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Research Article

Energy Recovery of Waste (Banana Peels, Mango Peels and Orange Peels) for the Production of Ecological Charcoal in the Republic of Guinea

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Abstract

This research aimed at the production of ecological charcoal from banana, mango and orange peel waste. These wastes were collected among the household solid waste of the city of Kindia, 135 km from Conakry. The methodology approach consists of: sorting and identifying the types of waste, producing ecological coal through the following steps (waste drying, carbonization, grinding, sieving, mixing, adding binders, molding, compacting and drying coal briquettes). The manufactured coal briquettes were characterized for the determination of moisture content, ash content, volatile matter content, carbon content and calorific value). The main results obtained are: (*i*) For the initial masses of waste, banana peels (5 kg), mango peels (2.532 kg), orange peels (1.68 kg); we obtained the masses of coal briquettes made from banana peels (0.328 kg), from mango peels (0.123 kg) and from orange peels (0.237 kg); (*ii*) the physicochemical characterization of the charcoal briquette samples gave a carbon content of charcoal briquettes made from mango peels (45.47%), charcoal briquettes made from orange peels (44.49%) and charcoal briquettes made from orange peels (29.95%); the humidity content of banana peel briquettes is 30.74%, briquettes made from mango peels (12.19%) and briquettes made from orange peels (12.33%); the ash content of charcoal briquettes made from banana peels (17.74%), from banana peels (9.67%) and orange peels (11.14%); the volatile matter rates of charcoal briquettes made from mango peels (90.33%), orange peels (88.86%) and banana peels (82.21%); the calorific value of charcoal briquettes made from banana peels (6580.8 kcal/kg), from mango peels (7226.4 kcal/kg) and from orange peels (7108.8 kcal/kg). Ecological charcoal briquettes are produced locally using less expensive materials and tools, which is an advantage for households in terms of energy, environment and economy.

Keywords

Energy Recovery, Ecological Coal, Household Waste

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1. Introduction

Energy is an essential factor in the functioning of a country's economy and in improving the living conditions of populations. No development is therefore possible without energy [1]. One of the important forms of energy use in developing countries is cooking, this need is generally satisfied by the direct combustion of wood and its derivatives [2]. Wood energy (firewood, charcoal, sawdust, shavings, etc.) used for cooking and heating contributes to more than 80% of the supply and destruction of forest energy resources in Africa [3, 4].

Therefore, it is important that the wood energy source be substituted for other energy sources such as the recovery of agricultural residues within the framework of a circular economy. Thus, the energy recovery of biomass from waste of various origins such as agricultural residues is currently highly encouraged in social, circular economic, especially energy and environmental issues in developing countries [5-7].

Today, global waste production is estimated at nearly 2.5 billion tons per year. This figure will increase by 70% by 2050. This is why, without immediate action and an inadequate or deficient management system, these organic waste products will cause harm to the environment and human health [8]. Waste contributes significantly to climate change, with more than 5% of global greenhouse gas (GHG) emissions [9]. However, the manufacture of green charcoal briquettes is a contribution to the preservation of forest cover and the improvement of sanitation [10]. The Republic of Guinea is full of immense energy potential. However, it still remains one of the countries with the least energy supply [11].

More than 80% of the energy consumed comes from wood and charcoal. The annual production of firewood is estimated at nearly 8000 tons and charcoal at 31,050 tons [12]. GHG emissions are estimated at more than 14266.292 Gg CO_2 equivalent [13]. This concern is now the subject of several areas of scientific research [14-20]. Ecological coal, which is an energy resource derived from biodegradable biomass (agricultural, forestry, household and industrial waste, etc.) rich in carbon, could be an alternative to this concern. This present work is part of this logic. It aims at a test of the recovery of organic waste (banana, mango and orange peels) for the production of ecological coal. To achieve these objectives, several field and laboratory tools were used.

2. Materials and Method

2.1. Materials

The materials used in this research relate to the types of waste, field tools and laboratory sampling and analysis equipment. The waste used for the production of ecological charcoal are: plantain peels, mango peels and orange peels. These residues were chosen from the solid household waste of the city of Kindia because of their seasonal abundance in the city and not recovered [21].

