat of Combustion (Hc): The specific heat of combustion (Hc) was calculated from the formula as shown in equation 5;

$$\text{Specific Heat of Combustion (Hc)} = 0.35\ (147.6 \text{ x } \%FC) + (144 \text{ x } \%VM) + (\%Ash)$$

$$\text{..............Equation 5}$$

2.6. Statistical Analysis

Analysis of variance (ANOVA) resulting from 18 treatment combinations and four replicates was carried out to evaluate the performance of each of the treatments. Where significant differences existed, Duncan's Multiple Range Test (DRMT) was used for mean separation to determine the magnitude of differences.

3. Results

3.1. Effect of Treatments and Starch Levels on Relaxed Density of the Briquette

The relaxed density of the briquettes ranged between 0.46g/cm3 and 0.53g/cm3 (Figure 1) Briquette made with groundnut shell particles had the highest relaxed density (0.53g/cm3), while briquette produced with the three combinations of A. leiocarpus, groundnut shell and corn cobs particles had the lowest (0.46g/cm3) mean briquette density. The statistical analysis revealed that groundnut shell had significantly higher effect on the relaxed density of the briquette, while the other particle treatments and treatment combinations were not significantly different from each other ($p \geq 0.05$).

The effect of starch levels on briquette relaxed density (Figure 2) indicated that briquettes produced at 20% starch level had the highest relaxed density (0.49g/cm3), while briquette produced at the lowest starch level (15%) had the lowest density (0.46g/cm3). The effects of the three starch levels on briquette relaxed density were not significantly different ($p \geq 0.05$) from each other, as there were little variations in the relaxed density of the briquettes produced from the three starch levels.

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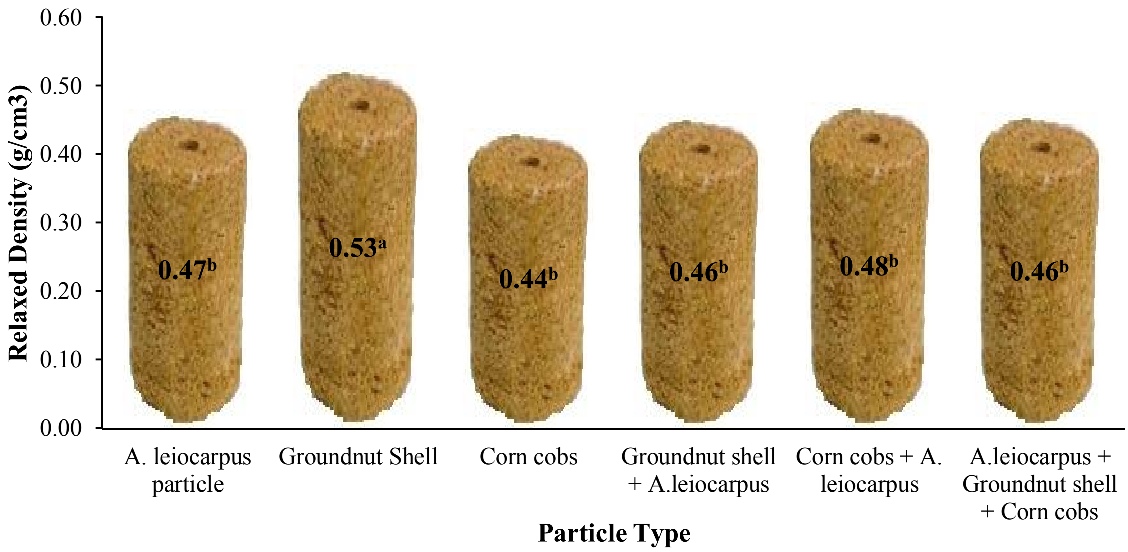

Figure 1. Mean Effect of Treatments on Density (g/cm³) of Briquette
Means in the same bar having the same superscript are not significantly different (p≥0.05)

