Universidad de Guayaquil
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Ingeniería Química y Desarrollo
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Pellet processing using the peel of breadfruit (Artocarpus Altilis) to be used as a biofuel

Elaboración de pellets usando la cáscara de la fruta de pan (Artocarpus Altilis) para ser utilizado como un biocombustible

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Recibido: 06/07/2020 – Recibido en forma revisada: 08/08/2020 -- Aceptado: 09/11/2020
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Abstract
For the production of pellets, the biomass of the breadfruit peel was used, which is a biomass that is generally discarded, which will be evaluated from the Pellet Quality standard according to Standard EN 14961-2 l, when characterizing The rind of the breadfruit reflects a humidity of 48.64%, 1.3 ºBrix, pH 6.2, acidity of 0.89%, density of 0.625 g / ml and an average number of seeds of 64, the which was carried out a separation from its microns in which it was filtered until a sieve of 600-400 microns was obtained which is optimal for the production of pellets in which the yield per filtration plate was determined which was of 44% for 600 microns, for the agglutination two binder media were used which were beeswax and paraffin wax at a different weight composition of (25-75) and (50-50) in which the percentage of ash was determined from of determination of ash in food and calorific value to from ASTM D5468 in which a calorific value of 30578 j/g respectively was determined.

Therefore, in the present titration work in which the objective is to make pellets using the breadfruit peel (artocarpus altilis) to be used as a biofuel, evaluating its characteristics under the norm Standard EN 14961-2 l

Keywords
artocarpus altilis, pellet, biomass, agglutination, calorific value, ash, microns.

Resumen
Para la producción de pellets se utilizó la biomasa de la cáscara de la fruta de pan la cual generalmente se desecha. Se evaluaó a partir de la norma de Calidad de Pellets EN 14961-2 l. Al caracterizar las cáscara de la fruta de pan esta reflejó una humedad del 48,64 %, 1,3 ºBrix, pH 6,2 , acidez de 0,89%, densidad de 0,625 g/ml y un número de semillas promedio de 64, a la cual se realizó una separación por tamización a partir del tamaño de partícula, en la cual se filtró hasta obtener un tamizado de 600- 400 micras, la cual es óptima para la producción de pellet de tal forma que se determinó el rendimiento por plato de filtración el cual fue de 44% para 600 micras, para la aglutinación se utilizaron dos medios aglutinantes los cuales fueron cera de abeja y cera de parafina a diferente composición de peso de (25 – 75) y (50 – 50) donde se determinó el porcentaje de ceniza a partir de determinación de ceniza en alimentos y el poder calorífico a partir de la norma ASTM D240 en la cual se determinó un poder calorífico de 30578 KJ/Kg respectivamente.

Por tanto, en el presente trabajo de titulación se tiene como objetivo la elaboración de pellets usando la cascara de la fruta de pan *(artocarpus altilis)* para ser utilizado como un biocombustible, evaluando sus características bajo la norma EN 14961-2 l.

Palabras claves
artocarpus altilis, pellet, biomasa, aglutinación, poder calorífico, ceniza, micras.

1. Introduction

Currently, the solid biofuel industries in Ecuador have been developing since 2015. These industries primarily implement pellets for food and the industrial sector. It is a new energy source that is overshadowing diesel, which is generally imported from Spain. This energy source is adopting new raw materials for its production [1]

The breadfruit, scientifically known as (*ARTOCARPUS ALTILIS* is a large and leafy tree that originates from Indonesia and Polynesia, from where it has spread to all tropical regions of the planet. It was introduced to tropical America, first in the French Antilles and then in Jamaica, during the famous Bounty expedition in the late 18th century. The propagation of this tree to the Latin American countries that are signatories of the Andrés Bello

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Agreement occurred in the early 19th century, and to West Africa in the mid-21st century. [2]

The main characteristic of this type of renewable energy is that it is a pellet, a solid biofuel made from dehydrated breadfruit peel, which is mixed with a binder, such as paraffin wax or beeswax, to achieve compaction.

