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Potential of *Manihot Esculenta* (Cassava) Peels for Electricity and Heat Co-Generation in Nigeria

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Abstract

Nigeria is the largest producer of cassava in the world and the peel accounts for between 5 -15% of the tuber. Cassava peel is often left unattended in the country, making it a source of methane gas which is one of the culprits of global warming. Agricultural residues are good sources of renewable energy. This study investigated the potential of electricity and heat generation from cassava peels. The dried peel was ground and used for proximate analysis according to ASTM D 5142-04 procedure, from where moisture, ash, Volatile Matter (VM) and the Fixed Carbon (FC) contents were determined. The Higher Heating Value (HHV) of cassava was calculated using the FC. Performance of four plants tagged A, B, C and D were simulated using thermodynamics equations. Plant A was simulated as a boiler-steam turbine combination, Plant B, gasifier-boiler steam turbine, Plant C, gasifier-gas turbine and Plant D, gasifier-internal combustion engine combination. Parameters investigated were power output, heat output, annual electrical energy generation per peel mass. Results gave the moisture, ash, VM and FC contents as 6.53, 3.78, 89.57 and 6.65 % respectively while the HHV was determined to be 15.422 MJ/kg. Estimated power output was 2.51 x 10^5, 1.78 x 10^5, 1.39 x 10^6 and 1.26b x 10^6 kW for Plants A, B, C and D respectively. In a like manner, the heat output is1.02 x 10^7, 7.24 x 10^6, 8.84 x 10^6 and 1.06 x 10^7 MJ/h. Annual electrical energy output was determined to be 9.03 x 10^8, 6.42 x 10^8, 5.00 x 10^9 and 4.52 x 10^9 kWh and the electrical energy generation per cassava peel consumption was 0.202, 0.144, 1.121 and 1.009 kWh/kg for Plants A, B, C and D respectively. Cassava peel possesses good potential for heat and electrical energy co-generation in Nigeria.

Keywords: Cassava, Residues, Proximate Analysis, Simulation, Fossil Fuel.

1. INTRODUCTION

Dearth of energy is the bane of growth and hence cause of poverty in most third world countries. Many countries rely on fossil fuels as their sources of energy because of their availability, though highly unaffordable in most developing nations. Some countries having large deposits of fossil fuels even find assessing them difficult due to inability to properly refine them for local consumption, making them to depend on importation. The developed nations on the other hand are gradually backing out of the use of fossil fuels energy source because of its implication on global warming causing attendant climate change with unfavourable effects on the ecological system. In addition, fossil fuels are finite in nature and so cannot be available forever making research into alternative fuels which are renewable very important. Most renewable fuels are derived from biomaterials that can be used directly or processed into cleaner fuels.

Any material that is capable of releasing energy after its chemical or physical structure has been altered is called fuel. Importance of the application of fuel in engineering lies in efficient harnessing and utilization of the energy released. Biomaterial is any carbon source that can be replenished within a specified period e.g. plants and animals. Agricultural residues are good sources of renewable energy (Dairo *et al.,* 2017).

Cassava is a major staple food in the developing countries probably because it is the third largest source of carbohydrates in the tropics (Diop, 1998). Nigeria is the largest cassava producing country in the world as it produced 59 million metric tonnes in 2017 (FAO, 2019; Otekunrin and Swicka, 2019) and has been projected to reach 150 million tonnes by the year 2020 and the peel accounts for between 5 – 15% of the tuber (FAO, 2004; 2008; Nwokoro *et al.*, 2005; Aro *et al.,* 2010). Local processing of this projection is expected to generate millions tonnes of residues including the peels.

Cassava peels are dumped untreated openly near homes and cottage industries by processors and are usually left to rot away or burnt to create space for more wastes. When they are burnt, useful energy is liberated into the atmosphere; when not burnt, offensive smell is released leading to environmental pollution. Methane, one of the culprits responsible for global warming is produced by the decomposition of organic materials and the leachates of these organic materials that have undergone chemical processes find their ways into underground waters and run-offs causing avoidable health challenges (Hasan *et al.,* 2016). Outbreak of fire can result from accumulation of methane even under small heat. It becomes important to find a way of proper disposal of cassava peels.