Plantain peels

Plantain peels (Figure 1), also called banana peels, are the rind of this fruit. Banana peels have many applications, including as biochemicals used in nutraceuticals, industrial biotechnology, animal feed, bioremediation (decontamination, water purification).

Mango peels

Mango peels (Kent variety) have quite a few more interesting antioxidant and anticancer properties than the flesh itself (Figure 2). It is also rich in triterpenes and triterpenoids, compounds that have demonstrated anticancer and antidiabetic qualities. Their waste is mostly left in landfills. However, they have an energy potential that can be exploited on a large scale for the production of ecological coal.

Sweet orange (citrus sinensis, sweet orange)

The orange (citrus sinensis/sweet orange) belongs to the Rutaceae family, they have variable shapes and colors, oblong to spherical, from dull greenish yellow to bright dark orange, when ripe. Their size is also very variable, from a few dozen grams to several kilograms depending on the species and varieties. The peel or skin (Figure 3), is generally quite thick compared to the size of the fruit and can even constitute the major part of it.

Figure 1. *Banana peels.*

Figure 2. *Mango peels.*

Figure 3. Orange peels.

2.2. Methodology

The methodology approach consists of: sorting and identifying the types of recoverable waste (plantain peels, mango peels and orange peels); produce ecological coal by going through the following steps (waste drying, carbonization, grinding, sieving, mixing, adding binders, molding, compacting and drying coal briquettes) and finally, determine the physicochemical characteristics (humidity rate, carbon rate, ash rate, volatile matter index and calorific value) of the coal briquettes produced [22].

Pyrolysis of organic biomass is the basis for the production of ecological coal. However, there are several types of processes. Pyrolysis is the decomposition of biomass under the action of heat in the absence of oxygen to give solid products (ecological coals), liquids (condensable vapors) and gases (H2, CO, CO_2, light hydrocarbons) [23]. The organic fractions of these different products depend strongly on the operating conditions (temperature, heating conditions) and the type of product sought.

Operating Mode

The operating mode of ecological charcoal production describes all the steps of the charcoal manufacturing process. This process goes from the choice of the type of waste or residue to obtaining charcoal briquettes. The main steps are described as follows.

Drying

After an initial weighing of each type of organic residue, we directly spread them in the sun in the open air. The residues were weighed daily until a relatively invariable weight was obtained, to conclude that they are dry. The drying times for each residue are: banana peels (7 days), orange peels (3 days) and mango peels (5 days).

Carbonization

A 5 kg aluminum box was used as a furnace to carbonize residue samples, charcoal was used as fuel for carbonization. The carbonization times of the residues are: banana peels (2 hours), orange peels (1 hour 15 minutes) and mango peels (2 hours). After this carbonization phase, the residues were reweighed.

Grinding

After carbonization, we ground each residue using a crank machine. Plastic bags were used to recover charcoal powders.

Adding binders and mixing

Cassava flour mixed with hot water was chosen as a binder. After cooling this yellow texture paste, we mixed it with the residue powder, stirred until a homogeneous black product was obtained.

Molding and compacting

Small diameter PVC pipes were used to mold the briquettes. They were pressed in order to have the well-compressed cylindrical charcoal briquettes.

Drying of briquettes

After all these steps, the charcoal briquettes are finally put in the sun in the open air for drying in order to improve the combustion of the briquettes. The drying of the charcoal briquettes lasted for two days, then they were weighed.

The steps of the ecological charcoal production procedure are illustrated in Figure 4.