The pellet is considered a second-generation fuel because it is transformed from biomass to a solid through a thermomechanical process. [3]

To analyze this issue, it is necessary to examine its causes. The primary cause is that breadfruit peel is an organic waste product, with around 7.1% of this waste being the peel itself. Since this biomass of solid waste is not utilized in the country, it could be reused as a solid biofuel for boilers or stoves, and if successful, it could be used in equipment that requires higher energy output, and even in homes or housing developments.

1.1. Origin of Biofuels

The origin of biofuels dates back to the late 19th century and begins with the use of hydrocarbons as an energy source. The idea of using vegetable oils as fuel for internal combustion engines dates back to 1895. In that year, Dr. Rudolf Diesel invented the first diesel engine, which was already designed to run on vegetable oils; an example of this is peanut oil, which worked adequately in early tests. Years later, Henry Ford created the first prototype of his Model T automobile in 1908, with the idea of using ethanol as fuel. Standard Oil, in the early 1920s, used 25% ethanol in gasoline in the Baltimore area, but high corn prices, from which ethanol was derived, along with high storage costs and shipping problems, led to the project being abandoned. Additionally, petroleum entered the market as a cheaper, more efficient, and more readily available alternative. The first time a biofuel was used was in 1938. [4]

With the oil crisis of the 1970s, the supply of oil decreased, causing its price to rise exorbitantly, along with the price of gasoline, which doubled. By the end of 1979, due to the oil price crisis, a blend of gasoline with ethanol was developed. This brought biofuels back into consideration as an option due to the rising oil prices and the possibility that non-renewable resources could be exhausted. [4]

In 1975, Brazil initiated a project called Proalcohol, which aimed to replace the use of hydrocarbons. Finally, the Kuwait war led to an increase in hydrocarbon prices, paving the way for new alternative energy sources. [4]

At the beginning of the 1970s, the wars in the Middle East led to an improvement in alternative energies. In October 1973, a major crisis began related to the war between Saudi Arabia and Israel. During this first oil crisis, gasoline prices doubled within three months, raising alarms about the supply of petroleum products. This situation led to the search for alternative energies, and by the end of the decade, a mixture of gasoline and ethanol began to be marketed in the United States to dilute gasoline and increase octane. In Brazil, initiatives were also developed to replace fuels, producing biofuels based on bioethanol derived from sugarcane. [4]

In the early 1980s, the second oil crisis occurred, related to the onset of the Iran-Iraq war, leading to a decrease in fuel extraction that was only recovered by the end of the 1980s. [5]

For this reason, along with the decline in crude oil prices, the energy transition plans that had begun in the 1970s were abandoned. In 1990, a new crisis began, this time stemming from Iraq's invasion of Kuwait, known as the Gulf War. Oil prices rose again, bringing biofuels back into the energy landscape of many countries. [5]

1.2. Origin of Solid Biofuels

Wood-derived products have been the first energy source used by humans until the Industrial Revolution. Even today, for most of the world's population, especially in developing countries, biofuels remain the primary energy source.

Although this solid biofuel is generally used directly, it also comes in other forms for energy purposes that require special conditioning. The most well-known forms are wood chips, sawdust, charcoal, pellets, and briquettes. [5]

1.3. Pelleting

Pellets have been invented for over a century using pressing methods to create small cylindrical elements produced by heat and using various types of waste materials for different purposes, including animal feed, heating, field fertilization, and more. [6]

Certain companies focused on manufacturing animal feed machinery in the mid-1970s, with very little research into how these pellets could be used for domestic and industrial heating. However, because fossil fuels were always very inexpensive at that time, machinery intended for fuel production using biomass never made it to the market.

