Physicochemical Characteristics of Biomass Briquette Derived from Orange Rind

Madu, P.C[1] Lajide, L[2]
1.Department of Chemistry, Nasarawa State University, Keffi. Nigeria.
2.Department of Chemistry, Federal University of Technology, Akure. Nigeria

Abstract
The present high cost of modern cooking fuels coupled with the challenge of its non-widespread distribution has resulted to a shift in the utilization of biomass residues as an alternative cooking fuels in most developing nations of the world. The major attraction therefore is the replacement of fire-woods and charcoals currently utilized in most rural communities with a more sustainable energy sources such as briquettes. Biomass briquettes made from solid agricultural wastes are being promoted as a better alternative for firewood and charcoal for heating, cooking and other industrial applications in both urban and rural communities. In this research, orange briquettes were produced from orange rind using local technology. Orange rind was generated from the peeled orange fruit after removing the inner fleshy part. The rind was dried and blended into powder using an electric blender. The orange rind and fresh banana peel was blended together in the ratios of 2:1 and 2:4. Four different briquettes were produced based on the ratios using locally fabricated mould and a wooden slab as the press. Physicochemical characteristics of the formed briquette was investigated. The results on the physicochemical properties of the briquettes showed that quality briquettes were produced from the orange rind with fresh banana peel as the binder. The compressed density and the durability rating of the briquettes were significantly influenced ($P<0.05$) when the binding type and binding ratio were varied. Considering the raw materials involved, the briquette was produced from a 100% recycled wastes making it an environmentally friendly product. This study therefore offers an alternative for a better utilization of orange rind biomass for value-added products.
Keywords: biomass, orange briquettes, binder, physicochemical properties value-added product.

1. INTRODUCTION

In both the rural and urban communities of Nigeria, firewood and charcoal has been the most dominant source of energy for cooking and many other heating applications. They are also the major source of renewable energy for many other developing countries of the world (Emerhi, 2011.). The continued utilization of firewood and charcoal as well as fossil fuels for energy have come with environmental related issues such as climatic change and this has become a big challenge to scientist worldwide. This therefore has called for the need for an independent energy supply to sustain economic growth. This drive has lead to the use of biomass energy from wastes of agricultural origin that provides a renewable source of fuel. Biomass represents the fraction of products, waste and residue from agriculture, forestry as well as fractions of industries and household waste which are biodegradable (Patel and Gami, 2012). It is one of the most common and easily accessible renewable energy resources and presents a great opportunity as feedstock for bioenergy (Phonphuak & Thiansem, 2012; Rabier *et al*. 2006; Mckendry, 2002.). The idea of utilizing the wastes from agricultural sector either as primary or secondary energy resources is considerably attractive. This is because they are available and abundant. Among the several kinds of biomass resources, agricultural residues/wastes-sawdust, rice husk, corn stover, cotton stalk, groundnut husk, beans husk etc. have become one of the most promising choices as cooking fuels due to their availability in substantial quantities as wastes annually. However, majority of the biomass residues are not appropriate to be used directly as fuel without further processing and this is quite challenging. This could be attributed to their low energy density per volume, sporadic burning, high moisture content and excessive amount of smoke they generate (Amaya *et al*. 2007). All these characteristics make it difficult to handle, store, transport and utilize the biomass residues in their raw form. Recent researches have therefore been geared towards the efficient utilization of these biomass. One of the methods of improving the thermal value of such biomass is the application of briquetting technology (Suhartini, *et al.* 2011; Wilaipon, 2007.). This technology converts the waste biomass into solid briquettes with high density.

