GSJ: Volume 12, Issue 4, April 2024, Online ISSN 2320-9186
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Study of the Performance of Organic and Inorganic Binders for the Production of Ecological Charcoal Fuels Based on Dead Biomass of *Azadirachta indica*

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Abstract

In Sahelian cities, desertification with its climatic corollary is due to the excessive use of firewood by increasingly growing populations. However, the dead biomasses of *Azadirachta indica* swept away from households and unnecessarily buried in urban waste dumps could be recycled into ecological charcoal. But, it is necessary to know the binder best suited to better recovery in order to produce high-performance ecological charcoal for cooking. Thus, in this study, its valuation as cooking energy aims to determine the performance of organic and inorganic binders for the production of combustible ecological charcoal based on the dead biomass of *Azadirachta indica*. The collection and sorting of these plants made it possible to prepare the raw material and the binder. The mechanical method allowed the production of ecological coal by way of carbonization. Their physical and chemical characterization made it possible to respectively obtain the average density which is 1.13 ± 0.02, the average moisture content which is 3.17 ± 0.04%, the average of volatile matter content which is 46.92±1.93%, while the average fixed carbon content is 10.28±1.04%. The energy efficiency of the charcoals show that average calorific value which is 30.83 ± 1.08 MJ / Kg, an average maximum temperature of 540.37 ± 11.53 ° C and a heat of the ash post combustion 262.95±18.37°C. The cooking test shows that with ecological charcoal based on *Azadirachta indica* (90%) bonded to organic matter (10%), the average start of boiling of water is 6.38 ± 1.76 minutes while the average boiling time of water is interesting with ecological charcoal based on *Azadirachta indica* (85 to 90%) bonded to inorganic matter (10 to 15%) of 12.8 ± 0.25 minutes.

Keywords: *Azadirachta indica*, ecological charcoal, Sahelian cities, Organic and Inorganic Binders

Introduction

In the Sahelian zone of Cameroon, firewood is the only source of energy accessible by more than 80% of rural and urban households (Folefack and Abou, 2009). In 2002, the supply of firewood to the major cities of northern Cameroon was estimated at more than 50,000 tons per year (Njomgang, 2002). In terms of energy, the overexploitation of wood energy has caused a widening of the circle of deforestation around the towns of Maroua and Garoua, leading to erosion and a drop in agricultural productivity (Madi, et al., 2003; Folefack and Abou, 2009). However, in urban areas, the share of debris and waste from dead plants is estimated at 79.02 kilograms per day, with little "value" in the eyes of households, and which could be recycled into ecological charcoal (Dzokom, et *al.*, 2022). One of the problems is knowing the most suitable binder for the production of ecological charcoal fuels based on the dead biomass of carbonized *Azadirachta indica* in order to make the by-products of the process profitable for the environment. *Azadirachta indica*, a species mainly planted in Sahelian towns, with an average defoliation of 1.28 kg/day (Tizé et al., 2013), has been described by the World Health Organization (WHO) as "the tree of 21st century" (IUCN, 2022). The dead stems of *Sorghum sp.*, the dead stems of *Zea mays L.*, the sap of *Acacia seyal* and the peels of *Saccharum officinarum* are organic binders on the one hand, while the sand from the dunes, the sand from the rivers, the monmorillonitic clay, and kaolinitic clay are inorganic binders whose effectiveness would allow better use. The objective of this work is to contribute to the determination of the performance of organic and inorganic binders for the production of ecological charcoal fuels based on the dead biomass of *Azadirachta indica*. Through a simple manual sorting, the inputs were selected and then prepared separately in order to obtain carbonized raw material and binder. The production of ecological coal followed by their physical and chemical characterization makes it possible to determine and control their physical state. Determining their energy efficiency through combustion tests makes it possible to classify binders for intensive production and less expensive use for households.

1. Materials and methods

1.1. Study zone

The city of Maroua, capital of the Far North region of Cameroon is located at an altitude of 423 m, between 10°29' to 10°41' North latitude and 14°15' to 14°27 ' East longitude. It is a linear city extending over 15 km in the direction of the West-East slope and covering 56 km^2 (Bouba, 2009). The Far North region, bordering Chad and Nigeria, covers an area of 34,263 km^2. The region belongs to the Sudano-Sahelian and Sudano-Guinean zones (MINEPAT, 2010; MINFOF, 2014). Five types of units are distinguished:

- the Logone alluvial plain which extends from Yagoua to Lake Chad is made up of sandy clay soils and vertisols on which we find woody vegetation dominated by *Acacia seyal, Acacia siberiana, Daniela olivieri, Ficus mitrgyna, Ziziphus mauritiana* and *Sesbania sesban*;
- the vast plains of Diamaré, Bénoué, Kaélé, and Kalfou characterized by vertisols and ferruginous soils with a san dy-clay texture. Woody vegetation includes *Acacia seyal, Balanites aegyptiaca, Guiera senegalensis, Sterculia setigera, Anogeissu sleiocarpa, Vitellaria paradoxa* and *Lannea humilis*. The Bénoué plain is much more wooded with Combretaceae, Caesalpiniaceae, *Terminalia spp., Khaya senegalensis* and *Daniella olivieri*;
- the Mandara Mountains from 800 to 1400 m in altitude, made of lithosols and which carry vegetation dominated by *Ziziphus mauritania, Boswellia dalzielii* and *Annonas senegalensis*;
- the foothills, transition zone between the Mandara Mountains and the plains, whose vegetation consists of *Terminalia macroptera, Diospiros mespiliformis, Annona senegalensis* and *Acacia albida*;
- woody formations (with *Prosopis spp., Acacia seyal, Mitragyna inermis*) rupicolous located in permanent waterways (Bénoué, Logone) and large mayos such as Serwel, Mayo-Nguétchéwé, Mayo-Tsanaga, Mayo-Boula, Mayo Louti.

1.2. Selection, sorting and preparation of dead leaves and leaf stems of *Azadirachta indica*

Dead biomass of *Azadirachta indica* was collected in bulk from their dumping grounds. Then, via a manual selective sorting process, it was separated from the dead leaves on the one hand and the branches on the other. Then, after drying, a total of 10 kilograms of dry biomass was obtained, i.e.:

Table 1: Preparation of raw materials

Raw material	Quantity after drying (gr)	Quantity after carbonization (gr)
***Azadirachta indica* dry dead leaves**	500	159.3
***Azadirachta indica* dry branches**	500	165.9

The total amount of charred raw material used in this study is 300 grams, consisting of charred *Azadirachta indica* dead leaves (150 grams) and charred *Azadirachta indica* dead branches (150 grams).

1.3. Selection, sorting and preparation of binders

The organic binders used in this work are: dead stems of *Sorghum sp.*, dead stems of *Zea mays L.*, Sap of *Acacia seyal* and peels of *Saccharum officinarum*. The inorganic binders used in this work are: Sand from the dunes, Sand from the rivers, monmorillonitic clay, and kaolinitic clay

Table 2: Preparation of binder materials

Organic binders				Inorganic binders			
Binder material	Fine quantity (0.2≤Ø≤1) (gr)	% Solution concentration	Viscosity (mPa.S)	**Binder material**	Fine quantity (0.2≤Ø≤1) (gr)	Plasticity index (Ip)	Swelling percentage (%)
Stem *Sorghum*	100	20	1280	**Dune sand**	100	0-10	0-1
Stem *Zea mays L.*	100	15	2010	**River sand**	100	0-10	0-1
***Acacia seyal* sap**	100	45	3000	**Monmorillonitic red clay**	100	10-20	1,5-5
***Saccharum officinarum* peel**	100	05	2830	**Kaolinitic clay from lowlands**	100	10-20	1,5-5

1.4. Physical chemical characterization of fuel samples based on dry dead leaves of *Azadirachta indica*

1.4.1. Moisture content

Moisture content was inspired by the methodological measurement procedures developed by (Tobiasson, et Coll, 1991). Moisture content was expresses the water content and has a strong influence on the calorific value and the ignition capacity of the briquettes. The moisture content is obtained by the following formula:

$$W(\%) = \frac{(\text{Wet matter} - \text{Dry matter})}{\text{Dry matter}} \times 100 \qquad (1)$$

With: W: moisture content; M wet: mass of the sample; M dry: mass obtained after heating to 105°C in an oven.

1.4.2. Density of charcoal

Kers et *al.*, (2010) indicate that the density of cooking fuels based on bio-waste depends on the density of the original bio-waste, the pressure applied during the manufacture of the cooking fuels and, by extension, the temperature and time. For this study, the formula was then established:

$$\rho = \frac{m}{V} \ (\text{gr/cm}^3) \qquad (2)$$

Where V is the volume of the briquette and m is the mass of the briquette.

1.4.3. Porosity of charcoal

The porosity of the briquettes, made in the laboratory, consists in determining the ratio between the volume of air present in the ground material (skeletal volume - apparent volume of the briquette) and the skeletal volume of the combustible briquette. Its formula is given by the relation:

$$\alpha b = 1 - \frac{\rho app}{\rho sq} \qquad (3)$$

With α_b: porosity; ρ_{app}: apparent density; ρ_{sq}: skeletal density

1.4.4. Charcoal Resistance Index

The Charcoal Resistance Index (CRI) or Green Coal Stability Test is determined by the compression tests that the green coal undergoes. The compressive strength of ecological coal in its cylindrical position is determined by the appearance of faults during its compression (Kers et *al.*, 2010).

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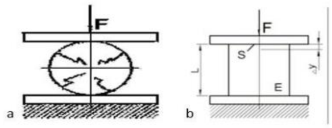

Figure 4: a)-Test of the compression force of briquettes and condition of appearance of cleavages; b) -Test of the axial compression force of briquettes and condition of appearance of cleavages (Kers et *al.*, 2010).

