# The Energy Potentials of Some Agricultural Wastes as Local Fuel Materials in Nigeria

Jekayinfa[1], S.O. and Omisakin, O.S.[2]

[1]Department of Agricultural Engineering, [2]Department of Mechanical Engineering,
Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Oyo State, Nigeria
Corresponding author: Jekayinfa S.O. E – mail: jekaysol@yahoo.com

## ABSTRACT

Ten agricultural wastes in Nigeria were subjected to ultimate and proximate analyses to determine their energy content using the method of Association of Official Analytical Chemists. The samples are: groundnut shell, yam peels, coconut shell, mango peels, palm oil mill effluents, corn cob, cherry, orange peels, melon shell, and black walnut hull. Results of analysis show that the mean higher heating values of the waste samples are 16505kJ/kg, 19597kJ/kg, 20647kJ/kg, 15891kJ/kg, 17303kJ/kg, 19458kJ/kg, 28203kJ/kg, 19299kJ/kg, 21392kJ/kg and 21143kJ/kg for groundnut shell, yam peels, coconut shell, mango peels, palm oil mill effluent, corn cob, cherry, orange peels, melon shell and black walnut hull respectively. All the waste samples considered have heat values greater than some well-known biomass-fuels and fall within the limit for the production of steam in electricity generation.  As a result of this, it is envisaged that industries that use their waste biomass for energy would simultaneously solve a waste disposal problem and save money on their energy needs.

**Keywords**: Agricultural wastes, ultimate analysis, heating value, Nigeria

## 1. INTRODUCTION

Agricultural wastes are potentially huge source of energy-giving materials. They are all forms of plant-derived materials that can be used for energy. These include wood, herbaceous plants, crop and forest residues, animal wastes, etc. In Nigeria, large quantities of these wastes are produced annually and are vastly under-utilized. The practice is usually to burn these residues or leave them to decompose. However, studies have shown that these residues could be processed into liquid fuels or combusted/gasified to produce electricity and heat (Soltes, 1983; Barnard and Kristoferson, 1983; Enweremadu et al., 2004)

The main benefits of the use of biomass as energy source are rural economic development, increase in farm income, market diversification, reduction of agricultural commodity surpluses and derived support payments, enhancement of international competitiveness, revitalization of retarded rural economies, reduction of negative environmental impacts. The new incomes that would accrue to farmers and rural populace improve the material welfare of rural communities and thus, resulting in the further activation of the local economy. This will eventually end up in reducing the emigration rates to urban environments. There is also the added advantage of the creation of a number of jobs in the area of production, harvesting and use. The use of agricultural wastes as energy also has many unique qualities that provide environmental benefits. It helps to mitigate climate change, reduces acid rain, soil erosion,

water pollution and pressure on landfills. It also provides wildlife habitat, and helps to maintain forest health through better management.

Several works have been reported in the literature concerning wastes and their energy potentials: orange pomace (Enweremadu et al., 2004), soy-bean and cowpea ( Enweremadu et al., 2004), rice husk (Singh et al.,1980), coffee wastes (Antolin et al.,1996), apple pomace (Jewell and Cummings, 1984), charcoal (Fapetu, 2000), fruit pomace (Nicholas et al., 1983).This present work is an effort to improve the utilization of some common agricultural wastes in Nigeria. For any reasonable shift to the use of these fuel materials, there is the need to know their energy content. The main objectives of this study are to determine the chemical composition of the selected biomass fuels and to use the chemical analysis results to estimate the higher and lower heating values of the biomass fuels.

## 2. MATERIALS AND METHODS

Wastes selected for the analyses (Groundnut shell, yam peelings, coconut shell, mango peelings palm oil mill effluent, corn cob, cherry, orange peelings, melon shell and black walnut hull) were obtained locally, some from the local sellers and others from processing centres where they are by-products.  The ultimate analysis was carried out at International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.  A standard laboratory dry oven and measuring dishes were used to conduct the required experiments.  The procedure followed, on the whole, the standard test methods for calorimetric analysis set forth by the American Society for Testing Materials (ASTM) D 2016 -93.