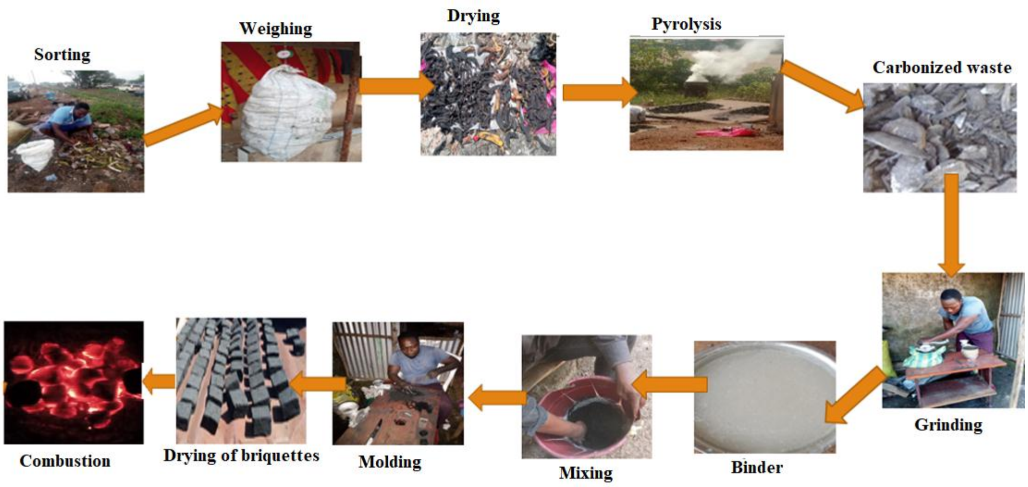

Figure 4. Steps of the ecological charcoal production procedure.

The ecological charcoals produced by each type of residue are illustrated in Figure 5 to 7.

Figure 5. *Briquettes made from banana peels.*

Figure 6. *Briquettes made from mango peels.*

Figure 7. *Briquettes made from orange peels.*

The combustion process of the charcoal briquettes produced are illustrated in Figure 8 to 10.

Figure 8. *Briquettes made from banana peels.*

Figure 9. *Briquettes made from mango peels.*

Figure 10. *Briquettes made from orange peels.*

Physicochemical characterization of coal briquettes

The physicochemical characterization of coal briquettes was carried out at the laboratory of the National Office of Quality Control of Matoto in Conakry. The parameters determined are: humidity rate, ash rate, volatile matter index and calorific value. This step is based on formulas 1 to 7 [24].

Moisture content: $H = \frac{m_i - m_f}{m_i} \times 100$ (1)

Ash content: $\%Ce = \frac{m_c}{m_{bc}}$ (2)

Volatile matter: $MV = H + MO$ (3)

Organic matter: $MO = 100 - (H + Ce)$ (4)

Carbon content: $C = \frac{MO}{1{,}72}$ (5)

Calorific value: $PCI = (100 - C_e) \times 80$ (6)

Briquette combustion energy

Since water is the body or substance to be heated, formula 7 is used.

$$Q_{eau} = m_{eau}.Cp_{eau}.(T_{feau} - T_{ieau}) \quad (7)$$

The specific heat capacity of water Cp water is 4180 J/kg ℃.

3. Results and Discussions

3.1. Results

The results obtained are given in Tables 1 and 2.

3.1.1. Proportions of the Quantities of Residues, Binder and Coal Briquettes

The proportions of the quantities of waste types residues, binder and coal briquettes are given in Table 1.

Table 1. *Proportions of the quantities of residues, binder and coal briquettes.*

Types of waste	Initial mass of waste	Mass after drying of waste	Mass of carbonized waste	Coal powder mass	Binding mass	Binder mass and kneaded powder	Dried coal briquette mass
Banana peels	5	1.352	0.502	0.475	2.750	3.225	0.328
Mango peels	2.532	0.379	0.156	0.155	1.392	1.547	0.123
Orange peels	1.68	0.764	0.486	0.270	0.924	1.194	0.237

3.1.2. Physicochemical Parameters of Coal Briquettes

The physicochemical parameters of coal briquettes: carbon content (C), nitrogen content (N), moisture content (H), ash content (Ce), organic matter (OM), volatile matter (VM) and Lower Calorific Value (LCV) of each type of ecological coal are given in Table 2.

Table 2. *Physicochemical parameters of coal briquettes.*

Types of coal briquettes	C (%)	H (%)	Ce (%)	MV (%)	LCV (kcal/kg)
Banana peel charcoal briquettes	29.95	30.74	17.74	82.21	6580.8
Mango peel charcoal briquettes	45.43	12.19	9.670	90.33	7226.4
Orange peel charcoal briquettes	44.49	12.33	11.14	88.86	7108.8

3.2. Discussions

The results obtained are illustrated by the diagrams in Figures 11 to 16 for their analysis and interpretation.

