Migration Letters

Volume: 20, No: S5(2023), pp. 928-940

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)

www.migrationletters.com

Evaluation of Sugarcane Cutting Residues for the Production of Solid Biofuel

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Abstract

Due to pollution and environmental deterioration, man needs to find other alternatives as energy sources, including biomass. The present research was conducted to evaluate the sugarcane-cutting resi-due; this biomass has no use and can be burned to obtain energy. Manufacturing pellets reduces the environmental impact of animals and plants on crops. To characterize, for the first time, physical treat-ments such as cleaning raw materials are carried out, drying, grinding, and sieving to have the optimal characteristics to be used in the pelleting stage. Then a proximal analysis was conducted based on the ASTM -3172-89 Standard and the determination of the calorific value using the ASTM D-240 Standard. Likewise, the pellets were analyzed in their final stage. This method analyzes the parameters of mois-ture content, volatile material, ashes, and fixed carbon. It was obtained as a result that for the raw mate-rial, the % Hydrogen=3.543, %Volatile matter =86.53, %Cz=6.939, % Fixed carbon= 2.987, and Calorific value= 15.702 KJ/kg; and for the elaboration of the pellets it was carried out using the mixing propor-tion, 53% sugarcane cutting residue with 47% binder, this was determined using the proximal analysis and the determination of the calorific value, from which the results of % Humidity=5,768 were obtained., %Volatile matter=82.313, %Ash=6.376, %fixed carbon= 5.543 and Calorific value= 15.635 KJ/kg. Sugarcane cutting residues meet the physicochemical properties to be used as raw material in producing solid bio-fuel.

Keywords: *Biomass; pellets; biofuel; binder; sugar cane cutting.*

1. Introduction

Due to pollution and environmental degradation, humans have had to develop alternative energy sources. This includes biomass, in this case from lignocellulosic residues such as (ASR) agricul-tural sugarcane residues, due to their high energy potential through photosynthesis, from the solar energy they store due to their low CO2 content, it is considered the best option to use it as a renewable energy source, thus preventing the environmental crisis from worsening.

Sugarcane production has increased in recent years, so the residues generated after the harvest will become waste, which has negative impacts on the environment, such as soil erosion, green-house gas emissions to the air, production of odors and particulate matter, and in terms of biodi-versity The flora and fauna of the area.

The residue produced after the sugarcane harvest consists of shoots, leaves, and roots, a part of this is used to readjust the soil in which the sugarcane was grown, leaving another residue un-treated due to its low density and transport to sugar mills or boilers. They are expensive for the sugar industry[1]. Power generating plants These agricultural sugarcane residues present accu-mulation problems for processing plants due to their low density and the large storage volumes required.

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During the sugarcane harvest, small farmers who use pre-harvest burning techniques are more prone to fire than large producers who use machinery. In both cases, there are negative environmental aspects; on the one hand, pollution from burning agricultural residues as it produces emissions of carbon dioxide and other greenhouse gases, and on the other hand, the residues are left on the ground after mechanical cutting. Of the sugar cane. To an increase in pests and fungi and further damage to the environment. For this reason, an alternative to the reuse of waste that generates a positive economic, social, and environmental impact is sought by develop-ing an ecological product for pollution-free energy, such as pellets.

(ASR) Agricultural sugarcane residues or (SCR) sugarcane cutting residues, which include dry leaves, roots, stems, and shoots, are among the most suitable biomasses for sustainable energy production. Agricultural sugarcane residues are a low-cost material and are readily available; for example, there is a production of 50 million metric tons in Ecuador annually. Some Latin American countries with the highest sugar production are Brazil, Guatemala, Argentina, and Colombia. The ASRs produced by these countries are related to their cultivation capacity and the type of sugar cane, so the amount of residue produced is between 11-15% of the harvested [2].

In Argentina, the amount of sugarcane waste produced is between 13,000 kg and 24,000 kg of ASR per hectare [3], and in Ecuador, the amount of ASR grew between 0.5 and 1 million tons of waste [4]. Renewable energy generated from organic matter or biomass combustion has focused on developing high-value products that supply great ecological, economic, and social benefits. Since there is a large quantity of these residues without being used, what is sought in this re-search work is to evaluate the sugarcane cut residues through a proximal analysis based on the ASTM D 3172-89 Standard to determine its calorific value and establish if it is optimal to be used as solid biofuel, in this case, pellets, which will also be subjected to the same analysis, some of these properties are represented in Table 1.

In his study, Coronel (2020) demonstrated the use of ASR as a substitute for electrical energy in the industry through the proximal analysis of biomass and the calculation of biomass energy, from which a calorific value of 3,352,513,680 kJ The combustion of Sugarcane cutting residues, therefore, can produce electrical energy that is 16,512 MWh per day based on the calorific value mentioned above, which is convenient for the company conducting the research [5].

Likewise, Velázquez and López (2016) focused on the use of these residues to produce ethanol since biomass contains optimal values of cellulose, hemicellulose, and lignin, which makes it an ideal raw material for the production of ethanol experimentally when developing Simulating with Aspen, they also concluded that 121,000 liters of ethanol could be produced per day with a yield of 78.57% [6].