1.4.5. Fuel moisture uptake rate

The moisture uptake test via a simple immersion test that is subjected to ecological coal makes it possible to characterize their potential resistance to thermal and environmental hazards of the storage location. It consists of measuring the diameter of the fuel before and after immersion in order to determine the difference in water imbibition and the percentage of inclusion of the materials in the ecological charcoal briquette (Olorunnisola, 2007). It is expressed in cubic centimeters (cm^3) (Dzokom et *al.*, 2022).

1.4.6. Volatile matter content

The BS EN 14,774-1 protocol, for the determination of the volatile matter of a fuel consists in weighing the dry sample then heating it under nitrogen, at a temperature between 890° and 910°C for 7 minutes in a crucible with lid and weigh it again. The formula developed by the standard method (ASTMD3175-17, 2017) is used to calculate the volatile matter rate:

$$\mathrm{M.O.V.} = \frac{((\mathrm{M850°C} - \mathrm{M899°C}) \times 100)}{\mathrm{Mdry}} (\%) \qquad (4)$$

With: MOV: Volatile matter content, $M_{850°C}$: Mass obtained after heating to 895°C, $M_{899°C}$: mass obtained after heating to 899°C

1.4.7. Ash content

In the context of this work, the ash content is the quantity of very small mineral matter contained in a fuel and released after complete combustion, under the effect of heat at high temperatures. The result is obtained by applying the formula developed by the standard methods (ASTMD5142-02, 2002 and ASTME711-87, 2004):

$$\mathrm{A.} = \frac{(\mathrm{M850°C} \times 100)}{\mathrm{Mdry}} (\%) \qquad (5)$$

With: A, $M_{850°C}$: mass of the powder obtained after incineration at 850°C, M_{dry}: dry mass of the sample.

1.4.8. Fixed carbon content

To determine fixed carbon, the BS EN 14.774-1 protocol was used. Two parts, each weighing 1 gram, of combustible briquettes were made, then they were introduced into an oven for calcination. One part was calcined for 10 minutes at a temperature of 550°C, while the other part was calcined for 10 minutes at a temperature of 850°C. The fixed carbon rate developed by the standard method (ASTME711-87, 2004) allows it to be calculated using the following formula:

$$\mathrm{Cf}(\%) = 100 - (\mathrm{Hsec} + \mathrm{Mce850°C} + \mathrm{Mv550°C}) \quad (6)$$

1.4.9. Fuel efficiency tests

a) Calorific value

The ASTME711-87 (2004) method and the MA protocol, 108-P.Cal. 1.0 helped measure and calculate calorific value. The heat capacity of the bomb and the tank was calculated from a test made with benzoic acid. The calorific value of the samples is measured by the following equation:

$$\mathrm{P.C.} = \frac{([1000 \times (\mathrm{T°f} - \mathrm{T°i}) \times \mathrm{W} - (\mathrm{Hh} \times \mathrm{a})])}{\mathrm{b}} (\mathrm{MJ/kg}) \qquad (7)$$

Where P.C.: calorific value of the sample (MJ/k g); $T°_f$: maximum final temperature of the water in the tank after firing (°C);

b) Determination of the ease of ignition of charcoal

The ignition test consists of determining the ease of ignition of combustibles in 5 minutes. It consists in measuring, using a thermocouple, the temperature of the fire of an incandescent sample ($T°_{it}$). The ignition of the fuel lasts 1 minute and the measurement of the temperature of the incandescent part of the fuel is done at 25 s ($T°_{t'}$) and at 300 s ($T°_{t''}$). Ease of ignition is written by Formula 1 (Souleymane et *al.*, 2020).

$$\mathrm{T°it} = \mathrm{T°t''} - \mathrm{T°t'} \qquad (8)$$

$T°_{it}$: ignition temperature, $T°_{t''}$: temperature at t equal to 5 min, $T°_{t'}$: temperature at t equal to 25 s.

c) Determination of the duration of combustion

The burning time (CD) test consists of determining the total burning time of 600 g of fuels introduced into an improved hearth with a clay combustion chamber. It begins with lighting until the ashes are obtained. The burning time is written according to Formula 2.

$$\Delta\mathrm{t} = \mathrm{tf} - \mathrm{ti} \qquad (9)$$

Δt: time taken by the fuels to be consumed; t_f: fuel combustion end time; t_i: sample combustion start time

d) Cooking test

The cooking test lasts 2 hours. It is determined from the onset and duration of water boiling, the quantities of water remaining and evaporated and then the fire temperature of the fuels. The results are obtained according to the relationships below:

Start of boiling

The onset of water boil is the time it takes for water to boil. It is expressed as follows

$$\mathrm{teb} = \mathrm{t\,deb} - \mathrm{t\,p} \qquad (10)$$

teb: start of water boiling; t deb: time from which the water boils; t p: time from which the pan is placed on the fire.