### 2.1 Ultimate and Proximate Analyses

The waste samples were collected into cellophane bag in order not to make them susceptible to dust, a factor that heightens the rate of decomposition.  The moisture contents in the wastes, most especially the palm oil mill effluent, were reduced so that they could be burnt off when used as source of heat.  Proximate analysis included six tests – loss of moisture when heated to 105oC for 1 hour volatile combustible matter; fixed carbon, crude protein, crude fibre and ether extract.  These tests had been carried out by earlier researchers on waste categorization.  (Tochobanoglous et. al; 1993; Shanklin et al., 1999; Rosentrater et. al; 1999; Nelson and Flores, 1994).

The ultimate analysis carried out is according to the guide lines of Association of Official Analytical Chemist (AOAC, 1986; Ferris et al. 1995; Flores, 1998; Flores et al, 1999)

### 2.2 Carbon and Hydrogen Contents

Carbon and hydrogen contents were determined simultaneously by Leibig-pregle method.  1g of sample flour was placed in a quartz test tube and burned off through the absorbents magnesium percolate to absorb water and sodium hydroxide to absorb carbon dioxide.  The amount of water and carbon dioxide is found from the difference between the two weightings, one before and the other after the absorption of water and carbon dioxide.  The percentage of carbon and hydrogen was evaluated thus:

$$\% \text{ Carbon} = \text{Weight of } CO_2 \times 0.2729 \times 100/\text{weight of sample} \qquad (1)$$
$$\% \text{ Hydrogen} = \text{Weight of } H_2O \times 0.1119 \times 100/\text{weight sample} \qquad (2)$$

The constants, 0.2729 and 0.1119, are from empirical equations derived in Lebig-pregle method.

## 2.3 Nitrogen Content

This was carried out by Dumas-Pregle method.  0.2g of each sample flour was mixed with powder of copper oxide in the ignition tube.  Air was displaced from the tube by passing through a stream of $CO_2$ until minute bubble appeared in the nitrogen flow meter filled with about 50% solution of potassium hydrogen.  The weighed sample was burned off at between $700^oC$ and $750^oC$ in a gas burner and later burned in an atmosphere of $CO_2$ with the gas cylinder shut off.  After ignition, the combustion product was displaced with carbon dioxide into the nitrogen flow meter at a rate of one bubble per second until minute bubble appear in the nitrogen flow meter.  The percentage nitrogen content was determined by the equation:

$$\% N = \frac{v \text{ x } 1.097}{g} \text{ x } 100 \qquad (3)$$

Where
        V = Volume of nitrogen in the nitrogen flow meter
        1.097 = Mass of 1ml of nitrogen at the test conduction
        g = Weight of sample

## 2.4 Colorimetric Analysis Procedure

The calorimetric experiments were conducted according to ASTM D2016 except for the fuel size.  The ASTM procedure for calorimetric analysis of coal dictates that the fuel be pulverized to pass through a 250μm or no. 60 sieve.  However, because of the high moisture content of the fuel used in the experiments, this was deemed unsuitable.  Therefore, the manures were simply dried as received.  The drying was still expected to be uniform because of the very small sample size.  (Rodriguez et al; 1998)

## 2.5 Sulphur Content

The product was absorbed with a mixture of water and hydrogen peroxide to oxidize the combustion product immediately.  The combustion product was titrated with a solution of barium percolate in the presence of the indicator Toron with a pH value of 4.5.

The percentage sulphur content was calculated using eqn (4)

$$\% \text{ Sulphur} = \frac{\{(\text{Titre value} - \text{Blank}) \text{ x } 0.1582 \text{ x } 100\}}{\text{Weight of Sample}} \qquad (4)$$

## 2.6 Determination of Dry Matter and Moisture Content

2g of sample was accurately weighed into a pre-weighed clean weighing dish provided with easily removable lid.  The uncovered dish with its lid opened was placed in a well-ventilated oven maintained at $100^oC$.  After 16 hours, the lid was replaced and transferred to a dessicator at room temperature to cool.  The new weight was then taken.

