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Study of the energy potential of pelletized Ecuadorian rice husk for use as fuel

Estudio del potencial energético de la cascara de arroz ecuatoriano peletizado para su uso como combustible

Ing. Luis Enrique Velázquez Áraque Ph.D. [1] , Josué Manuel Aguilar Sierra [2] & Edgar Alejandro Tulcán Álvarez [3]

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Abstract
Through the present research work will be released a study of the possibilities of pelletization of Ecuadorian rice husk and its use as a biofuel, because Ecuador, its agroindustrial industry this waste is not used in its entirety for which it is proposed to the use as a source of energy of biological origin thus giving rise to a product called pellet, which could be evidenced in previous research the energy potential of the exclusive use of this rice husk biomass, for which, an improvement was proposed to this product by adding a binder such as cassava starch of biological origin in different proportions which are subjected to different analyzes and it was obtained that the best ratio is 70% rice husk and 30% starch giving optimum values for their production.

Key Words
Pellet, rice husk, binder, biomass, agroindustrial waste

Resumen
Mediante el presente trabajo investigativo se dará a conocer un estudio de las posibilidades de peletización de la cáscara de arroz ecuatoriano y su utilización como biocombustible, debido a que el Ecuador, su industria agroindustrial este desecho no es aprovechado en su totalidad por lo cual se propone a la utilización como fuente de energía de origen biológico dando así el origen a un producto denominado pellet, los cuales se pudo evidenciar en previas investigaciones el potencial energético del uso exclusivo de esta biomasa de cascarilla de arroz, por lo cual, se propuso una mejora a este producto mediante la adición de un aglutinante como es el almidón de yuca de origen biológico en diferentes proporciones los cuales son sometidos a diferentes análisis y se obtuvo que la mejor proporción es de 70% cascara de arroz y 30% almidón dando valores óptimos para su producción.

Palabras Claves
Pellet, cascara de arroz, aglutinante, biomasa, residuos agroindustriales.

1. Introduction

Pellets are a type of biofuel made from agro-industrial residues (biomass). Their formation occurs by compacting this biomass into rollers or matrices, which shape it into tiny cylinders.
Burning these pellets produces thermal energy, which is highly utilized in various industrial processes such as steam or electricity generation. The main materials for pellet production worldwide are wood residues and biomass with agricultural characteristics.
Currently, there is an increasing need to seek various types of fuels to replace petroleum, which is the most commonly used fuel globally.

Ecuador, for its part, is taking a significant step by developing biofuels such as "extra gasoline," which contains 5% ethanol, thus considerably reducing the negative environmental impact caused by conventional petroleum-derived products.
This work was carried out to determine the physicochemical characterization of pellets made from Ecuadorian rice husk to comply with current international standards [1]

It also contributes to the development of our country's productive matrix by adding new ways to utilize agricultural residues produced by various industries, obtaining a solid biofuel that can be used in energy generation operations.

Experimentally, rice husk has been used in energy transformation, starting as waste and evolving into a heat source.

[1] Universidad de Guayaquil, Facultad de Ingeniería Química; orcid: 0000-0001-7890-012X; luis.velazqueza@ug.edu.ec
[2] Investigador Independiente; josueaguilar024@gmail.com
[3] Investigador Independiente; alejandroat9526@gmail.com

Countries such as Spain, Brazil, China, and Colombia began researching rice husk in the early 1990s, creating fluidized bed furnaces to burn rice husk to obtain high-silica ash, which was then used for building concrete structures.

Regarding its use in industrial processes, few studies have been conducted. However, various proposals exist that provide significant contributions to energy development. Among the main ones, we can mention the Agro-Food Technology Institute in Spain, which uses this type of biomass for cogeneration of electrical energy.

Similarly, the Renewable Energy Institute in South Korea employs this biomass reuse process to obtain gasification fuel in the form of pellets.

Rice has been used as food since ancient times. More than half of the world's population consumes rice as a staple component of their diet. Rice is divided into glutinous and non-glutinous types. The former contains about 83% amylopectin and about 17% amylose, while the latter contains about 27% amylose and about 73% amylopectin. The size of the rice grain as the final product depends on the variety used [2].