Boiling time

It corresponds to the boiling time of water. To do this, we make the difference between the time when the water stops boiling and the time it starts boiling. The expression is as follows

$$\Delta\,\mathrm{t} = \mathrm{t\,feb} - \mathrm{t\,deb} \qquad (11)$$

Δt: boiling time of water (min); t feb: end of water boiling; t deb: start of water boiling.

Amount of water remaining

The amount of water remaining corresponds to the mass of water remaining in the pan after the boiling test. It is written according to Equation 5.

$$\mathrm{Qr} = \mathrm{Qi} - \mathrm{Qf} \qquad (12)$$

Qr: amount of remaining water (gr); Q i: the initial mass of water + that of the saucepan; Qf: the final mass of water + that of the saucepan.

Amount of water evaporated

The amount of evaporated water is the mass of water that evaporates during boiling. To obtain it, we take the difference between the initial mass of water and the remaining mass of water.

$$Qv = Qi - Qr \qquad (13)$$

Qv: amount of water evaporated; Qr: amount of remaining water; Qi: the initial mass of water + that of the saucepan.

f) Heat of post-combustion ash

It corresponds to the temperatures maintained in the ash after 30 minutes of end of fuel combustion. To do this, we take the temperature after 30 minutes from the end of combustion.

2. Results and discussion

2.1. Physical characterization of charcoal

Table 3 shows the overall physical parameters of the samples of ecological charcoal based on *Azadirachta indica* (85-90%) bonded to inorganic matter (sand (10%) or clay (15%))

Table 3: Physical parameters of samples of ecological charcoal based on *Azadirachta indica* (85-90%) bonded to inorganic matter (sand (10%) or clay (15%))

Physical parameters	Moisture content (%)	Density (gr/cm^3)	Porosity	Resistance index (%)	Moisture uptake rate (%)
TOTAL AVERAGE	8.40±5.07	0.91±0.43	0.48±0.83	27.12±12.53	18.03±9.04

However, ecological charcoal based on *Azadirachta indica* (85-90%) bonded to inorganic matter (sand (10%) or clay (15%)) has an average moisture content of 12.62 ± 0.50% , an average density of 1.04±0.04gr/cm^3, an average porosity of 1.22±0.13, an average resistance index of 32.95±1.64%, and a moisture absorption content (18.29±1.41%). The ecological charcoal based on *Azadirachta indica* (85%) bonded to clays (Monmorillonitic red clay (15%) or Kaolinitic clay of lowlands (15%)) have an average moisture content of 6.04 ± 1, 17%, an average density of 1.15±0.03gr/cm^3, with a low average porosity of -0.43±0.03, an average resistance index of 31.11±0.007%, and a recovery rate humidity 25.96±2.10%.

Table 4 shows the overall physical parameters of the samples of ecological charcoal based on *Azadirachta indica* (90%) bonded to organic matter (*Sorghum sp.* stem (10%), or *Zea mays L.* stem (10%), or Sap of *Acacia seyal* (10%) or *Saccharum officinarum* peel (10%)).

Table 4: Physical parameters of samples of ecological charcoal based on *Azadirachta indica* (90%) bonded to organic matter (*Sorghum sp.* stem (10%), or *Zea mays L.* stem (10%), or *Acacia seyal* sap (10%) or *Saccharum officinarum* peel (10%)).

Physical parameters	Moisture content (%)	Density (gr/cm^3)	Porosity	Resistance index (%)	Moisture uptake rate (%)
TOTAL AVERAGE	3.17±0.04	1.13±0.02	0.67±0.03	73.96±3.29	1.43±0.19

The ecological charcoal based on *Azadirachta indica* (90%) bonded to the stems of cereals (Stem *Sorghum sp.* (10%), or Stem *Zea mays L.* (10%)) have an average moisture content of 3.17 ±0.07%, an average density of 1.14±0.03gr/cm^3, an average porosity of 0.66±0.04, an average resistance index of 74.32±2.87%, and a rate average humidity recovery of 1.33 ± 0.21% while the ecological charcoal based on *Azadirachta indica* (90%) bonded to the saps of *Acacia seyal* (10%) or the peels of *Saccharum officinarum* (10%)) have an average moisture content of 3.18±0.007%, an average density of 1.13±0.02gr/cm^3, an average high porosity of 0.69±0.03, an average resistance index of 73.6±4.86%, and a moisture uptake rate of 1.54±0.15%.