In this work, orange rind is used as the sample for conversion into bio-briquette. Orange rind is the chosen material in our proposal than other biomasses because it is available abundantly at no or low costs, it therefore has a potential to provide a low cost briquette for the rural populace. The orange rind do not have any immediate use for man and the only means available for its disposal is by burning or sometimes by dumping them indiscriminately around the environment. Such practices constitutes environmental problems. Converting the orange rind to briquette will not only add value to it but also serve as a way of cleaning the environment as there will be no need for their indiscriminate disposal. Briquetting technology as earlier stated entails the densification of the loose biomass to produce fuel briquettes which has better handling characteristics and enhanced volumetric caloric value (Oladeji, 2010.) compared to the biomass in its original state. There have been reports of improvement of heating value of biomasses demonstrated when they are compressed to a relatively high density with or without binder (Madu & Lajide, 2013, Frank & Akhihiro, 2013, Oyelaran, et al., 2014). It is expected that briquetting of the orange rind will help in improving the energy value thereby increasing the option for domestic fuel supply in the savannah region where this waste is abundant and cheap (Sotannde *et al.,* 2008). Recent researches conducted on agricultural waste biomasses have shown that high quality solid briquettes can be produced from banana peels called banachakol (www.farmradio.org/english/radio-scripts/76-5 scipt-en.asp), neem wood residues with gum Arabic and starch as binders (Sotannde *et al.,* 2010), water hyacent-dung admixture (Frank & Akhihiro, 2013), melon seed husk and fresh banana peels (Madu & Lajide, 2013), groundnut shell Oyelaran, et al., 2014). The production of briquettes from orange rind therefore exemplifies the potential of appropriate technology for the utilization of biomass residues which is abundant in large quantities in this part of the world. Successful briquette operations have been possible in most developed countries. This cannot be said to be the same with the developing countries where briquette production have not been fully adopted due to high cost of production, lack of awareness on its sustainability, lack of ready market and poor packaging and distribution system for the product (Emerhi, 2011.). Apart from tackling the production and marketing problems, there is the need to investigate the physicochemical characteristics of the briquettes if they are to be used efficiently as fuel. This study therefore was inspired to develop indigenous environmentally friendly processes for the production of bio-briquettes from orange rind using fresh banana peel as the binder and the determination of the physicochemical characteristics of the formed briquettes. The orange briquette in this research is therefore produced from a 100% recycled waste thereby making it an environmentally friendly product. This research hence offers an alternative for a better utilization of orange rind biomass for value-added products besides achieving zero waste strategies of the environment.

2. MATERIALS AND METHODS

Collection and preparation of samples

Mature and ripe oranges were purchased from Keffi central market in Nasarawa state Nigeria. The oranges were peeled with table knife to expose the inner white covering containing the orange juice. After squeezing out the juice, the inner fleshy parts were removed leaving only the white cover which is the rind. The rind was washed severally with water, sun-dried and crushed in a mortar to reduce to particle size. The rind was further blended into powder using Keenwood electric blender. The powder sample was kept in air-tight container prior to analysis. All reagents used were of analytical grade from BDH.

Briquette Production

Three different types of moulds were sourced locally and was used for the briquette production. One type mould was cut from a PVC pipe of capacity 60cm^3 measuring 5.9cm (height) x 3.6cm (diameter). The other type of mould was a 44cm^3 capacity crucible measuring 3cm (height) × 4.3cm (diameter), while the third type of mould was a 71cm^3 capacity metal container measuring 3.9cm (height) × 4.8cm (diameter). The press used consisted of a wooden slab on which the briquette is pressed. Fresh banana peel was first made into a paste by blending using an electric blender and this was used as the binder for all briquette productions. Orange rind briquette was formed by thoroughly blending the orange rind powder with fresh banana paste to give a uniform mixture in a ratio of 8:1. The blended mixture was transferred into the mould. This was covered with the wooden slab and was hand-pressed for 8 to 10 minutes. The orange rind briquette produced at the end of 10 minutes was then removed from the mould, sun-dried and was kept for further analyses. The experiment was repeated by varying the orange rind powder with fresh banana paste in the ratios of 4:1 and 2:1 to obtain the second and third types of orange rind briquettes, respectively. The above procedures were repeated using starch instead of fresh banana paste as binder to give another set of orange rind briquettes. In all about eighteen (18) briquettes were produced per batch.

3. Physical Characteristics of the Briquette

The physical characteristics analysed include relaxed density, relaxation ratio, compressed density as well as dimensional stability. These were determined in accordance with method described by Olorunnisola (2007) with slight modifications.