Therefore, Cruz and Guillén (2019) carried out a study in which their approach was to estimate the ASR suitable for energy production and obtain 32,000 tons in 4,455 years with a yield of 7.40 tons/ha [7]. In addition to characterizing the biomass, they got a calorific value result of 6,200 BTU/lb with a moisture percentage of 10.84, concluding that it has a 525 kWh/T power generation capacity. This rate becomes more energetic than the sugarcane scum.

Zamora et al. (2015) demonstrated that the characterization of sugarcane crop residues was performed using point-of-care analysis, a set of tests that determined higher calorific value, inorganic elements, and ash fusibility compared to the bagasse Sugar, which has obtained good results in industrial analyses, with a superior calorific value (PCS) of 16,313 kJ/kg [8], It can be concluded that ASR, compared to bagasse, is an excellent fuel to be used for energy.

SCR Sugarcane cutting residues are considered a Biomass type of bioenergy because their source is renewable, making it one of the most critical energy sources today. Types of organisms are known from agricultural, agro-industrial, and forest residues, such as crop residues, where leaves, straw, shells, etc., are found [9]. Biomass can be obtained in different ways, natural or care-fully processed in crops for specific needs and in the form of residues produced by industry or people at home, also known as waste. Biomass is intended to be a raw material for producing the so-called dual-fuel or green energy to reduce the environmental impact due to its low carbon con-tent, making it the producer with the lowest greenhouse gas emissions [10].

2. Materials and Methods

Biomass

Biomass is considered bioenergy because its source is renewable, and alternates are one of today's most vital energies. It is understood that the type of organisms, such as the remains of crops in which leaves, straw, shells, etc., from agriculture, agribusiness, and forest residues are found [11]. The way of obtaining biomass can be made in diverse ways, either naturally or made in crops destined for a specific need. The residual form produced by industries or people in their homes is also called, in another way, the garbage of humans. The purpose of biomass is the contribution as a raw material for producing so-called biofuels or green energy to reduce the environmental im-pact due to its low amount of carbon), making it a minor producer of greenhouse gas emissions. To know the qualities of biomass as a raw material for the production of energy or biofuel, it is necessary to take into account that it must have a high calorific value, the humidity percentage must be low, as well as the ash and carbon content; This can be known through an analysis where the total of each of the rates mentioned above can be learned[12].

Composition of biomass.

The biomass, in general, is composed of Hemicellulose, lignin, and cellulose; these can change according to the type of plant that comes from the biomass [13]. Lignocellulose residues reside in three primary chemical compounds or precursors of Hemicellulose and polyose, a pentose sugar in more significant quantities; cellulose, a glucose polymer; and lignin, a polymer of phenols lig-nin cannot be split in natural enzymes making it suitable for ethanol production processes and in the hydrolysis of cellulose to glucose, The type of biomass and its properties establish the amount of energy that is accumulated in it. The composition of sugars (pentoses and hexoses) requires the theoretical performance of biofuel.

Lignin.

It is considered a phenolic polymer that goes hand in hand with cellulose and Hemicellulose; through covalent bonds, these polymers in sets constitute part of the cellular tissues of plants; it is thanks to these components that it is considered essential in the biomass destined for the production of Biofuels [14] [15]; [16].

Cellulose.

It is considered a linear homopolymer and is composed of Glucopyranose and glycosidic; on the other hand, cellulose is a fundamental part of the cell walls of plants in the same way as Hemicellulose and lignin, the amount of cellulose present in these varies according to the type of plant, additional there are elements such as carbon, hydrogen, and oxygen that are part of cellulose so its chemical formula is written as $C6H10O5$ [17].

Hemicellulose.

Hemicellulose with the chemical formulae ($C5H8O4$) like cellulose and Hemicellulose is also part of the cell wall of plants. Therefore, it is considered a Heteropolysaccharide composed of pentoses and hexose. The structures of the biomass's lignocellulosic compositions are shown in Figure 1. [17]–[19].

Sugarcane-cutting residues are called residues from sugarcane crops. These residues are composed of dry leaves and green leaves, buds, remaining stems during the cutting of the cane, and even roots of the same; these residues have been left behind, depriving themselves of the option of giving it some energy use even though there are more and more cane crops of sugar which in turn, generate exuberant amounts of biomass, after the harvest of the cane the residues usually remain in the crop fields serving as soil fertilizers for the following plantations, others are collect-ed as animal feed however most of what remains within the farmland become burned. Hence, they need help with their collection, transport, and storage. Because these processes need high costs to be carried out[20], it would be necessary to implement collection methods that go hand in hand with the economy and sustainable practices so that biomass can be used.

Biofuels are those that are produced from the combustion of biomass, characterized by their low production of carbon dioxide and other polluting gases such as nitrogen oxide that are not made during production, for which biofuels are called a viable and sustainable source of energy since they emit fewer amounts of greenhouse gases [21]. There are different types of biofuels; these are classified according to the energy resource or the biomass where they come from. Solid biofuels, by definition, are those that, for their elaboration or production use, are made of biomass such as straw, leaves, stems, and chips, among others; this biofuel is in a solid state with the purpose that these can supply the energy requirements. The production of solid biofuels occurs initially with the mechanical treatment of biomass such as compaction, crushing, and chipping; another meth-od of obtaining solid biofuel is also through thermochemical treatments such as pyrolysis and gasification that result in coal. Solid biofuels exist, including briquettes, chips, and pellets [22].

