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Analysis of the calorific value of pellets and briquettes in the use of the pseudostem of Banana (Musa paradisiaca)

Análisis del poder calorífico de pellets y briquetas en el aprovechamiento del pseudotallo de Plátano (Musa paradisiaca.

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Abstract.
Solid biofuels belong to the second generation according to the type of biomass obtained from agricultural, forestry, and industrial wastes, such as banana pseudostem, which is a lignocellulosic biomass that can be used as an alternative for the generation of renewable energy in the form of pellets and briquettes due to its energetic properties. The study aims to determine the calorific value efficiency of solid biofuels based on Plantain (Musa paradisiaca) pseudostem. The study methodology was divided into three parts: (1) obtaining and conditioning of biomass, (2) elaboration of solid biofuels, and (3) physical, proximal, and energy potential analysis of biomass and the respective ANOVA of pellets and briquettes. A high calorific value was found for the compositions 55-45% in pellet with 22,657 MJ/kg and 50-50% in briquette with 22,680 MJ/kg, complying with the parameters established in the ENplus and NTC 2060 standards, respectively.

Keywords.
Pseudostem, Biomass, Calorific value, Pellet and Briquette.

Resumen.
Los biocombustibles sólidos pertenecen a la segunda generación de acuerdo con el tipo de biomasa, obteniéndose de desechos agrícolas, forestales e industriales como el pseudotallo de plátano que es una biomasa lignocelulósica la cual se puede emplear como una alternativa para la generación de energía renovable en forma de pellets y briquetas debido a sus propiedades energéticas. El objetivo de estudio es determinar la eficiencia del poder calorífico de los biocombustibles sólidos en base al pseudotallo de Plátano (*Musa paradisiaca)*. La metodología de estudio se dividió 3 partes: (1) Obtención y acondicionamiento de la biomasa, (2) elaboración de Biocombustibles Sólidos y (3) el análisis físico, proximal, potencial energético de la biomasa y el ANOVA respectivo de pellet y briqueta. Encontrándose un alto poder calorífico para las composiciones 55-45% en pellet con 22,657 MJ/Kg y 50-50% en briqueta con 22,680 MJ/kg, cumpliendo con los parámetros establecidos en las normas ENplus y NTC 2060 respectivamente.

Palabras clave.
Pseudotallo, Biomasa, Poder Calorífico, Pellet y Briqueta.

1. Introduction

Ecuador is a country that produces large amounts of biomass and lignocellulosic waste per year, which are not fully used in the agricultural area, even though biomass is of great importance in the generation of clean energy since it is explored as an alternative raw material for the production of solid biofuels. Therefore, biomass is an available resource, which has advantages such as its ease of combustion, cellulose content and carbon neutrality. [1]

According to the Bioenergy Atlas of Ecuador using the ESPAC database, in 2012 it had a productivity of 559 319 tons/year, where 372 576 t/year corresponds to field residues (leaves, pseudostem), from which a Lower Calorific Value (PCI) of 4,180 TJ/kg was obtained. However, according to the INEN in 2022, Ecuador registered 133,145 h of planted area, giving a harvest of 114,526 h, obtaining a production of 857,561.89 metric tons [2]. It is estimated that from a banana plant weighing around 100 kg, 88% is obtained, which represents the total residues and the bunch 12%, giving a ratio between crop residues and the bunch is 2:1 [3], [4]. The lignocellulosic residues generated are the parts of the crops of plant species discarded in the harvest period [5], which are not used for consumption, so in the agricultural sector 1.44 MMt of annual biomass are estimated, however, in the forestry sector 0.22 MMt/year are produced. [6]

Our country has a great demand for the export of green bananas, which comes from the gender *Muse* of the family *Musaceae,* of the species *paradisiaca L*. It is a large herbaceous plant, which is composed of a rhizome, a pseudostem, leaves, flowers and fruit (cluster). [7]

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Approximately to obtain a ton of green bunches, 150 kg of rachis was produced, 480 kg of leaves and 3 tons of pseudostem, so these residues are used as fertilizer and animal feed. [8]

The pseudostem that occurs in large amounts of residual biomass. It is a stem formed by wide pods, its size varied from 3.5 to 6 m and weighs about 50 kg. This structure is composed of lignocellulosic compounds such as: Cellulose, lignin, hemicellulose and other chemical compounds (K, Na, Ca, Mn, P). Due to its properties, it can be used as biomass for energy generation, through the production of biofuels and thus contribute to the reduction of emissions of gases that pollute the environment. Currently, Ecuador has been engaged in adopting renewable energy as a regular part of its energy supply, with the use of biomass accounting for 1.99% of electricity production. [9]

