Production of composite briquettes (orange peels and corn cobs) and determination of its fuel properties

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Abstract: Energy is one of the necessities for human existence. Currently, fossil fuel is the major source of energy from which the commonly used fuel products like kerosene and cooking gas are obtained. These sources of energy are not renewable and environmentally friendly. Therefore, it is necessary to explore renewable energy sources particularly from Agricultural residues. This study presents the investigation on the suitability of orange peels and corn cobs for composite briquette production. Due to the enormous wastes problem constituted by orange peels and corn cobs, it is necessary to utilise these wastes for energy purposes. Orange peels and corn cobs were collected from environment of Chanchaga and Kasuwan-Gwari Local Government Area of Minna, Niger State, Nigeria. The materials were sun-dried and milled using a locally available milling machine, sieved through a 2.36 mm sieve and mixed in the ratios of 20:80, 80:20, and 50:50 – orange peels to corn cobs. The samples were mixed at varying mass ratios with 80 g of pasty starch as a binder and compacted in a manually operated hydraulic jack briquetting machine. The formed briquettes were oven-dried and some physical and fuel properties were determined. Results showed sample A has the highest calorific value of 31886.04 kcal kg^{-1} followed by sample B with 31295.62 kcal kg^{-1} and the least was sample C with 31136.77 kcal kg^{-1} respectively. Sample A also had the highest carbon content followed by sample B and C respectively. This study revealed that the produced composite solid fuel could be used as a source of heat energy even in rural areas with little or no electrical power supply.

Keywords: orange peels, corn cobs, biomass, briquettes, composite solid fuel, proximate analysis, ultimate analysis, water boiling test

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1 Introduction

Energy is one of the necessities for human existence (Olajedi and Oyetunji, 2013). Currently, fossil fuel is the major source of energy from which the commonly used fuel products like kerosene and cooking gas are obtained (Demirbas, 2007). But their non-renewability (Ulutaş, 2005) and the negative impact on our environment has become a global concern (Hill et al., 2006).

In recent years, Nigeria and other countries in the sub-Sahara have faced the problem of forest degradation as a result of increased fuel-wood consumption among other causes (Leach and Mearns, 2013). Out of the total energy demand in Nigeria, fuel-wood use accounts for about 37% (Oyedepo, 2014). Therefore, minimizing the use of fuel-wood will significantly reduce the pressure mounted on the

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forest in search of wood (Onuegbu et al., 2012). Subsequent utilization of waste biomass in developing countries occurs at poor level, despite the fact, that it has great potential in solid biofuel production (Brunerová et al., 2017). Apparently, agro-biomass are so common and easily accessible in Nigeria. These biomasses have high potentials as alternative sources of energy in the developing countries of the world (Patomsok, 2008). But the improper utilization of these resources and their abundance result in huge waste in rural, semi-urban and even in some urban communities of the world. The most common way of disposing such wastes is by burning. However, because of the adverse effects from the intrinsic properties during their combustion and other properties like low density, low calorific value per unit volume and moisture; direct burning of biomass is not a better solution (Birwatkar et al., 2014).

Corn cobs are one of the potential agricultural biomass materials for renewable energy industries to reduce the present energy problems and greenhouse gases (Jin and Wang, 2011). In Nigeria, Maize (*Zea mays*) is one of three major grain crops grown all over the states of the country with up to 5.3 million hectares of maize grown annually. Oladeji and Enweremadu (2012) reported that according to Federal Office of Statistics (FOS) on Agricultural Survey, Federal Ministry of Agriculture, in 2006, Nigeria was ranked the second largest producer of maize in Africa with about 7.5 million tons after South Africa Republic with 11.04 million tons. The corn cob is one of the major wastes generated from the corn/maize. After the grain is shelled from the maize and processed for food, the larger portion being the cob forms waste and thrown away thereby causing environmental challenges (Oladeji and Enweremadu, 2012).

Nigeria is abundantly endowed with plenty of orange plantations in different parts of the country. The orange peel is a good material for waste-to-energy conversion (Akpan, 2014). Figure 1 and 2 show orange wastes and corn cob wastes.