The cut residues of the sugarcane harvest were requested from the Valdez Sugar Mill located in the city of Milagros; the sample consisted of leaves, buds, roots, and small stems of the sugarcane. We proceeded to clean the raw material and remove the remains of foreign materials to leave later the raw material composed of residues from the cane harvest exposed to the sun for 7 days so that the humidity in it decreased. The sample was minced and placed in the oven for 16 hours at 80°C because it still had significant moisture, and it was vital that it be dry to proceed with grinding. At this point, the particle size was reduced, and the hammer mill was used, which yielded a large sample so that the agricultural sugarcane residues were later passed through the ball mill to reduce its size further. The sieving was carried out in sieves from the Unitary Operations laboratory, of the University of Guayaquil Career, with different measurements in micrometers; plate No. 5 of 1.25 mm was used, plate No. 7 with a hole size of 0.8 mm, and finally, plate No. 8 with a hole size of 0.63 mm, 200 g of the sample were entered; to then obtain the percentage of weight retained per plate and the performance of the sieving; with the sieving, it was necessary to get a cleaner sample and with adequate particle size for the elaboration and compaction of the pellets. The percentage retained was calculated using the Equation % retained: $\%\ Retenido = (Mf/Mi)*100$. Where: Mf= is the mass contained in each plate Mi= the initial group that was placed. Once the ground raw material was obtained, it was placed in the oven for 24 hours at 180 °C; to reduce its humidity to less than 10%, the ideal percentage for the production of pellets, and the final step is to carry out a proximal analysis of the biomass sample.

Characterization of SCRs for Use as Biofuel.

To be used as a biofuel, it is necessary to take into account the composition and its physical and chemical properties themselves, which will depend on different factors such as the harvest method applied, the conditions in which the soil is located, and therefore the state of the cane at the time of harvest [23]. Thus, different studies on the chemical composition of ASRs have been conducted. According to Duque (2021), it comprises carbon, hydrogen, nitrogen, oxygen, sulfur, and chlorine; the proportions can be seen in Table 1 [24].

Other data that are necessary to be taken into account to recognize whether the residues of sugarcane cuts would be suitable for use in the production of biofuel are based on the properties that they have, among which are their percentage of moisture, percentage of ash, percentage of volatile matter, fixed carbon, superior calorific value, and its lower calorific value being one of the most relevant properties for SCR to be used as biofuels. And according to the literature, these are among the ranges specified in Table 2 below. Humidity is the amount of water in the biomass; it is essential since the mass, density, and even the calorific value will depend on it [25]. If there is a higher percentage of humidity, the amount of energy available will be less because the water absorbs it; therefore, ideally, the relative humidity present in the biomass should be less than 30%; however, if there are higher quantities, drying can be carried out to reduce humidity. The ash content is relevant in biomass because of its high ash content. Ash a result, the combustion temperature decreases, which means the heat transfer would be slow or difficult. Another characteristic of the pellets is the calorific value, the amount of energy or heat released from a material per unit of mass through combustion. There are two types of calorific value values generally considered: the upper calorific value and the lower calorific value. Therefore, the higher calorific value (PCS) is viewed as the heat that is entirely generated in the combustion, and the lower calorific value is the energy that does not use water condensation [6].

PelletsThe pellets are characterized by their cylindrical shape. However, they differ in their dimensions since the shells can be between 6 and 8 millimeters in diameter while their length can vary between 3.15 mm and 40 mm. Shots are the most used due to their variety and quality standards suitable for different types of equipment as they can be used at home in stoves and at an industrial level in boilers [26].

Pellet Specifications.

There are quality standards for pellets where the parameters that must be based on international standards are specified, among which are European standards such as EN14961, which refers to shots with biomass as their raw material. According to the functions, there are more European standards for industrial use, such as ISO 17225-1 and 17225-2 and biomass from pellets and for pellets from herbaceous and fruit biomass, which is the ISO 2014D standard detailed below [27], [28]. Some of these specifications are shown in Table 3Table 4Table 5,

The experimental development was divided into four processes: first, obtaining the raw material and its physical treatment; second, the characterization of the raw material; third, the pelletizing; and finally, the description of the pellets produced. First, the raw material was obtained from the Valdez Sugar Mill. Then, to continue with its physical treatment, the RAC was cleaned by drying in the sun for seven days to take the waste to the unit operations laboratory and grind it in the ball mill to reduce its size. Then, the sugarcane harvest residues were passed through a sieve and taken to the stove at 180°C for one hour to reduce humidity. Once the sample with a smaller parti-cle size was born, it was sent to the Polytechnic University of Guayaquil (Espol) laboratories for characterization. The tests conducted were moisture content, ash content, volatile matter, carbon content, and calorific value.

Then, with the elaboration of the pellets, a mixture of 53% SCR and 47% binder was made. Final-ly, samples of different shots were sent to analyze where it was considered: calorific value, mois-ture content, ash content, % volatile, and % of coal.

Stage characterization of the raw material.