This research article discusses the use of biomass of *Musa paradisiaca* for the production of solid biofuel in the form of pellets and briquettes, to reduce the pollutants produced by fossil fuels by choosing this replacement alternative to also reduce soil erosion, desertification, forest and crop degradation since they provide clean combustion. The quality standards established in the Enplus and NTC 2060 standards respectively will be used. In addition, ASTM 3172-89 was employed for proximal biomass and solid biofuel analyses. Therefore [10]The objective of the study is to determine the efficiency of the calorific value of solid biofuels based on the pseudostem of Banana (*Musa paradisiaca).*

1.1. Banana Pseudostem

The pseudostem weighs close to 50 kilograms and its length ranges between 3.5 and 7.5 meters, its main function being to support the leaves that emerge in the upper part and the cluster. These leaves, of a dark green tone and considerable extension, measure about 2 to 4 meters in length by 1.5 meters in width. Their structure resembles a tree trunk, is herbaceous in nature and usually has a robust and thick appearance due to the accumulation of plant fibers. Unlike trees, plane trees do not have a solid wooden trunk, instead, the pseudostem is composed of leaves arranged in concentric layers, which overlap each other. The pseudostem also serves the function of storing nutrients and water for the growth of the plant. [11] [12]

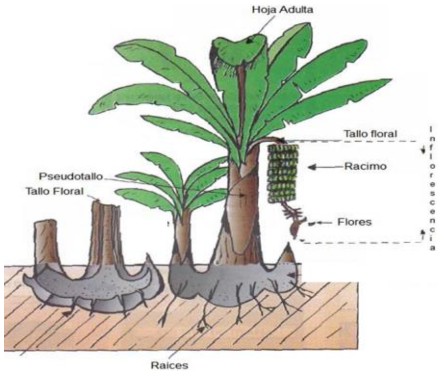

Figure 1 Banana Plant. Fountain: *[13].*

Banana cultivation in Ecuador is 128. 861 hectares planted, which is distributed in 21 provinces as shown in Figure 2, indicates that banana production at the national level was 763,455 tons.

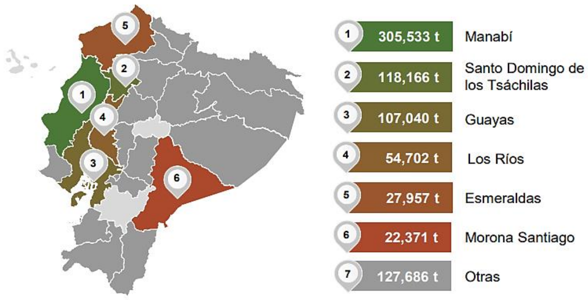

Figure 2 Production distribution. Fountain:. [14]

In contrast, in 2022 it was recorded in 133,145 hectares planted, as can be seen in Figure 3, the third place in planted area is obtained, achieving a production of 857,561.89 metric tons and a yield of 7.49 tonnes / hectares, which is the fourth place in permanent crops in Ecuador. [2] [15].

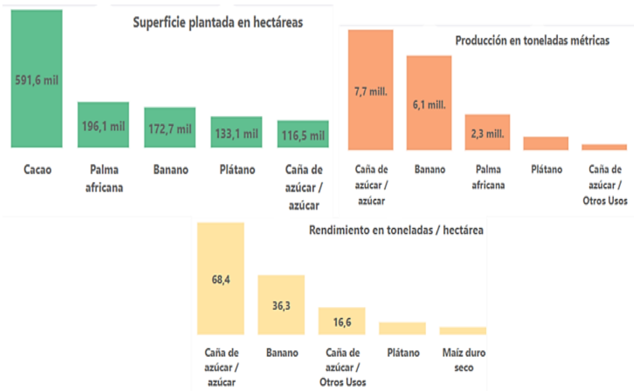

Figure 3 Banana planted area in Ecuador 2022. Fountain:. *[2]*

1.2. Biofuel

They are fuels that are manufactured with biomass, which allows greenhouse gas emissions to be reduced, only if their processes are sustainable, that is, they emit a small carbon footprint. In the generation of energy by combustion, the biomass used must have low percentages of lignin, in order to produce smaller amounts of carbonaceous waste, otherwise thermal degradation will produce large amounts of them. These biofuels are classified according to their generation: [1]

