Accessibility and effects of binder types on the physical and energetic properties of ecological coal

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ABSTRACT

The objective of this paper was to determine the effects of binders on the physical and energetic properties of briquettes as well as their accessibility. Proximate analysis and investigation on binder cost on local market were conducted. The results show that the addition of binder increases the durability and density, but decreases the LHV of briquettes. However, when the LHV of the binder is higher than that of the biomass used for briquette making, the LHV will increase. Among the binders used, cassava starch contains more LHV (19.082 ± 0.381 MJ/kg), followed by cow dung (17.088 ± 0.274 MJ/kg), arabic gum (16.015 ± 0.631 MJ/kg), bark of Grewia bicolor comes last with 14.020 ± 0.272 MJ/kg, and black clay does not contain energy. For a piece of briquette which weighs 20 g, bark of G. bicolor gives a better hardness with a crushing limit load of 22 kg, followed by arabic gum with 19.5 kg, and cow dung with 14 kg. Similarly, bark of G. bicolor gives the higher density, followed by arabic gum. A kg of gum arabic, G. bicolor and starch costs between US$ 1.60 and 3.17. It is important to afforest the plant species that produce binders.

1. Introduction

Access to energy is a primary requirement for economic and social development, as almost every production activity requires energy input (IRENA, 2013). According to Practical Action (2014), 80% of food consumed by humans requires cooking. When people's access to fuel for cooking is limited, especially for the most vulnerable, it exacerbates food insecurity (FAO, 2017b). Thus, since the Far North region of Cameroon has been one of the refuges of Nigerians who fled the abuses perpetrated by Boko Haram terrorists, pressure on wood resources has been exacerbated (URD, 2017; Adam Mahamat, 2021; Kodji et al., 2021). Clearing forests for wood fuel and other purposes has increased woodland degradation (Mahoro et al., 2022). The wood fuel, due to an increasing demand, consumer item acts as the source of conflict, therefore deserves special attention in the context of its sustainable management and its substitution by briquettes coal (Tize et al., 2020; Kodji et al., 2021), especially in an arid Region where the populations are trapped by a vicious circle of poverty (Madi et al., 2003). The inaccessibility of modern energy sources (petroleum products and electricity), the fluctuations in their prices, their irregularities on the markets, the recurrent electricity load shedding, the problem of climate change, and the very worrying desertification, all provide ample justification for focusing on renewable energies that are accessible and very affordable to all (Zakari et al., 2013; Carnaje et al., 2018; Djomdi et al., 2021; Kodji et al., 2021 and Obi et al., 2022). Ecological briquettes have many advantages in reducing household dependence on fossil fuels and stabilizing vegetation cover (Zakari et al., 2013 and Kodji et al., 2021; Obi et al., 2022) and it is smokeless, odorless and sparkles (Sen et al., 2016). Therefore, briquettes coal must be of good quality in order to guarantee food, health, economic and social security (Sen et al., 2016; Djomdi et al., 2021). But, when briquettes coal manufacturing formulations are not followed, they lose their quality after subjecting themselves to handling, transportation or storage (Zakari et al., 2013; Hounyevou et al., 2014; Dohn et al., 2016; Aransiola et al., 2019 and Mousa et al., 2022), and this encroaches its adoption by potential consumers (Mahoro et al., 2022). Thus, in the manufacture of briquettes, some physical properties such as density, durability, compressive strength (Mills, 1908; Borowski et al., 2017; Aransiola et al., 2019; Obi et al., 2022), hardness, moisture content (Nursani et al., 2020...
and Picchio et al., 2020) and the calorific value should be considered (Zakari et al., 2013). These properties depend on the binders, their ratios and types of biomass residues used for briquettes making. With this in mind, the objective of this study is to investigate the effects of five binders (Cassava starch, gum arabic, bark of G. bicolor, cow dung and black clay) on some physical properties just as durability, hardness and density and lower heating value of briquettes coal made from peanut shells, rice husks and straws as well as their accessibility in the Far North region of Cameroon. This, in order to find the best binder in briquettes coal making and facilitate the adoption of the latter by the populations.

2. Material and methods

The determination of the calorific value of the different briquettes was carried out using a Bomb Calorimeter (brand SPAN automation, Model: SABC-01). The density and durability of the different briquettes without/with the addition of binders were determined. Five types of binders were used, namely black clay, gum arabic, starch of cassava flour, cow dung and bark of Grewia bicolor to make the samples of ecological coal from rice husks, peanut shells and straws after carbonization. In addition, the economic aspect of the binders was evaluated on the local markets of the Far North region of Cameroon. Figure 1 illustrated the brief summary of the work.