The rice plant has highly branched stems and can measure between 0.6 and 1.8 meters in height. The stems end in an inflorescence, a panicle 20 to 30 cm long. Each panicle consists of 50 to 300 flowers or spikelets, from which the grains will form: the obtained fruit is a caryopsis.

The rice grain (paddy rice) consists of an outer protective cover, the husk, and the caryopsis or fruit of the rice (brown or hulled rice). Brown or hulled rice consists of the outer layers: pericarp, tegmen or seed coat, and nucellus; the germ or embryo; and the endosperm. The endosperm consists of the aleurone layer, with the subaleurone layer and the starchy or inner endosperm proper. The aleurone layer contains the embryo. The brown pigment of brown rice is contained in the pericarp, which is the outermost layer of the grain [3].

The husk or glume constitutes 20% of the weight of brown rice, though its values range from 16% to 28%. The weight distribution of brown rice is as follows: pericarp, 1-2%; aleurone, nucellus, and seed coat, 4-6%; germ, 1%; scutellum, 2%; and endosperm, 90-91% (Juliano, 1994). It has dimensions of 5-10 mm in length and 1.5-5 mm in width, and in terms of grain weight, a thousand grains weigh 27 g [3].

Rice husk has various applications, including: biomass conversion, where sugars are obtained that can be converted to other organic chemicals, such as ethanol and furfural; in the production of fertilizers and material for mushroom cultivation; obtaining paper and pulp in construction materials; as fuel; and obtaining silicon products from the husk or its ashes [4].

Rice husk has a strong, woody, and abrasive nature, making it resistant to environmental factors. It protects the rice grain from deterioration during the development period of the rice plant, due to insect or fungal attacks. Rice husk is not suitable for human consumption due to its high silica content, although in some cases, it is used for feeding farm animals. The husk provides almost no fiber to the animals' diet and can irritate the digestive tracts of animals that consume it because of its high silica content [3].

There are processes for densifying biomass or agricultural residues, including pelletization and briquette design, which aim to reuse these wastes for the production of thermal energy used as a natural and sustainable source. Pelletization involves compacting a certain amount of residues or wastes to obtain a product called pellets (Riegelhaupt, 2014).

Pellets are small portions of agglomerated material from any type of biomass, intended for energy production. They are considered a type of solid biofuel due to the biomass used in their production [2].

To determine univocal parameters and ensure greater protection for the final consumer, different standards have been adopted. These are not just product certifications but system certifications, examining the entire chain: production/reception of the raw material, fuel storage, and pellet delivery to the final consumer. Along with technical standards for pellet quality and traceability, the sustainability of the chain is also considered, which is increasingly relevant in the biomass sector. Additionally, to ensure compliance with sustainability issues, the producer must indicate the amount of raw material certified by FSC (Forest Stewardship Council) or PEFC (Programme for the Endorsement of Forest Certification), as shown in Table 1. In the near future, at least 70% of the raw material used must be certified by FSC or PEFC [5].

Table 1. Physical and chemical parameters for mixed biomasses according to French standards.

Parameters	Unit	Agro+	Agro
Diameter	Mm	6- 8	6 -16
Length	Mm	10 - 30	10 – 30
Humidity	% wt	< 11	<15
Calorific value	MJ/kg	> 15	> 14
Density	kg/m3	> 650	> 650
Ash content	% wt	< 5	< 7

Source: [6]

The French standards possess the ENplus certification and have an internal quality management system based on the EN ISO 9001 and prEN 15234 standards, which directly depends on the associations representing the interests of the pellet sector in the country [5].

Among the international standards adopted with ISO certification, the following countries stand out:

- Germany: DIN 51731 (mainly used to judge the quality and suitability of the pellet)
- Austria: ÖNORM M7135 (includes all requirements and control standards for pellets. It contemplates much stricter parameters than DIN 51731, and many producers have adopted it as a basis for building stoves and boilers that achieve maximum power and maximum efficiency with the burning of pellets that meet the requirements determined by it.)
- Scandinavia: SCAN standard.
- Italy: UNI/TS 11263 (classifies solid biofuels and defines their product characteristics for use as fuels) [7].

Table 2. Comparative table of selected German and Austrian requirements on pellets.