Cassava peel, being a biomaterial, is a source of fuel that can produce energy. It is also renewable as tons are disposed on daily basis. Cassava peel is a residue generated during food processing and its use for energy generation is not going to put pressure on global food security. This source of renewable energy, if well harnessed, can help in bridging the gap between demand and supply of electricity in developing nations like Nigeria, especially where cassava is cultivated in large quantities. Electricity supply is grossly inadequate to meet the demand and utilising agricultural wastes will go a long way in proffering a solution to the problem in addition to taking care of the environment by minimising contamination as a result of arbitrary disposal of organic wastes.

There are several bioenergy conversion technologies that can be considered for extracting energy from cassava peels. Bioenergy conversion techniques can be divided into two groups namely biochemical conversion and thermochemical conversion. The former involves the use of biological catalysts and biological organisms while the latter uses heat and chemical catalysts to produce energy from Biomass (Ravindranath, 1993). The two major categories of the biomass feedstock are dry and wet types. Biochemical technique is a wet process that produces methanol and biodiesel through fermentation while thermochemical technique involves dry processes of combustion, gasification and pyrolysis. In combustion, the chemical energy stored in biomass is obtained in form of heat by its direct burning in the presence of oxygen. Combustion of biomass takes place at the temperatures ranging from 800 to 1000°C and almost all available chemical energy in the biomass is recovered in form of flue gas. This process is only feasible if the moisture in the biomass is small (Goyal *et al*., 2008). A pre-treatment of biomass is important for efficiency compared with direct combustion (McKendry, 2002). Exhausted process steam generated in this technology can be utilized for other applications making this bio-energy conversion technology viable. Gasification is also a thermochemical conversion process to obtain energy from solid biomass in gaseous form in the presence of a medium like oxygen, air, and steam (Ravindranath and Hall, 1995) at temperatures ranging from 700°C to 900°C (Neves *et al.,* 2011). The gas produced by gasification is generally referred to as bio-syngas which consists mainly of CO, CO_2, H_2 and N_2. Dinkelbach (2000) in his work of thermochemical conversion of Willow from short rotation forestry reported that gasification had better efficiency compared with combustion. This was also corroborated by Prasara-A *et al.* (2012) who considered the environmental and economic performances of different technologies for power generation from rice husks. Hydrogen can be obtained in large scale through gasification (Saxena *et al.,* 2008).

Biochemical conversion technology is less expensive and more environmental friendly compared with thermochemical conversion technology but it has low hydrogen yield (Das and Veziroglu, 2001). Mierzwa-Hersztek *et al.* (2019) carried out an assessment of energy parameters of plant biomass (wheat straw, miscanthus straw, bark and sawdust), animal biomass (poultry manure), their biochars, leachability of heavy metals and phytotoxicity of their ashes. They concluded that the biomasses considered were good for energy generation but their biochars gave better results compared with the original feed stocks and could serve as fuel cells. Fast pyrolysis produces oil which is very good for heat production on a large scale and even co-firing in power plants (Prasara-A *et al*., 2012). Pyrolysis process for commercial electricity production is still being studied in Nigeria because of the technology involved (ASTM, 2008; Ame-Oko *et al.,* 2018). This work analysed the potential of cassava peels for electricity and heat generation from four power plants using thermochemical technique in conjunction with thermodynamic equations.

2. Methodology

Cassava peels harvested from processing factories at Abeokuta, South-Western Nigeria were washed to remove sands, grits and other impurities, sun-dried and ground.

2.1 Determination of moisture content

The moisture content in the sample was determined by placing the sample in the muffle furnace kept at 105°C for 2 hours. The change in moisture content was obtained using Equation 1.