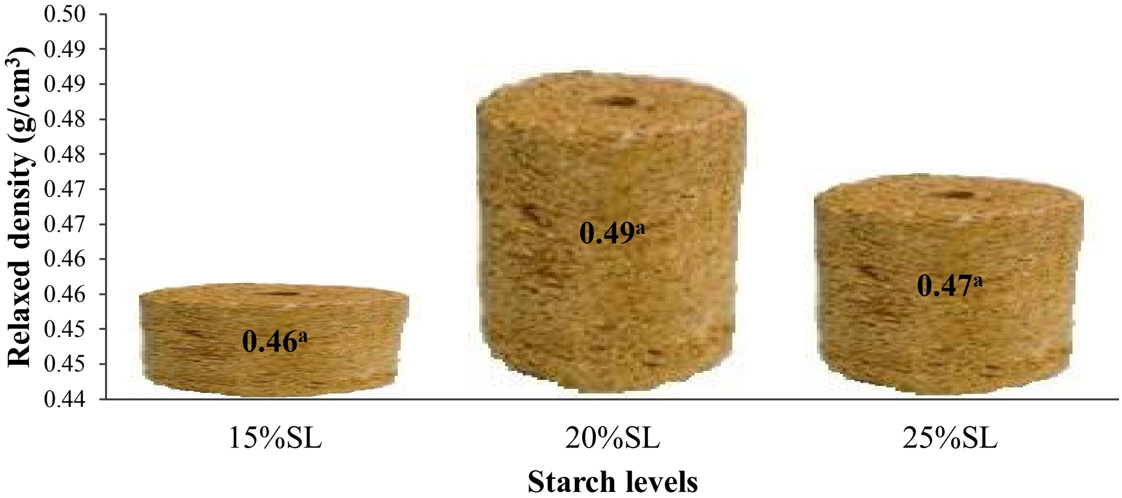

Figure 2. Mean Effect of Treatments on Density (g/cm³) of Briquette
Means in the same bar having the same superscript are not significantly different (p≥0.05)

3.2. Effect of particle types on combustion properties of the briquettes

The volatile matter (Figure 3) ranged between 26.4% and 34.9%. Briquettes made with A. leiocarpus and mixture of groundnut shell and A. leiocarpus had the highest (34.9%) and lowest (26.4%) volatile matter respectively. The statistical analysis revealed that the effects of all particle types excluding A. leiocarpus wood particle on volatile matter were not significantly different ($p \geq 0.05$) from each other. The volatile matter of briquettes produced from mixture of agricultural residues (A+gnut shell (26.4), A+corn cobs (28.5%) and A+G+C (28.4%) and wood particle were lower than briquettes produced from unmixed/uncombined particle types (A. leiocarpus (34.9%), groundnut shell (29.8%) and corn cobs (31.2%). Ash content (Figure 3) of the briquettes ranged between 3.4% and 4.9%. The ash content of the briquettes were not significantly different from each other, though corn cob briquette had the highest ash content (4.9%) while briquette from Anogeissus

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leiocarpus particle had the lowest ash content (3.4%). Mixture of agricultural residues (gnut shell and corn cobs) and wood particles had the same ash content.

The specific heat of combustion and fixed carbon ranged from 7362kca/kg to 8222kca/kg and 61.7% to 69% respectively (Figure 4). As similarly observed for volatile matter, the specific heat of combustion of the briquettes produced from mixed particles (groundnut shell and A. leiocarpus (7362kca/kg); corn cobs and A. leiocarpus (7561kca/kg), A. leiocarpus, groundnut shell and corn cobs (7589kca/kg)) were lower than the specific heat of combustion of briquettes produced from unmixed A. leiocarpus (8222kca/kg), groundnut shell (7677 kca/kg) and corn cobs (7882kca/kg) particles. On the other hand, the fixed carbon of briquettes produced from mixed particles (groundnut shell and A. leiocarpus (69%); corn cobs and A. leiocarpus (66.8%), A. leiocarpus, groundnut shell and corn cobs (67.7%)) were higher than the fixed carbon of unmixed particle types (A. leiocarpus (61.7%), groundnut shell (65.4%) and corn cobs (63%) particles). Briquette produced from mixture of groundnut shell and Anogeissus leiocarpus particles had the lowest specific heat of combustion (7362kca/kg) and highest fixed carbon content (69%). The specific heat of combustion and fixed carbon were not significantly different from each other (p≥0.05).