Parameters	Unit	DIN 517315	Ö NORM M 7135
Diameter	Mm	4 - 10	4 – 10
Length		< 50 mm	< 5 x D
Density	kg / dm3	1.0 - 1.4	> 1.12
Water content	%	< 12	< 10
Abrasion	%	--	< 2.3
Ash content	%	< 1.5	< 0.5
Energy content	Mj / kg	17.5 – 19.5	> 18
Sulfur content	%	< 0.08	< 0.04
Chlorine content	%	< 0.03	< 0.02
Nitrogen content	%	< 0.3	< 0.3
Heavy metals	%	Regulado	No regulado

Source: [8]

Austria is the country with the most current standards and certifications, including:

- Solid biofuels - Particle size distribution of disintegrated pellets (ISO 17830: 2016) ÖNORM EN ISO 17830: 2016 11 15
- Pellet burners for small boilers - definitions, requirements, tests, marking. ÖNORM EN 15270: 2008 03 01
- Solid biofuels. Determination of the mechanical durability of pellets and briquettes. Part 1: Pellets (ISO 17831-1: 2015). ÖNORM EN ISO 17831-1: 2016 04 01 [9]

The rice plant that is cultivated for one year is known as "semi-aquatic rice," and it grows in temperate and subtropical climates. In tropical climates, rice can survive as a perennial by regrowing after harvest.

The heights of the plants vary depending on each variety and the conditions of their growth, ranging from 0.4m to 1m as shown in Figure 1.

The study of rice morphology is divided into two phases:

a) **vegetative phase:** germination points, seedling, and the beginning and full tillering.
b) **reproductive phase**: from the initiation of the floral primordium to the emergence of the panicle to maturity. [10]

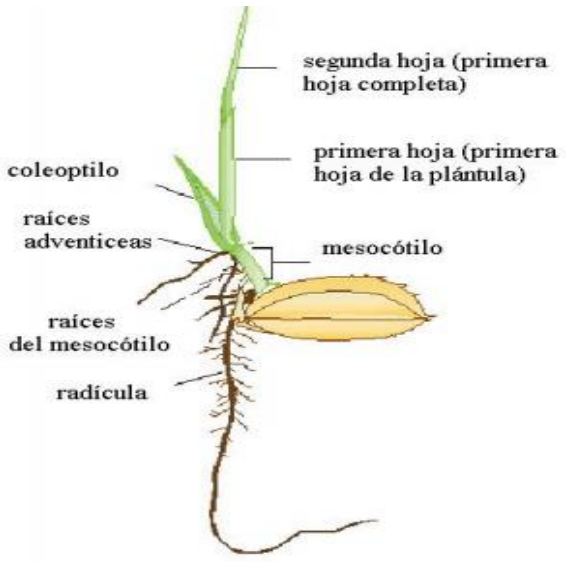

Fig. 1. Rice plant
Source: [10]

Environmentally friendly alternative, it would help combat climate change by substituting a significant portion of petroleum consumption in vehicles, resulting in a lower impact on environmental pollution [11].

Biofuel adapts to existing technology today, unlike hydrogen which would require a process with different technology, leading to the need to change all the technology solely for hydrogen use [12].

It is used as fuel, providing a heat and calorific value of 16720 KJ/Kg, and during the incineration process, the ash has a silica content greater than 90%, making it a source of silica.

However, this silica contains a high percentage of impurities such as Ca, Mg, Mn, Al, Fe, Br, and P, which need to be removed. If the precipitation method is applied, calcium silicates could be obtained [13].

Cenizas	18,59%
Sílice (SiO2)	94,50%
Oxido de Calcio	(CaO) 0,25%
Oxido de magnesio	(MgO) 0,23%
Oxido de Potasio	(K3O) 1,10%
Oxido de sodio	(Na2O) 0,78%
Sulfatos	(SO3) 1,13%

Fig. 2. Mineral properties of rice husks
Source: [14]

CENIZA DE CASCARILLA DE ARROZ	
Componente	%
Ceniza de Sílice(SiO_2)	94,1
Oxido de Calcio (CaO)	0,55
Oxido de magnesio (MgO)	0,95
Oxido de Potasio (K_2O)	2,10
Oxido de Sodio(Na_2O)	0,11
Sulfato	0,06
Cloro	0,05
Oxido de titanio (TiO_2)	0,05
Oxido de Alumínio (Al_2O_3)	0,12
Otros componentes (P_2O_5, F_2O_3)	1,82
Total	100,0

Fig. 3. Chemical property of rice husk ash
Source: [15]

2. Materials and Methods

This section involves determining the physicochemical properties of the pellets starting from 100% Ecuadorian rice husk and then combining Ecuadorian rice husk with a binding material in various proportions. These combinations must comply with international pellet manufacturing standards.