- First-generation biofuels use biomass from food agricultural crops.
- The second generation uses lignocellulosic biomass from forestry, agricultural and urban waste.
- The third generation, its biomass is from inedible species.
- Finally, the fourth generation is made from genetically modified microorganisms. [16]

Biofuels are also divided according to their status into: Liquids (Bioethanol, biodiesel, biooils), Solids (Pellets, chips, briquettes, coal) and Gaseous (biogas, biomethane, biohydrogen) [17]. This research focuses on solid biofuels (pellets and briquettes) that belong to the second generation, which allows a zero carbon footprint, because their raw material is lignocellulosic waste, which is a biological source not fully explored, which would be a great biomass alternative for the production of biofuels [18].

1.3. Solid Biofuels

Solid biofuels are forms of fuel made from organic material of plant or animal origin that can be used in different applications for power generation. They are acquired through physical methods such as compression, chipping, or crushing. Specifically, in the generation of electrical and thermal energy, solid biofuels produced from the remains of biomass from forestry or agro-industrial operations are used. The relevance of solid biofuels lies in their great capacity to meet the energy needs related to the increase in population. The use of solid biofuels will make it possible to replace fossil fuels in the generation of electricity and heat, while reducing the disadvantages caused by traditional fuels. Within the range of solid biofuels are chips, briquettes and pellets, which are compact forms with a high heat capacity. [19] [16] [20]

The main components used in the production of solid biofuels are derived from lignocellulosic materials, which come from agriculture or forestry, so waste from agribusiness has multiple potential uses, including the creation of organic fertilizer or the manufacture of biofuels. [16]

Table 1.- Types of Solid Biofuels.

Types	Source/source	Use
Splinter	Agricultural and forestry residues. Woody crops. Agri-food waste.	Bakery ovens, ceramics, in small industries, homes and heating.
Charcoal	Wood and plant residues.	Domestic.
Pellet & Briquette	Wood Industry. Example: Teak, alfalfa, etc.	Fuel: in industrial and large areas.

Note: Information obtained from. Fountain:. [21] [22]

Figure 4 Types of Solid Biofuels. Fountain:. *[21]*

Here are some characteristics of pellets and briquettes.

1.3.1. Pellets

They are cylindrical biofuels, of different types of biomass on which their color will depend (vegetable, animal, agro-industrial and urban solid waste), where their range of dimensions is: diameter of 6-8 mm and 3.15-40 mm in length. Where the fundamental property is calorific value ≥ 16,5 . Other properties are its moisture percentage of $\frac{MJ}{Kg}$ ≤10% This value determines the amount of energy that the pellets will produce when they are subjected to combustion, and in other words, if the water content is high, in combustion it will be eliminated first and then heat will be produced, obtaining a low calorific value. In addition, the ash must be 0.7% and a bulk density of [23]≤600 $\frac{Kg}{m^3}$ – 750 $\frac{Kg}{m^3}$, these properties are in accordance with the En Plus Standard. [24]

Figure 5 Pellets. Note: Pellets produced from rice husks. Fountain:. *[25]*

1.3.2. Briquettes

They are solid blocks of varied shapes (the most commonly used rectangular and round), which have a diameter of more than 5 cm and a length between. Where the fundamental property is calorific value from 12,500-21,000 $\frac{MJ}{Kg}$. Other properties are its moisture percentage of 2,5% and ash 30% these properties are according to the Colombian Standard. [26]

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Figure 6 Briquettes. Note: Briquettes of different materials and shapes. Fountain:. *[27]*

1.4. Biomass

It is a type of renewable energy that is obtained from organic matter, such as agricultural waste, forestry, food, manure, among others. This organic matter can be used as fuel for the generation of heat, electricity and biofuels (Tepale Gómez, 2020). In addition, biomass is a renewable energy source, as it comes from biological organisms that can be grown and regenerated in a relatively short period of time. This makes it a sustainable option for energy production, unlike fossil resources that are limited and cannot be regenerated. [20] [28]

Another benefit of biomass is that its processing and use does not require complex technologies. It can be used directly in the form of firewood, pellets or briquettes, or it can be converted into different forms of energy such as electricity, heat or biogas through combustion, gasification or fermentation processes. [6]

The use of biomass as an energy resource has several advantages compared to oil, coal and gas: [6]