Compressed Density

Compressed density was determined immediately after the removal of the briquette from the mould and three briquettes were randomly selected from each production batch for this test. The volume and mass of the mould were determined. Briquette was formed in the pre-weighed (X g) mould. The formed briquette and mould was weighed (Z g) immediately after formation and the difference in weight (Z – X = Y) gave the actual weight of the briquette. The mean compressed density was determined as a ratio of mass (g) over volume (cm^3).

Relaxed Density and Relaxation Ratio

The relaxed density and relaxation ratio were determined after 19 days of sun-drying at room temperature and relative humidity. At the end of 19 days, the weight of the dried briquette was measured. The relaxed density of the briquette was then calculated as a ratio of mass of obtained after 19 days of drying over volume. The relaxation ratio of the briquette was obtained as a ratio of compressed density over relaxed density as given by the equation below:

$$Relaxation\ ratio = \frac{Compressed\ density}{Relaxed\ density}$$

Durability Rating

The durability of the briquettes was determined in accordance with the Chartered Index described by Suparin *et al.* (2008). The briquette sample was dropped repeatedly from a height of 1.5 m onto a metal base. The fraction of the briquette that remained un-shattered was used as an index of briquette durability in percentage. The durability rating was computed using the equation below:

$$Durability\ (\%) = \frac{Weight\ of\ briquette\ before\ shatering\ (kg)}{Weight\ of\ briquette\ after\ shattering (kg)}$$

Combustion Properties of the Briquettes

The combustion properties which included percentage volatile matter, fixed carbon and ash contents of representative samples were determined based on ASTM standard E711 – 87 (2004), while the heating value was determined by Gouthal formula;

HV = 2.326 (147.6FC + 144V) (Aruofor, 2000)

Volatile Matter

Volatile matter was determined by weighing 1g of the briquette into a crucible of known mass and oven-dried at a temperature of 90^0C to constant mass, after which it was heated in the furnace at temperature of 600^oC for 10 min. The volatile matter was then expressed as the percentage loss in mass to the oven-dried mass of the sample.

Ash Content

The percentage ash content followed the same procedure as volatile matter, except that the sample was heated in the furnace for 3h.

Fixed Carbon

The percentage fixed carbon was calculated using the equation below.

FC = 100 – (V+A) (Akpan, 2007).

Where FC (%) = fixed carbon

V (%) = volatile matter

A (%) = ash content. The heating value (HV) ($mJkg^{-1}$) was calculated by using the equation stated below.

HV = 2.326 (147.6FC + 144V) (Aruofor, 2000)

4. RESULTS AND DISCUSSION

Briquette Formation and Characterization

The result of the physical characteristics of the orange rind briquettes for their compressed density, relaxed density, the relaxation ratios and durability rating is presented in Table 1. While Table 2 is the result for the combustion properties (volatile matter, ash content, fixed carbon as well as the heating value) of the briquettes. The data were further analysed using one way analysis of variance aided with SPSS software. The statistical calculations reported included: mean, standard deviation. Duncan multiple range taste was used for means separation at p = 0.05 (*Opeolu et al.* 2008).

Effect of binder type and blending ratio on the physical characteristics of briquettes

The physical parameter values for the fresh banana paste bonded orange rind briquettes is presented in Table 1. The values obtained for this set of briquettes compared favourably with those formed using starch as the binder. For instance, using banana paste as the binder the average compressed density and durability rating were 0.92 g/cm^3 and 93.95% respectively, while using starch as the binder for the same briquettes, the values were 1.16 g/cm^3 and 95.57%, respectively. This closely related values obtained in this work indicates that the bonding in the briquette materials is strong leading to higher durability rating. Briquetting using fresh banana paste as the binder is a deviation from the conventional use of either starch or gum Arabic as in briquette from Neem wood residues (Sotannde *et al.*, 2010), or other chemicals to achieve the same purpose. The attraction here is that the briquette is produced from 100% recycled waste thereby making it an environmentally friendly product. The result (Table 1) also revealed that both the binder type and the blending ratio significantly influenced the compressed density as well as the relax density of the briquettes (P<0.05) while the durability rating was not significantly influenced (P>0.05). The compressed density which is density immediately after compression and the relaxed density which is the density after 19 days of sun drying the briquette are important parameters for characterizing briquettes (Sotannde *et al*., 2010, Frank & Akhihiro, 2013, Oyelaran, et al., 2014). The banana paste bonded briquette had average compressed density of 0.92 g/cm^3 and relaxed density of 0.52 g/cm^3 for the melon briquettes.