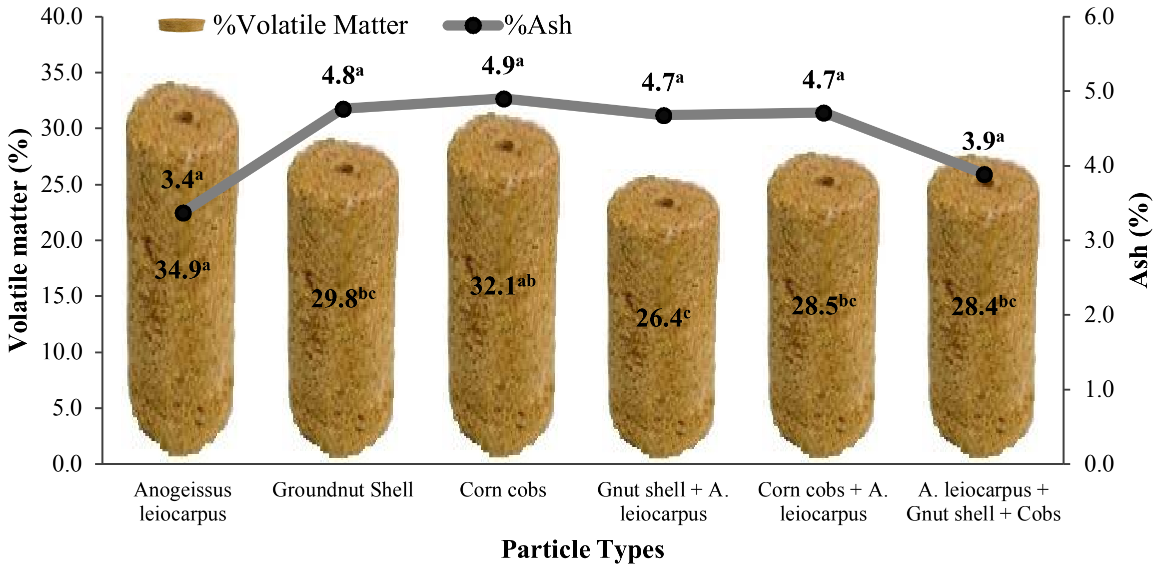

Figure 3. Effect of particle types on percentage volatile matter (%VM) and Ash content (%) of the briquette

Means in the same bar having the same superscript are not significantly different (p≥0.05)

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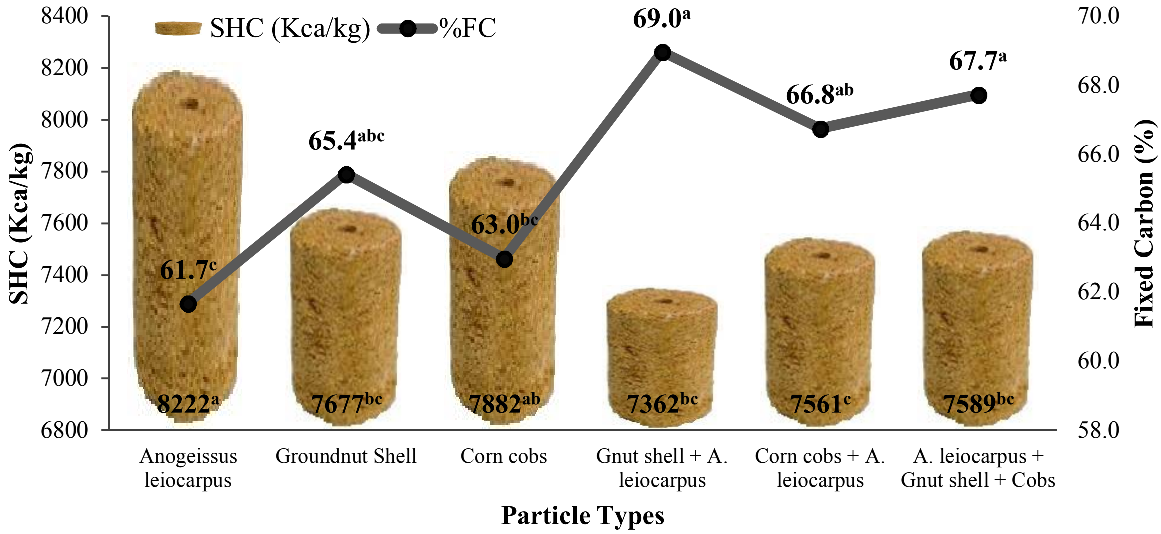