To evaluate the quality and characteristics of the product, it must meet the requirements of the ENplus standard and have an internal quality management system based on the

EN ISO 9001 and EN 15234 standards (pellet manufacturing).

2.1. Product Quality
The pelleted biofuel, according to the results obtained in the three configurations performed, and by analyzing its calorific value, ash percentage, moisture, mass loss over time, and friability, can be considered within the family of solid biofuels.

2.2. Characterization Tests
For the characterization of the Ecuadorian rice husk pellets, properties such as the following were determined:

- Calorific value
- Density
- Moisture
- Standardized mass
- Diameter
- Length
- Ash content
- Friability

2.3. Determination of Calorific Value
The determination of this test was carried out using a calorimetric bomb based on the MMQ-114 technique in the AVVE laboratories in the city of Guayaquil.

2.4. Results of the Calorific Value Test
The calorific value obtained for the composition of 100% rice husk was 14.32 MJ/kg, as shown in Table 3.

Table 2. Calorific Value Results of Different Pellet Configurations.

Sample	Configuration	Calorific value	Units
Rice husk and binder material	90%-10%	14.3962 *	Mj/Kg
Rice husk and binder material	80%-20%	14.4135 *	Mj/Kg
Rice husk and binder material	70%-30%	14.4460 *	Mj/Kg

Source: Authors
*Data obtained from AVVE Laboratories

2.5. Determination of Density
The volume and weight of a pellet were measured to determine the bulk density, according to the ÖNORM M7135 standard. A calibrated balance with a precision of 0.001 grams was used for the weight, and a graduated cylinder was used for the volume.

2.6. Results of Density Determination
For the geometric configuration of the pellets according to their diameter measurement, the following results are reported in Tables 4 and 5:

Table 3. Density Results for Different Pellet Configurations.

	6 mm	8 mm	10 mm
Density (kg/m3)	1662,28	2069,01	1502,42

Source: Authors

Table 4. Density results of the different pellet configurations.

Sample	Configuración	Densidad	Unidades
Rice husk and binder material	90%-10%	1862.10	Kg/m3
Rice husk and binder material	80%-20%	1655.20	Kg/m3
Rice husk and binder material	70%-30%	1448.30	Kg/m3

Source: Authors

It should be noted that the density of a pellet must be greater than 650 Kg/m³ according to the French standard for pellet manufacturing and quality.

2.7. Determination of Moisture
For the determination of this property, 100 grams of pellet samples from the three configurations were weighed, then placed in a dryer at a temperature of 110ºC for 1 hour, and finally the dry sample was weighed, according to the ÖNORM G 1074 standard. The moisture percentage is calculated using the following formula:

Moisture

$$H = \frac{Pi - Ps}{Pi} \times 100 \qquad (1)$$

Where:
H = moisture
Pi = initial or wet weight
Ps = dry weight

2.8. Determination of Standardized Mass
For the execution of this parameter, 10 pellets from each configuration were used. They were placed in a muffle furnace at 300ºC and removed every 30 seconds to produce a reduction in mass over time. The process ends

once the mass remains constant and cannot be further incinerated, resulting in Graph 1.

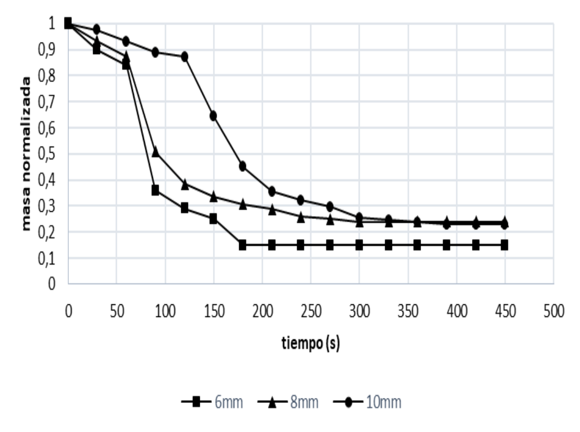

Fig. 4. Results of normalized mass determination for different pellet configurations.
Source: Authors

3. Results

This chapter details the results obtained from the experimental tests of pellets made from a mixture of rice husk and binding material. The tests were conducted in the Unit Operations Laboratory at the University of Guayaquil and AVVE Laboratories, where chemical analyses of the pellet configurations were performed.