On the other hand, for the starch bonded briquettes the observed compressed and relaxed density were 1.16 g/cm^3 and 0.38 gcm^3 for the orange briquettes. This gave the relaxation ratio of values of 1.81; 3.06; respectively for the two sets of briquette type. It was also observed that starch bonded briquettes compressed better at 1.16 g/cm^3 than fresh banana bonded briquettes at 0.38 g/cm^3, and this was also reflected in their relaxation ratios of 1.81 and 3.06, respectively. These values however are higher than those obtained by Sotannde *et a*l. (2010) at 0.506 g/cm^3 and 0.640 g/cm^3 compressed density for starch and gum Arabic bonded charcoal briquettes from Neem wood residues.

It was observed that the optimum compressed density and relaxed density for the two briquette types were obtained when the blending ratio (biomass-binder) was 2:1 by mass. This is clearly evident in the least relaxation ratio obtained at this level. This that both fresh banana paste and starch binders employed in this work gave a relatively stable and briquettes. Similar trends have been reported in briquette with a biobinder (Ivanov *et a*l., 2003), briquette with gum Arabic and starch binders (Sotannde *et al.,* 2010), briquette with starch binder (Jindaporn *et al.,* 2005), fuel briquette from waste paper and coconut husk admixture (Olorunnisola, 2007) and melon seed husk briquettes with fresh banana peels and starch (Madu & Lajide, 2013). When the durability rating of the briquettes was considered, it was observed that both the type of binder used and the blending ratio did not influence the durability rating of the briquettes (P>0.05). Durability rating of 95.57% obtained in the starch bonded briquettes was slightly higher than 93.95% obtained in fresh banana paste bonded briquettes (Table 1). These values are higher (88.4%) than that obtained by Wamukonya and Jenkins (1995) for sawdust and wheat straw briquettes. It is expected that starch bonded briquettes will withstand mechanical handling better than fresh banana bonded briquette. The reason for this might be because starch bonded briquettes compressed better than fresh banana bonded briquettes, as exemplified by higher mass per volume and higher relaxed density. The durability rating also increased with increased in binder fraction of the briquettes when the blending ratio was varied. Therefore, it can be stated that the durability of a briquette is a function of compressed density as well as the variation in the binder ratios (Hussain *et al.,* 2002; Wilaipon, 2007). Increase in compressed density and binder level enhances durability while moisture content reduces it (Olorunnisola, 2007).

Effect of binder type and blending ratio on the combustion properties of briquettes

The result of the combustion properties of the briquettes is presented in Table 2. The blending ratio significantly influenced the volatile matter of the orange briquettes produced (P<0.05) while the binder type did not (P>0.05). The average percentage volatile matter in starch bonded briquettes was higher than that for banana bonded types. For the starch bonded briquettes volatile matter increased from 6.55 to 7.99% , while the increased was from 6.19 to 8.11% for the banana bonded types. The values obtained in this work, were lower than those from Sotannde *et al.* (2010) at a range of 10.00 to 13.00% for briquettes produced from neem wood residues bonded with starch and gum Arabic. The is also lower than the values obtained (9.0 to 25.8%) in carbonizate produced from Velenje lignite at varying temperature (Zapusek *et al*., 2003). Having low values of volatile matter as obtained in this work may indicate that the briquettes might not be easy to ignite, but once ignited they will burn smoothly with clean flame with little or no smoke. Fuels related to smokeless grade are known to contain no more than 20% volatile substances (Ivanov *et al.,* 2003). While fuels containing large amounts of volatile matter are characterized with with low calorific values burning with a long and smoky flame (Aggarwal *et al.,* 2007). When the percentage ash content of briquettes was considered, it was discovered that both the binder type and blending ratio did not significantly influence the ash content of the briquette (P>0.05). The ash content of 3.48% obtained in banana bonded briquette was higher than the 3.17% value obtained in starch bonded type. The lowest ash content in banana and starch bonded briquettes was obtained when the blending ratio were 4:1 and 8:1, respectively. The low ash recorded is reflected in the high heating value obtained for the two briquette types. Similar low percentage ash content has been reported for briquettes from oil palm biomass (Nasrin *et al.,* 2008) and briquettes from lignite biobinders (Ivanov *et al.,* 2003). Ash content in the briquettes normally causes an increase in the combustion remnant in the form of ash, thereby lowering the heating effect of the briquette.

