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Valorization of Agricultural Waste into Ecological Coal in the Region of Vakinankaratra

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Abstract:

Ecological charcoal is coal produced from biodegradable residues rich in carbon, mainly from agricultural residues. This charcoal has been obtained with different operations such as carbonization, molding and compacting to obtain briquettes. To ensure the quality of the coal, several analyses were carried out in the laboratories. The physicochemical characteristics such as moisture content, ash content, fixed carbon content; volatile matter index and lower calorific value are analyzed to better exploit their uses. Its exploitation has many advantages especially in the field of health and environment, especially for the reduction of deforestation and air pollution. This research gives 5 varieties of ecological coal obtained by the valorization of agricultural waste in the region of Vakinankaratra, a region located in the highlands of Madagascar and known for its high potentiality in agriculture and livestock. It is about the valorization of rice straw, rice husk, corn straw, banana peelings, and soybean stalks.

Keywords:
ecologic charcoal, carbonization, molding, compaction, calorific value

I. Introduction

Access to energy, which is increasingly considered a fundamental right, is a necessary condition for any development process. In Africa, Latin America, and Asia including India and China, wood is becoming more and more difficult to find and it is time to look for and multiply alternative kinds of energy. Moreover, worldwide initiatives are multiplying to safeguard the environment and achieve Sustainable Development Goals.

Two billion people around the world depend on wood for their domestic energy needs. Particularly in Africa, wood accounts for 89% of energy sources (Guy, 2020) and people will not be able to afford hydrocarbon or solar energy, which means that they will soon be unable to cook their food. In Africa, wood is the main source of energy. Inside the African continent, wood energy accounts for an average of 70% of total energy used (IEA, 2014)

Under population pressure, large areas of communal forests in many countries are being cleared to make way for unsustainable agriculture or commercial logging. In 2010, the world had 3.92Gha of forest cover, covering 30% of its land area. By 2021, there was a loss of 25.3Mha of forest cover. (Global Forest Watch, 2021) In addition, the excessive use of wood as a domestic fuel, which is becoming increasingly expensive, has many major drawbacks.

As deforestation increases, the burden on women and children increases: they have to travel far to obtain fuelwood and other forest products. This additional burden reduces the time they could spend on other necessary tasks.

Deforestation and the abusive exploitation of wood as a source of energy lead to drought, desertification, climate change and increased greenhouse gas emissions. This situation contributes strongly to global warming. This situation recommends us to look for an alternative energy source (renewable or recyclable). The transformation of agricultural residues into ecological charcoal is one of the possible and beneficial solutions knowing that this contributes very well on the challenge of the circular economy with zero waste. "The circular economy proposes to transform waste into raw material that can be reused for the design of products or for other uses. In other words, no longer creating residues that the industrial and natural systems cannot absorb. The circle is complete..." (Gallouj & Viala, 2021).

It is also a winning strategy for a sustainable world (Le Moigne, 2018). Scattered in the countryside, still exploitable resources are unfortunately wasted, so alternatives for the valorization of waste deserve to be studied. The circular economy is an unavoidable transition (Sauvé,S. et al.2016) and a burning desire of territories (Levy. & Aurez, 2014)

Madagascar has a lot of unused and unexploited agricultural residues. The Vakinankaratra region, located in the central part of Madagascar, presents a great opportunity as it is a region with a high agricultural production capacity, where many varieties of organic plant waste can be found.

The quantity of solid waste deposited daily in the city of Antsirabe is high. Their lack of treatment poses difficulties in terms of hygiene and health. In addition, the existing dumps constitute sources of pollution of surface water and groundwater by percolation from the decomposition of waste.

If waste is abandoned in nature, it constitutes another source of pollution, sometimes invisible but very harmful for the soil and water.

The management of solid waste, often left to the personal initiative of the inhabitants, results in uncontrolled systems of disposal: households' resort to burying or burning on their plots or in the streets. In addition, the anaerobic decomposition (in the absence of oxygen) of household waste has adverse effects on climate change because it causes methane emissions. However, over a period of 20 years, methane is a greenhouse gas that has a warming effect about 80 times more powerful than CO2. (United Nations Environment Program 2021).

Among the solid waste produced in urban areas, there is a large stock of organic residues or biomass. In addition, there are also agro-industrial residues that are not very well valorized. Part of these organic residues could be transformed into ecological charcoal briquettes. Another part could be valorized in other forms: compost and biogas.

While a large number of trees are cut down each year to produce charcoal, 10 kg of wood are needed to make 1 kg of charcoal (Douard, 2010), millions of tons of organic waste constitute an unvalued resource and cause strong nuisances. The manufacture of ecological charcoal briquettes is a contribution to the preservation of the forest cover and to the improvement of sanitation.

Ecological charcoal briquettes are a product similar to wood charcoal in both appearance and use, but it avoids cutting down trees. (Laval, 2014).

The research consists in valorizing these agricultural wastes into biomass fuels. The objective is to reduce deforestation due to the manufacture of charcoal as firewood, or even to eliminate its use and replace it with ecological charcoal, as is always suggested during the International Conferences of the United Nations.

II. Material and Methods

Any organic residue can be carbonized and molded into green charcoal briquettes (Damien, (2013). It is necessary to evaluate their efficiency and profitability on the basis of their physico-chemical properties and especially their calorific value.

"*Green charcoal is charcoal that is produced without wood, from any vegetable waste. Indeed, there are many rejects and residues that are neither consumed nor used: various straws, crop remains such as cotton, millet, reed stalks, etc.*" (Delbard, 2017).

2.1 Plant Material Generating Agricultural Waste

There is a wide variety of biodegradable wastes, which can be carbonized to produce ecological charcoal, but not all of them yield charcoal of the same quality.

In this study, for the Vakinankaratra Region, the agricultural residues used to make ecological charcoal were rice straw, rice husk, corn straw, banana peelings, and soybean stalks.

Rice straw is part of the stalk that is cut during harvesting. Rice has some outer envelopes from the flower. These envelopes, called husks, are made up of the glumella and glumes and are not intimately linked to the grain as the pericarp can be, but they improve its protection as in the case of paddy rice (Cruz, .& *al.* 2020).

The rice husk is of a brown-beige color, of hard consistency, and much more resistant than that of wheat. This product, light and voluminous, whose density oscillates between 132 and 140 kg/m3, is practically rot-proof and unattackable by insects. In case of fire, it does not release toxic gasses. It is sensitive to fire. It has an average calorific value of 14 MJ/kg but requires carefully designed installations to avoid incomplete combustion caused by the high ash content (Indian Ocean Commission, 2018).

Rice husks exist in large quantities and are piled up on-site at rice husking plants for years. The rice husk represents a weight of 20% of the rice produced. (Halleux, 2013).

Corn straw is the corn stalk that may have been collected from the field after harvest.

The banana is an abundant fruit and exists all year round on the market, its consumption by the population is almost generalized, and its peels are then easy to find. The collection has been facilitated by the establishment of collection points in the markets.

In the region of Vakinankaratra, for several years, the cultivation of soybeans has been quite extensive and one can find the stems and bark scattered in nature, especially after the harvest. The stalks are not used by the farmers except sometimes for compost.

2.2. Pre-treatment Operation of Raw Materials: Drying

The production steps to make ecological charcoal are the collect and drying of raw materials, carbonization, compacting and finally drying the fabricated briquettes.
The drying time depends on the material.

- The rice husk obtained by hulling is almost dry, about 2 or 3 hours are enough to dry it. But the rice husk from paddy winnowing is wetter, and it takes 2 days to dry. Specifically, the rice husks were moved from the hulling unit and then sun-dried for 14 days. Drying reduces the moisture content from 18% to a fairly low moisture content (around 10%). They were then put in bags and stored in a warehouse (protected from rain and moisture) while waiting to be used in the pyrolysis reactor.
- The banana peel is dried for 2 or 3 days to facilitate carbonization which is easier if the raw material is drier. Its valorization can be part of the challenge Zero Waste which seeks to fight against environmental degradation and to promote responsible consumption
- Soybean stalks and rice straw are dried for 2 days to obtain a dry raw material.
- The drying of rice straw is quite fast and its process is done directly after harvest. Rice straw contains 87.18% of dry matter.
- The dry matter of maize straw is highly variable. Drying can take up to a week or more to ensure better carbonization.