It wasn't until the late 20th century and early 21st century that the research and propagation of this product, along with the invention of boilers and countless machinery based on the pellet format, generated significant momentum. Today, industries are rushing to solve problems arising from the continuous generation of an abundance of waste materials and the variety of materials to be pelletized—from plastics and various petroleum derivatives to a wide range of biomass from the field, among others. [6]

As fossil fuel prices, such as oil and LPG, continue to rise inevitably day by day, and with their increasing scarcity along with climate change, biofuel in the form of pellets becomes an economical and clean alternative energy source that helps reduce harmful emissions into the Earth's atmosphere. [6]

Additionally, the pellet format offers the following advantages:

- Feeding automatic systems.
- Being used as a fluid due to transport by suction and screw conveyors.
- Having high density.
- Being used in both domestic and industrial stoves and boilers, as well as in large-scale applications.
- Easy handling, storage, and transportation. [6]

1.4. Physical Characterization of Pellets

The ONORM M7135 standard is used as a reference, with more rigorous quality evaluation criteria in the field of pelleting [7]. The following criteria are evaluated:

- Pellet dimensions.
- Determination of density: volume (measuring cylinder) and weight (analytical balance).
- Determination of moisture in an oven: ((wet weight – oven-dried weight) / oven-dried weight) x100%.
- Impact resistance: subjecting samples to continuous drops from heights of approximately 1.50 meters, calculating resistance by their retained weight.
- Water resistance: applying the ASAE (American Society of Agricultural Engineers - Lindley and Vossoughi, 1989) procedure.
- Crush resistance: pellet resistance before cracking under specified compression conditions, following ASTM C39-96.

1.5. Uses and Applications

Pellets are used for heating systems in any household and for industrial use, in special pellet stoves that are convenient to use. Pellets are 100% natural, with many made from recycled materials that are non-toxic and non-polluting. They are also used for animal bedding because they contain no dust and are highly absorbent.

Some are used as feed supplements for livestock, helping with growth and nutrition. The use of pellets can reduce heating costs by up to 40% compared to fossil fuels. Their primary function is heat production for heating, water heating, or steam generation, with their most common use being in biomass boilers that sustainably adapt to the comfort of a home without generating pollutants [8].

1.6. Breadfruit (Artocarpus altilis)

Artocarpus altilis is very similar to Artocarpus heterophyllus as it belongs to the Moraceae family in the Artocarpeae tribe. It is one of the most cultivated species in the world. The fruit can measure between 9 and 20 cm in width and 30 cm in length, with an approximate weight ranging from 250 g to 6 kg. Its pulp has a yellowish tone, a fibrous and creamy texture, and the seed has a moisture content ranging from 35.1% to 56.8% per 100 g [9]. 80% of the seed is edible, and 20% is the peel. The tree reaches a height of between 9 and 18 meters.

1.7. Breadfruit (Artocarpus heterophyllus)

The breadfruit tree belongs to the Artocarpus genus of the Moraceae family, originating in India with hundreds of varieties. It is a tree approximately 10 to 25 meters tall, with mature oval leaves. Jackfruit, or "Jaca" as it is known in Spanish-speaking regions, is a fruit that weighs approximately 10 to 25 kg. Inside, the pulp is yellow, similar to mango, with a sweet taste and slight acidity. The fruit's surface is warty with small rounded protrusions. The pulp constitutes almost 40% of the fruit's weight and contains a high level of nutrients, including vitamins, minerals, enzymes, and carbohydrates [10].

A distinctive feature of the plant is that it produces a large hanging fruit with various medicinal and nutritional uses, and it is high in fiber. This fruit is produced and distributed in greater quantities to tropical countries [11].

The fruit bulb can be dried and fried like potatoes, and it can also be fermented to produce alcohol. In fact, most parts of the fruit can be consumed in different way.

1.8. Breadfruit Varieties

Fig. 1. Artocarpus Altilis
Source: [12]

Table 1.
Variety of Breadfruit 'Arbopán

Common or Vernacular Name	Breadfruit Tree, Breadfruit, *Arbopán*
Scientific or Latin Name	*Artocarpus altilis*
Family	Moráceas *(Moraceae)*
Origin	Native to Indonesia and New Guinea. Now cultivated in all tropical regions.
Characteristics	Leaves: 25x12 cm Weight: 1 to 2 kg, and measures 15 to 30 cm in diameter. Considered an energy food with a carbohydrate content between 20% and 37%, rich in calcium, iron, phosphorus, niacin, and vitamins C and B1.