Figure 4. Effect of particle types on specific heat of combustion (SHC) and fixed carbon (%FC) of the briquette

Means in the same bar having the same superscript are not significantly different (p≥0.05)

3.3. Effect of starch levels on combustion properties of the briquettes

The result of findings as shown in Figures 5 and 6 revealed that briquettes produced at 20% starch level had the lowest volatile matter (24.2%) and specific heat of combustion (7165Kca/kg), while 25% starch level produced briquettes with the highest volatile matter (33.5%) and specific heat of combustion (8051Kca/kg). On the other hand, briquettes produced at 20% starch level had the highest ash content (4.7%) and fixed carbon (71.1%), while 25% starch level produced briquettes having the lowest ash content (4.1%) and fixed carbon (62.4%). In addition, the volatile matter of briquettes produced at 15% and 25% starch levels were not significantly different from each other as similarly observed for specific heat of combustion and fixed carbon. The effects of the three starch levels (15%, 20% and 25%) on ash content of the briquettes were not significantly different from each other (p≥0.05). The effects of 20% starch level on fixed carbon and specific heat of combustion was significantly (p≤0.05) higher and lower respectively from the other starch levels (15% and 25%).

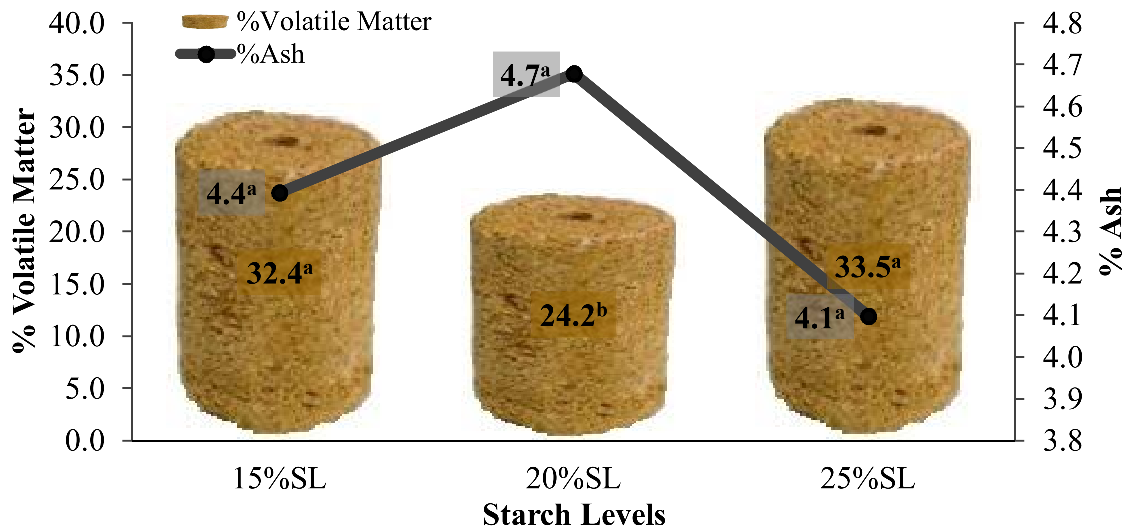

Figure 5: Effect of Starch levels on percentage volatile matter (%VM) and Ash (%) of the briquette

Means in the same bar having the same superscript are not significantly different (p≥0.05)