2.3. Methods of Manufacturing Ecological Charcoal Briquettes

a. Pyrolizer or Carbonizer

The priority of this post-drying study was to predict whether or not carbonization is interesting. Carbonization is applied for the pyrolysis of raw materials. This method depends on the nature of the raw materials. The moisture content of the raw materials is 2%, which favors and facilitates carbonization.

Carbonization is the thermal cracking of organic products at high temperature and in the absence of air. A solid residue containing carbon and mineral compounds (or ash) remains. This residue is called coke when the treated product is coal. A milder cracking process, which is not pushed to completion, produces a semi-coke. Charcoal is a coke or semi-coke of wood (Koller, E. 2006).

During classic or slow pyrolysis: the heating rate is of the order of 10 K.min-1. The char return, close to 30%, is higher as the heating rate is slow. This is the process that has always been used to produce charcoal in various types of reactors (Mermoud, 2006).

The C/N ratio is also essential for choosing the carbonization method.
The possible cases are as follows:
- If the content < 10, the raw material is difficult to valorize.
- If the content > 10, the raw material is recoverable.
- If the content = 10, the raw material is easily degradable. The method used is pyrolysis.
- If the content > 40, the raw material is difficult to degrade. It is the case of the peat. It is a product with a point. Direct combustion has been chosen for this case.

In summary, the ratio for rice straw, rice husk, corn straw, banana peelings, and soybean stalks is more than 10. So, the process to be applied in this operation is direct carbonization without an intermediary. It is enough to light the fire and to close quickly the reactor to avoid the entry of oxygen risking influencing the carbonization by supporting the formation of ash which is not beneficial for such a production.

- For rice husks, the carbonization time lasts 1h30min with a temperature variation from 80°C to 450°C. The rice husk can be molded without going through the carbonization phase, thus saving time and energy.
- For the banana peel, it was carbonized at about 1h, with a temperature rise to 400°C. It is easier to carbonize than rice husk.
- Soybean stalk, rice straw and corn straw have a moisture content of less than or equal to 2%, this factor makes carbonization quite easy to manage. Its pyrolysis time varied from 45 min to 1 hour. The temperature inside the reactor was from 100°C to 450°C. It was necessary to regulate the fire because if the temperature is very high, the carbonized material turns into ash while the calorific value of the ash is negligible or even null.

For this work, a carbonization reactor made according to a traditional method was used. This carbonization equipment is made from a recovery drum of 1000 liters. It is equipped with a sheet metal pipe of 1m in length to ensure the exit of fumes and a hole for the activation of the ignition of raw materials. A small tank of 100 liters containing the raw materials is placed inside this drum.

***Figure 1**. Carbonizers Used during the Treatment*
Source: Author

It is a low-tech reactor, at a low price so that even the farmers can make it.

The physical properties of green charcoal are closely related to those of the organic material used in its production. The components of green charcoal are produced by carbonization of biomass. Depending on the temperatures reached during pyrolysis and the nature of the initial biomass, the physical and chemical properties of the resulting green charcoal product may change (Keech, & *al*, 2005).

b. The Specific Surface Area and Porosity

Ecological charcoal has a large specific surface area which can vary from a few hundred to 3000m2/g (Downie, & *al,* 2009).

This large specific surface area provides shelter for microorganisms and storage for soil nutrients (Chan, & Xu, 2009). Ecological charcoal consists of thousands of pores that are formed during pyrolysis. For this reason, it is able to absorb up to five times its own weight in water as well as nutrients in dilute form.

c. Grinding and Sieving

The crushing of carbonized materials is done with mortars in case of carbonizat with a very large granulometry. This is still a traditional method. If the material is still hard, roasting is necessary to reduce the size of the carbonizat. In order to obtain a more valuable product, sieving was done manually. The 2 mm mesh sieve used has a rectangular shape of 50 cm in length and 30 cm in width. In our experimentation, only the soybean stalk requires sieving.

d. Mixing and Addition of Binders

To ensure the adhesion between the coal particles and the strength of the fuel briquettes, a binder can be added. This can be starch, gum arabic, molasses or clay. The percentage varies between 10% and 20% in the case of clay. For this operation, the mixing was done in a basin and cassava starch was used as a binder.

e**. Compacting or Pressing**

The compaction was done with a manual press with 8 molds. In each mold and at each test, 80g of the mixture were taken in order to obtain ecological charcoal briquettes. This press was locally and handcrafted, while it still needs further development to achieve more reliable performance.

Figure 2. *Manual press with 8 molds*
Source: Author

This press is a manual press and easy to handle

f. **Drying of the Briquettes**

The briquettes coming out of the press are spread out in the open air to dry.

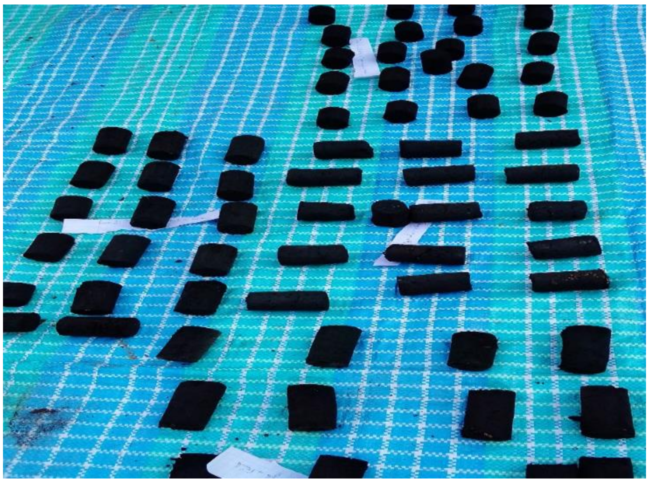

Figure 3. *Drying of Briquettes*
Source: Author

The briquettes were put on a cloth in a spaced manner to dry well for about a day.

2.4. Quality Control of the Ecological Charcoal Briquettes

Quality control was carried out at the laboratory of the National Center of Industrial and Technological Research in Antananarivo.

To have good quality of ecological charcoal, it is necessary to take into account the following properties:
- the rate of moisture;
- the rate of ashes;
- the index of volatile matters;
- the fixed Carbon indexes
- the calorific value.

a. The Rate of Moisture

The purpose of this parameter analysis is to determine the water content of a sample of ecological charcoal.

The moisture content determines the percentage of water contained in a material, in the case of green coal. It is a determining factor for use in combustion. The less moisture green coal contains, the more efficient it will be as a fuel (Antal & *al,* 2000).

This analysis accompanies any determination of Lower Calorific Value (LCV), ash content and volatile matter index of coal.

The principle is as follows:
- Drying at 105°C □ 3°C of a test sample for 1 to 1.5 hours in a hot air oven.
- Calculation of the humidity from the loss of mass compared to the initial mass.
- The sample used in this case is a particle of coal of diameter lower than 0,20mm.
- The procedure for moisture analysis is as follows:
- Dry the container in an oven at 105°C, then cool it in the desiccator, then weigh it (m1).
- Place 2 to 3 g (weighed to the nearest 0.1 mg) of charcoal (m1) in a tare box that has been dried at 105°C, cooled and weighed.
- Spread the charcoal evenly in the container, and place it in the oven heated at 105°C for 1 to 1.5 hours.

- Remove and place the whole in the desiccator for 30 min then weigh to the nearest 0.1 mg (m2)
- Perform 3 determinations per sample.