-Improvement of the socio-economic situation of rural areas: The use of agricultural residues to generate energy from biomass can generate employment and income in rural areas, boosting the economic development of these areas. [6]
-Reduction of polluting emissions: By using biomass instead of fossil fuels, emissions of pollutants such as sulfur, particulate matter, carbon monoxide (CO), methane (CH4) and nitrogen oxides (NOx) are reduced, which has a positive impact on air quality and public health. [6]
-CO2 neutral cycle: Biomass has the advantage of being a renewable resource and its combustion does not contribute to the greenhouse effect significantly, since the carbon dioxide (CO2) released during burning is the same that was absorbed by plants during their growth. This helps reduce greenhouse gas emissions and mitigate climate change. [29]
-Potential of Latin America and the Caribbean: These regions have a large amount of natural and agricultural resources, which positions them as potential producers of biomass. The development of the bioeconomy in these areas can boost their socio-economic development, as well as promote energy security and reduce dependence on fossil fuels. [6]

In summary, the use of biomass as an energy resource has several advantages, both socio-economically and environmentally, which makes it an interesting and sustainable alternative compared to traditional fossil fuels. [6]

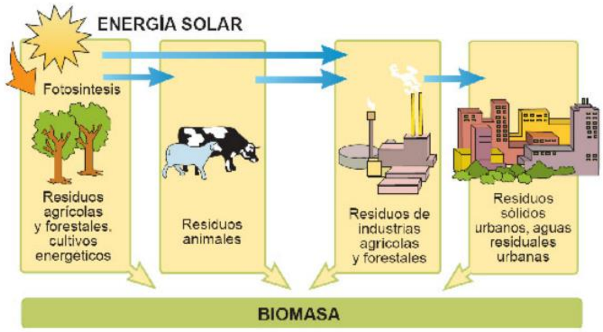

Figure 7 *Biomass. Fountain:* [21].

1.5. Features

1.5.1. Moisture Content

For the test, the procedure of the ASTM D-3173 standard was followed, in which the formula was used:

$$\%H = \frac{A - B}{A} * 100 \qquad (1)$$

Where:

A: grams of initial sample in g.
B: grams of final sample in g.

1.5.2. Ash Content

The ash content of a mass is determined according to the amount of minerals it contains and for this the following formula is used. [30]

$$\%C = \frac{m_3 - m_1}{m_2 - m_1} * 100 \qquad (2)$$

m_1: Empty crucible dough and lid.
m_2: Crucible mass and lid +1 g sample.
m_3: Crucible mass and lid + heated muffle sample.

1.5.3. Density

For this test, the biofuels were weighed and their determined volume was obtained, and then the following equation was applied:

$$d = \frac{m}{v} \qquad (3)$$

d= density
m = mass
v =volume

1.5.4. Calorific Value

Is The amount of energy that can be obtained by burning a substance. It refers to the ability of a substance to produce heat by performing a complete combustion chemical reaction [31].Calorific value is measured in units of energy per units of mass such as joules or calories.

1.5.5. Volatile Material:

This test of the percentage of volatile material was worked according to the standard, using the following equation: [32]

$$\%MV = \left(\frac{m_2-m_3}{m_2-m_1} * 100\right) - h \qquad (4)$$

m_1: Empty crucible dough and lid.
m_2: Crucible mass and lid +1 g sample.
m_3: Crucible mass and lid + sample

1.5.6. Fixed Carbon

It is the subtraction of 100 and the result of the sum of the percentage of moisture, ash and volatile material [33].

$$C.Fijo = [100 - (H\% + C\% + MV\%)] \qquad (5)$$

H: Percentage of moisture.
C: Percentage of ash.
MV: Percentage of volatile material.

2. Materials and methods.

Study Area

The study area includes lot 9 of the Canaán I urbanization of the Cumandá Canton (Chimborazo-Ecuador).

2.1. Methodology

The methodology of the study is divided into 3 sections: (1) Obtaining and conditioning of biomass (raw material), (2) production of pellets and briquettes and (3) Methods of physical characterization, proximal and structural analysis and the respective anova.

2.2. Obtaining and conditioning of biomass

The choice of this biomass is based on its abundant availability as agricultural waste in Ecuador and its high content of lignocellulosic components, suitable for the production of solid biofuels. This initial step also includes an analysis of the plants' growing conditions to ensure uniformity in the samples, including data on plant age, soil conditions, and harvest time.