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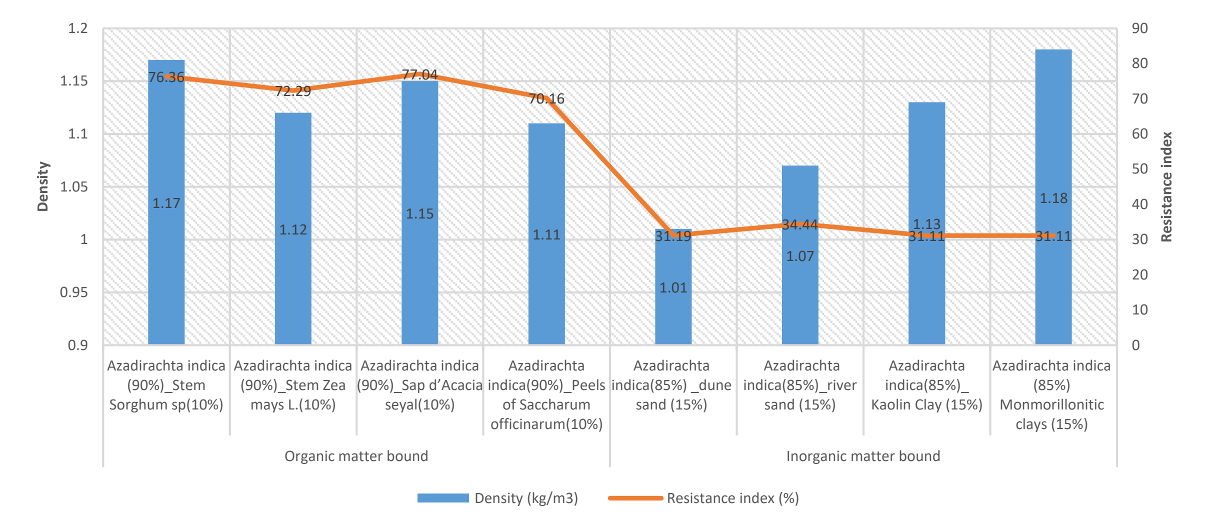


Graph 1: Major global physical parameters of ecological charcoal based on *Azadirachta indica* (85-90%) bonded to organic matter (10%) and inorganic matter (10-15%)

Among the samples of ecological charcoal based on *Azadirachta indica* (85-90%) bonded to inorganic matter (10-15%), those of *Azadirachta indica* (85%) bonded to Kaolin Clay (15%) have an average density of 1.18 ± 0.94 gr/cm3 higher to that of charcoal (0.21) [9] and a low average resistance index of 31.11 ± 0.31%. Among the samples of ecological charcoal based on *Azadirachta indica* (90%) bound to organic matter (10%), those of *Azadirachta indica*_ Stem of *Sorghum sp.* have a high average density of 1.17 ± 0.02 gr/cm^3 higher than that of wood charcoal (0.2 to 0.6) (Badea et *al.*, 2008) but the best average resistance index of 77.04 ± 0.73% is that of *Azadirachta indica* bound to sap of *Acacia seyal* (Gum Arabic).

2.2. Chemical characterization

Table 5 shows the overall chemical parameters of the samples of ecological charcoal based on *Azadirachta indica* (85-90%) bound to inorganic matter (sand (10%) or clay (15%)).

Table 5: Chemical parameters of ecological charcoal based on *Azadirachta indica* (85-90%) bound to inorganic matter (sand (10%) or clay (15%))

Chemical parameters	Volatile Matter content (%)	Ash content (%)	Fixed carbon content (%)
Total average	29.46±13.16	5.87±3.94	10.57±4.85

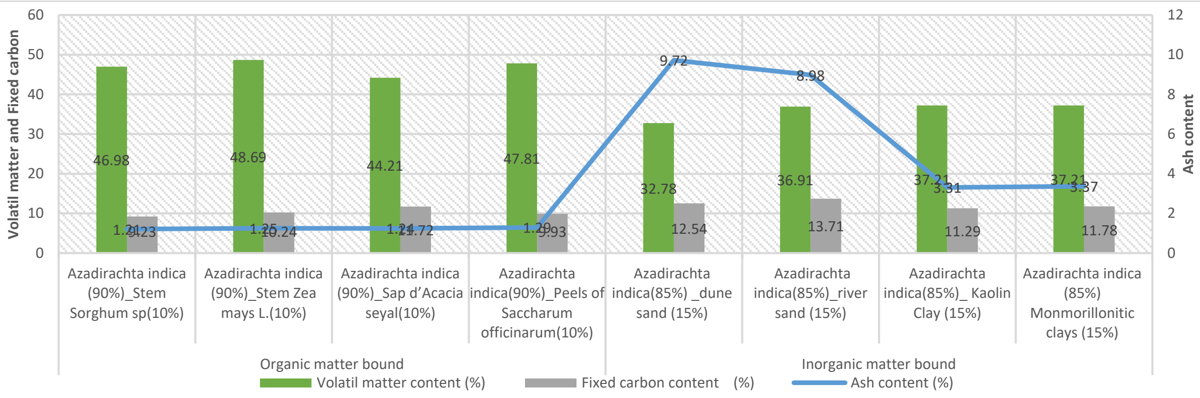
However, ecological charcoal based on *Azadirachta indica* (90%) bonded to sands (dune sand (10%) or river sand (10%)) has an average volatile matter content 34.84 ± 2.92 %, an average ash content of 9.35 ± 0.52%, an average fixed carbon content of 13.12 ± 0.82, while the ecological charcoal based on *Azadirachta indica* (90%) bound to clays (Monmorillonitic red clay (10%) or lowland kaolinitic clay (10%)) have an average volatile matter content of 34.66±3.60%, an average ash content of 3.34±0.04 % , an average fixed carbon content of 11.63±0.48%.