2.1. Preparation of binders

The preparation of binders depends on the type of binder. Thus, the following points present the preparation of each binder used in this work.

2.1.1. Gum Arabic

Gum arabic is a natural gum made from hardened sap, taken from two species of the acacia tree: Acacia senegalensis and Acacia seyal. These species are found in abundance in the Waza National Park and scattered throughout the Far North region of Cameroon. Gum arabic is a binder used in the manufacture of briquettes. It had been used by Himbane et al. (2018) by mixing 1kg of gum arabic (40%) for 1.5 L of water (60%) and await 24 h, and the resulting gelatinous solution is taken in ratio of 20% for 80% carbonized powder. In this work, after drying, grinding and sieving through a 0.5 mm mesh sieve, the proportions of 5, 10 and 20% of this binder had been used.

2.1.2. Black clay

Black clay is used in the manufacture of ecological coal as a binder at proportions of 15–20% (Himbane et al., 2018; Tize et al., 2020). In this work, it was prepared as follows: after the collection of black clay, it was ground in a mortar and then sieved through a 0.5 mm mesh sieve. Thus, the proportions of 5, 10, and 20% of clay were taken for the mixture with the different carbonized powders of the residue biomasses used.

2.1.3. Cassava starch

Starch (cassava flour) is one of the materials used as a binder in the manufacture of briquettes (Bintu et al., 2014; Borowski et al., 2017; Obi et al., 2022). So, it was crushed and sieved through a 0.5 mm mesh sieve. The measure of cassava flour was ten measures of water. This mixture underwent gentle heating until the slurry thickened, after which it was ready for mixing at desired proportions with the carbonized residues biomass powders. In this work, the proportions of 5, 10, and 20% were tested.

![Figure 1. Brief summary of the study.](image-url)
2.1.4. Bark of Grewia bicolor

The species *G. bicolor* is a bushy shrub of 4–8 m height. Its bark is smooth, cracked and grey. In the Far North region of Cameroon, the bark of *G. bicolor* is used to make cowpea fritters digestible; the brewers of traditional wine (bil-bil) use it as a flocculant; it is also used to smooth the inside of huts (floor as well as wall) and as a binder in the molding of traditional tobacco. Thus, it was tried in this work as a binder in the manufacture of ecological coal. Thus, it was taken, dried, crushed in a mortar, and sifted with a sieve of mesh 0.5 mm and used in proportions of 5, 10 and 20%.

2.1.5. Cow dung

Cow dung has been used at a proportion of 30% as a binder in the manufacture of ecological coal based on chips (Carnagey et al., 2018). Similarly, in this work, it will also be used as a binder. In a cow pen, straws were spread in order to prevent cow dung from being mixed with the soil. Thus, only cow dung that has not been in contact with the soil and not trampled by the cow is collected on these straws. For this purpose, the dry dung was ground in a mortar and sieved through a 0.5 mm mesh sieve. Thus, proportions of 5, 10 and 20% had been used for the manufacture of ecological coal. Dry or fresh dung can be soaked in water, and not trampled by the cow is collected on these straws. For this purpose, the dry dung was ground in a mortar and sieved through a 0.5 mm mesh sieve. Thus, proportions of 5, 10 and 20% had been used for the manufacture of ecological coal. Dry or fresh dung can be soaked in water, and await 24 h for the mixture to be sticky before using it.

2.2. Determination of density

To determine the density of these different shapes of compacted ecological coal, it is important to measure their volume and take their mass. For a coal with a rectangular shape, the base area has been taken into account, because according to the local markets of the Far North Region of Cameroon.

\[ V = l \times L \times H \]  

(1)

where:

- \( V \): volume of briquette
- \( l \): width of briquette;
- \( L \): length of briquette;
- \( H \): height of briquette.

By integrating of Eq. (1) in Eq. (2) to deduce the density of ecological briquettes according to their shapes.

\[ \rho = \frac{m}{V} \]  

(2)

where:

- \( \rho \): Density,
- \( m \): mass of briquette and
- \( V \): volume of briquette.

2.3. Determination of the durability of ecological coal

The durability of an ecological coal is a parameter that needs to be taken into account, because according to the findings, the briquettes sinter during handling, transportation and storage (Dohm et al., 2016). Thus, the determination of durability was done via a crushing limit load. This is a mass that an ecological coal can withstand when stacked during transport or storage without sintering. To do this, on a piece of ecological coal whose mass is known, put a minimum load and add gradually until reaching a limit load to crushing. The Figure 2 show the steps for the determination of the crushing load of the ecological coal used in this work.