Source: [12]

Fig. 2. Artocarpus Camansi Blank
Source: [13]

Table 2.
Variedad de fruta de pan la castaña

Common or Vernacular Name	Breadfruit Tree, Breadfruit, *La Castaña*
Scientific or Latin Name	*Artocarpus camansi Blank*

Family	Moráceas *(Moraceae)*
Origin	Native to Indonesia and New Guinea. Now cultivated in all tropical regions.
Characteristics	Tree: 10–15 m Weight: 800 g, and measures 7 to 12 cm in diameter. Considered an energy food, it contains calcium, iron, phosphorus, niacin, and vitamins. Male and female flowers.

Source: [13]

Fig. 3. Artocarpus Integer
Source: [14]

Table 3.
Variedad de fruta de pan champedack

Common or Vernacular Name	Breadfruit Tree, Breadfruit, *Champedack*
Scientific or Latin Name	*Artocarpus integer*
Family	Moráceas *(Moraceae);* Orden; Rosales
Origin	Native to Indonesia and New Guinea. Now cultivated in all tropical regions.
Characteristics	Tree: 20 m, with fruit measuring 10 to 15 cm in width and 20 to 35 cm in length. Thin, leathery skin. Considered an energy food, it contains calcium, iron, phosphorus, niacin, and vitamins. Male and female flowers.

Sources: [14]

1.9. Categorization of Breadfruit

The following Table 4 shows the taxonomy and morphology of *Artocarpus Altilis*

Table 4.
Taxonomy and Morphology of Breadfruit

Taxonomy and Morphology of Breadfruit	
Kingdom	*Plantae Phylum*
Phylum/Division	*Magnoliophyta*
Class	*Magnoliopsidae*
Subclass	*Humadelidae*
Order	*Urticales*
Family	*Moraceae*
Genre	*Artocarpus*
Species	*Altilis*
Scientific Name	*Artocarpus Altilis*
Common Names	Breadfruit (inglés), árbol de pan, fruta de pan

Source: Author's elaboration

1.10. Chemical Composition of Breadfruit

Breadfruit contains vitamins A and C, thiamine, riboflavin, calcium, and niacin, among many other nutrients. It is a rich source of potassium, with 352 mg found in 100 g of breadfruit. Studies show that potassium-rich foods help lower blood pressure. The human body does not produce vitamin C, so it is essential to consume foods rich in vitamin C, which is an antioxidant, strengthens the immune system, and maintains healthy gums. Additionally, this fruit contains phytonutrients: lignans, isoflavones, and saponins, which have anticancer, antihypertensive, anti-ulcer, and anti-aging properties. Therefore, they can prevent the appearance of cancer cells, lower blood pressure, and slow the degeneration of skin cells. It contains niacin, also known as vitamin B3, which is necessary for metabolism, nerve function, and the synthesis of certain hormones. [15].

1.11. Breadfruit Production in Ecuador

In Ecuador, breadfruit tree production is found in the Coastal and Amazon regions. The cultivation of the breadfruit tree is minimal in the country because it is not a traditional fruit and is only sold in markets near the cultivation areas and in wholesale markets in some parts of the country. Ecuador is an ideal place for the cultivation of this fruit because a large part of the country has a subtropical climate where the fruit can adapt very easily. Most of the crops in the coastal area are located in Esmeraldas and along the Amazon Region [16].

The plant's germination rate is 100%, which occurs around 15 days, and it can be transplanted 75 days after germination. The fruit can be harvested manually after 5 to 6 years when it has a greenish-yellow hue. The main harvesting periods are from January to March and from July to September, which are the peak production times for this fruit [17].

2. Materials and Methods

The project aims to utilize the waste presented in breadfruit peel, which is discarded when separating the seeds from it. The extracted peel is entirely discarded. The proposal is to use it as raw material for the production of a pellet, thereby creating a new source of income.