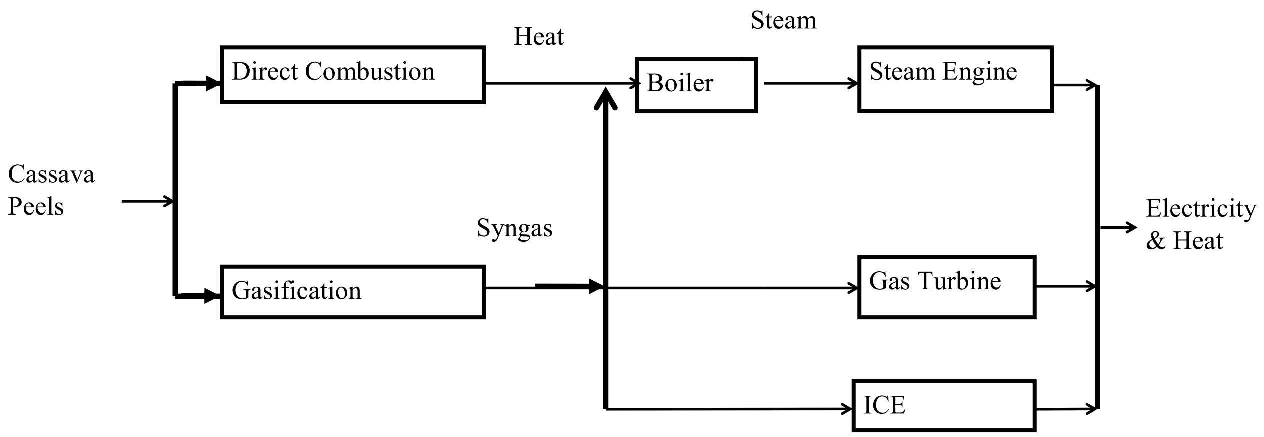

Figure 1: Chart of Electricity and Heat Generation from Cassava Peels (Ame-Oko *et al.,* 2018)

$$\%MC = \frac{M_f - M_i}{M_i} \quad (1)$$

where, MC is moisture content, M_i is the initial mass before drying and M_f is the final mass.

2.2 Proximate analysis

Proximate analysis was carried out on the ground sample in a muffle furnace according to ASTM D 5142-04 procedure in three replications (Dermirbas, 1997). The percentage volatile matter, percentage ash content and percentage fixed carbon were then determined.

Determination of volatile matter

The volatile matter was determined by heating the sample in the furnace at 900°C for 7 minutes and then cooled. The percentage volatile matter was obtained using Equation 2.

$$\%VM = \frac{M_m - M_v}{M_i} \times 100 \quad (2)$$

Where, VM is the volatile matter, M_i is the initial mass before heating and M_v is the volatile mass.

Determination of ash content

The ash content of the sample was determined by heating the mass already heated to 105°C in an oven for 6 hours at 750°C and cooled. The ash content was calculated using the relationship in Equation 3.

$$\%AC = \frac{M_r}{M_2} \times 100 \quad (3)$$

where, AC is ash content, M_r is the mass of residue and M_2 is the mass of sample heated to 105°C.

Determination of fixed carbon content

The percentage fixed carbon content was determined by subtracting the percentages of volatile matter and ash content from 100 percent according to Equation 4.

$$FC = 100 - VM - AC \quad (4)$$

2.3 Determination of heating value

The heating value of the sample was reported in terms of higher heating value (HHV) of cassava peels as given by Demirbas (1997) in Equation 5.

$$HHV(MJ/kg) = 0.196FC + 14.119 \quad (5)$$

where, FC is fixed carbon content of the proximate analysis.

2.4 The potential analysis for electricity and heat generation

Four plants were considered in this study where the potential of electricity and heat generation from cassava peels was analysed using thermodynamics equations in thermochemical techniques as shown in Figure 1 (Ame-Oko *et al.,* 2018).

Plant A: Steam Turbine-Combustion Module

Plant A comprises of a steam turbine that is run on heat from combustion of cassava peels. The plant has two modules, boiler and steam generators. The boiler is powered by direct combustion of cassava peels to generate heat that produces superheated steam of desired temperature, pressure and flow-rate to drive the turbine for electricity generation (Ame-Oko *et al.,* 2018). The equations for the determination of the electric power output and the thermal output of the plant are given according to Goldstein (2003) and Ame-Oko *et al.* (2018) as

$$H_r = \frac{M}{h} \quad (6)$$

$$E_i = H_r \times HHV \quad (7)$$

$$H = E_i \times \eta_b \quad (8)$$

$$P_e = \eta_{ste} \times H \times c_f \quad (9)$$

$$P_t = \eta_{stt} \times H \quad (10)$$

where, H_r is the input rate of cassava peel to the system in kg/hr, M is the mass of cassava peels in kg, h is the number of hours of operation of the plant per year, E_i is the total input energy to the system in MJ/hr, H is the input heat to steam turbine generator in MJ/hr, η_b is the efficiency of boiler, η_{ste} is the electric efficiency of the steam turbine in percentage (%), η_{stt} is the thermal efficiency of the steam turbine in percentage (%), c_f is a conversion factor of 0.25 (Aso *et al.,* 2018), P_e is the electrical power output in kW and P_t is the heat output in MJ/hr.