3.2.1. Charcoal Residues and Briquettes

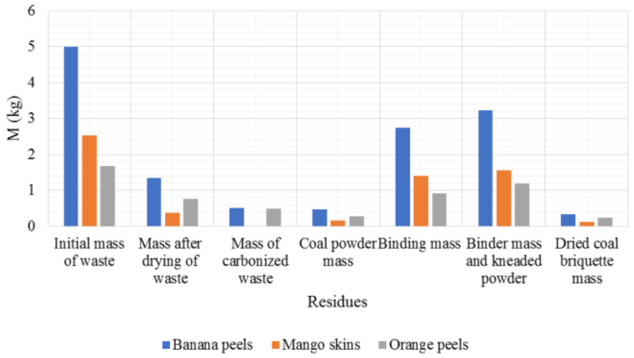

Figure 11. *Characteristics of the obtained charcoal residues and briquettes.*

The charcoal briquettes produced have a height of 6 cm and a diameter of 3 cm. The diagrams in Figure 11 show that:

For an initial mass of 5 kg of banana peels, we obtained: a mass of dried residue of 1.352 kg, a carbonized mass of 0.502 kg, a mass of powder of 0.475 kg, the mass of the cassava starch binder is 2.75 kg, the mass of the mixture of charcoal powder and binder is 3.225 kg, the total mass of briquettes after drying is 0.328 kg;

For an initial mass of 2.532 kg of mango skins we obtained: a mass of dried residue of 0.379 kg, a carbonized mass of 0.156 kg, the powder obtained has a mass of 1.55 kg, the binder used is cassava starch of mass 1.392 kg, the mixing between the powder and the binder gave a mass of 1.547 kg and the total mass of dry charcoal briquettes produced is 0.123 kg;

For an initial mass of orange peels 1.68 kg, we obtained: a mass of dried residue of 0.764 kg, a carbonized mass of 0.486 kg, the powder obtained has a mass of 0.27 kg, the cassava starch binder of mass 0.924 kg, the mixture of binder and charcoal powder is 1.194 kg. The total mass of briquettes after drying is 0.237 kg;

In view of these results, it appears that, for (1 kg) of each type of these wastes, it is possible to produce the following quantities of ecological charcoal briquettes: (0.0656 kg) for banana peels; (0.0485 kg) for mango peels (0.141 kg) for orange peels.

3.2.2. Physicochemical Parameters of Charcoal Briquettes

The results of the physicochemical characterization of the charcoal briquettes produced are illustrated by the diagrams in the following figures.

Carbon Rate

The carbon rates of the samples of the charcoal briquettes produced are represented by the diagrams in Figure 12.

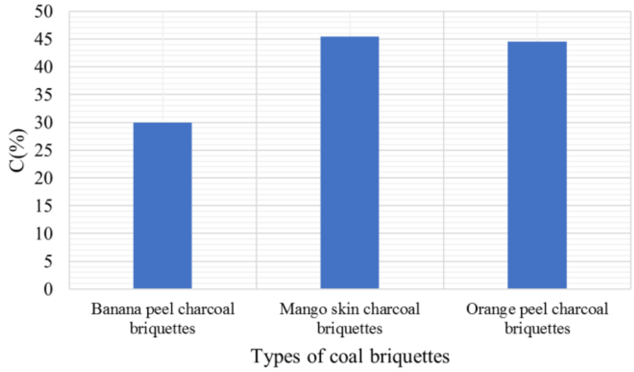

Figure 12. *Carbon Content Diagram.*

The diagrams in Figure 12 show that the carbon content of the briquette samples produced are respectively: charcoal briquettes made from mango peels (45.47%), charcoal briquettes made from orange peels (44.49%) and charcoal briquettes made from orange peels (29.95%). In general, it has been observed that the lower the carbon content, the harder, heavier and easier to ignite the briquettes tend to be [25].

Moisture Content

The moisture content of the samples of the produced charcoal briquettes are represented by the diagrams in Figure 13.