The promotion of this project contributes to social development among farmers dedicated to breadfruit cultivation and the Faculty of Chemical Engineering in an endemic way, by engaging in practices that facilitate the utilization of this fruit.

The following are the equipment used during the pellet production process:

Table 5.
Equipment Used in the Pellet Production Process

EQUIPMENT	CAPACITY
Dryer	50°C
Grinder	---
Refractometer	˚Brix
pH Meter	pH (0-14)
Water Bath Equipment	100°C
Filtration Tower	Micrómetros
Pelletizer	---
Muffle Furnace	550°C

Source: Author's elaboration

The following materials were used during the pellet production process:

Table 6.
Materials Used

MATERIALS	QUANTITY
100 ml Graduated Cylinders	2
Vernier Caliper	1
Funnel	1
Beaker	1
Filter Paper	6
Flask	3
Analytical Balance	1

Source: Author's Work

2.1. Raw Material Yield

Formula Used

$$Raw\ material\ yield = 100 * \frac{MC}{M_T} \qquad (1)$$

$$Percentage\ of\ elimination = 100 * \frac{M_T - M_x}{M_T} \qquad (2)$$

Where:
MC= Mass of the peel
MT= Total mass of the fruit

Calculations for the Raw Material Yield

$$Peel\ yield = 100 * \frac{500g}{7050g} = 7{,}09\ \% \qquad (3)$$

$$Percentage\ eliminated\ (fruit\ and\ peel) = 100 * \frac{7050g - 500g}{7050g} = 92{,}91\ \% \qquad (4)$$

2.2. Raw Material Characterization

The analyses were conducted in the microbiology laboratory of the Faculty of Chemical Engineering. These include: Physical analyses of the raw material: size, weight, volume, peak sizes; and chemical analyses: pH, Brix, % moisture, titratable acidity, and maturity index.

2.3. Determination of pH

To measure the pH, the NTE INEN 389 standard was applied to neutralize the pH meter electrode by immersing it in the electrode during the characteristic buffer solution tests of 4 and buffer solution of 7.

Subsequently, 100 ml of the breadfruit solution was allowed to cool to a temperature of 20°C. After this, the pH electrode was immersed in the solution to determine if it was acidic or basic.

Fig. 4. Digital pH Meter
Source: [18]

2.4. Determination of Total Solids

To determine the total soluble solids, calculations were made according to AOAC method 932.12/90, which indicates that a triplicate measurement should be performed to determine the soluble solids in the sample. A solution was made using 100 ml of distilled water with 20 grams of breadfruit, which was also used for pH measurement with temperature control at 20°C. A refractometer with a measurement range of 0-32 on the reading scale was used for this solution.

Fig. 5. Blending of Breadfruit Peel with Distilled Water
Source: [18]

Fig. 6. Filtration of the Blend
Source: [18]

Fig. 7. Solids from the Blend
Source: [18]

Fig. 8Filtrate for Analyzing Titratable Acidity
Source: [18]

Calculations of % Acidity of Immature Breadfruit

$$\%\text{Acidity} = \frac{(28)(0{,}1)(0{,}0064)}{(0{,}1)(25)} * 100 \qquad (5)$$

$$\%\text{Acidity} = 0{,}7168 \qquad (6)$$

2.5. Determination of the Maturity Index

The maturity index was determined through a ratio between the Brix degrees and the titratable acidity; this technique is commonly used for measuring the ripeness of fruits.