A proximal analysis of the biomass sample from the cutting residues of already ground sugar-cane was conducted in the Polytechnic University of the Littoral laboratories, where they used the ASTM D-3189 method, which is detailed below. This analysis described the content of moisture, ash, volatile material, and fixed carbon, in addition to analyzing the content of lignin, cellulose, and Hemicellulose contained in the SCR.

Methodology for obtaining lignin, cellulose, and Hemicellulose.

To obtain the lignin, the TAPPI 222 Standard was used, which consists of a quantitative acid hy-drolysis procedure that is divided into two parts: the first with sulfuric acid of concentration 72 % that allows hydrolyzing the polysaccharides in oligosaccharides and, therefore, the acid at 4% where the oligomers are transformed into monosaccharides, It is necessary to take 1gr free of ex-tractable, and then be placed inside a beaker, where additional 72% H_2SO_4 is added, during con-stant stirring, where this sample began to change from a light color to a dark one when this char-acteristic is observed, the contents of the 1L precipitate vessel are emptied, and a 4% solution of H_2SO_4 is made with boiling distilled water at low flame for 4 hours. Once this process is finished, it is expected to precipitate the sample to decant and filter. Finally, be taken to the stove at 105 °C for a day and proceed with the final selection weighing [29]. Next, the TAPPI 203 Standard was used to obtain cellulose and Hemicellulose, which consists of treating the sample, in this case, the SCR, with an aqueous solution of 17.5% sodium hydroxide for approximately 45 min, and thus be able to reduce the concentration of this to 8.3%, To obtain as precipitate the alpha-cellulose, remaining in solution the beta-cellulose and gamma-cellulose. First, a tiny amount of the filtrate is taken and titrated with the acetic acid solution until it reaches a pH between 6 and 7 to precipi-tate the beta-cellulose. Next, the precipitate is separated, washed with distilled water, and dried at 105 °C until a constant weight is obtained. Finally, Hemicellulose is determined by subtracting the total values of (alpha-cellulose and the total beta-cellulose [30], [31].

3. Results

Solid Biofuels

Chips consist of pieces from solid wood or mass that have been reduced into smaller particles of irregular shape [32]. Those are characterized by a cylindrical shape where their dimensions can be from 50 to 130 millimeters, and their diameters can be from 5 to 30 millimeters; they can be made with the help of presses that run at high pressures and temperatures. In addition, binders are added to the briquettes to improve their compaction [33].

A proximal analysis determined the characteristics that biomass must have to be an energy source; a 300g sample was sent for research, and this characterization of the SCR resulted in the calorific value being 15,702 MJ/kg, a moisture percentage of 3.54%, the volatile material of 86.53% and an ash content of 2.987%, these results fall into the ranges of sugarcane residue properties, according to research conducted by Golato Marcos et al., (2019) and Duque Jonathan, (2021). As shown in Table 2, What makes the raw material (SCR), according to its characteristics obtained, suitable for production in pellets [34], [35].

Lignocellulosic biomass is composed of 35-55% cellulose, 20-40% hemicellulose, and 10-25% lignin. The type of biomass and its properties prove the amount of energy accumulated in it. The composition of sugars (pentoses and hexoses) requires the theoretical performance of biofuel. That is why it was figured out by an analysis that an amount of these biomass components is present in the SCR, obtaining that the most significant amount current is cellulose with 28.9%, followed by Hemicellulose with 23.4%, and finally lignin with 18%. It can be shown that the lig-nocellulosic percentages described above are within the ranges except for cellulose which is be-low the field; however, as lignin and Hemicellulose are within the contents, the raw material (SCR) is still suitable for use in the production of biofuel because it would supply a satisfactory performance of it.

Table 7 shows that the moisture percentage obtained for the pellets was lower, with a moisture content of 5.768%. By French standards, these values are within the range for producing pellets, between 11-15%.

Ash content

The ash content is the number of inorganic compounds present in the pellets. It is inversely proportional to the calorific value since the higher the percentage of ash generated by the shots, the lower the calorific value will be. Therefore, the elaborated pellets had a lower value of ash content of 6.376%, which was suitable according to the standards.

Volatile material content: The combustible material influences the combustion speed; if the volatile material content is higher, the biofuel is more flammable [36].

Physical Characterization

Friability test: Ten pellets were taken for each proportion to find friability, thrown from 1 meter above the ground. The value obtained for this parameter stands for a higher content of volatile matter, 82.313%. This value is acceptable since it allows the pellets to ignite while keeping high combustion temperatures easily.

Fixed carbon content: The fixed carbon is inversely proportional to the calorific value since, if the selected carbon content is lower, the energy content of the pellet will be higher and vice versa. Then it was obtained that the pellet sample has a carbon content of 5.543%, within international parameters. Therefore, it is equivalent to a high energy content.

Calorific value measurement: The results obtained for the calorific value, according to Table 3, have a higher energy content with a weight of 15,635 KJ/kg. Therefore, it is best for the quality of the pellets. In addition, the friability of the shots at the proportion of 53% ground SCR and 47% binder presented greater friability; this is because they have a more incredibly adequate amount of binder that allows better adherence of the ground SCR to each other and therefore makes the pellets have more excellent resistance to falls or blows.