The expressions of the results of the moisture analysis are as follows:
The moisture of the coal M expressed in mass percentage is given by the formula:

$$\mathbf{M} = \frac{m_2 - m_3}{m_2 - m_1} \times 100$$

With:

- **m_1:** mass of the empty and dry container
- **m_2:** mass of the container + mass of the sample before drying
- m_3: mass of the container + mass of the sample after drying and cooling

b. The Rate of Ashes

The objective of this operation is to determine the rate of the residue obtained after the combustion of coal.

The purpose and principle of ash analysis are as follows:
- Combustion of a test sample in a muffle furnace at 950°C.
- The ash content corresponds to the amount of residue in relation to the mass of the test sample.
- At the same time, the moisture content of the sample must be determined.
  - The sample has a particle size of less than 0.20 mm.
  - The procedure for ashes analysis is as follows:
- Calcinate a silica pod in an oven at 950°C for 20 min.
- Cool for 30 min in a desiccator and weigh 0.1 mg (m_1)
- Weigh 1 to 2 g of the sample to the nearest 0.1 mg (m_2).
- Spread the charcoal evenly in the basket
- Place the basket in the muffle furnace (initial furnace temperature should not exceed 300°C) and heat the furnace at a rate of 250 to 300°C / h to reach 950°C ± 20°C.
- Maintain the pod for 3 h at this temperature then remove and cool in the desiccator.
- Weigh to the nearest 0.1 mg (m_3).
- Perform 3 determinations for each sample.

The ash content expressed as a percentage by mass of the raw fuel is given by the following formula:

$$\mathbf{As} = \frac{m_2 - m_3}{m_2 - m_1} \times 100$$

With:
- **m_1:** mass in grams of the nacelle
- **m_2:** mass in grams of the nacelle and the charcoal
- **m_3:** mass in grams of the nacelle and the ashes

c. The Volatile Matter Indexes

The volatile matter index is the mass loss expressed in percentage, obtained under standard conditions, after pyrolysis of coal heated in the absence of air, disregarding the loss of mass due to the evaporation of water from the moisture.

The principle of determination is as follows:
- heating of a sample in the absence of air, at 950°C for 1 hour

- protection of the charcoal against oxidation during pyrolysis, using charcoal covering the crucible containing the sample (double crucible method)
- parallel determination of the moisture content of the sample

The charcoal particles to be analyzed have a granulometry less than 0.20mm. The procedure for the volatile matter index analysis is as follows:

- Heat a silica crucible with its lid in a muffle furnace for 30 min at 950 °C ± 20°C, cool it in a desiccator and weigh it to the nearest 0.1 mg (m1).
- Place 2 to 3 g of the sample in the crucible and weigh to the nearest 0.1 mg (m2).
- Cover the bottom of a second larger silica crucible with a 1cm layer of charcoal.
- Insert the crucible containing the sample to be analyzed, with its lid, into the large silica crucible and fill it completely with charcoal. Cover with the lid and place the whole in the muffle furnace at 950 °C± 20°C.
- Let it stay for 1 hour at this temperature, cool it down in a desiccator then take out the crucible containing the sample, clean the outside with a brush and weigh it to the nearest 0.1 mg (m3).
- Perform 3 determinations on each sample.

The volatile matter index in percent by mass of the sample is equal to:

$$\mathbf{VM} = 100 \times \frac{m_2 - m_3}{m_2 - m_1} - \mathbf{H}$$

With:

- m_1 = mass in grams of the empty crucible and its lid.
- m_2 = mass in grams of the crucible, the lid and the sample before heating.
- m_3 = mass in grams of the crucible, its lid and its contents after heating.
- H = moisture in percent by weight of the sample analyzed.

d. Fixed Carbon Index

The fixed carbon index is determined by difference, then by:

- $\mathbf{FC}_{raw} = 100 - (H + VM + As)$

  Where:
- **FC**: fixed carbon
- **H**: humidity
- **VM**: volatile matter
- **As**: ash

e. The Calorific Value

There are two types of heating values:

- The high calorific value (HCV) is obtained when all the ecological charcoal has been transformed into energy, including the water vapor released and the flue gases.
- The lower calorific value (LCV) is the thermal energy released by the combustion of one kilogram of ecological charcoal in the form of sensible heat, excluding the energy of vaporization of the water present at the end of the reaction.

This standard describes a method for determining the constant volume gross calorific value of solid fuels. It also gives a method for calculating the lower calorific value. (Erol, M. and *al.* 2010) But in our case, we are only interested in the lower heating value. This characteristic is called the absorption capacity (AC) of the coal. This capacity is a function of the type of biomass pyrolyzed and the pyrolysis temperature (Mullen, & al, 2010).

The result is calculated from the following **CASSAN** formula:

$$\mathbf{LHV = (100 - As) \times 80}$$

With:

- LHV: lower calorific value
- As: ash content

The LHV depends on the ash content. The higher the ash content, the lower the LHV and vice versa.

f. “Nondestructive" method for the sample

To know the resistance of our briquettes to shocks, tests were carried out. The first test consists of lifting a briquette with the hand to heights varying from 0.5m, 1m and 1.5m from the ground, then leaving them in free fall. It is a simulation of the falls that these coals would undergo during their possible handling. When the coal falls to the ground, the result is noted and this test is repeated for 5 briquettes per type of coal and for each release height. Some briquettes broke easily, but others remained intact.

g. “Sample destruction” method or Compressive strength of samples

It is the most widely used technique to easily determine the value of the maximum compressive strength of a material using an appropriate machine following an international standard. The samples must undergo this compression test to ensure and determine the maximum strength of the manufactured sample.

The test is done in the technical block of Ankatso with a device called TESTWELL. The compression test is done in the following way:

The sample of cylindrical form is positioned between two plates by acting with two opposite axial forces. In order to obtain satisfactory results, the sample must be well positioned, all of the same height and section to obtain a logical evolution of the shape.

The two forces act progressively on the sample to be tested. Once the sample starts to be destroyed, the crank is quickly released to obtain the final result.

Figure 4. *Multifunctional TESTWELL hydraulic press (compaction, maximum strength) at the Ankatso Technical Block*
Source: Author

h. Test of the briquettes' suitability for combustion and firing
1. Briquette firing test (BFT)

Regarding the combustion of briquettes, several tests were conducted. These tests were made for each briquette having undergone the same test.

These are the different tests carried out:

Test 1: Lighting three briquettes with paper
Test 2: Lighting three briquettes with pine wood (with pine resin)
Test 3: Preparing a fire with wood. When the fire is lit, place a single briquette in the fire.

2. Briquette durability and efficiency test

To know the longevity of the briquettes and their efficiency, we made cooking tests for each type of briquette. In this test, we prepared rice for 5 people. The cooking test was repeated three times for each type of briquette.

III. Result and Discussion

Throughout our different experimentations, we tested several molds of varying dimensions in order to determine the suitable dimensions for the briquettes. At the beginning, we chose cylindrical briquettes with the following dimensions: a height of 6.5 cm, and a diameter of 3.5 cm. We soon realized that these dimensions favored a quick drying of the briquettes and that the preliminary combustion tests gave good results.

In fact, briquettes with a size between 10 and 13 cm long take quite a long time to dry and do not favor good combustion. On the other hand, briquettes between 4 and 5.5 cm in size dry very quickly and burn relatively well compared to the larger sizes.

3.1 Physico-chemical Properties of Formulated Briquettes

Given the quantity of samples remaining, the determination of hardness was done as follows:

- Sample N°2 for rice straw: Rice straw 92% + Cassava starch 8%.
- Sample N°3 for rice husk: Rice husk 70% + peat 24% + Cassava starch 6%.

- Sample N°1 for corn straw: Corn straw 92% + clay 8%.
- Sample N°2 for banana peel: Banana peel 95% + clay 5%.
- Sample N°1 for soybean stems: Soybean stems 96% + Cassava starch 4%.

The results of the determination of these physicochemical parameters are grouped in a table.