It was determined using the following formula:

$$IDM = \frac{\text{Brix degrees taken with a refractometer}}{\text{percentage of acidity}} \qquad (7)$$

Calculations of the Maturity Index of Ripe Breadfruit

$$IDM = \frac{1{,}3}{0{,}89} = 1{,}46 \qquad (8)$$

Calculations of the Maturity Index of Unripe Breadfruit

$$IDM = \frac{1,1}{0,72} = 1,53 \qquad (9)$$

2.6. Determination of Physical Properties

For the breadfruit, the height, width, and its peaks were determined using a Vernier caliper, which varied depending on the fruit's maturity. Additionally, the weight and volume were determined, given that the fruit's volume has an ovoid shape. The volume was calculated based on its density, and the seed content per fruit was also determined.

$$volume = \frac{mass}{density} \qquad (10)$$

2.7. Percentage of Drying of the Raw Material Formula Used

$$\%Moisture \ = 100 * \frac{MFC}{M_{PT}} \qquad (11)$$

$$\%Active\ Moisture \ = 100 * \frac{M_{PT} - M_{FC}}{M_{PT}} \qquad (12)$$

Where:
MFC= Final Mass of the Peel
MPT= Mass of the Tray with the Peel

<u>Calculations for the Yield of the Drying Operation</u>

$$\%Moisture = 100 * \frac{300g}{613g} = 48,94\ \% \qquad (13)$$

$$\%Active\ Moisture = 100 * \frac{300g - 613g}{613g} = 51,06\ \% \qquad (14)$$

Recording Moisture Loss During the Drying Operation.

Table 7.
Recording Moisture Loss

Time	Temperature	Weight of the Capsule and Sample	Moisture Loss
(t=min)	50 ºC	(g)	(Px=g)
0	50 ºC	613	500
5	50 ºC	605	492
10	50 ºC	582	469
15	50 ºC	573	460
20	50 ºC	566	453
25	50 ºC	557	444
30	50 ºC	549	436
35	50 ºC	538	425
40	50 ºC	533	420
45	50 ºC	526	413
50	50 ºC	519	406
55	50 ºC	508	395
60	50 ºC	497	384
65	50 ºC	488	375
70	50 ºC	479	366
75	50 ºC	470	357
80	50 ºC	468	355
85	50 ºC	455	342
90	50 ºC	443	330
95	50 ºC	438	325
100	50 ºC	424	311
105	50 ºC	418	305
110	50 ºC	415	302
115	50 ºC	413	300
120	50 ºC	413	300

Source: Author’s work

Fig. 9. Wet Breadfruit Peel
Source: [18]

Fig. 10. Breadfruit Peel with Moisture Loss
Source: [18]

Fig. 11. Dry Breadfruit Peel with Constant Weight
Source: [18]

2.8. Heat Capacity

To measure the calorific value of the produced pellet, a bomb calorimeter was used. The pellets were placed in the calorimeter and combusted, thus analyzing their calorific value.

2.9. Ash Percentage

The ash percentage was determined based on the determination of ash in foods. 20 g of the sample were weighed and placed in a crucible, which was then placed in a muffle furnace at 550°C for one hour. Afterward, the sample was allowed to cool for 30 minutes while covered, and then weighed on an analytical balance. The sample should be tested in triplicate for greater accuracy in obtaining the ash percentage.

3. Results

3.1. Determination of Raw Material Yield

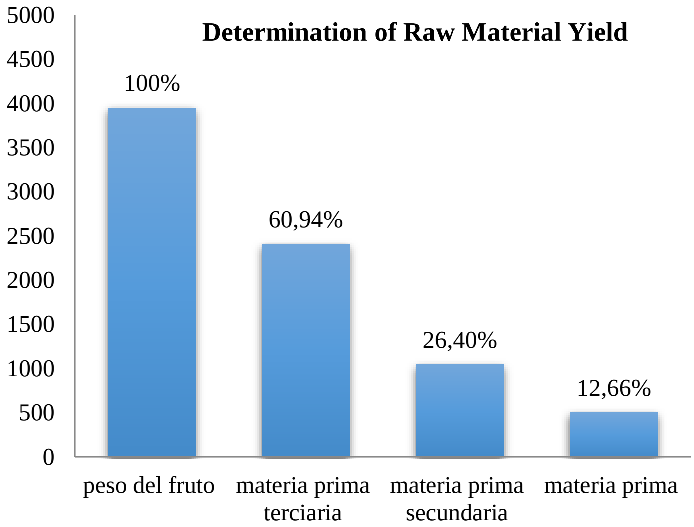

Fig. 12. Determination of Raw Material Yield
Source: [18]

In Figure 12, the average weights of breadfruit are represented, showing the average weights of pulp and pulp peel, seeds and seed peel. The seed peels of breadfruit are used as raw material, yielding 12.66% primary material, 26.40% secondary material, and 60.64% tertiary material of pulp and pulp peel.