The percentage moisture content was calculated using:

$$\% \text{ Moisture Content} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \tag{5}$$

Where; $W_1$ = Weight of dish and lid
$W_2$ = Weight of dish, lid and sample before drying
$W_3$ = Weight of dish, lid and sample after drying
$W_2 - W_1$ = Weight of sample prepared for drying
% Dry matter content = 100 - % Moisture content

## 2.7 Ash Content

The crucible after it had been washed and dried in the oven was allowed to cool in a dessicator and weighed.

2g of dried sample was weighed into an empty porcelain crucible which had been previously ignited and weighed. The sample was then ignited over a hot plate in the fume cupboard to char organic matter.

The crucible was placed in a muffle furnace maintained at a temperature of $600^{o}C$ for 8 hours, and transferred directly to a dessicator; cooled and weighed immediately.

The calculation of the percentage ash content was determined using the formula given below:

$$\% \text{ Ash} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \tag{6}$$

Where; $W_1$ = Weight of empty crucible
$W_2$ = Weight of crucible + sample
$W_3$ = Weight of crucible + ash

## 2.8 Oxygen Content

The percentage oxygen content was determined as follows:

$$\% \text{ Oxygen} = 100 - (C+H+N+S+Ash) \tag{7}$$

Where: C = % carbon content in the biomass fuel
H = % hydrogen content in the biomass fuel
N = % nitrogen content in the biomass fuel
S = % sulphur content in the biomass fuel and
Ash = % ash content in the biomass fuel

## 2.9 Determination of Crude Protein

0.2g of sample flour was shaken with 100ml of 0.05M of sodium Hydroxide Solution for 15 minutes. It was then centrifuged at 600rpm for 10 minutes in a 500ml graduated cylinder. 5ml clear extract was added and diluted to 50ml with 30% Sulphur Salicylic acid solution. It was inverted several times and immediately the degree of turbidity at 450nm in a 4cm cell read against the sulphur salicylic acid solution as instrument blank. The percentage protein content was determined using the equation:

$$Y = 2.53 + 18.20X \tag{8}$$

Where;　　$Y$ = Calorimeter reading

　　　　　$X$ = % protein

## 2.10 Determination of Ether Extract

1g of the sample was stirred with 2ml of alcohol and then 7ml of concentrated HCL acid and 3ml of water were added.  The material was heated at about $80^{\circ}C$ for about an hour.  10ml of alcohol was added to the cooled hydrolysed mixture followed by 25ml of light petroleum and the fat extracted three times of 25ml of the ether.

## 2.11 Energy Evaluation

The approximate energy value (higher heating value) was evaluated using Dulong-Petit formula (Perry and Green, 1997).

$$Q_n = 337C + 1428 (H - O/8) + 95S \text{ (kJ/kg)} \tag{9}$$

Where;　　$C$ = % of carbon

　　　　　$H$ = % of hydrogen

　　　　　$O$ = % of oxygen

　　　　　$S$ = % of sulphur

The lower or net heating value (LHV) was determined by Eqn. 10

$$HHV - 2465M_w \tag{10}$$

Where;　　$M_w$ = Product of the fraction of hydrogen in the waste sample and 9kg.

## 3. RESULTS AND DISCUSSION

The results obtained for ultimate and proximate analyses are presented in Table 1and 2 respectively.  Table 3 presents the combustion characteristics of the waste samples, while Table 4 compares these characteristics with those of some well-known biomass.   Table 2 revealed that yam peels have the highest moisture content of 64.50% while the palm oil mill effluent has the lowest moisture content of 7.52%.  The moisture contents of other eight wastes specimens that is, mango peels, corn cob, cherry, melon shell, coconut shell, black walnut hull, orange peels and groundnut shell are respectively 56.54%, 42.98%, 37.75%, 27.60%, 12.22%, 11.56%, 10.82% and 8.76%.  These results compare well with the typical proximate analysis of fruit and other agricultural wastes that have been reported in literature (Kranzler and Davis, 1981; Ledward et. al; (1983).  The comparatively high moisture contents of these wastes indicated that they would have to be dried so that they could easily burn off when used as sources of heat.