Table 6 shows the overall chemical parameters of ecological charcoal based on *Azadirachta indica* (90%) linked to organic matter (*Sorghum sp.* stem (10%), or *Zea mays L.* stem (10%), or sap of *Acacia seyal* (10%) or *Saccharum officinarum* peel (10%)).

Table 6: Chemical parameters of samples of ecological charcoal based on *Azadirachta indica* (90%) bonded to organic matter (*Sorghum sp.* stem (10%), or *Zea mays L.* stem (10%), or *Acacia seyal* sap (10%) or *Saccharum officinarum* peel (10%))

Chemical parameters	Volatile Matter content (%)	Ash content (%)	Fixed carbon content (%)
Total average	46.92±1.93	1.24±0.03	10.28±1.04

Ecological charcoal based on *Azadirachta indica* (90%) bound to the stems of cereals (Stem *Sorghum sp.* (10%), or stem of *Zea mays L.* (10%)) have an average volatile matter rate of 47.83± 1.20%, an average ash content of 1.23 ± 0.02%, an average fixed carbon content of 9.73 ± 0.71% while the ecological charcoal based on *Azadirachta indica* (90%) bound to the saps of *Acacia seyal* (10%) or the peels of *Saccharum officinarum* (10%)) have an average volatile matter content of 46.01 ± 2.54%, an average ash content of 1.26 ± 0, 03%, an average fixed carbon content of 10.82±1.26%.



Graph 2: Overall chemical parameters of samples of ecological charcoal based on *Azadirachta indica* (90%) bound to organic matter (10%)

Among the samples of ecological charcoal based on *Azadirachta indica* (90%) linked to organic matter (10%), those based on *Azadirachta indica* bound to stem of *Zea mays L.* have a high average volatile matter content of 48.69 ± 1.45% higher than that of charcoal between [12-15]% (Badea et *al.*, 2008). Ecological charcoal based on *Azadirachta indica* (90%) linked to River sand (10%) has the highest average fixed carbon content is 13.71 ± 0.55%, lower than that of the French standard for wood charcoal which is 65% (NF 444_NF, 2019). The ecological charcoal based on *Azadirachta indica* (90%) bonded to dune sand (10%) has a higher ash content of 9.72 ± 0.67% higher than that of charcoal (4.26 ± 1.64%) and lower than that of Typha coal linked to clay which is 37.68 ± 0.97% (Kévin et *al.*, 2016).

2.3. Energy efficiency

Table 7 shows the overall energy efficiency of ecological charcoal based on *Azadirachta indica* (85-90%) bounded to inorganic matter (sand (10%) or clay (15%)).

Table 7: Overall energy efficiency of ecological charcoal based on *Azadirachta indica* (85-90%) bound to inorganic matter (sand (10%) or clay (15%))

Energy efficiency parameters	Calorific value (MJ/Kg)	Combustion time (minutes)	Ignition time (secondes)	Post-combustion ash heat (°C)	Maximum temperature during combustion (°C)
AVERAGE TOTAL	24,01±10,53	304,75±142,91	11,16±5,81	112,56±55,29	274,98±130,40

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However, ecological charcoal based on *Azadirachta indica* (85-90%) bonded to inorganic matter (sand (10%) or clay (15%)) have an average calorific value of 26.61±3.06 MJ/ Kg, an average charcoal combustion time of 379.65±16.65 minutes, an average ignition delay of 15 seconds, a post-combustion ash heat of 127±1.41°C and a maximum temperature during combustion 319 ± 9.89 ° C while ecological charcoal based on *Azadirachta indica* (85%) bound to clays (monmorillonitic red clay (15%) or lowland kaolinitic clay (15%)) have an average calorific value of 30.58±0.65 MJ/Kg, average charcoal burning time of 336.46±1.76 minutes, average ignition delay of 11 seconds, post-combustion ash heat of 146.5±2.12°C and a maximum temperature during combustion of 341.5±0.70°C.