In addition to the determination of the crushing limit load, the same quantities of the manufactured ecological coal samples had been loaded in bags and others into boxes, and subjected to the shocks during handling and transportation on 70 km of road with potholes. This test provides a good determination of losses due to frictional forces, and attritional forces (Dohm, 2016).

2.4. Determination of lower heating value (LHV)

The LHV of the different residue biomasses and binders was determined by the calorimetric bomb method according to American Standard Testing Methods (ASTM) D5865-10a (2010). The sample to be burned was weighed on a precision electronic balance (0.0001 g) and introduced into the bomb. An ignition wire (10–13 cm long) is attached to two electrodes of the canister in such a way that it touches the compacted sample deposited in the crucible. Then the bomb is sealed and filled with oxygen at 30 atm. The bomb is introduced into a thermostatic bath of distilled water. We waited 5–10 min for the ambient temperature of the water to stabilize before initiating the electrical ignition of the sample. At the end of the burn, we measured the length of the remaining wire and the ash content to automatically calculate the heating value of the fuel. For each sample, the test was repeated 4 times. The heat capacity of the calorimeter or device constant (W) is the sum of the heat capacities of the different components of the calorimeter, including the can, the bucket, and the water in the bucket. It is given by Eq. (3):

\[ W = \frac{(M_{\text{benzoic acid}})^* (LHV_{\text{benzoic acid}})}{\Delta \theta} \]  

(3)

Where:

- \( W \) (cal/C): Heat capacity of the calorimeter determined with benzoic acid (C6H5COOH); \( M \) (in g): mass of the sample of a benzoic acid; LHV (cal/g): calorific value of the benzoic acid; \( \Delta \theta \) (°C): temperature variation during the combustion of benzoic acid.

It is also important to mention that the equivalent energy depends on the setting of the operating conditions (ASTM-D5865-10a, 2010). The determination of the heating values of the other samples being done under the same conditions. Thus, the heating value (Hg) of a fuel has been determined according to Eq. (4):

\[ H_g = \frac{(M_f)^* (W)}}{\Delta \theta} \]  

(4)

\( H_g \) (Cal/g): heat of combustion; \( M_f \) (g): mass of a fuel; \( \Delta \theta \) (°C): temperature variation during combustion of a fuel; \( W \) (cal/C): instrument constant or heat capacity of the calorimeter.

2.5. Accessibility to the binders

Another factor to be determined in the choice of binder is the cost of its acquisition. Thus, the price of different binders was evaluated on the local markets of the Far North Region of Cameroon.

![Figure 2. Determination of the crushing limit load. a) minimum load, b) adding the load, c) crushing.](image-url)
3. Results and discussion

The choice of binders depends on several factors: density, durability, effect on LHV and economic aspect.

3.1. Effects of binder on the density of ecological coal

The density of a fuel plays a very important role in combustion. In this work, we compared the effect of the increase of binder proportion to briquettes density without binder. Tables 1, 2, and 3 illustrate the different results of the proportion of binders’ effects on the briquettes density.

As regards the ANOVA (fisher test, P < 0.05), the results having the same letters in exponent on the same column are not significantly different. The results in Tables 1, 2, and 3 show that in general the addition of binders in the manufacture of ecological briquettes increases the density. But the increase of density depends on the type of binder and biomass used. Thus, in this work, it is noted that the bark of G. bicolor and gum arabic appear as the best binders giving 0.636 ± 0.001 and 0.633 ± 0.002 g/cm³ respectively for briquettes made with straws. These results are almost similar to those obtained by Chirchir et al. (2013) reporting that the density increases with increase in amount of binder, and the mean density they found were 0.580 g/cm³, 0.614 g/cm³ and 0.645 g/cm³ respectively for briquettes made with straws.

Density differences of the proportion of binders were found to be significantly different. The results in Tables 1, 2, and 3 show that in general the addition of binders in the manufacture of ecological briquettes increases the density. But the increase of density depends on the type of binder and biomass used. Thus, in this work, it is noted that the bark of G. bicolor and gum arabic appear as the best binders giving 0.636 ± 0.001 and 0.633 ± 0.002 g/cm³ respectively for briquettes made with straws. These results are almost similar to those obtained by Chirchir et al. (2013) reporting that the density increases with increase in amount of binder, and the mean density they found were 0.580 g/cm³, 0.614 g/cm³ and 0.645 g/cm³ respectively for briquettes made with straws.

3.2. Hardness and durability of ecological coal

The determination of the crushing limit load of ecological coal was used to determine the durability in this work. It depends on the constituent materials of the ecological coal (type of raw material and the binder used). Table 4 shows the crushing limit loads of the manufactured briquettes.