Table 1. Moisture, Volatile Matter, Ash, Fixed Carbon and Calorific Value of Formulated Coal Briquettes

	Rice straw	**Rice husk**	**Corn straw**	**Banana peel**	**Stalks soybean**	**Average**	**Standard deviation**
M (%)	5,39	6,55	5,55	11,13	14,21	8,57	3,93
VM (%)	11,64	40,57	12,90	16,38	9,53	18,20	12,75
As (%)	23,79	36,26	26,17	44,52	36,61	33,47	8,47
FC_{raw} (%)	51,62	16,62	43,25	27,90	39,62	35,80	13,70
LHV (kcal/kg)	6423,00	5099,50	6850,00	4438,24	5071,00	5576,35	1014,53

Source: Author

These results can be translated into histograms or 3D graphical representations which are the following.

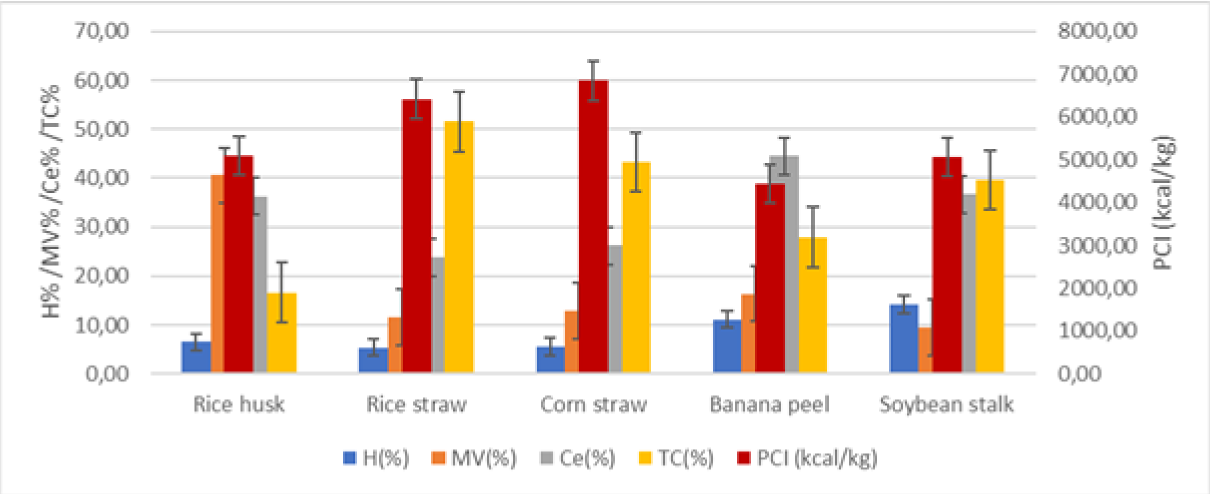

Figure 5. *Histogram of the Moisture, Volatile Matter, Ash, Carbon Number and Calorific Value of Formulated Coal Briquettes*
Source: Author

According to these results, the Charcoal Briquette based on Corn Straw has the best quality. In fact, its lower calorific value LHV is the highest. Moreover, it has a low moisture content (H% or M%), a medium ash content (As) and a high fixed carbon content (FCraw %). These three parameters are determining the quality of this biofuel.

The Rice Straw Charcoal Briquette ranks second in terms of quality. In fact, the LHV is high and the other determining parameters (H, As, FCraw) have values close to those of the banana peel briquettes.

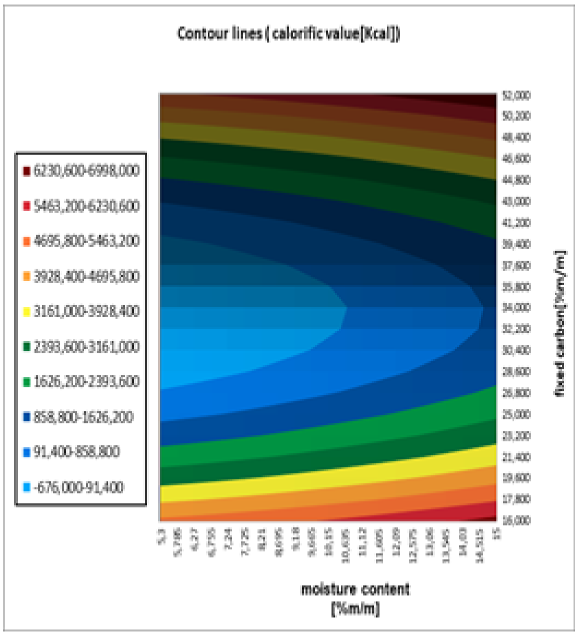

Figure 6*. Graphic representation D2 of the moisture, volatile matter, ash, carbon number and calorific value of formulated coal briquettes*
Source: Author

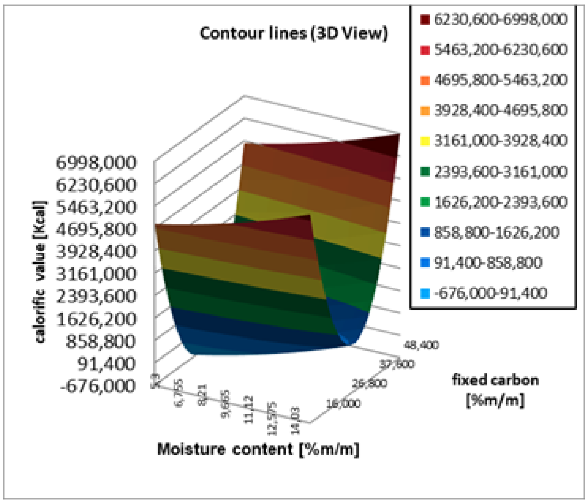

Figure 7*. Graphic representation D3 of the moisture, volatile matter, ash, carbon number and calorific value of formulated coal briquettes*
Source: Author

The high ash content of Rice husk briquettes handicaps their efficiency compared to rice straw. In fact, the ash of the rice husk has a high content of Silica which is not favorable energetically.

The briquette based on soybean stalk has a fairly high fixed carbon content but its moisture content of about 14.21% has a negative impact on its calorific value, and therefore on its quality.

Banana peel briquettes are the least efficient of the 5 biofuels in this study. In fact, the ash rate is very high at 44.52%, the moisture content at 11.13% is not favorable for good fuel.

3.2 Nondestructive Method for the Sample

Each briquette sample was dropped from a height of 0.5 m to 1.5 m. After each drop, the condition of the briquette is noted and the results of this test are as follows.

Table 2. Results of the Impact Resistance Test

Height (m)	Rice straw	Rice husk	Corn straw	Banana peel	Soybean stalks
0,5	++	++	+	±	+
1	±	+	+	-	±
1,5	-	+	+	--	-

Source: Author

Ratings:
(++): More resistant to shocks (100%)
(+): Shock resistant (75%)
(±): More or less resistant (50%)
(-): Not resistant to shocks (25%)
(--): Easy to break (0%)

The briquettes based on corn husk and straw had a constant resistance i.e., they keep their appearance whatever the height of the fall.

According to this table, briquettes made from corn straw are the most resistant to impact.

3.3 Sample Destruction Method

Using the compression method with the multifunctional TESTWELL hydraulic press, the following results were obtained.

Table 3. Results Obtained from the test of maximum resistance by the Testwell of the samples

Samples	Rice straw	Rice husk	Corn straw	Banana peel	Soybean stalks
Rc (MPa)	9.87	11.04	10.95	9.47	11.65

Source: Author

According to this table, it is the briquette based on rice husk (11.04 MPa), with the highest maximum strength in the maximum strength test, followed by corn straw (10.95 MPa) and rice straw (9.87 MPa).

On another side, the strength depends on the nature of the binder used with the cellulosic waste, that is to say, there is a proportionality between the two. The briquette (rice husk and corn straw) made with clay binder is more resistant than the one with cassava starch (rice straw briquette).