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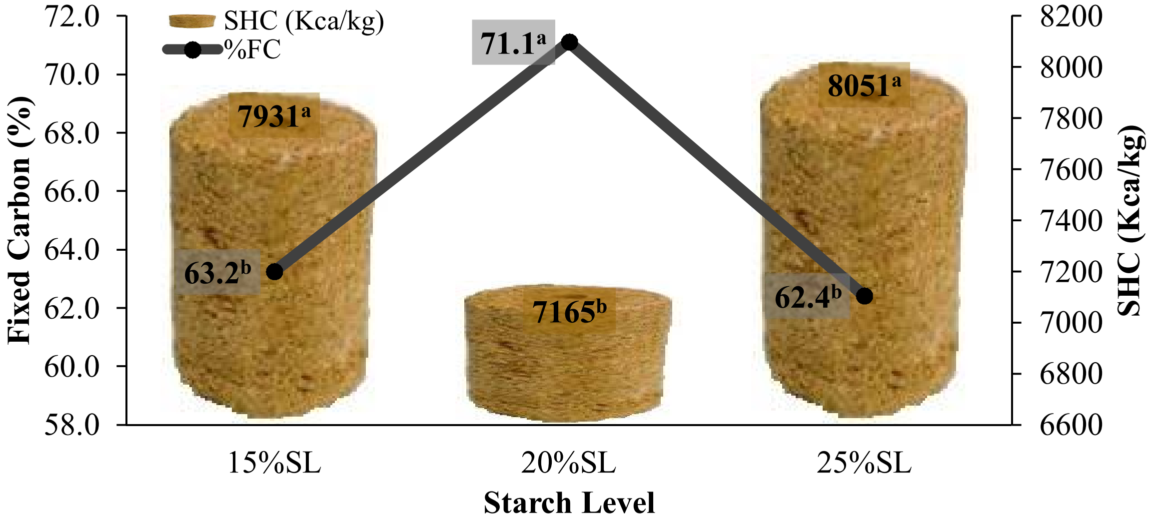

Figure 6: Effect of Starch levels on percentage specific heat of combustion (Kca/kg) and fixed carbon (%FC) of the briquette

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

4. Discussion

4.1. Relaxed Density

The briquette produced from groundnut shell had poor compaction and agglomeration at higher starch level which contributed to its higher significant effect on density (Figure 1). This assertion contradicts the report of Egbewole et al. [14] on poor agglomeration of briquette at lower starch levels of 10% and 15% for wood sawdust. The implication of this is that particle sizes and type have great influence on density of briquettes as similarly observed by Aina et al. [17]. Quality of the mixture composition and technological characteristics of the bio-raw material have a very important influence on the particle agglomeration during the pressing process [18]. In collaboration with the findings of Tembe et al. [15] on comparative analysis of combustion properties of briquettes from groundnut shell and rice husk, the starch level had no significant effect on the briquette density. The relaxed density obtained in the study is within the range of values as obtained by Ige et al. [19] and Onuegbu et al. [20] who reported a relaxed density range between 0.319g/cm^3 and 0.590g/cm^3. In addition, high density is an indication of longer burning time, as such briquettes produced from groundnut shell (0.53g/cm^3); admixture of corn cobs and A. leiocarpus (0.48g/cm^3); and A. leoicarpus (0.47g/cm^3) particles will tend to burn for a longer time compare to others.

4.2. Volatile Matter

The range of values for volatile matter (24.2% and 34.95%) of briquettes produced in this study (Figures 3 and 5) is lower than 43% to 49% obtained by Adegoke et al. [13] from mixed sawdust briquettes of tropical hardwood species, 72.33% to 77.44% of briquettes produced from three hardwood species as reported by Emerhi [21] and 68% stated by Ige et al. [18]. Adetogun et al. [22] in their study on briquettes from maize cobs reported a higher volatile matter ranging between 57.82% and 62.91% compared to a lower value of 31.2% and 33.5% for briquettes made from maize cob in this present study (Figures 3 and 5). Conversely, Egbewole et al. [14] and Sotannde et al. [23] reported a lower volatile matter for briquettes made from wood sawdust (13.89% to 19.33%) and neem-wood residues (10% to 13%) respectively.

Volatile matter which is a mixture of short and long chain hydrocarbons, aromatic hydrocarbons, methane, hydrogen and carbon monoxide, and incombustible gases like carbon

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dioxide and nitrogen proportionately increases flame length, and helps in easier ignition and influences secondary air requirement and distribution aspects. Lower volatile matter is an indication that the briquettes might not be easy to ignite, but once ignited they will burn smoothly with clean flame without smoke, while high volatile matter results in high combustibility at low ash content [24]. In contrast, the higher the volatile matter of a briquettes, the higher the amount of emissions during burning. This implies that low volatile matter is required for good quality briquette and it typically range between 20 and 35%. The volatile matter values obtained in this study is with the acceptable quality values required for fuelwood.