3.2. Physicochemical Characterization of Breadfruit

Table 8.
Characterization of Breadfruit

Physicochemical Characterization		
Parameters	**Ripe Breadfruit**	**Unripe Breadfruit**
Total Soluble Solids (°Bx)	1,3	1,1
pH	6,2	5,7
Titratable Acidity (%)	0,89	0,72
Maturity Index (%)	1,46	1,53
Moisture (%)	48,64	48,68
Density (g/ml)	0,625	0,625
Mass (g)	1464	1132
Volume (ml)	2343	1811

Number of Seeds	64	64

Source: [18]

In Table 8, the results of the analyses obtained from the breadfruit and its different stages of ripeness studied are presented.

3.3. Chemical Properties

- **Total Soluble Solids:** he total soluble solids determined the total sugar content and, in turn, represent the carbohydrate content present in the breadfruit, which showed 1.3 °Brix for the ripe fruit and 1.1 °Brix for the unripe fruit.

- **pH:** The pH of the breadfruit at different stages of ripeness showed a pH of 6.2 for the ripe fruit and 5.7 for the unripe fruit, indicating a slight acidity.

- **Titratable Acidity:** The titratable acidity values of the samples ranged between 0.89% and 0.72%, similar to those reported by APAÉSTEGUI and LIULITH (2011), and were found within the range of 0.9099 ± 0.7149.

- **Maturity Index:** The maturity index was determined through a ratio between the Brix degrees and the titratable acidity, which showed a maturity index of 1.46 for the ripe fruit and 1.53 for the unripe fruit.

- **Moisture:** The moisture content for the seeds of ripe breadfruit was 48.64%, and for the seeds of unripe breadfruit, it was 48.66%. These values are within the range reported by APAÉSTEGUI and LIULITH (2011), which is between 35.10% and 56.80%.

3.4. Physical Properties

- **Mass:** The mass of the ripe breadfruit was 1464g, and for the unripe breadfruit, it was 1132g, which is within the range established by APAÉSTEGUI and LIULITH (2011), between 695.2g and 1467.5g.

- **Density:** The density of the fruit was determined using Archimedes' principle. Both fruits at different stages of ripeness showed the same density, which was measured in triplicate and resulted in an average density of 0.625 g/ml for both.

- **Volume**: The volume of both ripeness stages of the breadfruit was obtained based on the density using Archimedes' principle. The volume for the ripe fruit was 2343ml, and for the unripe fruit, it was 1811ml.

- **Number of Seeds:** The number of seeds for both ripeness stages of breadfruit was 64 seeds for both fruits, which is within the range established by APAÉSTEGUI and LIULITH (2011), between 35 and 65 seeds.

3.5. Drying Curve

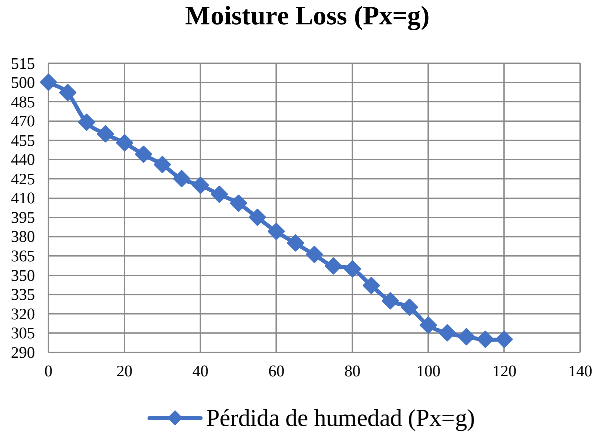

Fig. 13. Moisture Loss in the Drying Curve
Source: [18]

Figure 13 represents the moisture loss curve, where we observe that after 100 minutes, the greatest proportion of water starts to be consumed. The raw material reaches its maximum moisture loss at 120 minutes.