3.4. Briquette Firing Test

The results obtained during the tests carried out are summarized in the table below.

Table 4. Briquette Combustion Test

Test	Results				
	Rice straw	**Rice husk**	**Corn straw**	**Banana peel**	**Soybean stalks**
Test 1: Lighting three briquettes with paper	Positive	Positive	Positive	Positive	Positive
Test 2: Lighting three briquettes with soft pine wood	Positive	Positive	Positive	Positive	Positive
Test 3: Preparing a fire with wood. When the fire is lit, place a single briquette in the fire	Positive	Negative	Positive	Negative	Negative

Source: Author

Positive: it worked
Negative: it was not successful

The values of the lower calorific value (LHV) obtained previously explain the results of the combustion tests. In fact, the corn straw briquettes, with the highest LHV equal to 6850 Kcal/kg, burn faster than the other briquettes. The banana peel briquettes burned more difficult; this can be explained by the values of its physicochemical properties measured previously (LHV = 4438 Kcal/kg).

3.5. Briquette Durability and Efficiency Test

The test which consisted of cooking rice for 5 persons was repeated three times per type of briquette and the time when boiling started and the duration of cooking rice for 5 persons were noted and given in the following table.

Table 5. Results of the Longevity and Efficiency Test

Raw material	Test	Boiling time water (minutes)	Rice cooking time (minutes)	Residue	Smoke
Rice straw	1	14	26	x	x
	2	15	29	x	x
	3	13	27	x	x
	Average	14,00	27,33		
	Standard deviation	1,00	1,53		

Rice husk	1	14	25	x	x
	2	15	27	x	x
	3	16	29	x	x
	Average	15,00	27,00		
	Standard deviation	1,00	2,00		
Corn straw	1	11	25	x	x
	2	13	26	x	x
	3	13	26	x	x
	Average	12,33	25,67		
	Standard deviation	1,15	0,58		
Banana peel	1	18	37	x	x
	2	18	35	x	x
	3	17	40	x	x
	Average	17,67	37,33		
	Standard deviation	0,58	2,52		
Soybean stalks	1	15	26	x	x
	2	16	27	x	x
	3	17	30	x	x
	Average	16,00	27,67		
	Standard deviation	1,00	2,08		

Source: Author

X: means that there is normal residue and normal smoke

There are residues and smoke like any coal. Among the 05 types of briquettes made in this study, the results in this table further confirm that charcoal briquettes obtained from corn straw have the best quality.

3.6 The Rate of Moisture

Soybean stalk briquettes have a higher moisture content than others. This high rate is related to the season and the drying method (open-air drying).

Soybean stalk briquette has a moisture content equal to 14.210% while that of corn straw is 5.55%. The moisture content of the corn straw briquette is the lowest, which facilitates its combustion.

The moisture content and the lower calorific value are related. If the raw material is dry, it is easier to burn and its calorific value is higher.

3.7 Ash Content (As) and Carbon Content (FCraw)

All the briquettes gave off smoke, but a little less for the rice husk and corn straw briquettes. During the experimentation, they left little residue.

Concerning the fixed carbon content, the higher the content, the less smoke the charcoal produced and the better the quality of the briquette. This is the case for rice straw and corn straw briquettes.

Banana peel contains on average only 27.901% Carbon. It gives off much more smoke than the others.

The ash content (As) for the banana peel briquette is the highest at 44.522% and its calorific value is the lowest at 4438.24 Kcal/kg. The ash has no calorific value to contribute to the fuel, so the higher the ash content, the lower the calorific value and the lower the quality of the coal.

3.8 The Calorific Value

The corn straw charcoal briquettes have a calorific value equal to 6850 Kcal/kg, while the banana peel briquettes only have a calorific value of 4438.24 Kcal/kg. During the tests of the suitability of the briquettes for combustion and cooking, the results showed that the banana peel briquettes ignite more difficulty than the others and take much longer for cooking.

This property refers to the quality of the coal. From these data, the maize straw briquettes have the best quality, followed by rice straw briquettes. They have the highest calorific value.

The calorific value of the rice husk briquette 5099.5 Kcal/kg and that of the soybean stalk briquette 5071 Kcal/kg do not differ much, although the carbon content of the rice husk briquette (16.619%) is lower than that of the soybean stalk briquette (39.623%). It is then possible to think that they have the same quality. However, this is not true because the results of the durability and efficiency tests showed that the boiling and cooking time of rice husk briquettes is shorter, and therefore more economical, than those of soybean stalk briquettes. The high moisture content of the soybean stalk briquette (14.21%) may explain its inefficiency in cooking and boiling. A conclusion can be drawn to confirm that the rice husk briquette is more efficient and of better quality than the soybean stalk briquette even if their internal calorific values are not very different.

3.9 “Nondestructive" Method for the Sample

Briquettes made of rice husks, rice straw and corn straw are the strongest and resist well to shocks. During the operation, only a very small number of particles of these coals are detached from the briquettes.

On the other hand, rice husk briquettes and corn straw briquettes made with clay as a binder are more resistant than rice straw briquettes, which have cassava starch as a binder, which is more friable.

Only the BCPM can resist the shock at 75% at a height of 1,5 m. They have constant resistance; they keep their appearance whatever the height of the fall.

After their free fall followed by their contact with the ground, the different briquettes break into two or three pieces. Even if the briquette does not break, one observes either cracks on the briquettes or a detachment of a significant quantity of the particles. This detachment concerns particularly the briquettes based on soybean stalk which do not resist any more from a height of fall of 1m.

The briquettes based on banana peel are the most fragile, in fact they resist only to a height of 0,5 m, and they break easily to a higher height.

Whatever the method used for the measurement of hardness: the "Destructive" method of the sample or the "non-destructive" method of the sample. The results obtained are consistent.

3.10 Test of the Briquettes' Suitability for Combustion and Firing

For the 1st ignition test, i.e., igniting the five briquettes with paper, all the briquettes, except the banana peel briquette, were able to ignite after using a lot of paper as a starting fire. For the banana peel, the result was negative. The briquettes blackened and did not ignite until after a long time, or even never ignited.

For the 2nd test, all the briquettes were lit with a piece of flammable pine. All briquettes were able to ignite. The briquettes ignited very well and the combustion was maintained.

The results of the third test are negative for the three briquettes (rice husk, banana peel, soybean stalk), they ignite with difficulty. Nevertheless, knowing that the rice straw and corn straw briquettes have the highest LHV and fixed carbon values, their ignition was possible but rather difficult because it took much longer.

These factors are then related to the ignition fire, the nature of the briquettes, their composition and the type of binder used. The organic binder facilitates ignition and combustion. Clay is a mineral binder and does not participate in combustion. It is just a support that lengthens the combustion time.

3.11 Briquette Durability and Efficiency Test

For the efficiency and longevity test, the results obtained indicate that the cooking and boiling times of the corn straw and rice straw briquettes are the shortest and therefore the most cost-effective. Boiling and cooking were easily achieved. Their valorization deserves to be developed in this country with agricultural vocation.

The boiling and cooking times for rice husk and soybean stalk briquettes are reasonable and also profitable. These two green coals are also beneficial in terms of energy sources. They have a higher heating value than firewood.

The duration of cooking and boiling depends on the calorific value: the higher the calorific value, the faster the water boiling test. Therefore, in descending order, charcoal briquettes made from corn straw, rice straw, rice husks and soybean stalks are the most effective.

The results of the various tests conducted in this study show that banana peel briquettes are the least effective.

However, since we can always find a lot of banana peels scattered in nature, especially in the vicinity of the market, it is always imperative to recycle it to preserve the environment.

Indeed, despite the results obtained in this study which ranks it last in comparison with the other 4 charcoal briquettes, the value of its Inferior Calorific Value (4438.24 Kcal/kg) remains higher than that of firewood (3800 Kcal/kg). This value can be considered as satisfactory from the calorific value point of view, especially if we try to improve the qualities by adding other organic elements to enrich the physicochemical characteristics.