Plant B: Steam Turbine-Syngas Module

Plant B is a steam turbine plant that is powered by syngas. This plant consists of three modules: gasifier, boiler and generator. Gasification of the cassava peels is done to convert it to syngas that then burns in the boiler to generate the steam that is now used to drive the turbine for electricity generation. Equations 6 - 10 given earlier, served the operations of Plant B in addition to Equation 11 which gave the total input energy (Ame-Oko *et al.*, 2018).

$$E_i = H_r \times \eta_g \times HHV \quad (11)$$

where, η_g is the efficiency of the gasifier in percentage (%)

Plant C: Gasifier-Gas Turbine Module

Plant C does not consist of a boiler, rather it requires that the cassava peels be converted to syngas in the gasifier module which now serves as fuel in the turbine module for electricity generation. Equations (6), (11) - (13) were used to determine the electric power output and the thermal output of the plant. The electric power output and heat output of Plant C are given by

$$P_e = \eta_{gte} \times E_i \times c_f \quad (12)$$

$$P_t = \eta_{gtt} \times E_i \quad (13)$$

where, η_{gte} is the electrical efficiency of the gas turbine generator in percentage (%); η_{gtt} is the thermal efficiency of the gas turbine generator in percentage (%).

Plant D: Gasifier-Internal Combustion Engine Module

Plant D comprises of two modules: a gasifier module coupled to an Internal Combustion Engine (ICE). The cassava peel is converted to syngas in the gasifier and this now powers the ICE for electricity generation. Equations (6), (11), (14) and (15) were used to determine the electric power output and the thermal output of Plant D (Ame-Oko *et al.*, 2018).

$$P_e = \eta_{ice} \times E_i \times c_f \quad (14)$$

$$P_t = \eta_{ict} \times E_i \quad (15)$$

where, η_{ice} is the electrical efficiency of the ICE in percentage (%) and η_{ict} is the thermal efficiency of the ICE in percentage (%).

2.5 Data Sourcing

Data used to evaluate the Combined Heat and Power (CHP) potential of the four plants comprised of secondary data from the literature, field study of cassava cottage industries and results of the proximate analysis carried out. The data collected and their sources are summarized in Table 1.

Table 1: Parameters Collected

	Value
Electrical efficiency IC Engine	33.00 %
CHP efficiency IC Engine	78.00 %
Electrical efficiency, gas turbine generator	36.50 %
CHP efficiency, gas turbine generator	65.00 %
Electrical Efficiency, steam turbine generator	7.00 %
CHP efficiency, steam turbine generator	79.57 %
Efficiency of fluidised boiler (HHV)	67.00 %
Efficiency of gasifier (HHV)	71.00 %

Source: Ame-Oko *et al.* (2018)

3. Results and Discussion

The results of proximate analysis of the cassava peels are shown in Table 2.

Table 2: Mean Proximate Anaysis of Cassava Peels

Proximate analysis	(wt. %)
Moisture content	6.53
Volatile matter content	89.57
Ash content	3.78
Fixed carbon	6.65

The Higher Heating Value (HHV) for the cassava peels obtained from proximate analysis was 15.422MJ/kg.

The graphs of potential heat output, electricity output and the consumption rate of the cassava peels for plants A, B, C and D are shown in Figures 2, 3 and 4 respectively. The potential annual electrical energy production for the plants is given in Table 3.