4.3. Ash Content

The low ash content as observed in this study (Figure 3 and 5) is a reflection of the high specific heat of combustion/heating value (Figures 4 and 6) which is an indication that the briquette does not contain high mineral (non-combustible) matters. As posited by Sotannde et al. [23] ash content normally causes an increase in the combustion remnant, thereby lowering the heating effect. The briquettes produced at 25% starch level had the lowest ash content (Figure 5) thus indicating its suitability in briquette production. The low ash content as observed in this study corroborates the findings of Akowuah et al. [25], Adetogun et al. [22] and Sotannde et al. [23] who all reported a lower ash content of 2.6%, 1.06% to 1.23% and 3.50% to 5.75% respectively. On the contrary, higher ash content ranging from 19.07% to 21.72%; 10.44% to 42.33%; 18.67% to 22.06%; and 18% were reported by Emerhi [21], Ogbuagu et al. [26], Ikelle and Anyigor [27], and Ige et al. [19] respectively. Lower ash content is an indication of good quality briquette and generally range between 5% and 20% [28]. Ash is an impurity that will not burn. Higher ash content in a fuel usually leads to higher dust emissions, air pollution and affects the combustion volume and efficiency of combustion [29]. Consequently, the lower ash content as observed in this study validates the high quality and improved efficiency of the briquettes.

4.4. Specific heat of combustion

The specific heat of combustion values ranging between 7362kcal/kg and 8222kcal/kg (Figures 4 and 6) as obtained in this study is within the range of values (7500kcal/kg and 8000kcal/kg) as similarly reported by Bamiyo [30]. However, Egbewole et al. [14] and Tembe et al. [15] in their findings reported a lower specific heat of combustion ranging from 4908.52kcal/kg to 5257.66kcal/kg and 3284kcal/kg to 3980kcal/kg respectively.

4.5. Fixed Carbon

Fixed carbon gives an indication of the proportion of char that remains after the devolitization phase or after volatile matter is distilled off. It gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning [25]. The fixed carbon as observed in this study (Figures 4 and 6) is close to the high fixed carbon content of briquette obtained by Sotannde et al. [23] and Egbewole et al. [14] of 85.25% and 85.95% respectively. According to Sotannde et al. [23], it is expected that the high fixed carbon and its smokeless flame will enhance the heat value and combustion duration of briquette. However, the fixed carbon as reported in this study is relatively higher than 9.06% to 11.46% obtained by Adegoke et al. [13] 5.75% to 8.28% stated by Emerhi [21], 16.80% - 20.90% quantified by Adetogun et al. [22] and 15% fixed carbon estimated by Ige et al. [19]. A good quality and efficient fuel briquette is dependent on lower volatile matter and ash content with a higher fixed carbon content [31] in collaboration with result of findings of this study.

5. Conclusion

The study examined the physical and combustion properties of briquettes produced from agricultural wastes (groundnut shells and corn cobs) and wood residues (*Anogeissus leiocarpus*) as well as homogenous combination of the particles. The study affirmed that briquettes produced from *A. leiocarpus* particles and a combination of groundnut shell and *A.leiocarpus* particles produced at

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25% starch level had better quality in terms of density, agglomeration, compaction and combustion properties with respect to high volatile matter, low ash content, high fixed carbon and high specific heat of combustion. There were little variations in the quality of the briquette produced from these two particle types compared to other homogeneous and heterogeneous particle types. This study has been able to confirm that agricultural wastes alongside wood waste can be utilized in producing quality briquettes. As such, wood wastes from *A. leiocarpus* and a combination of groundnut shell and *A. leiocarpus* particle type using 25% starch level are suitable for briquette production due to better combustion performance.

Subsequently, the briquettes will provide better and efficient environmentally friendly alternatives to other forms of energy source, help to solve agricultural and wood wastes management issues, help in the restoration of already destroyed forests by proving alternative fuel wood. It could also enhance market diversification, rural economic empowerment and job opportunities.

Author Contributions: The first author conceived the research idea, adopted and designed the fabricated briquette moulder, wrote the original draft manuscript, analyzed the data and review and editing of the manuscript. The second author participated in the investigation and production process, reviewed and edited the manuscript. The third author conducted the laboratory analysis and contributed to manuscript preparation and review. The fourth author sourced and fabricated the materials used for the methodology, participated in the investigation and production process as well as contributed to manuscript preparation.

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Conflicts of Interest: The authors declare no conflicts of interest.

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