Percentage of pellet yields

A calculation was made to obtain the yield percentage for each pelleting process according to its proportion. Then, calculate the performance with the accurate and theoretical performance data, according to the proportions made from 47-53; 50-50; 70-30, from the sugar cane, cutting residue, and binder.

To determine the quality of the pellets, the moisture content, ash, volatile material, and fixed carbon were characterized for each of the samples made with different mixtures of SCR and binder, being M1 (53% SCR-47% binder), M2(50% SCR-50% binder) and M3 (70% SCR-30% binder). The data of the proximal analysis of the mixtures made with different proportions are presented in Table 8.

The calculation of the total cost is done by adding the total variable costs and the total fixed costs; these results are found in Table 9 and Table 10;

Total cost = total fixed cost + total variable cost;

Total cost = 582.48+ 42.7

Total cost= $625.18

The data shown in Table 10 refers to the fixed costs to produce the first 300 g of pellets in one day. Adding the analysis costs is unnecessary for the next production since the same procedure will be followed. The total price is shown in Table 9, which was required to produce 300 g of pellets dur-ing this investigation. The quantity produced is due to the efficiency of the equipment (manual pelletizer) and the amount of raw material used. If you want to reduce costs, a market study must be carried out, since an investment must be made in more efficient machinery, physical location if necessary, and have a source of suppliers to produce x quantity of a final marketable product and thus achieve a reasonable cost. And in the same way, to obtain the final price of the pellets. The net worth it presents refers to the expenses from the investment of the pelletizing machine, includ-ing raw materials and inputs.

3.1. Figures, Tables, and Schemes

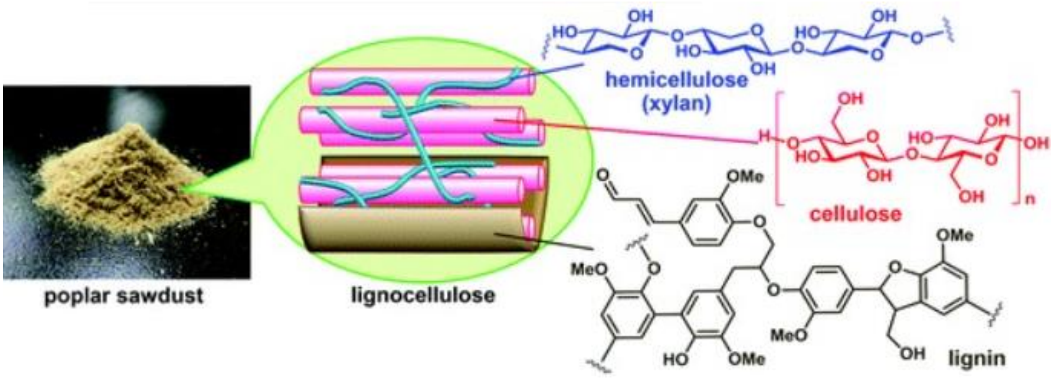

Figure 1. Structure and visualization of the Hemicellulose, lignin, and cellulose.

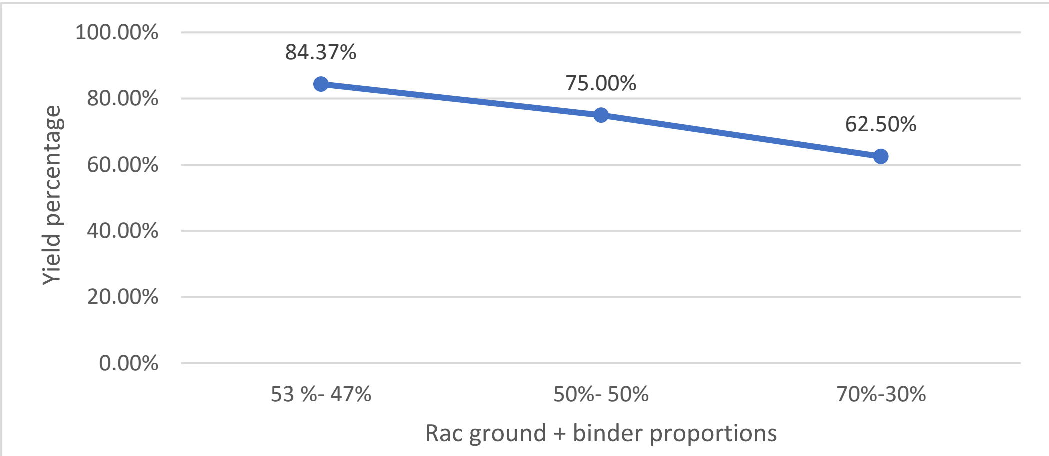

Figure 2. Yield Percentage Pellets

Table 1. Composition of sugarcane crop residues

Composition	Percentage
Carbon	44.2-46.2 %
Hydrogen	5.4-6.2%
Nitrogen	0.5-0.6 %
Oxygen	38.7- 43 %
Sulfur	0,1- 0.08 %
Chlorine	0.3- 0.1%

Tables Taken from Development and energy evaluation of a System for compaction of sugarcane crop residues (Scr), by J. Duque, 2021, Uni-versidad del Valle [34]. It may have a footer.