From this Table 4, it can be seen that the crushing limit load of the different ecological coal is between 14.4 and 22.4 kg for a piece of briquette weighing 20 g. The bark of G. bicolor gives a rigid form to the ecological coal. This would weigh an average of 22 kg. Thus, after handling and transport in three trials over a distance of 70 km (Mokolo-Maroua), a loss of 1–3% has been recorded of the ecological coal that were inside the boxes compared to those that were loaded in bags where the losses were between 15 and 20%. The shape of the briquettes also plays an important role in their degradation. Spherical shaped briquettes sinter quickly, followed by cylindrical shapes. The rectangular shape would be the best because it leaves less void. Therefore, the ecological coal experience less shock. This remark was also observed by Mills (1908) and Krah et al. (2019).

3.3. Effect of binder on calorific value

The determination of the lower heating value of the 5 different binders used allows to better appreciate their influence on the ecological briquettes. Table 5 shows the calorific value of the different binders used.

From Table 5, it can be seen that among the binders used, cassava flour has the highest LHV (19.082 ± 0.381 MJ/kg), followed by cow dung (17.088 ± 0.274 MJ/kg), and the LHV of black clay is 0 MJ/kg. For the different biomasses of residues used at 100 without addition of binder, present of LHV as presented by Table 6.

From Table 6, it appears that peanut shells have the more LHV (26.28 ± 0.55 MJ/kg), followed by straw (22.25 ± 0.35 MJ/kg) and rice husks come in last position with 14.54 ± 0.55 MJ/kg. Thus, after addition of
the binders to proportions of 5, 10 and 20% in the manufacture of the ecological coal of these biomasses of residues (see Table 2), rise by Tables 7, 8, and 9 of the LHV.

The analysis of the data in Tables 7, 8, and 9, shows that in terms of energy, by comparing the average of LHV of different binders and referent to the biomass LHV, starch (cassava flour) at a proportion of 5% maintains the LHV close to that of the ecological coal at 100 of biomass, followed by cow dung and black clay comes in last position. Thus, cassava starch is the best binder in terms of optimizing the calorific value to the ecological coal. We notice that when the LHV of the biomass is higher than that of the binder, the addition of the latter decreases the calorific value of the ecological coal. The results reported by Anatasya et al. (2019), on the briquettes made from cow manure mixed with starch as binder and sugar cane, observed the decrease of LHV from 3900 Cal/g to 3400 Cal/g for 5%–25% of binder proportion respectively for, Nursani et al. (2020), have found 4360.84 kcal/kg, 3783.02 kcal/kg and 3290.71 kcal/kg when adding binder at proportion of 0%, 3% and 6% respectively, and AIP Conference Proceedings (2021) worked on influence of starch binder composition on properties of biomass briquettes from Durian peel, showed that the increase of the proportion of binders, decrease the calorific value of briquettes. In fact, when the LHV of the binder is lower than that of biomass, the increase of the proportion of binder, decrease the LHV of charcoal briquettes and vice versa. The black clay decreases the LHV of the ecological coals. According to the results obtained by Alula et al. (2015) on the manufacture of sesame stalks briquettes, the increase of the proportion of clay used as binder, decreases the LHV of briquettes. However, it allows to store the energy contained in these briquettes to release it slowly during cooking.

### 3.4. Accessibility to binders

The binders used in the manufacture of ecological coal in this table are presented in Table 10 giving the price of 1 kg of each binder and the ecological coal that can be produced. The choice of binder in the manufacture of ecological briquettes must take into account the economic aspect. The high cost of the binder limits its accessibility and has an effect on the ecological coal intended for marketing, for it will not be profitable. Table 10 shows that in the region's markets, the price of 1 kg of cassava flour, and G. bicolor bark is sold at US$ 1.60 and 1 kg of gum arabic at US$ 3.17. If we consider a proportion of 90% biomass and 10% of binder, then 1 kg of each binder can only be used to make 10 kg of ecological coal. Indeed, the very high price of gum arabic is due to the fact that it is not available in large quantities on local markets in the region. In addition, the little that is available is very used by the laudeners to starch hats. Similarly, the bark of G. bicolor (called kielé in foulfould) is disappearing from the forest of the region. It is also highly prized by doughnut sellers, ‘bil-bil’ brewers as a flocculant and some use it as a vegetable. This strong pressure on this species shows that it is not available in sufficient quantities, thus limiting its accessibility. As for cow dung and black clay, they remain available and accessible.