Considering the percentage fixed carbon values obtained, it was observed that the starch bonded briquettes was slightly higher than that of banana bonded briquettes, with mean values of 89.11 and 88.89%, respectively (Table 2). The highest percentage fixed carbon of 90.35% and 90.34% was obtained when the orange-binder blend was 8:1. Nevertheless, the percentage fixed carbon obtained was within the 84.7-96.9% range obtained in carbonisate produced from Velenje lignite at varying temperature (Zapusek *et al*., 2003). The implication of high percentage of fixed carbon obtained in this work is that the heating value and combustion duration of briquette will be enhanced. Heating value is the most important combustion property for determining the suitability of a material as fuel. It is an indication of the quantity of fuel required to generate a specific amount of energy. The heating value of 33.98 MJ kg^{-1} obtained for starch bonded briquette was quite close (33.84 MJ kg^{-1}) with that for banana bonded briquette. The high value obtained for the briquettes produced in this work could be attributed to their high compressed density, volatile matter, fixed carbon and low ash content. The binder type as well as variation in blending ratio did not to have significantly influenced the heating values of the briquettes (P>0.05). The heating value reached the peak (33.59 MJ kg^{-1}) when the orange-starch blend was 8:1 compared to the highest value of 33.29 MJ kg^{-1} obtained when 4:1 orange-banana blend was used (Table 2). These values were however found to be higher than 14.1 MJ kg^{-1} in maize cob briquette (Wilaipon, 2007) and 24-27 MJ kg^{-1} for lignites with biobinder (Ivanov *et al.,* 2003). This work has thus demonstrated that heating value quality briquettes can be produced from orange rind using fresh banana peels as the binder. Again the materials used for the production (press, mould and binders) are cheap and locally sourced and require low technology, making the production cost-effective.

5. Conclusion

In this work orange briquette was produced from orange rind which is solid agricultural by-product usually treated as waste using simple technology. The orange rind was hence given a new value which is beneficial to man in this work. This type of briquette was produced from a 100% recycled waste as fresh banana peel was used as the binder, making it an environmentally friendly product. Further work is suggested here on the possibility of producing a bind-less orange briquette using high pressure technology.

REFERENCES

Aggarwal, O. P., & Aggarwal, A. (2007). Engineering Chemistry. 3rd edition, Khanna publ. Nai Sarak Delhi, 827 – 828.

Akpan, M. (2007). Hygroscopic property of neem (*Azadriachta indica A. Juss*): An experimental determination of the shrinkage characteristics. *Global Nest J*. 9(2): 1635 – 1641.

Amaya, A, Medero, N, Tancredi, N, Silva, H, Delan, C. (2007). Activated carbon briquettes from biomass materials. *Bioresourc. Technol.* 98(8) 1635 – 1641.

Aruofor, R.O, (2000). Review and improvement data related to wood-products in nigeria. An output of the EC-FAO Partnership Programme (1988 – 200) – Project GCP/INT/679/EC – Data collection and analysis for sustainable forest management in ACP countries, Lagos, Nigeria.

Association of Official Analytical Chemists (AOAC) (1984). Official methods of analysis, 15th edition Washington, DC, 850 – 851.

ASTM Standard E711 – 87, (2004). Standard test method for gross calorific value of refuse-derived fuel by bomb calorimeter. West Conshohocken, PA, USA.

Emerhi, E.A, (2011). Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders. *Adv. Appl. Sci. Res.* 2(6) 236 – 246.