Table 2. Percentage-Ranges of Sugarcane RAC Properties

Property	Percentage (%)
Humidity	9.72 - 10,30
Ash	7.66 -13,89
Volatile	71.34 - 81.55
Higher calorific value (MJ/kg)	16.98 - 17.74
Lower calorific value (MJ/kg)	15.6 - 16.51

Data were taken from Duque (2021) and Golato et al. (2017) [34]

Table 3. Pellet parameters according to the European standard ISO 2014D

Properties	Value
Longitude	Minimum 3.15mm Maximum 40 mm
Humidity	Minor15%
Ash	Lower 10%
Durability	Greater than or equal to 96%
Fine	Less than 35
Density	Greater than or equal to 600kg/m^3
N2 content	Less than 2% on a dry basis
Net Caloric value	14.56 MJ/kg

Note. It is adapted from the agricultural waste revaluation to produce fuel pellets in Querétaro by C. Silva et al. (2020) [12]

Table 4. Comparison of German and Austrian parameters for pellets

Parameters	Unit	DIN 517315	O NORM EN7135
Diameter	Mm	4-10	4-10
Longitude	Mm	< 50mm	< 5 x D
Humidity	%	< 12	< 10
Abrasion	%	-	< 2.3
Density	kg/dm3	1.0 – 1.4	> 1.12
Caloric Value	MJ/kg	17.5 – 19.5	>18
Ash Content	%	< 1.5	< 0.5
Sulfur Content	%	< 0.08	< 0.04
Chlorine Content	%	< 0.03	<0.02
Nitrogen Content	%	< 0.3	< 0.3

Note. It was adapted from a Study of the pelletized Ecuadorian rice shell's energy potential for fuel by L. Velázquez et al. (2020)[37], Journal of Chemical Engineering and Development.

Table 5. Physical parameters for mixed biomass

Parameter	unit	Agro +	Agriculture
diameter	Mm	6-8	6-16
Longitude	Mm	10- 30	10-30
Humidity	%wt	< 11	< 15
Caloric Value	MJ/kg	> 15	> 14
Density	kg/m3	> 650	> 650
Ash Content	%w	< 5	< 7

Note. The parameters shown in Table 7 are based on French standards[6]

Table 6. Lignin, cellulose, and hemicellulose content.

Parameter	Unit	Results	Analysis method

Lignin	%	18.8	TAPPI 222
Cellulose	%	28.9	TAPPI 203
Hemicellulose	%	23.4	TAPPI 203

Note. C. Silva et al. (2020) [12]; The parameters shown are based on French standards, redirected to ISO 9001

Table 7. Results of proximal analysis of the pellets

Parameters	**Unit**	**Pellets (53 %-47 %)**
Humidity	%	5.768
Ash	%	6.376
Caloric Value	%	82.313
Fixed Carbon	%	5.543
Caloric Value	KJ/kg	15.635

Note. C. Silva et al. (2020) [12]; The parameters shown are based on French standards.

Table 8. Proximal Analysis of Rac and Binder Pellets

Parameter	**Unit**	**M1 (53-47)**	**M2 (50-50)**	**M3 (70-30)**
Humidity	%	5.768	6.187	5.813
ashes	%	6.376	6.709	6.761
volatile materials	%	82.313	81.258	81.719
fixed coal	%	5.543	5.081	5.819
calorific value	KJ/kg	15.635	14.897	15.017

Note. C. Silva et al. (2020) [12]; The parameters shown are based on French standards, redirected to ISO 9001

Table 9. Net cost of production of 300 g of pellets

Raw material	**Quantity**	**Total cost (USD)**
SCR	300 g	$0,09
Cassava starch	20 g	$0,06
Water	250ml	-
Labor	2	$42,4
Packaging	1	$0,15
Total		$42,7

Note. C. Silva et al. (2020) [12]; The parameters shown are based on French standards, redirected to ISO 9001

Table 10. Fixed cost to produce 300 g of pellets

Concept	Quantity	Cost (USD)
Production equipment		
Manual pelletizer or compactor	1	$70
Plastic containers for mixing	2	$2
ASR physical-chemical analysis*	1	$168
Chemical, physical analysis of pellets*	1	$342,48
Total		$582,48

The parameters shown are based on French standards. [1]

4. Discussion

The proximal analysis of the sugarcane cut residue was conducted. As a result, its functionality as a raw material is suitable for producing biofuels since they have adequate parameters representative of biomass and, in turn, are related to the physicochemical parameters of the pellets. On the other hand, the lignocellulosic component supports the excellent performance that solid biofuel could have. As shown in Figure 2, based on the results obtained from the yield calculation, the highest yield in pellet processing can be observed in a ratio of 53% ground SCR and 47% binder since the amount of binder added gives more excellent adhesion, so there is not much loss of product, unlike the granules with a ratio of 50-50%, because this significant difference in the binder keeps the mass more humid. Therefore, there is a loss because when it's the wettest material, some of it still sticks to the container the mix was made in, so mixes with a 70-30% ratio have the lowest yield because the binder ratio is lower the ground does not stick very well to each other, Plus the residues cannot enter the manual pelletizer.