Briquetting or densification is the process which involves compaction of the biomass residue into a uniform solid fuel called briquettes. Production of briquettes from agro-waste can help fuel-wood users (particularly rural dwellers) access alternative source of energy at lower cost. The briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for variety of applications. Biomass transformed into briquette has higher density and energy content and less moisture compared to its raw form (Sriram et al., 2014).

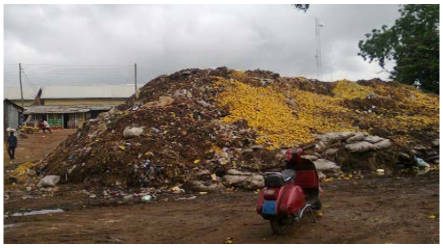


Figure 1 Orange wastes

Figure 2 Corn cob wastes

Many studies have been reported on the production of briquettes from various types of agricultural residue, including coconut shell, sugarcane bagasse and cassava rhizomes, coconut husks, sawdust, rice husks and coffee husks, soda weed and rice bran (Kongprasert et al., 2019; Krizan et al., 2018; Thabuot et al., 2015). Suitability of tropical waste biomass originating from production of rice (*Oryza sativa*), Date fruit (*Phoenix dactylifera L.*) and Jatropha fruit (*Jatropha curcas*) were studied, the study revealed that Jatropha fruit (*Jatropha curcas*) exhibited the highest net calorific value. Overall evaluation proved greatest suitability for Jatropha fruit waste (cake), followed by date fruit waste and lowest potential was determined for Rice waste (Brunerová et al., 2017). The Effect of densification variables on water resistance of corn cob briquettes was also reported, For the three processing parameters examined, binder ratio, particle size and pressure showed the most positive attributes (Onifade et al., 2019). Bamboo fibre and Sugarcane skin as Bio-briquette fuel has also been researched and documented in literature, the study revealed that all the observed values and factors influencing the investigated biomass proved that both waste biomass materials, bamboo fibre and sugarcane skin, can be used as a suitable feedstock materials for bio-briquette fuel production in which the produced bio-briquette samples can be used as high-quality fuel (Brunerová et al., 2018). However, there is no available information on composite briquette production from orange peels and corn cobs. Large volumes of orange peels and corn cobs are produced yearly and constitutes environment problems. Composite biomass solid fuels have been reported with higher energy value compared to using a single biomass as fuel. Therefore, the aim of this research is to produce and determine some solid fuel properties using orange peels and corn cobs mixed in ratios.

2 Materials and Method

2.1 Materials

The biomass materials used for this study were orange peels and corn cobs using cassava starch as the binder. The Orange Peels were collected from orange sellers around Chanchaga and Kasuwan Gwari Areas of Minna, Niger State, Nigeria while the corn cobs were picked from within Chanchaga Area of Minna, Niger State. The binder (cassava starch) was obtained from Kasuwan Gwari market also in Niger State.

2.2 Materials preparation

The orange peels and the corn cobs were sun-dried for five (5) days to reduce the moisture content for the ease of milling. They were milled using a local electrical milling machine available at FUT Minna mini market.

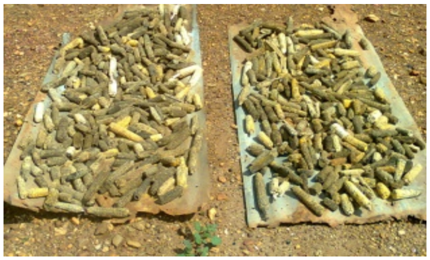


Figure 3 Drying of the corn cobs

Figure 4 Size reduction

Figure 5 Sun-drying of the orange peels

Figure 6 Milling

The grounded pieces were then sieved through a 2.36 mm ASEW 110055 made in China sieve (Orhevba et al., 2015). Eighty grams (80g) of the starch was weighed using digital weighing balance (OHAUS CORP AR3130 Model – Made in China) as 10% of the total weight of the sample (Orhevba et al. 2015; Oladeji et al., 2016) and mixed with 100 mL of water and stirred to soak and break the crumbs. 1000 mL of boiled water was then poured into the solution and stirred properly to homogenize the paste formed. Known weight of the mixed ratios (as shown in Table 1) were then gradually poured into the starch paste and stirred properly until the mixture becomes very saturated and suitable for compaction in the briquetting machine as reported by Jittabut (2015).