The ash contents of the wastes varied from 0.76% for groundnut shell to 19.57% for melon shell.  The ash contents of other selected wastes are 10.97%, 4.87%, 4.56%, 4.33%, 4.10%, 3.80%, 3.47% and 2.66% for palm oil mill effluent, corn cob, yam peels, mango peels, black walnut hull, cherry, coconut shell and orange peels respectively.  These results show that except for palm oil mill effluent and melon shell with ash contents more than 10%, other eight waste specimens have values lower than 5%.  These fall below values obtained for coal (10.3%) and rice hulls (17.4%) and slightly higher than those of well known biomass fuel like grape pomace (2.7%), apple pomace (4.0%) and wood (0.1%) (kranzler et al., 1983; Nelson

et al., 1950; Babcock and Wilcox, 1978).  The results of ash content show the amount of inorganic substance that would remain after burning.

Table 1. Ultimate composition of the selected agricultural wastes

| Wastes | Parameters | | | | |
|---|---|---|---|---|---|
| | % Carbon | % Hydrogen | % Nitrogen | % Oxygen | % Sulphur |
| Groundnut shell | 14.99 | 16.42 | 1.21 | 63.62 | 3.00 |
| Yam peels | 25.35 | 13.54 | 2.67 | 49.60 | 4.34 |
| Coconut shell | 20.68 | 16.26 | 1.14 | 54.49 | 3.96 |
| Mango peels | 19.83 | 13.19 | 2.40 | 55.39 | 4.86 |
| Palm oil mill effluent | 12.74 | 16.49 | 0.41 | 58.33 | 1.06 |
| Corn cob | 19.73 | 15.56 | 0.38 | 54.98 | 4.48 |
| Cherry | 19.54 | 21.19 | 0.65 | 51.13 | 3.69 |
| Orange peels | 16.23 | 17.10 | 0.76 | 60.26 | 2.99 |
| Melon shell | 21.61 | 14.71 | 0.26 | 39.03 | 4.82 |
| Black walnut hull | 23.09 | 15.66 | 0.94 | 52.25 | 3.96 |

Table 2.  Proximate composition of the selected agricultural wastes

| Waste | (%) | | | | |
|---|---|---|---|---|---|
| | Dry matter | Fixed Carbon | Crude protein | Crude fiber | Ether extract |
| Groundnut shell | 70.50 | 15.50 | 5.23 | 5.35 | 3.42 |
| Yam peels | 73.75 | 14.50 | 3.62 | 2.51 | 5.62 |
| Coconut shell | 71.51 | 8.78 | 6.53 | 10.35 | 2.83 |
| Mango peels | 75.25 | 9.57 | 3.51 | 8.58 | 3.09 |
| Palm oil mill effluent | 70.51 | 10.52 | 7.21 | 8.12 | 3.64 |
| Corn cob | 65.25 | 8.75 | 6.25 | 16.50 | 3.25 |
| Cherry | 46.50 | 23.50 | 7.75 | 16.95 | 5.30 |
| Orange peels | 45.65 | 25.51 | 6.95 | 14.23 | 7.66 |
| Melon shell | 60.55 | 21.53 | 4.15 | 10.25 | 3.52 |
| Black walnut hull | 71.25 | 13.91 | 4.65 | 6.53 | 3.66 |

Table 3. Combustion characteristics of the ten selected agricultural processing wastes

| Wastes | Heat contents (kJ/kg) | | Ash (%) | Moisture content (as received, wet basis) (%) |
|---|---|---|---|---|
| | Higher | Lower | | |
| Groundnut shell | 17428 | 13785 | 0.76 | 8.76 |
| Yam peels | 19437 | 16433 | 4.50 | 64.50 |
| Coconut shell | 20838 | 17231 | 3.47 | 12.22 |
| Mango peels | 16093 | 13167 | 4.33 | 56.54 |
| Palm oil mill effluent | 17530 | 13872 | 10.97 | 7.52 |
| Corn cob | 19480 | 16028 | 4.87 | 42.98 |
| Cherry | 28068 | 23367 | 3.80 | 37.75 |
| Orange peels | 19416 | 15622 | 2.66 | 10.82 |
| Melon shell | 21779 | 18516 | 19.57 | 27.60 |
| Black walnut hull | 21193 | 17719 | 4.10 | 11.56 |