Frank. O. Oroka and Akhihiero Thelma. E. (2013). Fuel briquettes from water Hyacinth-Cow Dung Mixture as Alternative ENERGY FOR Domestic and Agro-Industrial Application. *Journal of Energy Technology and Policy* 3(6) 56 – 61.

Husain, Z, Zainac, Z, & Abdullah, Z, (2002). Briquetting of palm fibre and shell from processing of palm nut to palm oil. *Biomass and Bioenergy,* 22 **:** 505 – 507.

Ivanov, I.P; Sudakova, I.G, & Kuznetsovv, B (2003). Manufacture of briquetted and granular fuels from lignite with biobinders and heated die. *Chem. Sustai. Devel.,* 11 847 – 852.

Jindaporn, J, Chadchawan, P, Aurawan, T, & Songchai, W (2005). Physical properties and combustion performance of briquettes produced from two pairs of biomass species. ENETT 49 – 137, 27 – 29.

Madu, P.C and Lajide, L (2014). Physicochemical Characteristics of Biomass Briquettes Derived from Melon Seed Husk. *Proceedings of 37th Annual International Conference of Chemical Society of Nigeria (CSN)* 120 -126.

Mckendry, P (2002). Energy production from Biomass (part 1): overview of biomass. Resource Technol. 83 37 – 46.

Nasrin, A.B, Ma, A.N, Choo, Y.M, Mohamad,S, Rohaya, M.H, Azali, A, & Zainal, Z. (2008). Oil palm biomass as potential substitution raw materials for commercial biomass briquettes production. *Am. J. Appl. Sci.* 5(**3**) **:** 179 – 183.

Oladeji, JT, (2010). Fuel characterization of briquettes produced from corncob and rice husk residues. *Pac. J. Sci. Technol.* 11(1) 101 – 106.

Olorunnisola, A (2007). Production of fuel briquettes from waste paper and coconut husk admixtures.

Agricultural Engineering International: the CIGR E journal. Manuscript EE 06006. Vol. ix. February.

Opeolu, B.O, Bamgbose, O, Arowolo, T.A & Adetunji, M.T (2008). Sorption of lead 11 ion from aqueous solution using chemically modified and unmodified Dioscorea alata (yam) and manihot esculenta (cassava) peels. *J. Chem. Soc. Nigeria (CSN)* 33(2): 1 – 10.

Oyelaran, O.A, Bolaji, B.O, Waheed, M.A & Adekunle, M.F (2014). Effects of binding ratios on some densification characteristics of groundnut shell briquettes. *Iranica Journal of Energy & Environment* 5(2) 167- 172.

Patel, B and Gami, B (2012). Biomass characterization and its Use as Solid Fuel for Combustion. *Iranica Journal of Energy and Environment*, 3:123 – 128.

Phonphuak, N, Thiansem, S, (2012). Using charcoal to increase properties and durability of fired test briquettes. *Constr. Build. Mater*. 29, 612 – 618.

Rabier, F, Temmerman, M, Bohm, T, Hartmann, H, Jensen, PD, Rathbauer, J, Carrasco, J, Fernandez, M. (2006). Particle density determination of pellets and briquettes. *Biomass Bioenergy* 30 954 – 963.

Sotannde, O.A, Oluyege, A.O, & Abah, G.B (2010). Physical and Combustion of Charcoal Briquettes from Neem Wood Residues. *Int. Agrophysics* 24 **:** 189 – 194.

Suhartini, S, Hidayat, N, Wijaya, S. (2011). Physical properties characterization of fuel briquette made from spent bleaching earth. *Biomass Bioenergy,* 35, 4209 – 4214.

Suparin C, Suwit S and Prattana, K (2008). Development of fuel briquettes from biomass-lignite blends. *Chiang Mai J. Sci*. 35(1) 43 – 50.

Wamukonya, L. and Jenkins, B. (1995). Durability and Relaxation of Sawdust and wheat-straw briquettes as Possible Fuels for Kenya. *Biomass and Bioenergy,* 8(3): 175 – 179.

Wilaipon P., (2007). Physical characteristics of maize cob briquettes under moderate die pressure. *Am. J. Appl. Sci.* 4 **:** 995 – 998.