Table 1 Briquette formulation (All formulations were Orange peels: Corn cobs)

Materials	Sample A 20:80	Sample B 80:20	Sample C 50:50
Moisture Content (%)	11.62±0.3	10.81±0.8	11.89±0.1
Starch (g)	80	80	80
Water (mL)	1000	1000	1000
Quantity added (g)	650	700	800

Figure 7 Preparation of the binder

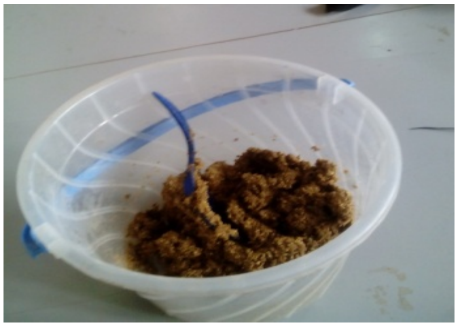


Figure 8 Preparation of sample mixture with binder

Figure 9 Ejection of the produced solid fuel

2.3 Production of the briquette

The process of making a briquette is by mixing the material with binder or adhesive (Sutrisno et al., 2006). The mixtures of the different ratios were fed into the cylindrical moulds (46 mm in diameter and height of 85 mm) of the manually operated hydraulic jack briquetting machine in different batches respectively. The lid of the briquetting machine was then firmly tightened and the handle of the hydraulic jack with a pressure rating of 2175 psi (Pounds per Square inch) was jacked up to compress the sample inside the moulds. The lid was loosened, and the formed briquettes were ejected. The procedure was repeated, and four sets of briquettes were produced from the machine for each round. The weight of the produced briquettes was taken and recorded for each sample using the OHAUS CORP AR3130 Made in China digital weighing balance. The produced briquettes were transferred to a SEARCTECH DG-9101-2SA made in China dry oven and were oven-dried at 105°C for 24 hours and the weight was taken again, and then stored (Orhevba et al., 2015).

2.4 Characterization of the solid fuel produced

2.4.1 Physical properties of the briquettes

The physical property of a material refers to the physical attributes of that material. In determining the physical properties of the briquettes, ten briquettes were chosen randomly from each production group for the determination. The mass was obtained by weighing the briquettes using OHAUS CORP AR3130 Made in China digital weighing balance (Efoma and Gbabo, 2015).

2.4.2 Determination of density of the briquettes

The density of a material is defined as the mass per unit volume of that material. (Akpan, 2014) The density of the briquette was determined by using Equation 1.

$$\rho = \frac{m}{v} \tag{1}$$

Where, ρ = density of the material (kg m^{-3})

M = mass of the material (kg)

V = volume of the material (m^3)

The average maximum density of the briquettes was determined by taking the mass immediately after ejecting them from the mould (Aliyu et al., 2017; Efoma and Gbabo, 2015).

2.4.3 Determination of the mass of the briquette

The mass of the briquette was determined by weighing the briquette on a digital weighing balance (OHAUS CORP AR3130 Model – Made in China), immediately after ejection from the machine and the average weight taken and weighing after oven drying at 105°C for 24 hours (Orhevba et al., 2015).