The sulphur contents of the ten waste specimens varied between 1.06% for palm oil mill effluent and 4.86% for mango peels (Table 1). Other results include 4.82%, 4.48%, 4.34%, 3.96%, 3.96%, 3.69%, 3.00% and 2.99% respectively for melon shell, corn cob, yam peels, coconut shell, black walnut hull, cherry groundnut shell and orange peels. The sulphur content was observed to fall below 5% in all the samples, which would mitigate the emission of sulphur dioxide ($SO_2$) into the atmosphere causing acid rain. Sulphur contents are much higher for all the ten waste specimens than for #2 fuel oil. Natural gas (methane) produces virtually no sulphur (Perry and Chiton, 1973 and Hsu and Luh, 1980).

From the analysis, nitrogen content is less than 3% in the waste samples. These results are comparable to coal (1.2%) and #2 fuel oil (0.006) (Elliot, 1980; Perry and Chilton, 1973). Fuel bound nitrogen is an important contributor to oxides of nitrogen ($No_x$) emission from biomass combustion system (Schaub and Leonard, 1996; Brannstein, 1981).

The molar ratios of hydrogen to carbon (H/C) for the waste samples are 13.14, 6.41, 9.45, 7.98, 15.53, 9.49, 13.0, 12.67, 8.17 and 8.16 for groundnut shell, yam peels, coconut shell, mango peels, palm oil mill effluent, corn cob, cherry, orange peels, melon shell and black walnut hull respectively. These values depicted by Fig.1 are higher than those obtained for methane (4.0) and iso-octane (2.25) which are good examples of hydrocarbon fuels (Enweremadu et al; 2004).
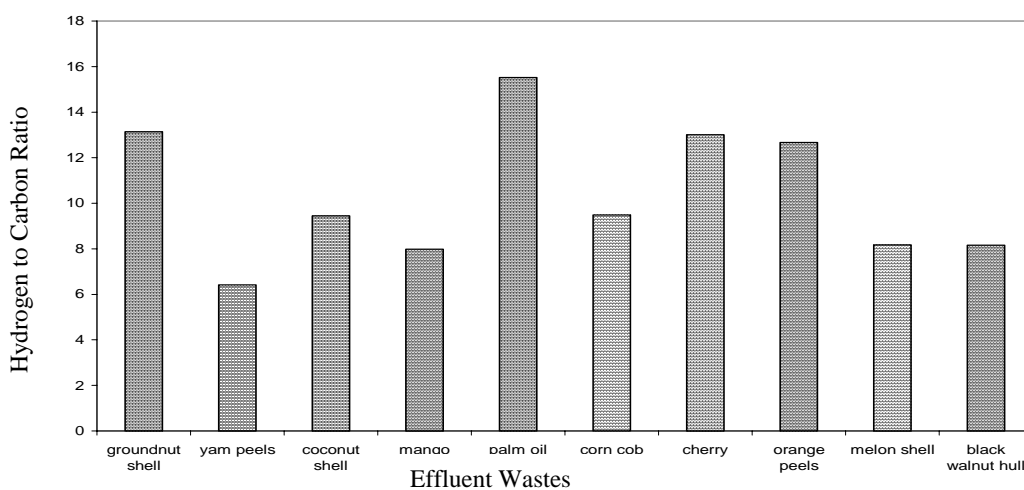


Figure 1. The molar ratio of hydrogen to carbon (H/C) for the 10 waste samplers

Table 2 reveals that the mean higher heating values of the waste samples from the ultimate analysis are 17428kJ/kg, 19437kJ/kg, 20838kJ/kg, 16093kJ/kg, 17530kJ/kg, 19480kJ/kg, 28068kJ/kg, 19416kJ/kg, 21779kJ/kg and 21193kJ/kg for groundnut shell, yam peels, coconut shell, mango peels, palm oil mill effluent, corn cob, cherry, orange peels, melon shell and black walnut hull respectively. Except for groundnut shell, mango peels and palm oil mill effluent, every other waste sample has heat content similar to bone-dry apple pomace (18000kJ/kg). The highest heat value of 28068kJ/kg obtained for cherry is 93% that for coal, 65% that for #2 fuel oil and 51% that for natural gas i.e. methane (Table 4). All the waste samples considered have heat values greater than some well known biomass-fuel like rice hulls (13390kJ/kg) and apple pomace (18096kJ/kg). The results of proximate analysis (Table

2) show relatively high percent dry matter in all the ten samples, indicating that a higher percentage (varying from 45.65 for orange peels to 75.25 for yam peels) would be available for combustion.