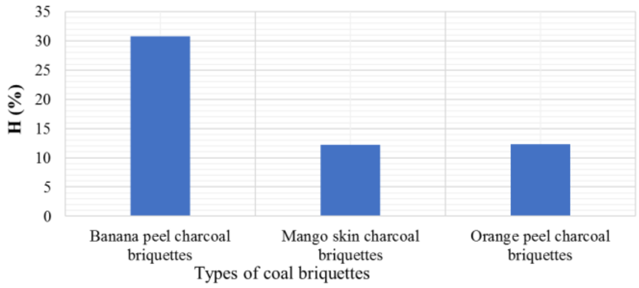

Figure 13. *Moisture Content Diagram.*

The diagrams in Figure 13 show that the moisture content of the produced charcoal briquettes are relatively high compared to the literature review, which is set between (5 - 10%) for good quality briquettes made from agricultural waste. The banana peel briquette has a rate of 30.74% while for the briquettes made from mango and orange peels are respectively: 12.19% and 12.33%. The banana peel briquette has a high rate compared to the other three. This high rate is related to the season and the outdoor drying method.

For some authors, moisture content is an important characteristic of the quality of briquettes. Generally, a high moisture content leads to swelling of the briquettes and their rapid degradation. Moisture content of the briquette above the tolerance level decreases its thermal efficiency as well as its combustion rate. Another disadvantage of high moisture content is the facilitation of a breeding ground for fungi and other microorganisms [26].

Ash Content

The ash contents of the samples of the charcoal briquettes produced are represented by the diagrams in Figure 14.

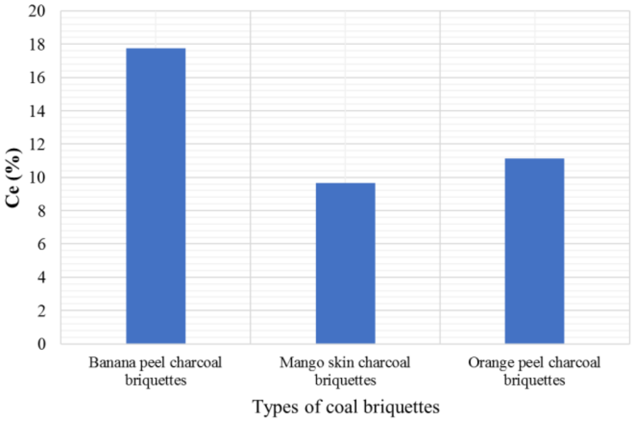

Figure 14. *Ash Content Diagram.*

The diagrams in Figure 14 show that, charcoal briquettes produced from banana peel have a higher ash content (17.74%) compared to briquettes produced from banana (9.67%) and orange peel (11.14%). According to the authors, the tolerance level of ash content for fuel is less than 4%, it should be noted that charcoal produced from agricultural waste biomass has a relatively high ash content, ranging from 9.4% to 22.1% [8]. Our results of ash content of briquettes made from banana, mango and orange peels are within the recommended range.

Volatile Matter Rates

The volatile matter rates of the samples of charcoal briquettes produced are represented by the diagrams in Figure 15.

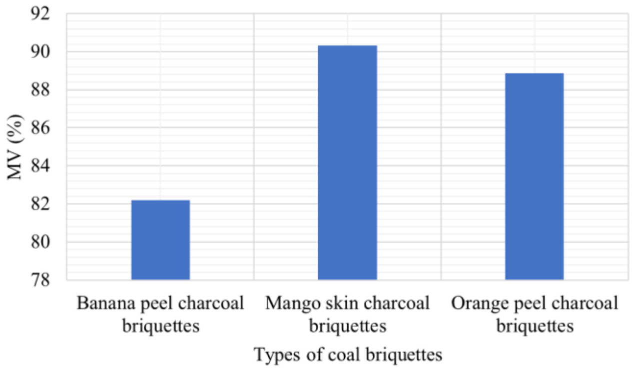

Figure 15. *Volatile Matter Diagram.*

The results in Figure 15 show that the Volatile Matter rates of the samples of charcoal briquettes produced are high compared to the literature which sets between 70% to 86% as high rates. The mango peel based charcoal briquette sample has the highest volatile matter content (90.33%), followed by orange peel-based briquettes (88.86%) and banana-based briquettes (82.21%) respectively. The high volatile matter content is an indication of the ability of the fuel samples to ignite. In terms of briquette quality, high volatile matter content implies that the briquette will produce a high proportion flame during combustion [26].