Samples of banana pseudostem of the Dominican and Barragañete species were collected randomly after harvest, then they were cut into a rectangular shape (2cmx5cm) and the pieces were exposed to the sun for 8 days, to reduce the moisture content. The samples were then dried by an oven at a temperature of 60°C for 12 hours in aluminum cans. Then, it was introduced into a hammer mill, in order to reduce its size, and then placed in a vibrating machine for 5 minutes, until the particles decreased to a mesh size of 0.8 mm, 0.63 mm and 0.315 mm. To finish with the conditioning of the biomass, the humidity was removed at 100°C for 6 h.

2.2.1. Chemical composition of Biomass

Proximal analysis, performed according to ASTM D3172-89 to determine cellulose, hemicellulose and lignin content. The average composition obtained was 31.27% cellulose, 15.07% hemicellulose and 23.9% lignin, which shows a high energy content suitable for use in biofuels.

2.3. Pellet and briquette production

In this stage, the biomass was homogenized with the binder according to the selected compositions where the following amounts of biomass-binder were used.

Table 2 *Compositions of Solid Biofuels*.

Composition	Amount of Biomass (g)	Amount of binder (g)	Amount of Residue (g)	Quantity of Biofuels
Pellet 50-50	26	26	2	14 Pellets
Pellet 55-45	28,6	23,4	2	13 Pellets
Pellet 60-40	31,2	20,8	3	11 Pellets
Briquettes 50-50	205	205	8	6 Briquettes
Briquettes 55-45	270,6	221,4	6	6 Briquettes
Briquettes 60-40	246	164	11	6 Briquettes

Note: Information Obtained from . [22]

With the quantities used in each composition, a compact mass was obtained by means of the pellet and briquetting machine. To finish with the drying in the environment for 72 hours of the pellets and briquettes produced.

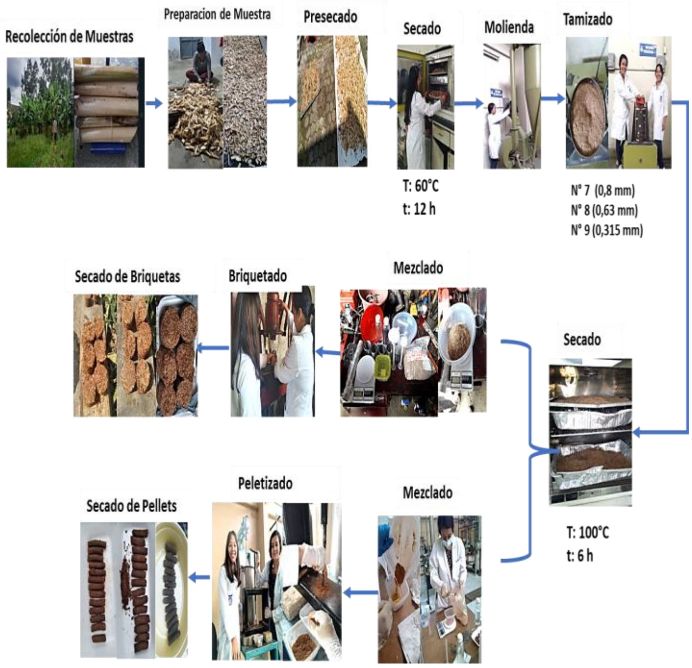

Figure 8 Flow Chart. Fountain:. *[22]*

2.4. Methods of physical characterization, proximal analysis, structural analysis and anova.

The calorific value was evaluated using a calorimetric pump under the ASTM D5865 standard. This analysis included the measurement of the energy content in MJ/kg of the samples produced in different compositions. In addition, ANOVA statistical analysis and Tukey's post-hoc test were used to determine the significance of the differences between pellet and briquette compositions

2.4.1. Physical characterization

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This characterization was based on the procedures of the ASTM S3172-89 standard for moisture content for ground biomass. On the other hand, for solid biofuels, the same wet content standard was applied and their density was found. Preliminary analyses are essential to understand the composition of the pseudostem. You can include an analysis of the amount of cellulose, hemicellulose and lignin, which are key elements in the calorific value of biomass. Based on previous studies, banana pseudostem has high cellulose (between 30-60%) and lignin values, indicating its suitability as a solid biofuel

2.4.2. Proximal analysis
The characterization of the ground biomass was carried out using the ASTM D3172-89 standard, which describes the methods for determining the content of ash, volatile material and fixed carbon. For the study of the calorific value, the ASTM D240 standard was applied by the LAQUINS ESPOL laboratory.

2.4.3. Structural Analysis
The samples were sent to the LAQUINS ESPOL laboratory, for the characterization of lignin, cellulose and hemicellulose. These analyses were performed according to TAPPI T 203 and 222.