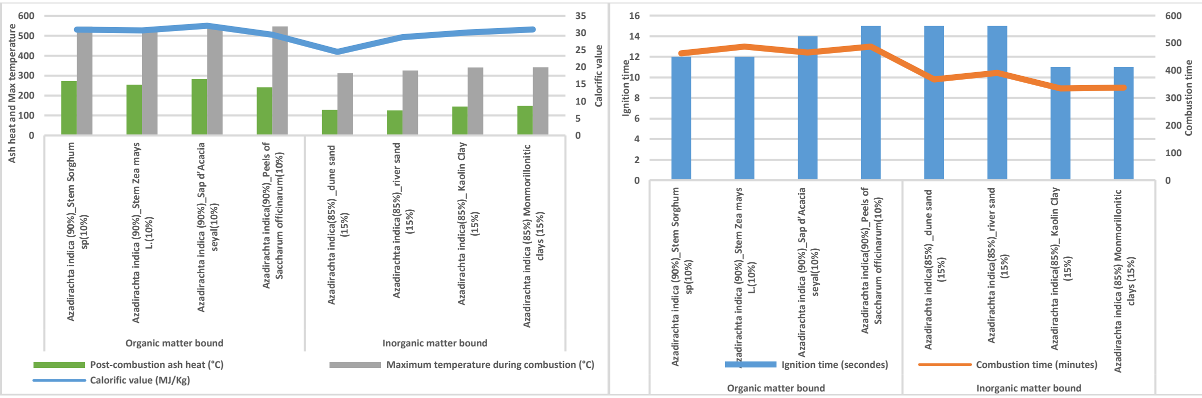
Table 8 shows the overall energy efficiency of ecological charcoal based on *Azadirachta indica* (90%) bound to organic matter (*Sorghum sp.* stem (10%), or *Zea mays L.* stem (10%), or Sap of *Acacia seyal* (10%) or *Saccharum officinarum* peel (10%)).

Table 8: Overall energy efficiency of samples of ecological charcoal based on *Azadirachta indica* (90%) bonded to organic matter (*Sorghum sp.* stem (10%), or *Zea mays L.* stem (10%), or *Acacia seyal* sap (10%) or *Saccharum officinarum* peel (10%)).

Energy efficiency parameters	Calorific value (MJ/Kg)	Combustion time (minutes)	Ignition time (secondes)	Post-combustion ash heat (°C)	Maximum temperature during combustion (°C)
AVERAGE TOTAL	30.83±1.08	475.75±13.32	13.25±1.5	262.95±18.37	540.37±11.53

However, ecological charcoal based on *Azadirachta indica* (90%) bound to stems of *Sorghum sp.* (10%), or to stems of *Zea mays L.* (10%), have an average calorific value of 30.87±0.14 MJ/Kg, an average fuel combustion time of 475.06±17.52 minutes, an average ignition time of 12 seconds, a post-combustion ash heat of 264.04±13.13°C and a maximum temperature during combustion of

534.93±16.58°C while the eco-friendly carbon based on *Azadirachta indica* (90%) bound with the sap of *Acacia seyal* (10%) or the peel of *Saccharum officinarum* (10%) have an average calorific value of 30.79±1.87 MJ/Kg, a combustion time average combustibles of 476.44±14.94 minutes, an average ignition time of 14.5±0.70 seconds, an ash post-combustion heat of 261.87±28.9°C and a maximum temperature during of combustion 545.81±2.39°C.



Graph 3: Parameters Overall energy efficiency of ecological charcoal based on *Azadirachta indica* (90%) linked to organic matter (stem of *Sorghum sp.* (10%))

Among the samples of ecological charcoal based on *Azadirachta indica* (90%) bonded to organic matter (10%), those based on *Azadirachta indica* linked to Sap of *Acacia seyal* (gum Arabic) have a high average calorific value of 32.12 ± 1.33 MJ/Kg, higher than that of charcoal which is 28.7 MJ/Kg and than that of Typha-Gum coal which is 17.75 MJ/Kg (Kévin et *al.*, 2016), and the highest ash heat for ecological charcoal based on *Azadirachta indica* bonded to *Acacia seyal* sap which is 282.31 ± 03.16°C. Ecological coal based on *Azadirachta indica* bonded to stem *Sorghum sp.* has an average maximum temperature during the highest combustion which is 546.66 ± 02.23°C. The ecological charcoal based on *Azadirachta indica* bound to stem of *Zea mays L.* has a high combustion time of 48.67 ± 02.22 minutes while the charcoal based on *Azadirachta indica* (85%) linked to Monmorillonitic Red Clay (15%) and those based on *Azadirachta indica* (85%) linked to Lowland Kaolinitic Clay (15%) have a low flammability after 11 seconds similar to those of Typha Charcoal – Clay obtained by Kévin et *al.*, (2016).