Compared to pelleting, dry roasting represents a thermal process that converts biomass into carbonized products with better properties, such as higher carbon content and lower moisture content, making the material easier to grind or pulverize, transport, and store and increasing its energy density. Typical roasting temperatures range from 200 to 300°C under certain conditions. After the roasting process, the biomass dries out entirely and loses its fibrous structure, which makes it easier to crush later. Hemicellulose is most active in the 100 to 260°C range, but its maximum degradation begins above 200°C. Cellulose begins to degrade at 270°C, and lignin gradually degrades in the range of 250-500°C; above 300°C, the maximum loss of lignin begins, pos problems for densification processes such as pellet [38].

The quality of biomass roasting can be expressed by three parameters: energy density, generally low biomass content, and a large volume required to provide a certain amount of energy. Through roasting and subsequent pelletization, the energy density of the biomass is increased, which reduces costs in terms of logistics, such as the transport of materials. Mass and energy yield are two other quality parameters for roasting ASR and different types of biomasses. The mass yield (%) expresses the proportion of burned biomass mass about the feed biomass. In contrast, the energy yield (%) is the proportion of original biomass energy retained in the product. Some energy content may be lost during this process since energy yield defines the retention of this energy by increasing the product's density [39].

The moisture content directly influences the calorific value of the pellet; that is to say that the more moisture there is in the pellet, the calorific value is lower, and, on the contrary, if the moisture level is low, the efficiency and combustion performance increase. The results show that the highest percentage of moisture was obtained in the pellets of sample 2 with an amount of 6.187% and sample 1 with the lowest value with a moisture content of 5.768%. These values are within the range established for producing pellets, between 11-15%.

The results obtained for the calorific value according to Table 8, sample 1 has a higher energy content with a weight of 15,635 KJ/kg and sample 3 with a value of 15,017 KJ/kg. Hence, these two samples are optimal for the pellet quality; however, sample 2 with 14,897 KJ/kg is the lowest val-ue obtained. Among the three samples, it can be seen that sample 1 is the one with the highest calorific value. Hence, producing pellets with the proportion of 53% SCR and 47% binder is the best option regarding the calorific value, being within the parameters established in international standards.

5. Conclusions

A sample of pellets in different proportions was prepared, with the balance of 53% SCR or ASR and 47% binder that had the best performance at the time of its production, followed by the pellets in the same proportion sent for their respective proximal analysis. The physical and chemical characteristics of the shells were evaluated; where as a result, shots of 8 mm in diameter and 30 mm in length were obtained; it as evidence that the highest density, 1000 kg/m3, was for the pellets with a proportion of 53-47%, being the most suitable since it allows more significant storage space and ease of transport, however, in the same way, the friability is more important pellets with a proportion of 53-47%, this is because this amount of binder is ideal since that allows better compaction and resistance to blows. On the other hand, the humidity, % ash, and volatility, or the 53-47 ratio, are suitable and give veracity of the quality of the pellets produced, according to international regulations,

To conclude, the sample with a 53% SCR-47% binder ratio is the best since it had a higher calorific value, which shows the effectiveness of the pellets for their proper combustion, adding that the value results were remarkably similar to international standards.

The manufacture of pellets from SCR is also an alternative; the shell can produce fuel for heating or electricity generation, for internal consumption in plant boilers, or for export, especially to Europe, the world's largest pellet market. The pellets can also be used in animal feed. One of these processes is to mix dry chopped SCR (15% moisture and 1% ash), mix it with a binder, and mix it with bagasse or any other biomass with the same combustible property's binder. The agent is usually a starch or lignin compound, which can also be molasses (edible granules).

6. Patents

There is no patent in this research.

Author Contributions: The Conceptualization and methodology, Denisse Bermeo and Flor Reyes; to the validation Eduardo Arango; investigation, resources, Sandra Peña, and Carmen Forero; writing—original draft preparation, Sandra Peña; review Francisco Velasco and editing, Sandra Peña; visualiza-tion, supervision, project administration, Carmen Forero.

Funding: "This research received no external funding."

Acknowledgments: The authors gratefully acknowledge the financial support provided by the Colombia Scientific Program within the framework of the call Ecosistema Científico (Contract No. FP44842- 218-2018); and Coal Science and Technology Laboratory of the Universidad del Valle, Cali- Colombia. The gratitude for the support received by the Petroleum Laboratory of the Faculty and Career of Chemical Engineering of the University of Guayaquil, Guayaquil-Ecuador

Conflicts of Interest: "The authors declare no conflict of interest."

References

[1] Centro Ecuatoriano de Eficiencia de Recursos, 'Guía para el cultivo de caña de azucar ', Eco Business Fund, Jun. 2021.

[2] Gutierrez, 'Combustión y Gasificación de la Biomasa', in Seminario biomasa, D. I. de la M. Facultad de Ciencias Forestales, Ed., Chile: Universidad de Chile, 2003.

[3] S. Moreno, 'Estudio de sistemas de captura de CO2 y métodos de concentración de CO2 en corrientes gaseosas aplicados a ciclos combinados', Universidad de Sevilla, 2019.