2.4.4. Anova
It is the statistical procedure used to evaluate hypotheses known as ANOVA and is used to contrast two or more averages associated with a common factor. This method is applied to the dataset, which generates variations, where it is subjected to different conditions where it is verified if it is similar or unequal. It has Null and Alternate hypotheses, which in order to reject the null hypothesis must not meet the condition that one of the means is different from the rest. And on the other hand, for the alternative hypothesis to be rejected, all the means must be equal. [34]

2.4.5. Tukey's method
The Tukey method complements the information obtained from ANOVA, allowing the comparison of the sample means obtained from an experimental trial. The Tα value is calculated from the following equation (Cajal, 2022):

$$T\alpha = q\alpha(K, N-K)\sqrt{CM_E/n_i} \qquad (6)$$

$T\alpha$ = HSD number (Honestly Significant Difference)
qα= quantiles of the Tukey distribution (table with relative significance of 0.05% equal to 95% reliability)
n = number of repetitions of the study
CME = Mean Square Error Factor represents the standard error of each average

The tukey test states that when the variation between two means is greater than the value of *The,* it is considered unequal, however, if the difference is smaller, it is considered to be statistically identical. [35]

3. Analysis and Interpretation of Results.

The physical characterization, proximal and structural analysis of the ground banana pseudostem biomass is shown in Table 3.

Table 3 Biomass Characterization Results

Parameter	Unit	Result	Method of Analysis
*Calorific value	$\frac{MJ}{Kg}$	14,44	ASTM D240
Humidity	%	4,24	ASTM D3172-89
Ash	%	6,76	ASTM D3172-89
Volatile Material	%	80,65	ASTM D3172-89
Fixed Carbon	%	8,34	ASTM D3172-89
*Lignin	%	23,9	TAPPI T 222
*Hemicelulosa	%	12,9	TAPPI T 203
*Cellulose	%	13,7	TAPPI T 203

Note: The analyses were carried out in the Laboratory of our Faculty. *Result taken from the report of the Laquins Espol Laboratory. Fountain: [36].

The results of the proximal analysis of the biomass from the banana pseudostem, corresponding to 4.240%, 6.761%, 80.659% and 8.3406% for the percentage of moisture, ash, volatile material and fixed carbon respectively, as well as 14.447 MJ/Kg of calorific value, which according to the En plus standard and the Colombian NTC 2060 standard is a value close to the permissible limit of energy content for the production of solid biofuels.

On the other hand, the results of the proximal analysis carried out on the biomass indicated that 23.9% lignin was obtained, representing the largest component of the banana pseudostem, followed by hemicellulose and cellulose with lower fractions with the percentages of 12.9% and 13.7% respectively. These values allowed homogeneous combinations to be obtained in the mixing stage.

Table 4 Comparison of the parameters of the results of the Pellet with the Spanish Standard.

Parameter	Unit	50%-50% 1	55%-45% 2	60%-40% 3	ENplus
*Calorific value	$\frac{MJ}{Kg}$	22,566	22,657	20,835	Meets
Humidity	%	5,190	6,888	6,403	Meets
Ash	%	3,641	3,425	4,248	Not compliant
Volatile Material	%	87,001	86,301	86,181	-
Fixed Carbon	%	2,685	3,385	3,167	-
Density	$\frac{Kg}{m^3}$	750	650	273	Turns 1 and 2

Note: The analyses were carried out in the Laboratory of our Faculty. *Result taken from the report of the Laquins Espol Laboratory. Fountain: [36] and Authors.

Table 4 specifies the results of the proximal pellet analysis. Given that the moisture content in biofuels is an important factor since as it decreases the calorific value increases, it can be deduced that this is not reflected in the pellets obtained, since as the moisture content increases by 5.19% so does its calorific value according to compositions 50-50 and 55-45. which means that the heat released in combustion that is used to evaporate the water, does not adversely influence the calorific value. Taking into account that the composition 55-45 has 22,566 MJ/kg of BW, the pellets are considered to meet the quality parameters of solid biofuel ideal for energy production, according to the ENplus standard.

According to the Spanish Standard, the pellet density value must be greater than or equal to 600, therefore, the compositions 50-50 and 55-45 obey that condition, since they consist of a density of 750 and 650, however, $\frac{Kg}{m^3}\frac{Kg}{m^3}\frac{Kg}{m^3}$with the data obtained from the pellet ash content, no composition meets that parameter, however, the 60-40 composition has a higher percentage of ash, which can be related to the fact that the biomass contains a high content of inorganic compounds. The ash content is inversely proportional to the calorific value.