3.12 Carbon/Nitrogen (C/N) Ratio and Optimal Waste Recovery

The Carbon/Nitrogen ratio is the quantity of nitrogen and carbon in an organic material (material which has a Carbon/Nitrogen ratio of 25/1 means that it contains 25 times more Carbon than Nitrogen)

The harder, dry, woody, brown organic material is, the more body it has. This material also contains a higher proportion of carbon if it is possible to hold it in our hand and we can feel it. For example, straws are rich in carbon.

However, an organic material contains a higher proportion of Nitrogen if it is wetter, greener, softer, less consistent or even liquid.

The results already mentioned above indicate that the 5 agricultural wastes analyzed are all recoverable as ecological charcoal briquettes with their respective qualities. From these results, it can be concluded that the best recovery for maize straw, rice straw and rice husk are ecological coals. This further confirms the results obtained with the calorific value comparisons

If a material can react with oxygen at high temperature, it burns in contact with it. When these conditions are met, the oxidation reaction is exothermic. It gives off more heat than it consumes - and this heat is used to support the reaction of other molecules in the body with oxygen, if there is enough left. This reaction is possible because of the Carbon present in the coal which is capable of reacting chemically with oxygen. Carbon reacts very well with oxygen, these are fuels. (Rapagnà, & al 2000).

In order to find other alternatives, we calculated their carbon-nitrogen ratios (C/N) to propose other possibilities of valorization such as biogas and compost.

3.13 Biogas

As with aerobic digestion, the ratio of Carbon to Nitrogen in the organic matter is important for the proper functioning of the reactors. The ideal ratio is between 10 and 40.
However, if the C/N ratio is lower than 10, i.e., an increase in Nitrogen, this can lead to an increased production of ammonia, which can harm the micro-organisms and inhibit the methanisation.

3.14 Compost

Composting is a biological process for converting organic matter into a stabilized product, similar to a a soil rich in humic compounds (d'Arras*, 2008).

For optimal compost production, the right Carbon/Nitrogen (C/N) ratio should be between 20-30. The chemical element carbon (C) must be 20 to 30 times greater than the quantity of the chemical element nitrogen (N). In fact, if the mixture to be composted is too low in nitrogen, it will not heat (no degradation).

By adding carbonaceous organic matter, the soil we will be enriched. The carbon will lighten the heaviest soils and make the lightest soils heavier. Carbon affects the physical fertility of the soil and its structure. This carbon will increase the porosity by allowing air and oxygen to penetrate better.

It is just as important as providing nitrogen in the short term. The roots of plants will be in an aerated, humid, living, organic context.

3.15 Optimal Waste Valorization

The results obtained previously have shown that the valorization of these agricultural wastes into ecological coal is already acquired. However, it is also interesting to see their valorization into biogas and/or compost.

To identify the best method of valorization to these organic wastes, analyses were carried out. It consists of determining the C/N ratio of each material used in this study. After laboratory analysis, the results on the carbon-nitrogen ratio of these materials lead to the following recommendations.

The results presented in the following table provide a framework for decision making for the actions to be taken.

Table 6. C/N Ratio and Valorization

	C/N	COMPOST	BIOGAS
Corn straw	41.19	Additional nitrogenous elements	add animal excrements
Rice straw	79.41	More quantity of additional nitrogenous elements	add animal excrements
Rice husk	31.36	Additional nitrogenous elements	add animal excrements
Soybean stalk	43.54	Additional nitrogenous elements	add animal excrements
Banana peel	82.06	More quantity of additional nitrogenous elements	add animal excrements

Source: Author

- -Biogas: for a better valorization of this agricultural waste into biogas, it is necessary to add animal excrements in the initial composition.
- -Compost: if the carbon-nitrogen ratio is higher than 40, the material is difficult to degrade. It is necessary to put additional nitrogenous elements. The best proportion for best quality compost is: 1 part Nitrogen and 1 part Carbon. Livestock manure, dried blood, ground or roasted horns, bone meal and grass clippings can be used to increase the nitrogen content of agricultural waste compost

IV. Conclusion

The efficiency and usefulness of charcoal briquettes made from agricultural residues have been demonstrated during this research. These raw materials are collected in the district of Antsirabe in the region with high agricultural potential Vakinankaratra.

On the one hand, the idea of this production is to replace the use of charcoal and firewood; and on the other hand, to turn the page of waste of resources and to tend towards the Zero Waste movement. This new fuel aims to reduce the abusive exploitation of the forest or deforestation, which can cause harmful effects on the environment and health. In order to obtain this new product, different operations have been carried out such as the collection of raw materials, drying, and carbonization, compacting and drying of the obtained briquettes.

In order to ensure the quality of the briquettes obtained, analyses were carried out in the laboratory of the National Center for Industrial and Technological Research. Several tests to obtain the best results were carried out. Concerning the analysis in the laboratory, different parameters such as the moisture content, the fixed carbon content, the ash content, the volatile matter index and the low calorific value were determined. The results obtained show that among the five briquettes tested, those prepared from corn straw and rice straw have the best qualities in terms of calorific value. These two briquettes have the higher calorific value: the briquette of corn straw charcoal has a calorific value equal to 6850 Kcal/kg and that of rice straw has an LHV of 6423 Kcal/kg. The briquette of banana peel has the lowest LHV compared to the others analyzed in this study, equal to 4438.24 Kcal/kg. As for the results obtained regarding the moisture content, the volatile matter index, the ash content and the fixed carbon content of the selected samples, they are consistent and usable.

The briquettes obtained are better than charcoal, they do not give off too much smoke, and leave little ash according to the analyses. For rice husk and rice straw, the ash content is respectively equal to 36.262% and 23.793%. For soybean stalk, it is equal to 36.611%, while for banana peel it is 44.522% the highest compared to the others. According to the standard, the rate of ash for ecological coal is 50%. While the result obtained from the ash rate is less than 50%. This is another indication of the efficiency of the ecological coal made in this research.

The tests carried out have also been able to demonstrate that the tests made are convincing compared to the charcoal. For the boiling rate of water and the cooking time, the ecological charcoal is faster than the charcoal. According to the results obtained, we can confirm that green charcoal is more efficient than wood charcoal. The use of green charcoal has many advantages, as it does not have too much soot and smoke.

The production of green charcoal obtained by the valorization of agricultural residues will have the effect of slowing down or even replacing the production of charcoal.

Ecological coal, compost, biogas is tangible evidence to justify the feasibility of actions in the framework of the Zero waste circular economy. There should be no question of wasting these resources "residues and waste" knowing that they can be useful for development.
The socio-economic impact of the present study will be even more positive by raising awareness on a massive scale for the effective involvement of the population concerned.

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ANNEX 1.