2.4.4 Determination of the volume of the briquette

The volume was determined by taking the dimensions of the cylindrical briquettes (i.e. the radius and the height respectively) and by applying the formula for the volume of a cylinder in equation 2.62 to obtain the volume of the produced briquette (Aliyu et al., 2017; Efoma and Gbabo, 2015).

$$\mathrm{V} = \pi R^2 H \tag{2}$$

The radius was obtained by measuring the diameter using venire calliper then applying theoretical formula for radius in Equation 3.

$$R = \frac{D}{2} \tag{3}$$

Where D is the diameter and R is the radius and H is the height all in mm

2.5 Proximate analysis of briquette

2.5.1 Moisture content of the briquette

The moisture content was determined by pulverizing 1g of the dried sample of the briquettes into a crucible and placed inside an electric oven set at 105°C for 24 hours. It was then removed with the aid of tong and placed immediately in the desiccators to cool. The weight was then taken using OHAUS CORP AR3130 Model – Made in China, digital weighing balance (Sanger et al., 2011). The procedure was repeated for all the samples and the moisture content was calculated using Equation 4.

$$\text{Moisture content (\% wb)} = \frac{w_2 - w_3}{w_2 - w_1} \times 100 \tag{4}$$

Where,

w_1 = weight of crucible, (g)

w_2 = weight of crucible with the sample before heating (g)

w_3 = weight of crucible with the sample after heating (g)

2.5.2 Volatile matter of the briquette

The volatile matter of the briquettes was determined by pulverizing 1 g of dried sample in a crucible, covered and oven-dried until a constant weight was attained. It was then heated in a 'GALLENKAMP S2-OG1105 made in England' muffle furnace at 600°C for 6 minutes then at 900°C for another 6 minutes based on ASTM-3275. The difference in the weight as a result of loss of volatile matter was taken as the total volatile matter in the sample on percentage basis (Sanger et al., 2011).

$$\text{Volatile matter (\%)} = \frac{w_3 - w_4}{w_2 - w_1} \times 100 \tag{5}$$

Where,

W_1 = weight of the crucible (g)

W_2 = weight of crucible with the sample before oven drying (g)

W_3 = weight of crucible with the sample after oven drying (g)

W_4 = weight of crucible with the sample after heating in muffle furnace (g)

2.5.3 Ash content of the briquette

The ash content was determined by pulverizing 1 g of dried sample of the briquettes into a crucible and heat without lid in a 'GALLENKAMP S2-OG1105' muffle furnace at 750°C for 90 minutes. The crucible was taken out and placed in a desiccator for cooling. The sample was then weighed. The procedure was repeated until a constant weight was attained. Based on ASTMD-3174, the residue was reported as the ash content on percentage-basis (Sanger et al., 2011).

$$\text{Ash content, (\%)} = \frac{w_3 - w_4}{w_2 - w_1} \times 100 \tag{6}$$

Where,

W_1 = weight of the crucible (g)

W_2 = weight of crucible with the sample before oven drying (g)

W_3 = weight of crucible with the sample after oven drying (g)

W_4 = weight of crucible with the sample after heating in muffle furnace (g)

2.5.4 Fixed carbon of the briquette

The percentage of fixed carbon in a material was determined by subtracting the sum of moisture content, volatile matter and the ash content of the material from 100% (Sanger et al., 2011).

Fixed carbon(%)=100-% of moisture content+% of ash+% of volatile matter (7)

2.5.5 Calorific value of the briquette

The calorific values of the fuel briquettes were determined by the ASTM-3174 standard procedure as reported by Sanger et al. (2011).

$$\text{Calorific value (\%)} = 2.326(147.6\ FC + 144\ VM) \qquad (8)$$

Where,

FC = Percentage fixed carbon (%)

VM = Percentage Volatile matter (%)

2.6 Ultimate analysis of briquette

2.6.1 Carbon content of the briquettes

The carbon content was determined by using Equation 9 as reported by Sanger et al. (2011).

$$\text{Carbon content (\%)} = [(0.97FC) + 0.7(VM - 0.1) - M(0.6 - 0.01)] \qquad (9)$$

Where,

FC = percentage fixed carbon content (%)

VM = percentage volatile matter and (%)

M = percentage moisture content (%)

2.6.2 Hydrogen content of the briquettes

The hydrogen contents of the samples were determined using Equation 10 as reported by Oladeji (2012).

$$\text{Hydrogen Content (\%)} = [(0.036\ FC) + 0.086\ (VM - 0.1\ A) - (0.0035\ M^2)\ (1 - 0.02\ M)] \qquad (10)$$

Where,

FC = percentage fixed carbon content (%)