3.6. Analysis of the Obtained Pellet

Table 9.
Characterization of the Produced Pellet

Pellet Produced	**Pellet (25-75) Beeswax with Raw Material**	**Pellet (50-50) Beeswax with Raw Material**	**Pellet (25-75) Paraffin Wax with Raw Material**	**Pellet (50-50) Paraffin Wax with Raw Material**
Diameter (mm)	6	6	6	6

Length (cm)	1.235	1.241	1.255	1.264
Volume (cm)	0.0873	0.0866	0.0935	0.0954
% Ash	1.69%	1.72%	1.71%	1.72%
Calorific Capacity KJ/Kg)	26568	30578	24459	29352

Source: [18]

In Table 9, the physical and chemical characterization of the produced pellet is presented; parameters that were considered to achieve the highest calorific capacity, which was 30578 J/g, belonging to the (50-50) sample of beeswax with breadfruit seed, and the lowest ash percentage, which was from the sample produced with (25-75) beeswax and breadfruit seed. This analysis was conducted in the laboratories of the University of Guayaquil, where the technique for determining ash in food was employed at a temperature of 550 ºC for each of the samples in triplicate, obtaining an average ash percentage of 1.71%. The calorific capacity analysis was determined in the laboratories of the Escuela Superior Politécnica del Litoral, which recorded an average calorific capacity of 27739 J/g, being an optimal calorific capacity for a combustion pellet.

Table 10.

Poder calorífico superior para distintas fuentes de biomasa

Biomass	**HHV (poder calorífico) MJ /Kg**
Coking Coal	25 a 30
Wood	10 a 20
Coconut Shell	18 a 19
Straw	14 a 16
Coffee Husk	16
Cotton Stalks	16
Cocoa Shell	13 a 16
Oil Palm Kernel	15
Rice Husk	13 a 14
Corn Stalks	13 a 15
Sawdust	11
Sawdust Pellet	20.5
Wood Pellet	20.3
Sample 1	30.578
Sample 2	26.568
Sample 3	29.3525
Sample 4	24.459

Source: [19]

- Sample 1 = 50/50 beeswax and breadfruit peel
- Sample 2 = 75/25 beeswax and breadfruit peel
- Sample 3 = 50/50 paraffin wax and breadfruit peel
- Sample 4 = 75/25 paraffin wax and breadfruit peel

The most efficient pellet, which produced the highest combustion, was the one made from 50/50 beeswax and breadfruit peel.

4. Conclusion

- Regarding the physicochemical characterization of the pellet produced from breadfruit peel (Artocarpus Altilis), the varieties of pellets with different mixtures of binding agents were determined. The lowest ash percentage was 1.69% for sample 2, composed of 25% beeswax and 75% treated raw material, and a calorific value of 30,578 KJ/Kg for sample 1, which had a productivity yield of 7.1% from the breadfruit peel (Artocarpus Altilis).

- The operational parameters for pellet production were determined, which included moisture loss, achieved through weight control that reduced moisture content to 60%, and sieving control to 600 microns, the ideal size for pellet production.

- Bibliographic sources on pellet production from other agricultural residues and the characteristics of breadfruit varieties were collected, and the reproducibility of applied tests was determined by comparing them with the bibliographic sources.

- The physical and chemical parameters of breadfruit peel for pellet production were determined, including an average seed count of 64, an average density of 0.625 g/ml, where maturation did not affect pellet production with a moisture content of 60% and an average ash percentage of 1.71%.

- It was determined that the highest calorific value was for sample 1 (50-50) beeswax and breadfruit peel, recording a heating value of 30,578 and an ash percentage of 1.72. The least efficient sample was number 4, with a heating value of 24,459 J/g and an ash percentage of 1.72. Therefore, both sample options are recommended for a combustion pellet.

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