Table 2. Weight Change of *Irvingia smithii* Almond-fed and Non-almond-fed Mice as a Function of Time

	T01	T02	T03	T04	T05	∑T0	MOY	SD	T11	T12	T13	T14	T15	∑T1	MOY	SD	T21	T22	T23	T24	T25	∑T2	MOY	SD
PJ1	19,08	19,11	18,22	16,73	18,18	**91,32**	**18,26**	**0,97**	17,03	19,86	17,53	17,62	18,86	**90,9**	**18,18**	**1,16**	17,31	18,67	17,57	19,27	18,01	**90,83**	18,17	0,8
PJ2	18,27	19,67	18,47	17,26	16,52	**90,19**	**18,04**	**1,21**	19,43	17,86	20,08	19,77	21,08	**98,22**	**19,64**	**1,17**	16,97	17,44	17,18	18,53	19,23	**89,35**	17,87	0,97
PJ3	18,49	19,53	19,18	16,63	18,35	**92,18**	**18,44**	**1,12**	18,45	17,05	18,74	18,56	19,04	**91,84**	**18,37**	**0,77**	16,04	16,5	16,4	18,3	19,09	**86,33**	17,27	1,34
PJ4	19,71	19,81	18,99	17,04	17,62	**93,17**	**18,63**	**1,25**	20,21	19	20,41	20,18	20,79	**100,6**	**20,12**	**0,67**	15,38	15,87	15,63	17,2	18,64	**82,72**	16,54	1,37
PJ5	18,8	19,75	18,52	16,45	18,92	**92,44**	**18,49**	**1,23**	19,98	19,51	20,63	19,75	20,47	**100,3**	**20,07**	**0,47**	15,36	14,63	15,24	15,85	18,02	**79,1**	15,82	1,3
PJ6	18,83	20,22	19,17	17,3	19,11	**94,63**	**18,93**	**1,05**	20,7	19,22	20,1	20,77	21,42	**102,2**	**20,44**	**0,83**	18,41	17,53	18,55	18,48	20,15	**93,12**	18,62	0,95
PJ7	19,01	20,27	19,81	17,59	19,73	**96,41**	**19,28**	**1,05**	21,59	19,63	21,04	20,99	22,17	**105,4**	**21,08**	**0,94**	17,19	15,67	17,03	17,47	20,03	**87,39**	17,48	1,59
PJ8	17,16	20,19	19,83	17,25	20,24	**94,67**	**18,93**	**1,59**	21,6	20,17	21,16	21,65	22,46	**107**	**21,41**	**0,84**	17,41	15,96	17,16	17,46	20,5	**88,49**	17,7	1,68
PJ9	16,41	21,4	20,01	17,93	19,97	**95,72**	**19,14**	**1,97**	22,06	20,39	21,49	21,45	22,58	**108**	**21,59**	**0,82**	18,19	16,71	17,98	17,81	20,36	**91,05**	18,21	1,33
PJ10	15,89	21,25	20,37	18,2	20,54	**96,25**	**19,25**	**2,2**	22,28	20,37	21,24	21,27	22,09	**107,3**	**21,45**	**0,77**	17,32	16,36	17,37	17,18	19,95	**88,18**	17,64	1,36
PJ11	15,3	20,91	20,04	18,22	20,22	**94,69**	**18,94**	**2,26**	22,67	21,37	21,85	21,13	22,86	**109,9**	**21,98**	**0,77**	18,12	16,34	18,09	17,63	20,43	**90,61**	18,12	1,48
PJ12	15,12	21,13	20,41	18,16	20,08	**94,9**	**18,98**	**2,42**	23,02	21,61	21,88	21,98	23,11	**111,6**	**22,32**	**0,69**	18,34	16,86	18,21	17,46	20,52	**91,39**	18,28	1,39
PJ13	16,23	20,96	20,39	17,96	20,18	**95,72**	**19,14**	**1,99**	23,42	22,16	22,44	22,68	23,64	**114,3**	**22,87**	**0,64**	19,04	17,3	18,77	17,88	20,63	**93,62**	18,72	1,27
PJ14	16,78	21,03	20,49	18,37	20,35	**97,02**	**19,4**	**1,78**	23,73	22,47	22,79	22,71	24,08	**115,8**	**23,16**	**0,7**	18,99	16,84	18,93	17,45	20,87	**93,08**	18,62	1,57
PJ15	17,49	21,17	21	18,02	19,97	**97,65**	**19,53**	**1,69**	24,2	22,6	23,33	23,79	24,67	**118,6**	**23,72**	**0,8**	19,03	17,41	18,92	17,54	21,36	**94,26**	18,85	1,59
PJ16	18,21	21,84	21,13	18,62	20,35	**100,2**	**20,03**	**1,57**	23,81	21,8	22,68	22,45	23,63	**114,4**	**22,87**	**0,84**	19,35	17,53	19,36	17,47	21,25	**94,96**	18,99	1,57
PJ17	18,35	21,52	21,35	18,28	19,82	**99,32**	**19,86**	**1,56**	24,2	22,59	23,35	23,2	24,53	**117,9**	**23,57**	**0,78**	19,01	17,15	19,35	16,84	20,6	**92,95**	18,59	1,58
PJ18	18,73	22,35	22,14	19,21	20,26	**102,7**	**20,54**	**1,66**	24,66	22,75	23,73	23,67	24,71	**119,5**	**23,9**	**0,81**	18,93	16,79	19,44	16,95	21,23	**93,34**	18,67	1,85
PJ19	19,45	22,74	21,9	20,21	20,21	**104,5**	**20,9**	**1,36**	25,32	23,37	24,35	24,37	25,17	**122,6**	**24,52**	**0,78**	19,27	17,66	20,55	17,45	21,76	**96,69**	19,34	1,85
PJ20	19,78	23,12	22,33	19,91	20,12	**105,3**	**21,05**	**1,56**	24,93	23,49	23,72	24,24	25,13	**121,5**	**24,3**	**0,72**	18,99	17,32	20,66	17,54	21,39	**95,9**	19,18	1,82
PJ21	19,98	23,65	22,62	20,34	20,86	**107,5**	**21,49**	**1,58**	25,13	23,77	24,95	24,16	25,21	**123,2**	**24,64**	**0,64**	19,17	17,14	21,14	17,67	21,88	**97**	19,4	2,08
PJ22	20,5	23,12	22,56	20,49	20,74	**107,4**	**21,48**	**1,26**	25,07	23,98	25,06	24,79	25,44	**124,3**	**24,87**	**0,55**	18,63	17,1	20,96	17,82	21,73	**96,24**	19,25	2,01
PJ23	20,99	22,74	21,76	20,32	21,04	**106,9**	**21,37**	**0,92**	25,19	23,95	24,74	24,85	25,66	**124,4**	**24,88**	**0,63**	18,71	16,69	21,34	17,55	21,64	**95,93**	19,19	2,22
PJ24	20,85	22,79	21,73	19,75	20,99	**106,1**	**21,22**	**1,13**	24,2	23,45	24,7	24,36	24,8	**121,5**	**24,3**	**0,54**	18,26	15,65	20,75	18,18	20,95	**93,79**	18,76	2,18