VM = percentage volatile matter (%)

A = percentage ash content and (%)

M = percentage moisture content (%)

2.6.3 Nitrogen Content of the briquettes

The nitrogen content was determined using Equation 11 as reported by Oladeji (2012).

$$\text{Nitrogen Content (\%)} = 2.10 - 0.020\ VM \qquad (11)$$

Where,

VM = percentage of Volatile Matter (%)

2.6.4 Oxygen content of the briquettes

The oxygen content was determined using Equation 12 as reported by Oladeji (2012).

$$\text{Oxygen Content (\%)} = 100 - (C + H + N + A) \qquad (12)$$

Where,

C = Carbon content (%)

H = Hydrogen content (%)

N = Nitrogen content (%) and

A = Ash content (%)

2.6.5 Sulphur content of the briquettes

The sulphur contents were determined by igniting 1g of the samples and two portions of calcium and magnesium oxide with the other portion in an anhydrous sodium carbonate. The sulphur was then dissolved in water and precipitated as barium sulphate. The precipitate was then filtered, and the ash content of the precipitate was determined and weighed. The sulphur content was then calculated using Equation 13 as reported by (Oladeji, 2010)

$$\text{Sulphur content (\%)} = \frac{A - B}{C} \times 13.74 \qquad (13)$$

Where A = mass of barium sulphate from sample (g)

B = mass of barium sulphate from blank (g)

C = mass of the sample used (g)

2.7 Ignition Time

The ignition time was determined by igniting the briquettes on a Bunsen burner by setting by the edges of the briquettes under a steady flame from the burner (Adekunle et al., 2015). The time it takes for each sample to ignite and sustain combustion was recorded with the aid of a stopwatch. This was done for a second time to obtain a replicate result and the average time was taken as reported by Davies et al. (2013) and Sutrisno et al. (2017).

2.8 Water boiling test

The water boiling test was performed by using 90 g of each sample of the produced briquettes in a briquette stove to boil 350 mL of water and the time it takes for each sample to boil the water with the aid of a stop watch was recorded as reported by Davies et al. (2013).

3 Results and discussion

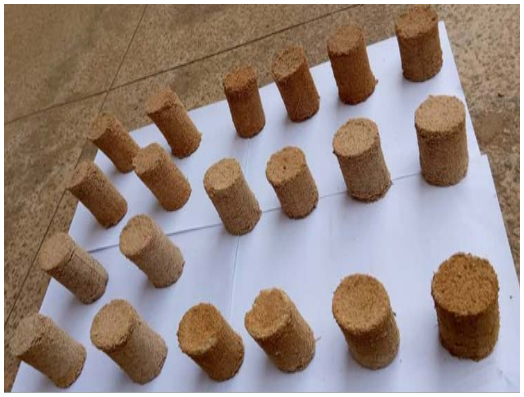
3.1 Results of the physical properties of the solid fuel

The physical properties of the produced briquettes are shown in Table 2.

Table 2 Results of physical properties of the briquettes

S/N	Parameters	Sample A	Sample B	Sample C
1	Height (mm)	80.30±0.05	71.92±0.08	66.98±0.03
2	Diameter (mm)	45.73±0.04	42.43±0.02	40.86±0.07
3	Mass (kg)	0.036±0.01	0.055±0.03	0.038±0.04
4	Volume (m^3)	120.91±0.02	121.71±0.01	120.84±0.01
5	Density (kg m^{-3}) x10^{-3}	0.28±0.05	0.54±0.02	0.44±0.03

Note: Sample A = 20:80; B = 80:20; C = 50:50 Orange peels to corn cobs respectively.



Samples ejected from the mould

Figure 10 Samples of the produced solid fuels before drying

Sample A
Orange peel: 20 %
Corn cob: 80 %

Sample B
Orange peel: 80 %
Corn cob: 20 %

Sample C
Orange peel: 50 %
Corn cob: 50 %

Figure 11 Samples A, B and C of the produced solid fuels after drying

From the result of the physical properties of the briquette shown in Table 2, the relatively short height and the diameter of the briquette samples implies that they can easily be packaged and transported when compared to the raw form of the biomass. This also applies to the mass and the low density of the briquettes. The low volume of the samples implies they will occupy little space which will ease transportation and storage when compared to fuel-wood as reported by Oladeji et al. (2012).