Table 5 Comparison of the parameters of the Briquette results with the NTC Standard.

Parameter	Unit	50%-50%	55%-45%	60%-40%	NTC Standard
*Calorific value	$\frac{MJ}{Kg}$	22,680	19,907	19,416	Meets
Humidity	%	5,005	4,357	4,132	Not compliant
Ash	%	2,736	3,613	4,512	Meets
Volatile Material	%	85,576	87,425	87,4227	Not compliant
Fixed Carbon	%	6,682	4,603	3,882	Meets
Density	$\frac{Kg}{m^3}$	569,4	592,9	376,7	-

Fountain:. [36] [22]

As can be seen in table 5, the results obtained from the physicochemical tests: the moisture content is linked to the energy content, in this case it is visualized that the lower the moisture content the lower the calorific value is obtained, so in the 60-40 composition the higher moisture content and the same higher energy content was obtained. therefore, it is considered that this characteristic does not affect the calorific value in this type of biofuel, which includes that the composition 50-50 with 22,680 $\frac{MJ}{Kg}$ has a higher energy content with respect to the proportions of 55-45 and 60-40 with 19,907 $\frac{MJ}{Kg}$ and 19,416 respectively, to a certain extent although the percentages of moisture content are not within the permissible limits of the NTC 2060 standard, your PC, if it is, as well as the ash contents. $\frac{MJ}{Kg}$

The proximal analysis of each briquette indicated that the composition of 55-45 has a higher density of 592.9 $\frac{Kg}{m^3}$, followed by the 50-50 ratio with 569.40 and 60-40 with a lower value of 376.7. $\frac{Kg}{m^3}\frac{Kg}{m^3}$

4. Discussion

4.1. Comparison of calorific value between pellet and briquette

Table 6 Ideal solid biofuel.

Parameter	Unit	Pellet 50%-50%	Pellet 55%-45%	Briquette 50%-50%	Briquette 55%-45%
Calorific value	$\frac{MJ}{Kg}$	22,566	22,657	22,680	19,907

Fountain:. [36]

In the pellets of the 55-45 composition, a higher calorific value (CP) was obtained, but in the 50-50 it decreased, giving 22.657 $\frac{MJ}{Kg}$ and 22.566 respectively. On the other hand, in briquettes it gave a high energy content in the composition of 50-50 with 22.680, while in 55-45 it was reduced to 19.907$\frac{MJ}{Kg}\frac{MJ}{Kg}\frac{MJ}{Kg}$. Therefore, it is considered that the use of the banana pseudostem as biomass for energy use gave an optimal result in the briquette of composition 50-50, according to the PC.

It should be considered that the 55-45 pellet configuration does not have significant variation in the CP compared to the 50-50 briquette composition, so it was considered that the *Musa paradisiaca* is suitable as a raw material for the production of solid biofuels in the aforementioned proportions.

Table 7 Variance of pellet calorific value results.

Groups	Account	Sum	Average	Variance
Composition 50-50%	3	67,697	22,56566667	1.23333E-05
Composition 55-45%	3	67,972	22,65733333	1.23333E-05
Composition 60-40%	3	62,506	20,83533333	1.23333E-05

Fountain:. [22]

Table 8 *ANOVA.*

Origin of the variations	Sum of squares	Degrees of freedom	Average of squares	F	Probability	Critical value for F
Between groups	6,322140222	2	3,161070111	256302,982	1,60E-15	5,14325285
Within the groups	7.4E-05	6	1.23333E-05			
Total	6,322214222	8				

Fountain:. [22]

Decision

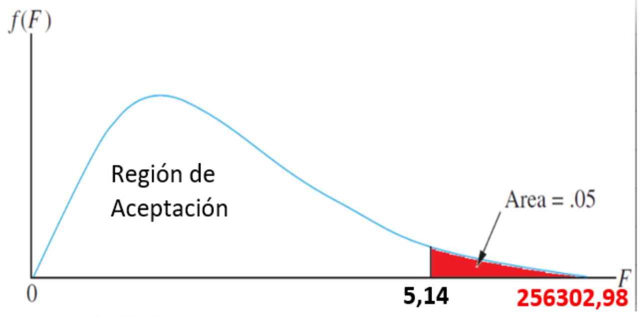

Figure 9 Distribution F. Source: . *[37]*

Figure 9 indicates that the value corresponding to F exceeds the critical value of 5.14 according to the acceptance zone, and that there is a significant difference, the null hypothesis was rejected.