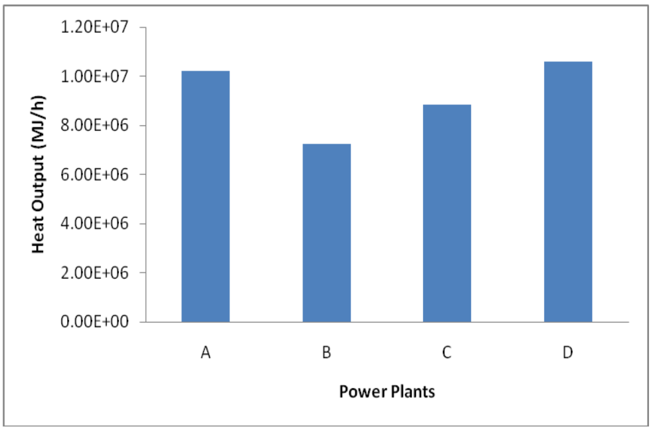

Figure 2: Potential Heat Output of the Plants Using Cassava Peels

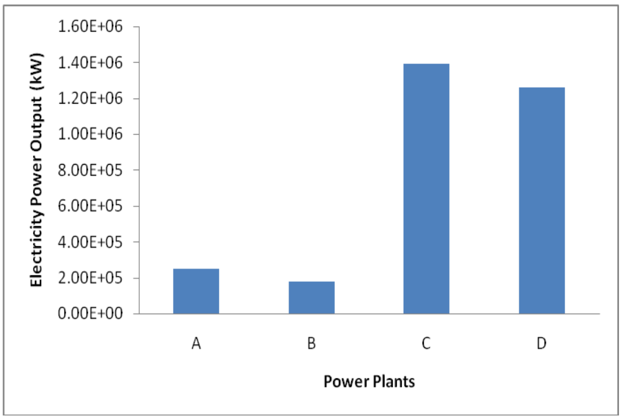

Figure 3: Potential Electricity Output of the Plants Using Cassava Peels

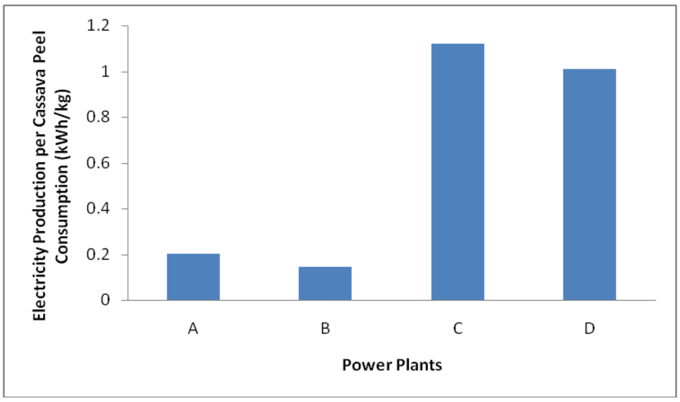

Figure 4: Cassava Peels Consumption Rate of Plants

Table 3: Annual Potential Electricity Energy Production

Plant	kWh
A	9.03×10^8
B	6.42×10^8
C	5.00×10^9
D	4.52×10^9

Potential Electrical power and cogenerated heat output in Nigeria for power plants A, B, C and D using the same quantity of cassava peels (4.46×10^9kg) have been presented with Figure 3. Consideration of the proximate analysis revealed that the moisture content and the volatile matter were similar to those of sawdust; the fixed carbon which is the measure of the heating value of any material was also similar to that of poultry litter (Mierzwa-Hersztek *et al.,* 2019). The ash content was well below those of fossil fuels and the benefit of this is that there is reduced time of removal of ash during operation and also, the ash of organic materials can be used as additives in fertilizer production. It can be seen that all the plants have potentials for electrical power output with Plant C having the highest followed by Plant D and Plant B producing the lowest. Potential of cogenerated heat is in the order: Plant D > Plant A > Plant C > Plant B as shown in Figure 3. The potential electricity energy output per cassava peels consumption is as given in Figure 4. It can be seen from this figure that Plant C will generate the highest quantity of electrical energy per cassava peel consumption (1.121 kWh/kg) closely followed by Plant D (1.009 kWh/kg) compared with Plants A and B. The potential annual electrical power production is as given in Table 2. Considering the efficiency (25% conversion factor), large quantity of cassava peels will be required to satisfy the energy need of the country which will in turn require large holding land. If it is considered from the angle of supplementing the energy that is available at the present and combating global warming, application of cassava peels for both electricity and heat cogeneration may not be a bad idea. Modules consisting of gasifier produced better results in electricity generation compared with others. This agrees with the works of Dinkelbach (2000); Prasara-A *et al.* (2012) and Ame-Oko *et al.* (2018).

4. CONCLUSION

Electricity and heat generation potentials of four power plants using cassava peels were investigated in this work. It can be concluded from the study that generation of electricity and heat from cassava peels is feasible considering the quantity of peels available round the year in the country.

REFERENCES

Ame-Oko A., Adegboye B.A, Tsado J. (2018). Analytical Method to Determine the Potential of Using Rice Husk for Off Grid Electricity and Heat Generation. Nigerian Journal of Technology (NIJOTECH) 37(1): 222 – 225.

(Aso, S.N., Teixeira, A.A. and Achinewhu, S. C. (2018). Cassava Residues Could Provide Sustainable Bioenergy for Cassava Producing Nations, DOI:10.5772/intechopen.7216. https://www.intechopen.com/books/cassava/cassava-residues-could-provide-sustainable-bioenergy-for-cassava-producing-nations.

ASTM Standards (2008) *ASTM D 5142-04: Standard Test Method for Proximate Analysis of the Analysis Sample of Coal and Cokeby Instrumental Procedures*. ASTM Standards 5.