3.2 Results of the proximate analysis of the samples

The result of proximate analysis of the samples are shown in Table 3.

Table 3 Results of the proximate analysis of the three samples

S/N	Parameters	Sample A	Sample B	Sample C
1	Moisture Content (%)	4.64±0.05	4.19±0.01	5.28±0.02
2	Volatile Matter (%)	4.05±0.03	0.76±0.08	4.77±0.01
3	Ash Content (%)	2.39±0.09	4.64±0.07	3.92±0.05
4	Fixed Carbon (%)	88.93±0.02	90.42±0.04	86.05±0.09
5	Calorific Value (kcal kg^{-1})	31886.04±0.09	31295.62±0.06	31136.77±0.02

Note: Sample A = 20:80; B = 80:20; C = 50:50 Orange peels to corn cobs respectively.

Proximate analysis is a way of analysing the moisture content, volatile matter, fixed carbon and the ash content of a solid fuel (Prasityousil and Muenjina, 2013). The fuel quality of briquettes is affected by important properties such as their physical and chemical attributes. For proper utilization of biomass residue as household and industrial fuel, they must be characterized. Comparison of burning characteristics and some chemical elements in biomass materials show that the composition of samples varies considerably (Mitchual et al., 2014). In general, biomass has proximate analysis of 80% volatile matter and 20% fixed carbon (moisture free and ash free basis), whereas bituminous coal has 70% to 80% fixed carbon with 20% to 30% volatile matter (Maciejewska et al., 2006).

Moisture content is one of the most important properties that influences the burning rate of biomass (Yang et al., 2005). The moisture content greatly affects the results of the proximate analysis of the material's composition. Decrease in moisture content of briquettes, affects the flame speed of the briquette, low moisture content in a briquette enhances faster ignition of the briquette (Sutrisno et al., 2017; Yang et al., 2009). Biomass usually contains high moisture content leading to a relatively low calorific value of the fuel. The moisture content of biomass influences its combustion properties. Higher moisture content will reduce the combustion temperature and increase the residence time in a burning chamber. Consequently, this could lead to partial combustion and increases the volume of flue gas produced per energy unit (Maciejewska et al., 2006). According to ASTM-3173, loss in weight implies the amount of moisture (in percentage) in the materials (Sanger et al., 2011). The results of the proximate analysis on dry basis (Table 3) showed sample C present the highest moisture content of 5.28% while sample A and B had 4.64%, 4.19% respectively.

The volatile matter is the substance released by the material either as gas or vapour during combustion (Rezania et al., 2015). The thermal behaviour of solid fuels can be affected by the volatile matter present in it. Volatile matter of a material is the quantity of organic matter present in that material. Biomasses with higher amount of volatile matter have less fixed carbon contents. Volatile matter contents in a material enhances its ease of ignition but releases smoky flame because of the presence of combustible gases such as methane and other volatile hydrocarbons (Thabuot et al., 2015).

Volatile matter of a material is the quantity of organic matter present in that material. Biomass with higher amount of volatile matter have less fixed carbon contents. Volatile matter contents in a material enhances its ease of ignition but releases smoky flame because of the presence of combustible gases such as methane and other volatile hydrocarbons (Thabuot et al., 2015). The results in Table 3 showed that the volatile matters of the samples were relatively low with sample C (50:50; OP:CC) having the highest value of 4.77% followed by sample A, while sample B had the lowest volatile matter of 0.76%. These however, deviate from the 70% - 80% volatile matter of biomass briquettes reported by Maciejewska et al. (2006). This also deviates from the 97.82% recorded for corn cob by Thabuot et al. (2015). Meanwhile, materials with high volatile matter releases smoky flame as reported by Thabuot et al. (2015). The low volatile matter in these briquettes implied that the produced briquettes would release less smoke which might be due to the presence of the orange peels since sample B (08:20; OP:CC) with a higher proportion of orange peels had the least volatile matter of 0.76% and previous works have shown high volatile matters in corn cobs. This was followed by sample A and then C in ascending order of their smoke releasing tendency. When compared with fuel-wood, this is a good characteristic of the produced briquettes which will minimize the health hazard caused by high smoke or fuel-wood as reported by Onuegbu et al. (2012). Biomass with higher amount of volatile matter have less fixed carbon contents (Thabuot et al., 2015). This conforms to the high amount of fixed carbon recorded as shown in Table 3.