It could be observed that the heating values of the ten waste samples considered are within the limit for the production of steam in electricity generation.

Table 4. Comparison of selected analyses for the 10 selected agricultural Processing wastes and fossil fuels

| | Ground nut shell | Yam peels | Coconut shell | Mango peels | Palm oil mill effluent | Corn cob | Cherry | Orange peels | Melon shell | Black walnut hull | Coal [a] | # 2 Fuel Oil [b] | Natural Gas (95% Methane) [c] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ultimate Analysis % | | | | | | | | | | | | | |
| Carbon | 14.99 | 25.35 | 20.68 | 19.83 | 12.74 | 19.73 | 19.54 | 16.23 | 21.61 | 23.09 | 75.5 | 87.3 | 74.9 |
| Hydrogen | 16.42 | 13.54 | 16.26 | 13.19 | 16.49 | 15.56 | 21.19 | 17.10 | 14.71 | 15.66 | 5.0 | 12.6 | 25.1 |
| Oxygen | 68.79 | 48.70 | 55.56 | 56.52 | 59.60 | 55.10 | 50.37 | 60.91 | 41.19 | 52.53 | 4.9 | 0.004 | - |
| Nitrogen | 1.21 | 2.67 | 1.14 | 2.40 | 0.41 | 0.38 | 0.65 | 0.76 | 0.26 | 0.96 | 1.2 | 0.006 | - |
| Sulphur | 3.00 | 4.34 | 3.96 | 4.86 | 1.06 | 4.48 | 3.69 | 2.99 | 4.82 | 3.96 | 3.1 | 0.22 | - |
| Ash | 0.76 | 4.56 | 3.47 | 4.33 | 10.97 | 4.87 | 3.80 | 2.66 | 19.57 | 4.10 | 10.3 | - | - |
| $H_2O$ | 8.76 | 64.50 | 12.22 | 56.54 | 7.52 | 42.98 | 37.75 | 10.82 | 27.60 | 11.56 | - | - | - |
| Higher Heat Content | | | | | | | | | | | | | |
| (Btu/Ib) | 7493 | 8357 | 8959 | 8959 | 7537 | 8375 | 12067 | 8348 | 9364 | 9112 | 13000 | 18670 | 23885 |
| (KJ/Kg) | 17428 | 19437 | 20838 | 16093 | 17530 | 19480 | 28068 | 19416 | 21779 | 21193 | 30238 | 43427 | 55557 |
| Lower Heat Content | | | | | | | | | | | | | |
| (Btu/Ib) | 5927 | 7065 | 7408 | 5661 | 5964 | 6891 | 10046 | 6716 | 7961 | 7618 | 12523 | 17469 | 21491 |
| (KJ/Kg) | 13785 | 16433 | 17231 | 13167 | 13872 | 16028 | 23367 | 15622 | 18516 | 17719 | 49989 | 40632 | 49989 |

[a]Elliot, 1980
[b]Perry and Chilton, 1973
[c]Hsu and Luh, 1980

## 4. CONCLUSIONS

The following conclusions can be drawn from this study:

1. Sulphur contents of the samples are less than 5% and this is good for combustion since good fuels are known to have low sulphur contents.

2. The observed high molar ratio of hydrogen to carbon may favour efficient combustion of the waste samples.

3. The low composition of nitrogen in virtually all the sample selected will result in low emission of oxides of nitrogen into the atmosphere and there may not be need for equipment for the removal of oxides of nitrogen in the design of equipment for the conversion of these agricultural wastes to energy.

4. All the waste samples considered have heat values greater than some well-known biomass-fuels and fall within the limit for the production of steam in electricity generation.

5. From the foregoing, it is envisaged that industries that use their waste biomass for energy simultaneously would solve a waste disposal problem and save money on their energy needs.

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