Aro, S.O., Aletor, V.A., Tewe, O.O., Agbede, J.O. (2010). Nutritional Potentials of Cassava Tuber Wastes: A Case Study of a Cassava Starch Processing Factory in South-Western Nigeria. Livest Res Rural Dev 22: 11.

Dairo, O.U., Olayanju, A.T., Ademola, A.A., Ademola, E.A., Adeosun, J., Iyerimah, R.B. (2017). Development of An Anaerobic Digester for Animal Waste. FUOYE Journal of Engineering Technology, 2(2): 17-22.

Das, D., Veziroglu, T.N. (2001). Hydrogen Production by biological Processes: A Survey of Literature. International hydrogen Energy 26:13 – 28.

Demirbas, A. (1997). Calculation of Higher Heating Values of Biomass Fuels. Fuel 76(5):431-434.

Dinkelbach, L. (2000). Thermochemical Conversion of Willow from Short Rotation Forestry, Netherlands Energy Research Foundation.

Diop, A. (1998). Storage and Processing of Roots and Tubers in the Tropics. In: Calverley DJB (ed) Agro-industries and Post-Harvest Management Service, Agricultural Support Systems Division, Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/3/x5415e/x5415e00.htm

Food and agriculture Organization of the United Nations (FAO), FAOSTAT Statistical Database, Statistical Division, Rome (2019). http://www.fao.org/statistics/en/.

Food and agriculture Organization of the United Nations (FAO) (2008) Biofuels: Prospects, risks and opportunities. http://www.fao.org/3/i0100e/i0100e00.htm.

Food and Agriculture Organization of the United Nations (FAO) (2004). Cassava production. http://www.fao.org/3/y5548e/y5548e07.htm.

Hasan, M., Sajana, U., Hossain, M., Hasan, M. (2016). Municipal Solid Waste Management of Pabna Municipality and Prospect of Electricity Production from the Collected Waste IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) 10(10):22-28.

Goldstein, L., Hedman, B., Knowles, D., Freedman, S.I., Woods, R., Schweizer, T. (2003). Gas - Fired Distributed Energy Resource Technology Characterizations. Office of Scientific and Technical information, U. S. Department of Energy. https://www.osti.gov/biblio/15005819-gas-fired-distributed-energy-resource-technology-characterizations.

Goyal, H.B., Seal, D., Saxena, R..C (2008). Bio-fuels from thermochemical conversion of renewable resources: A review. Renew Sustain Energy Rev 12(2):504–17.

McKendry, P. (2002). Energy Production from Biomass (Part2): Conversion Technologies. Bio Resource Technology 83(1):47–54.

Mierzwa-Hersztek, M., Gondek, K., Jewiarz, M., Dziedzic, K. (2019). Assessment of Energy Parameters of Biomass and Biochars, Leachability of Heavy Metals and Phytotoxicity of Their Ashes. Journal of Material Cycles and Waste Management 21:786-800. https://doi.org/10.1007/s10163-019-00832-6

Neves, D., Thunman, H., Matos, A., Tarelho, L., Gómez-Barea, A. (2011). Characterization and Prediction of Biomass Pyrolysis Products. Prog Energy Combustion Science 37(5):611–30.

Nwokoro, S.O., Adegunloye, H.D., Ikhinmwin, A.F. (2005). Nutritional Composition of Garrisievates Collected from Some Locations in Southern Nigeria. *Pakistan Journal of Nutrition,* 4 (4), 257-261.

Otekunrin, O.A., Sawicka, B. (2019). Cassava, A 21st Century Staple Crop: How Can Nigeria Harness Its Enormous Trade Potentials. ACTA Scientific Agriculture 3(8):194 – 202.

Prasara-A, J., Čuček, L., Varbanov, P.S., Klemeš, J.J. (2012). Environmental and Economic Performances of Different Technologies for Power Generation from Rice Husks. Chemical Engineering Transactions 29: 1-6.

Ravindranath, N.H. (1993). Biomass Gasification: Environmentally Sound Technology for Decentralized Power Generation, A Case Study from India. Biomass and Bioenergy 4:49-60.

Ravindranath, N.H., Hall, D.O. (1995). Bio-mass energy and environment. Oxford University Press, New Delhi.

Saxena, R.C., Seal, D., Kumar, S., Goyal, H.B. (2008). Thermochemical Routes for Hydrogen Rich Gas from Biomass: A Review. Renew Sustain Energy Rev 12 (7):1909–1927.