A typical biomass has less ash content than coal and their composition is based on the chemical components required for plant growth, whereas the ash content in coal reveals the composition of mineral in it. In both coal and biomass, ash-forming matter can be present in four general forms: easily leachable salts, inorganic elements associated with the organic matter of the biomass, minerals included in the fuel structure and inorganic material - typically sand, salt or clay. Alkaline metals that are usually responsible for fouling of heat transfer surfaces are high in biomass ashes and are released in the gas phase during combustion. Ash contents of different biomass fuels can differ extensively

(Huang et al., 2013). Straw and other herbaceous fuels like grass usually have more ash contents than wood because they use relatively more nutrients during growth (Maciejewska et al., 2006). The ash content of a material is the quantity of substance left after the complete combustion of that material. It shows the slagging behaviour of the material during burning. Slagging simply refers to formation of molten or partially fused deposits on furnace walls or convection surfaces exposed to radiant heat. The more the amount of ash content in biomass the higher its slagging behaviour. Low amount of ash in a material could lead to the high heating value of that material (Thabuot et al., 2015). Ash has a significant control on the transmission of heat to the surface of a fuel and the distribution of oxygen to the fuel surface during burning of char. Since ash is a non-combustible impurity in a material, fuels that have low quantity of ash are more suitable for thermal utilization than fuels with high ash content. More ash content in a fuel usually results to more dust emissions and influences its burning rate and efficiency (Deepak and Jnanesh, 2015). From the results in Table 3, sample B (80:20; OP:CC) has the highest quantity of ash content of 4.64% followed by sample C with 3.92%, while sample A has the least ash content among the three samples with 2.39% ash content. Meanwhile, these values are higher than the 0.14% reported for corn cobs briquette by Thabuot et al. (2015).

Fixed carbon of a material is the quantity of carbon contents present in the material (Thabuot et al., 2015). When there is more quantity of fixed carbon in a biomass the calorific heating value of the biomass increases (Thabuot et al., 2015). From the result in Table 3, sample B (80:20; OP:CC) recorded the highest fixed carbon content of 90.42% followed by Sample A with 88.93% while sample C has the lowest with 86.05% fixed carbon. These values were much greater than the 1.41% for only corn cobs reported by Thabuot et al. (2015), this showed that the addition of orange peels had led to the significant increase in the calorific values.

The calorific heating value is the quantity of energy for each kilogram given off during its combustion (Ciriminna et al., 2014). The calorific value in a material can be affected by the amount of fixed carbon in that material. There are different factors that influence the calorific value of a briquette. These factors include the ambient conditions, the compressing machine and the quantity of inorganic matter in the biomass. The amount of the calorific value can be used as the competitive decision on the fuel potential. The calorific values obtained showed that sample A has the highest calorific value of 31886.04 kcal kg^{-1}, followed by sample B with 31295.62 kcal kg^{-1} while sample C has the least calorific value among the samples with 32236.77 kcal kg^{-1}. These values are in close agreement with calorific values of 32242.88 kcal kg^{-1} and 30161.20 kcal kg^{-1} corn cobs and rice husk briquette reported by Orhevba et al. (2015) and 3113.15 kcal kg^{-1} of areca leaves briquette (Deepak and Jnanesh, 2015).

3.3 Results of the ultimate analysis of the samples

The results of the ultimate analysis of the samples are shown in Table 4.