Calorific value

The calorific value values of the produced charcoal briquette samples are represented by the diagrams in Figure 16.

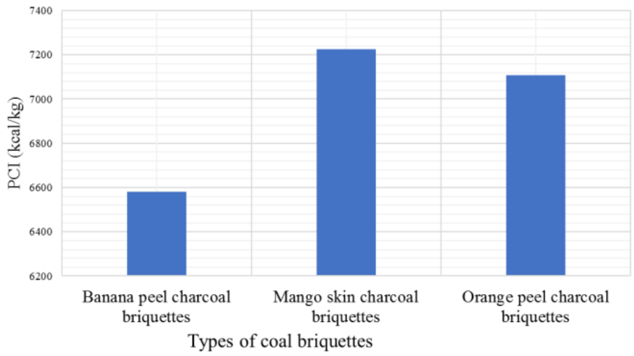

Figure 16. *Calorific value diagram.*

Calorific value is the most important parameter in the combustion of charcoal briquettes, it determines the amount of thermal energy present in a material [27, 28]. Based on the results of Figure 16, charcoal briquettes made from banana peels have a lower calorific value (6580.8 kcal/kg) than the others, mango peels (7226.4 kcal/kg) and orange peels (7108.8 kcal/kg). The quality of charcoal made from banana peels is almost good, even if its LCV is lower than that of the other two.

4. Conclusion

This work is a continuation of our research work in the framework of the management and energy recovery of organic solid waste (household, industrial, agricultural and forestry). The study made it possible to manufacture ecological charcoal from banana, mango and orange peels. The quantities of banana peels (5 kg), mango peels (2.532 kg), orange peels (1.68 kg), allowed us to manufacture charcoal briquettes made from banana peels (0.328 kg), from mango peels (0.123 kg) and from orange peels (0.237 kg). These results correspond to 6.56% of charcoal obtained from 5 kg of banana peels; 4.85% of charcoal from 2.532 kg of mango peels and 14.10% of charcoal from 1.68 kg of orange peels. The physicochemical characteristics (humidity rate, carbon rate, ash rate, volatile matter index and calorific value) of the charcoal briquette samples were evaluated. These results prove that the charcoals produced are combustible and they are of good quality from an environmental and economic point of view. This experimental work should be continued and popularized in Guinea, which would limit deforestation with the abusive use of firewood and charcoal; also to locally reduce greenhouse gas emissions.

Abbreviations

H	Coal Moisture Content (%)
m_i	Initial Mass of Coal Briquettes (kg)
m_f	Final Mass of Coal Briquettes (kg)
m_c	Ash Mass (kg)
m_{bc}	Dry Coal Mass
MV	Volatile Matter Content (%)
MO	Organic Matter Content (%)
Ce	Taux de Cendres (%)
LCV	Lower Calorific Value (J/kg)
m_{water}	Amount of Water to be Heated (kg)
Cp_{water}	Specific Heat Capacity (kcal/kg °K)
T_{iwater}	Initial Water Temperature (°C)
T_{fwater}	Final Water Temperature (°C)

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Author Contributions

Ansoumane Sakouvogui: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review and editing

Wogbo Dominique Guilavogui: Conceptualization, Investigation, Supervision, Writing – review and editing

Adama Moussa Sakho: Funding acquisition, Methodology, Validation, Writing – review and editing.

Cellou Kante: Supervision, Validation, Writing – review and editing

Aly Abdoulaye Camara: Formal analysis, Validation, Writing – review and editing

Mamby Keita: Supervision, Validation, Writing – review and editing.

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Data Availability Statement

All data generated or analyzed during this study can be made available upon request. If necessary, you can contact the corresponding author to obtain an electronic copy of the data.

Conflicts of Interest

The authors declare no conflicts of interest.

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