PJ25	21,32	22,66	21,85	19,39	20,84	**106,1**	**21,21**	**1,22**	25,21	24,46	25,2	25,16	25,6	**125,6**	**25,13**	**0,41**	18,3	16,49	22,01	18,89	22,08	**97,77**	19,55	2,44
PJ26	21,03	21,9	21,62	18,7	21,48	**104,7**	**20,95**	**1,29**	25,79	25,31	25,62	25,31	25,83	**127,9**	**25,57**	**0,25**	18,22	16,38	22,04	19,33	22,06	**98,03**	19,61	2,47
PJ27	21,1	22,99	22,25	19,01	21,41	**106,8**	**21,35**	**1,5**	25,28	25,03	25,65	25,02	25,66	**126,6**	**25,33**	**0,32**	18,22	16,87	22,13	19,57	22,37	**99,16**	19,83	2,41
PJ28	21,21	22,96	21,95	19,44	21,68	**107,2**	**21,45**	**1,29**	25,19	24,9	25,41	25,36	25,21	**126,1**	**25,21**	**0,2**	18,31	17,36	22,69	20,22	22,83	**101,4**	20,28	2,49
PJ29	21,22	23,05	22,15	19,68	21,91	**108**	**21,6**	**1,26**	25,79	25,2	25,57	25,5	25,87	**127,9**	**25,59**	**0,26**	18,05	17,38	22,81	20,44	23,07	**101,8**	20,35	2,63
PJ30	21,99	23,09	21,76	19,78	22,55	**109,2**	**21,83**	**1,26**	25,92	25,48	26,12	25,72	26,12	**129,4**	**25,87**	**0,27**	18,36	17,57	22,94	20,67	22,8	**102,3**	20,47	2,47
PJ31	21,69	22,43	21,31	19,89	23,33	**108,7**	**21,73**	**1,29**	26,46	26,38	26,91	26,56	26,62	**132,9**	**26,59**	**0,2**	19,76	18,61	23,18	21,32	23,19	**106,1**	21,21	2,04
PJ32	22,02	22,04	21,59	20,47	23,2	**109,3**	**21,86**	**0,98**	26,73	26,4	26,75	26,32	26,23	**132,4**	**26,49**	**0,24**	19,22	18,47	23,25	21,78	23,15	**105,9**	21,17	2,22
PJ33	22,22	22,24	21,81	19,83	23,75	**109,9**	**21,97**	**1,41**	26,53	26,4	26,43	26,29	25,87	**131,5**	**26,3**	**0,26**	19,14	18,73	23,44	22,48	23,83	**107,6**	21,52	2,42
PJ34	22,01	21,89	22,02	19,69	23,57	**109,2**	**21,84**	**1,39**	26,99	26,67	26,82	26,89	26,43	**133,8**	**26,76**	**0,22**	19,56	19,22	24,05	22,85	23,65	**109,3**	21,87	2,3
PJ35	22,24	22,01	21,45	18,88	23,11	**107,7**	**21,54**	**1,6**	27,18	26,86	26,9	26,54	26,45	**133,9**	**26,79**	**0,29**	19,22	19,58	24,06	23,18	23,93	**110**	21,99	2,4
PJ36	22,5	22,16	21,84	19,52	22,93	**109**	**21,79**	**1,33**	27,52	27,33	27,18	26,56	26,62	**135,2**	**27,04**	**0,43**	18,95	19,36	23,84	22,92	23,85	**108,9**	21,78	2,43
PJ37	22,35	22,05	21,8	19,6	22,81	**108,6**	**21,72**	**1,24**	27,2	27,24	26,69	26,51	26,62	**134,3**	**26,85**	**0,34**	18,77	18,47	23,56	22,5	23,02	**106,3**	21,26	2,44
PJ38	22,45	22,32	21,94	19,5	21,96	**108,2**	**21,63**	**1,21**	27,05	26,84	26,57	26,09	26,39	**132,9**	**26,59**	**0,38**	18,74	19,57	23,45	22,37	23,57	**107,7**	21,54	2,25
PJ39	22,79	22,21	22,01	20,05	23,03	**110,1**	**22,02**	**1,18**	27,67	27,06	26,91	26,59	26,88	**135,1**	**27,02**	**0,4**	19,76	19,93	23,53	22,39	23,68	**109,3**	21,86	1,91
PJ40	22,98	22,67	22	20,45	22,92	**111**	**22,2**	**1,05**	28,16	27,38	27,34	26,72	26,31	**135,9**	**27,18**	**0,71**	19,38	19,99	23,99	22,59	24,27	**110,2**	22,04	2,26
PJ41	22,67	22,72	22,12	20,55	22,94	**111**	**22,2**	**0,97**	27,25	26,69	26,83	26,32	25,79	**132,9**	**26,58**	**0,55**	18,77	19,86	23,83	22,29	24	**108,8**	21,75	2,35
PJ42	22,99	22,94	22,32	20,45	23,01	**111,7**	**22,34**	**1,1**	27,76	27,78	27,3	26,78	26,65	**136,3**	**27,25**	**0,53**	19	20,73	23,98	22,97	24,12	**110,8**	22,16	2,23
PJ43	23,56	22,14	21,99	21,05	22,24	**111**	**22,2**	**0,9**	27,99	27,51	27,01	26,93	26,93	**136,4**	**27,27**	**0,47**	19,11	19,75	24,19	22,58	24,24	**109,9**	21,97	2,43
PJ44	23,78	23,12	21,85	21,01	23,28	**113**	**22,61**	**1,14**	27,74	27,72	27	26,74	26,62	**135,8**	**27,16**	**0,53**	19,55	20,06	24,13	23,08	24,25	**111,1**	22,21	2,25
PJ45	23,85	23,78	22,35	21,04	23,49	**114,5**	**22,9**	**1,2**	28,13	27,32	26,47	26,65	27,15	**135,7**	**27,14**	**0,65**	20	20,14	24,21	23,12	24,22	**111,7**	22,34	2,12
PJ46	23,89	23,54	22,45	22,01	23,49	**115,4**	**23,08**	**0,8**	29,01	27,93	26,74	27,3	26,78	**137,8**	**27,55**	**0,95**	20,05	19,94	24,26	23,52	24,6	**112,4**	22,47	2,3
PJ47	23,76	23,35	21,02	21,55	22,78	**112,5**	**22,49**	**1,17**	28,71	28,52	26,97	27,52	27,35	**139,1**	**27,81**	**0,76**	20,84	20,24	24,49	24,15	25,12	**114,8**	22,97	2,25
PJ48	24,01	23,65	21,21	21,75	22,7	**113,3**	**22,66**	**1,2**	28,02	27,85	27,36	28,14	27,26	**138,6**	**27,73**	**0,4**	21,44	20,87	24,71	24,71	25,42	**117,2**	23,43	2,11
PJ49	23,82	24,05	21,25	22,05	23,24	**114,4**	**22,88**	**1,2**	28,75	28,59	27,58	28,35	27,5	**140,8**	**28,15**	**0,58**	22,2	21,25	25,35	25,21	25,65	**119,7**	23,93	2,05
PJ50	23,25	23,75	21,47	22,13	23,5	**114,1**	**22,82**	**0,98**	29,25	29,18	27,51	28,25	27,64	**141,8**	**28,37**	**0,82**	22,64	22,31	25,56	25,43	25,15	**121,1**	24,22	1,6
Somme	1026	1102	1060	967,6	1066	**5221**			1250	1210	1225	1221	1242	**6148**			939	902,3	1062	1004	1108	**5015**		
Moyenne	20,52	22,04	21,2	19,35	21,31	**20,88**			25	24,21	24,5	24,41	24,84	**24,59**			18,78	18,05	21,25	20,07	22,17	**20,06**		
Ecart-type	2,537	1,259	1,165	1,491	1,77	**1,644**			2,932	3,215	2,693	2,711	2,247	**2,76**			1,371	1,717	2,895	2,704	1,981	**2,134**		

Variance	6,438	1,584	1,356	2,224	3,132	**2,947**	8,599	10,33	7,251	7,349	5,049	**7,716**	1,881	2,948	8,381	7,31	3,925	**4,889**
C.V.	12,36	5,71	5,494	7,707	8,305	**7,916**	11,73	13,28	10,99	11,11	9,046	**11,23**	7,302	9,514	13,63	13,47	8,938	**10,57**
Min	15,12	19,1	18,2	16,45	16,52	**15,12**	17,03	17,05	17,53	17,62	18,86	**17,03**	15,36	14,63	15,24	15,85	18,01	**14,63**
Max	24,01	24,05	22,62	22,05	23,75	**24,05**	29,25	29,18	27,58	28,35	27,64	**29,25**	22,64	22,31	25,56	25,43	25,65	**25,65**
Pf – Pi	3,45	4,64	3,25	5,4	5,32	**22,78**	12,22	9,32	9,98	10,63	8,78	**50,93**	5,33	3,64	7,99	6,16	7,14	**30,26**
% G.P.						**24,95**						**56,03**						**33,31**
C.V/Gr	9,1	28,9	7,8	38,3	10,7		10,3	9,57	2,37	4,55	6,2		32,1	50	29,6	0,23	52,6	

Legend :

WD1 : Weight at the first day

T0 : Group of mice as control (exclusively fed standard feed)

T01 : First mouse of control group

T1 : Group of mice fed standard feed supplemented with 25% *Irvingia smithii* almond powder

T12 : Second mouse of Group T1

T2 : Group of mice fed standard feed supplemented with 50% *Irvingia smithii* almond powder

T23 : Third mouse Group T2

Pf – Pi : Live Weight Gain = Final weight – Initial weight