Table 4 Results of the ultimate analysis of the three samples

S/N	Parameters	Sample A	Sample B	Sample C
1	Carbon Contents (%)	86.29	85.57	83.67
2	Hydrogen Contents (%)	6.29	3.57	3.39
3	Oxygen Contents (%)	10.64	8.42	5.28
4	Nitrogen Contents (%)	2.02	2.08	2.01
5	Sulphur Contents (%)	0.11	0.34	0.28

Note: Sample A = 20:80; B = 80:20; C = 50:50 Orange peels to corn cobs respectively.

The ultimate analysis is the evaluation of the important chemical elements that constitutes the biomass. These are carbon, hydrogen, oxygen, nitrogen and sulphur (Jittabut, 2015). The ultimate or elemental analysis gives the mass concentrations of the main elements such as carbon, oxygen, hydrogen, nitrogen and sulphur in the sample. The standard is stipulated in EN15104: 2011 as the European standard for solid biofuels. The ultimate analysis of a material can be estimated by some mathematical formulae reported in literature, using the values obtained from proximate analysis (Sanger et al., 2011).

The most significant elements in combustion are the elements of carbon and hydrogen. During the chemical reaction, the carbon elements react to produce CO_2 which is the combustion product given off into the surrounding air after the combustion process. The results of the ultimate analysis in Table 4 showed high contents of carbon which implies that the briquette will burn efficiently (Sutrisno et al., 2017).

The oxygen element in the fuel aids its ease of ignition. The result of the oxygen content implies that sample C will burn with ease. Nitrogen and sulphur are the elements in a material which causes pollution during combustion. These elements react with the surrounding air to produce the harmful NO_x and SO_x oxides (Sutrisno et al., 2017). Thailand Industrial Standards Institute specified that the sulphur content of solid fuel briquettes should not exceed 5% by weigh as reported by Prasityousil and Muenjina (2013). The low sulphur and nitrogen content in the briquettes implied that the solid fuel will be environmentally friendly during combustion (Rezania et al., 2015)

3.4 Results for the Ignition Time

The results of the ignition time are shown in Table 5.

Table 5 Result for the Ignition Time

S/N	Sample	Ignition Time (Minutes)
1	A	3.58±0.91
2	B	5.35±0.75
3	C	4.56±0.32

Note: Sample A = 20:80; B = 80:20; C = 50:50 Orange peels to corn cobs respectively.

The result of the ignition time shows that sample A has the shortest ignition time which implies that the sample will ignite fastest among the produced briquettes.

3.5 Result for the water-boiling test

The results of the water boiling test for the produced solid fuel are shown in Table 6.

Table 6 Water Boiling Test Results

S/N	Sample	Mass Used (g)	Volume of Water (mL)	Time Taken to Boil (Minutes)
1	A	90	350	8.20±0.54
2	B	90	350	14.28±0.82
3	C	90	350	12.51±0.27

The water boiling test was performed to compare the cooking efficiency of the briquettes. It measures the time taken for each briquette to boil an equal volume of water under similar condition (Ikelle and Ivoms, 2014).

The result of the water boiling test in Table 6 shows that sample A has the shortest water boiling time of eight (8.20±0.5) minutes which implies that the solid fuel sample boils water faster than the other samples while sample B took the longest time (14.28±0.8) for the same volume of water used.

3 Conclusion

This investigation has shown that briquettes can effectively be produced from biomass composite of orange peels and corn cobs. Assessment of the observed results revealed the suitability of the composite biomass materials for heating purposes, thus, proved their suitability for solid fuel formulation. From the results of the proximate and ultimate analysis, the mixtures made up of 20% orange peels and 80% corn cobs have the highest calorific values as well as the carbon content which are the most desirable qualities of a good solid fuel. Meanwhile, 80% orange peels and 20% corn cobs have shown some promising qualities as a good briquette. This has shown that agro-waste composite of orange peels and corn cobs can produce a good solid fuel that can serve as an alternative source of fuel for sustainable bio-energy production and application. The production process was also economical due to low energy input and can also be applied effectively in rural areas where there is little or no electrical power supply. Commercial production of this solid fuel will also aid environmental sanitation and save cost of procuring fossil fuel for heat energy applications.

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