Table 9 Try Tukey a Pellets according to their calorific value.

Compositions A (50-50); B(55-45); C(60-40)	Sample difference	Decision
µA - µB	0,09	Significant
µA - mC	1,73	Significant
µB - mC	1,82	Significant

Note: µ= sample average in absolute value. Fountain:. [22]

According to the Tukey test, the values of the sample difference expressed in absolute value are compared with Tukey's Tα= 0.009, showing a significant difference in more than one test, which indicates that the null hypothesis is rejected and the alternate hypothesis is accepted.

Table 10 *Variance of briquette calorific value results.*

Groups	Account	Sum	Average	Variance
Composition 50-50%	3	68,042	22,681	9.33333E-06
Composition 55-45%	3	59,721	19,907	9E-06
Composition 60-40%	3	58,248	19,416	1E-06

Fountain:. [22]

Table 11 ANOVA.

Origin of the variations	Sum of squares	Degrees of freedom	Average of squares	F	Probability	Critical value for F
Between groups	18,59235622	2	9,296178111	1442510,397	8.99506E-18	5,14325285
Within the groups	3.86667E-05	6	6,44E-06			
Total	18,59239489	8				

Fountain:. [22]

4.2. Decision

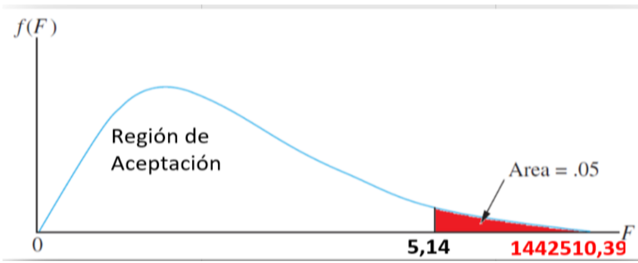

Figure 10 Distribution F. Fountain:. [37]

In the *Figure 10*, the distribution of the F-values with a significant probability of 0.05 is shown. The null hypothesis is rejected, since the value of F is outside the acceptance region, indicating a significant difference between the values of calorific value of the briquettes.

Table 12 Try Tukey Pellets according to their calorific value.

Compositions A (50-50); B(55-45); C(60-40)	Sample difference	Decision
µA - µB	2,77	Significant
µA - mC	3,26	Significant
µB - mC	0,49	Significant

Note: µ= sample average in absolute value. Fountain:. [22]

In *Table 12,* they show that the values of sample difference given in absolute value are higher compared to the value of Tα= 0.006, which indicates that all compositions have a significant difference approving the alternative hypothesis, which specifies that at least one value must be different from the others, contrary to the null hypothesis that expresses that the difference of the values of the means must be equal, that is, they do not show significant difference, to be accepted.

5. Conclusions.

Banana plant waste is a raw material generated in large quantities in Ecuador. In this research, the efficiency of solid biofuels was determined from calorific value analysis, resulting in both pellets and briquettes being within the regulations for solid biofuels, with a 22,657 MJ/Kg and 22,680 MJ/Kg respectively. Therefore, it is evident that the solid biofuel with the highest calorific value is the briquette based on banana pseudostem, where 5% humidity and a production yield of 98.04% were achieved. Therefore, the results show that the banana pseudostem is viable and a great biomass alternative for the production of briquettes, because from the ground biomass 14.44 of $\frac{MJ}{Kg}$ calorific value was reached, which stands out because without the application of a binding substance it complies with the NTC 2060 Standard where it establishes that for it to be classified as briquette its calorific value must be between the range of 12.5 - 21 $\frac{MJ}{Kg}$. In addition, this research marks the beginning of more studies on the waste from the banana plant, in which

100% biomass is used without the need for binders, where the amount of waste from this plant could be reduced, for the generation of energy in a renewable way and with a zero carbon footprint. which contributes to the care of the environment.

6.- Author Contributions (Contributor Roles Taxonomy (CRediT))

1. Conceptualization: Nahir Alondra Pérez
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4. Project management: Sandra Peña
5. Resources: Sandra Peña
6. Supervision: Sandra Peña
7. Validation: Darla Vaca
8. Visualization: Sandra Peña
9. Writing - original draft: Nahir Alondra Pérez and Sandra Peña
10. Writing - proofreading and editing: Sandra Fajardo
11. Review: Eddie Zambrano and Pablo Fajardo

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