Zapusek, A, Wirtgen, C, Weigandt, J, & Lenart, F. (2003). Characterization of carbonizate produced from *velenje* lignite in lab-scale reactor. *Acta Chim Slov.*, 50 **:** 789 – 798.

(http://www.farmradio.org/english/radio-scripts/76-5 scipt-en.asp). An alternative fuel source: Make charcoal briquettes from banana peels. [accessed 12/08/2006]253.

First Author: Dr. P.C Madu is an associate Professor of Industrial Chemistry at Nasarawa State University, Keffi, Nigeria. Dr. Madu became a professional member of the Institute of Chartered Chemists of Nigeria (ICCON) in 2007, a member of Chemical Society of Nigeria (CSN) in 2007. Dr. Madu P.C was born at Okrika-Nweke, Ahiazu-Mbaise LGA, Imo state Nigeria on the 9th of January 1964. Dr Madu obtained his B. Sc degree in Industrial Chemistry from Ahmadu Bello Univ. Zaria in 1988, M.Sc degree in Analytical Chemistry from Federal Univ. of Tech. Owerri in 1997 and a Ph.D in Industrial Chemistry from Nasarawa State Univ. Keffi in 2013. All the degrees were obtained from Nigerian institutions. The authors major field of study is on Industrial/Environmental Chemistry.

Table 1: Effects of binder type and blending ratio on the physical properties of the orange briquettes

Variables	Compressed density* (g/cm^3)	Relaxed density* (g/cm^3)	Relaxation ratio*	Durability rating* (%)
Binder type				
Fresh banana paste	0.92	0.52	1.81	93.95
Starch	1.16	0.38	3.06	95.57
Blending ratio				
Orange: Binder				
8 : 1	0 .96^{a}	0.39^{a}	2.52^{ab}	93.84^{a}
4 : 1	1. 05^{ab}	0.43^{b}	2.50^{a}	93.41^{a}
2 : 1	1.10^{b}	0.53^{c}	2.28^{a}	97.04^{b}
Orange : Banana				
8 : 1	0.80	0.41	1.94	91.29
4 : 1	0.96	0.49	1.96	92.22
2 : 1	0.98	0.65	1.51	98.35
Orange : Starch				
8 : 1	1.12	0.36	3.10	96.38
4 : 1	1.13	0.37	3.04	94.60
2 : 1	1.22	0.40	3.04	95.72
Significance level				
Binder type:	P = 0.043	P = 0.031	P = 0.001	P = 0.0567
Blending ratio:	P = 0.023	P = 0.021	P = 0.230	P = 0.751

*Means of three replicate samples. Values with the same alphabet in each column are not significantly different at $\alpha = 0.05$ using Duncan range test

Table 2: Effects of binder type and blending ratio on the combustion properties of the orange briquettes.

Variables	Parameters			
	Volatile matter*	Fixed Carbon* (%)	Ash*	Heating Value* ($MJKg^{-1}$)
Binder type				
Fresh banana paste	7.24	89.27	3.48	33.10
Starch	7.33	89.56	3.17	33.19
Blending ratio				
Orange: Binder				
8 : 1	6.83[a]	90.35[a]	2.83[b]	33.30[b]
4 : 1	7.00[a]	89.72[ab]	3.34[a]	33.19[ab]
2 : 1	8.51[b]	88.15[b]	3.81[a]	32.95[a]
Orange : Banana				
8 : 1	6.19	90.34	3.47	33.09
4 : 1	7.44	89.47	3.09	33.29
2 : 1	8.11	88.01	3.88	32.92
Orange : Starch				
8 : 1	7.46	90.35	2.19	33.51
4 : 1	6.55	89.96	3.59	33.08
2 : 1	7.99	88.28	3.73	32.98
Significance level				
Binder type:	P = 0.677	P = 0.051	P = 0.191	P = 0.073
Blending ratio:	P = 0.041	P = 0.001	P = 0.345	P = 0.901

*Means of three replicate samples. Values with the same alphabet in each column are not significantly different at α = 0.05 using Duncan range test