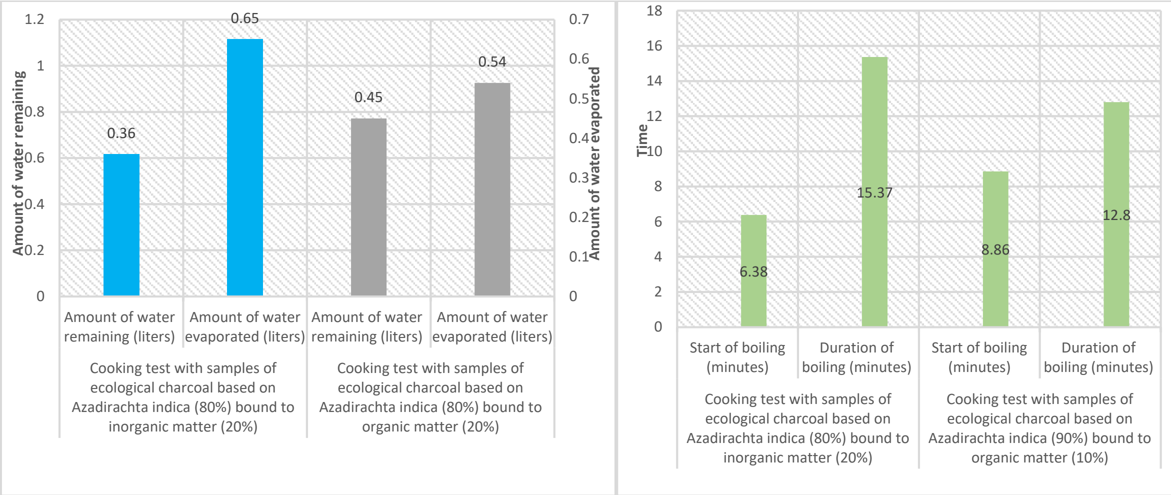
2.4. Cooking test

Table 9 shows the overall parameters of ecological charcoal based on *Azadirachta indica* (85-90%) bound to inorganic (10-15%) and organic matter (10%).

Table 9: Cooking test with samples of ecological charcoal based on *Azadirachta indica* (85-90%) bound to inorganic (10-15%) and organic matter (10%).

Cooking test parameters	Start of boiling (minutes)	Duration of boiling (minutes)	Amount of water remaining (liters)	Amount of water evaporated (liters)
Average	7.62±2.05	14.08±1.41	0.41±0.15	0.6±0.15

When cooking with samples of ecological charcoal based on *Azadirachta indica* (85-90%) bonded to inorganic (10-15%), the average onset of water boiling is 8.86±1.61 minutes, the average boiling time of water is 12.80±0.45 minutes. At the end of cooking, the average quantity of remaining water is 0.36±0.11 liter and the quantity of evaporated water 0.65±0.08 liter when the initial water is 01 liter.



Graph 4: Baking test parameters

In addition, the cooking test with ecological charcoal based on *Azadirachta indica* (90%) bound to organic matter (10%) has an average start of water boiling of 6.38 ± 1.76 minutes while the average boiling time of water is interesting with ecological charcoal based on *Azadirachta indica* (85-90%) linked to inorganic (10-15%) of 12.8 ± 0.25 minutes. At the end of cooking, the lowest average quantity of remaining water is 0.36±0.20 liters and the quantity of evaporated water 0.65±0.01 liters.

Conclusion

The objective of this study is to determine the performance of organic and inorganic binders for the production of combustible ecological charcoal based on the dead biomass of *Azadirachta Indica*. The energy efficiency of the fuels made it possible to determine that among the samples of ecological charcoal based on *Azadirachta indica* (90%) bonded to organic matter (10%), those based on *Azadirachta indica* bonded to Sap of *Acacia seyal* (Gum arabic) have a high average calorific value of 32.12 ± 1.33 MJ/Kg and a higher post-combustion ash heat for ecological charcoal based on *Azadirachta indica* bonded to *Acacia seyal* sap's which is 282.31 ± 03.16°C. The ecological charcoal based on *Azadirachta indica* bonded to stem *Sorghum sp.* has an average maximum temperature during combustion, the highest, which is 546.66 ± 02.23°C. The ecological charcoal based on *Azadirachta indica* bonded to stem *Zea mays L.* has a high combustion time of 48.67 ± 02.22 minutes while the charcoals based on *Azadirachta indica* (90%) linked to Monmorillonitic red clay (10%) and those based on *Azadirachta indica* (90%) bonded to Kaolinitic clay of the lowlands (10%) have a low flammability after 11 seconds.
During the cooking test with ecological charcoal based on *Azadirachta indica* (90%) bound to organic matter (10%), the average start of boiling of water is 6.38 ± 1.76 minutes while the average boiling time of water is interesting with ecological charcoal based on *Azadirachta indica* (90%) bonded to inorganic matter (10%) of 12.8 ± 0.25 minutes because, at the end of cooking, the lowest average remaining amount of water is 0.36±0.20 liters and the amount of evaporated water 0.65±0.01 liters.
The performance of the binders being linked to that of combustible ecological charcoal based on the dead biomass of *Azadirachta Indica*, the most efficient binders are the sap of *Acacia seyal* (Gum arabic), the stem *Sorghum sp.*, the stem *Zea mays L.* for binders from organic materials and monmorillonitic red clay and kaolinitic clay from lowlands for binders from inorganic materials

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