![Figure 3. Box model for the packaging of ecological coal.](image)

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**Table 5. LHV of the different binders used for the manufacture of ecological coal.**

| Binders               | Types of binders | LHV (MJ/kg) |
|-----------------------|------------------|-------------|
| Starch (cassava flour)| Organic          | 19.082 ± 0.381|
| Gum arabic            | Organic          | 16.015 ± 0.631|
| Cow dung              | Organic          | 17.088 ± 0.274|
| Bark of Grewia bicolor| Organic          | 14.020 ± 0.272|
| Black clay            | Mineral          | 0           |

**Table 6. LHV of the residue biomasses at 100% (Kodji et al., 2021).**

| Raw Materials (100%) | LHV (MJ/kg) |
|----------------------|-------------|
| Peanut shells        | 26.28 ± 0.55|
| Rice husks           | 14.54 ± 0.55|
| Straws               | 22.25 ± 0.35|

**Table 7. Variations in LHV as a function of 5% binder.**

| Proportion of binders/biomass | LHV of Ecological coal (MJ/kg) |
|------------------------------|--------------------------------|
| Rice husks                   |                                |
| 0%                           | 14.540 ± 0.55                 |
| 5%                           | 14.655 ± 0.106                |
| 10%                          | 14.603 ± 0.111                |
| 15%                          | 13.811 ± 0.140                |
| 20%                          | 14.654 ± 0.171                |
| 25%                          | 14.514 ± 0.102                |

**Table 8. Variations in LHV as a function of 10% binder.**

| Proportion of binder/biomass | LHV of Ecological coal (MJ/kg) |
|------------------------------|--------------------------------|
| Rice husks                   |                                |
| 0%                           | 14.540 ± 0.55                 |
| 10%                          | 14.772 ± 0.113                |
| 20%                          | 14.671 ± 0.110                |
| 30%                          | 13.064 ± 0.107                |
| 40%                          | 14.991 ± 0.073                |
| 50%                          | 14.408 ± 0.182                |
Table 9. Variations in LHV as a function of 20% binder.

| Proportion of binder/biomass | LHV of Ecological coal (MJ/kg) | Straws |
|-----------------------------|--------------------------------|--------|
| Rice husks                  |                                |        |
| Biomass at 100%             | 14.540 ± 0.550                 | 26.280 ± 0.550 | 22.25 ± 0.35 |
| Cow dung at 20%             | 15.04 ± 0.039                  | 24.452 ± 0.401 | 21.215 ± 0.32 |
| Arabic gum at 20%           | 14.715 ± 0.132                 | 24.351 ± 0.212 | 21.002 ± 0.13 |
| Black clay at 20%           | 11.502 ± 0.104                 | 22.062 ± 0.112 | 17.689 ± 0.20 |
| Starch of cassava flour at 20% | 15.446 ± 0.037          | 24.779 ± 0.171 | 21.622 ± 0.11 |
| Cow dung at 20%             | 14.396 ± 0.012                 | 23.424 ± 0.131 | 20.611 ± 0.45 |

Table 10. Price of binders and quantity of briquette produced.

| Types of binders | Price of 1 kg of binder (in US$) | Briquettes that can be made with 10% of binder for 90% of biomass (kg) |
|------------------|----------------------------------|--------------------------------------------------------------------|
| Bark of G. bicolor | 1.60                             | 10                                                                  |
| Arabic gum       | 3.17                             | 10                                                                  |
| Black clay       | -                                | 10                                                                  |
| Starch of cassava | 1.60                             | 10                                                                  |
| Cow dung         | -                                | 10                                                                  |

4. Conclusion

It was in this work to determine the effect of binder on briquettes properties and their accessibility. Among the binders tested, the results show that the addition of binder, increases the durability and density, but decreases the LHV of briquettes coal. The bark of G. bicolor offers a better hardness and density with a crushing limit loads of 22.3 kg of 20 g briquettes coal, and 0.636 g/cm³, followed by gum arabic with 19.6 kg as crushing limit loads and 0.632 g/cm³ as density of briquettes. But, in terms of calorific value, cassava starch at proportion of 5% would be better for maintaining the LHV of briquettes. Among the binders used in this work, only cow dung and black clay can be collected even without being purchased, but do not yield good quality to briquettes coal as well as bark of G. bicolor, gum arabic and cassava starch. Therefore, it is important to promote afforestation of senegalesis and Acacia seyal species to produce more binders and G. bicolor for its bark.

Declarations

Author contribution statement

Kodji Exéchéil: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data, wrote the paper.

Tize Koda Joel: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data, wrote the paper.

Awono Abdon, Djoulde Darman Roger: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data, wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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