The most suitable configuration, whose characteristics adhere to international standards for pellet manufacturing, is the 8 mm geometric configuration due to the results obtained. When combined with the binding material, the best configuration is 70% rice husk and 30% binding material, showing greater impact resistance as well as higher calorific value, as shown in table 6.

Table 6. Selection of the optimal configuration for the manufacturing process and pellet quality

Parameters	Unit	90%-10%	80%-20%	70%-30%
Diameter	mm	8	8	8
Length	mm	10	10	10
Humidity	%wt	10	10	10
Calorific value	Mj/Kg	14.3962	14.4135	14.4460
Density	Kg/m³	1862.10	1655.20	1448.30
Ash content	%wt	19.81	18.92	17.43
Friability	--	0.33	0.33	0.5

Source: Authors

Table 6 compares the 3 configurations, determining each of the physicochemical characteristics. It should be noted that the ash content is high due to the manual manufacturing process of the pellets, which prevents greater compaction of the particles.

Once the results of this test were obtained, it can be observed that the pellet with 100% rice husk configuration presents a high calorific value, and when adding the binding material, given its characteristics, its value increases, with the 70-30 configuration being better compared to the other two configurations. This is due to the improved compaction of the particles present in it.

The results obtained from the density analysis showed that the 8 mm configuration with 100% rice husk is the most suitable to be used. When combining Ecuadorian rice husk, it was determined that the 90-10 configuration reports the highest density among the 3 samples. This is an important factor in terms of the compaction of the particulate material before becoming a pellet.

The moisture content result is the same in all configurations. Due to the specifications of the international quality standard, a prior drying of the raw material was carried out. Consequently, as the final product does not undergo any process of moisture increase, it remains constant until the end of the process.

The results obtained from this test reveal the time it takes for the pellet in its different configurations to be completely incinerated, with the 8 mm and 70-30 configuration pellet maintaining the best condition, surpassing the other 2 configurations.

The ash content obtained in the 6 configurations is higher than that specified by international pellet manufacturing standards, given that their production was manual using a pelletizer adapted for the process, conditioned by the authors of this work. This influences the compaction of the particles and, at the time of incineration, causes wear much faster than usual.

This parameter demonstrates that a higher percentage of binder results in much greater impact resistance. The best friability result was obtained from the 6 mm and 70-30 configuration, while the remaining 2 remain equal.

Upon completion of the quality analyses of the Ecuadorian rice husk and binder pellets, it was determined that their production is viable as it meets the specifications imposed by the Agro and Agro+ standards.

The 8 mm geometric shape with 70% Ecuadorian rice husk and 30% binding material stands out as the best configuration, resulting in table 7.

Table 7. Comparison of results obtained against international pellet quality standards

Parameters	Unit	Agro+	Agro	70%-30%	Parameters
Diameter	mm	6- 8	6 - 16	8	Diameter
Length	mm	10 - 30	10 – 30	10	Length
Humidity	% wt	< 11	<15	10	Humidity
Calorific value	MJ/kg	> 15	> 14	14.4460	Calorific value
Density	kg/m³	> 650	> 650	1448.30	Density
Ash content	% wt	< 5	< 7	17.43	Ash content

Source: Authors

4. Conclusions

It was determined that the ideal configuration for energy generation is 70% Ecuadorian rice husk and 30% binding material, making it suitable for use in industrial furnaces or boilers.

The characterization of the pellets made from a mixture of rice husk and binding material, through the determination of physicochemical characteristics, allowed for the assessment of their quality, meeting the standards set by the international Agro and Agro+ norms. The addition of cassava starch as a binding material notably improved their friability.

The use of 70-30 configuration pellets can be advantageous for industries requiring large amounts of energy, resulting in significant savings compared to conventional fuels.

The utilization of pellets at an industrial level aims to promote the country's productive development matrix, generating new ways of energy regeneration through agro-industrial waste, thereby creating added value for these residues.

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