[4] S. Peña, C. Forero, and F. Velasco, 'BIBLIOMETRIC STUDY OF THE COMBUSTION OF RAC IN THE CAPTURE OF CARBON DIOXIDE,' International Journal of Mechanical and Production Engineering, vol. 9, no. 11, pp. 24–30, 2021, [Online]. Available: http://iraj.in

[5] Coronel, C. Regalado, E. Kristian Asesor, N. Vásquez, and P. Edwar, 'UNIVERSIDAD NACIONAL "PEDRO RUIZ GALLO" TESIS Para Optar el Título Profesional de INGE-NIERO MECÁNICO ELECTRICISTA', 2020.

[6] Y. D. C. Velásquez Riascos and J. E. López, 'Estudio de prefactibilidad para el diseño de una planta de etanol a partir de residuos de cosecha de caña de azúcar', Revista Mutis, vol. 6, no. 2, pp. 74–81, Oct. 2017, doi: 10.21789/22561498.1152.

[7] Cruz y Guillen, 'RESIDUOS AGRÍCOLAS DE CAÑA DE AZÚCAR COMO BIOMASA ALTERNATIVA PARA LA GENERACIÓN DE ENERGÍA ELÉCTRICA', 2019.

[8] G. Del et al., 'CARACTERIZACIÓN ENERGÉTICA DEL RESIDUO AGRÍCOLA DE COSE-CHA DE CAÑA DE AZÚCAR (RAC) DE TUCUMÁN, ARGENTINA'. [Online]. Available: www.eeaoc.org.ar

[9] Y. Vargas-García, J. Pazmiño-Sánchez, J. Dávila-Rincón, Y. Vargas-García, J. Pazmiño-Sánchez, and J. Dávila-Rincón, 'Potencial de Biomasa en América del Sur para la Produc-ción de Bioplásticos. Una Revisión', Revista Politécnica, vol. 48, no. 2, pp. 7–20, 2021, doi: 10.33333/RP.VOL48N2.01.

[10] Peña Sandra, 'DETERMINACIÓN DE LA CINÉTICA DE REACCIÓN DE LA GASIFICA-CIÓN DE RESIDUOS AGRÍCOLAS DE CAÑA DE AZÚCAR (RAC)EN LA CAPTURA DE CO2MEDIANTE SIMULACIÓN CON ASPEN PLUs', 2021. [Online]. Available: http://www.fiq.ug.edu.ec

[11] U. Kanerva, 'Characteristics of various new oxygen carriers for CLC,' no. March, pp. 2009–2011, 2010.

[12] N. W. Silva Reyna, C. Agrarias, P. De Cosecha, E. N. Corte, M. De, and C. De Azucar, 'PERDIDAS DE COSECHA EN CORTE MANUAL DE CAÑA DE AZUCAR (Saccharum officinarum L.)', 2022. [Online]. Available: https://orcid.org/0000-0001-5734-0303

[13] M. Golato, E. Feijóo, F. Franck Colombres, D. Paz, and G. Cárdenas, 'Estudio preliminar del aprovechamiento de los residuos agrícolas de cosecha de la caña de azúcar como combustible adicional para calderas bagaceras de Tucumán (Argentina)', Revista Indus-trial y Agrícola de Tucumán, vol. 94, no. 2, pp. 21–31, 2017.

[14] S. Peña and E. Zambrano, Bioremediación de suelos contaminados con hidrocarburos derivados del petróleo, vol. 1, no. 5. 2022. doi 10.22490/24629448.351.

[15] A. A. Guilherme, P. V. F. Dantas, E. S. Santos, F. A. N. Fernandes, and G. R. Macedo, 'EVALUATION OF COMPOSITION, CHARACTERIZATION AND ENZYMATIC HY-DROLYSIS OF PRETREATED SUGAR CANE BAGASSE,' Brazilian Journal of Chemical En-gineering, vol. 32, no. 1, pp. 23–33, Mar. 2015, doi: 10.1590/0104-6632.20150321s00003146.

[16] W. B. and T. Services, 'Furfural Chemicals and Biofuels from Agriculture,' Development, no. 06, p. 39, 2006, [Online]. Available: http://www.rirdc.gov.au

[17] L. Faba, E. Díaz, and S. Ordóñez, 'Transformación de biomasa en biocombustibles', Made-ra y Bosques, vol. 20, no. 3, pp. 11–24, 2014.

[18] I. Jesús, D. Artigas, A. D. Concepción, A. J. R. Piñero, and A. A. Álvarez, 'Briquetas energe-ticas con aserrín y corteza de pino', Ingeniería Energética, vol. XLI, pp. 1–6, 2020.

[19] L. Faba, E. Díaz, and S. Ordóñez, 'TRANSFORMACIÓN DE BIOMASA EN BIOCOMBUS-TIBLES DE SEGUNDA GENERACIÓN', Madera Bosques, vol. 20, no. 3, pp. 11–24, 2014, [Online]. Available: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-04712014000300002

[20] I. Z. Azucarera, 'Instituto azucarero dominicano -inazucar-', vol. 2009, pp. 1–5, 2018.

[21] I. Luis Enrique Velázquez Áraque, J. Manuel Aguilar Sierra, and E. Alejandro Tulcán Ál-varez, 'Estudio del potencial energético de la cascara de arroz ecuatoriano peletizado para su uso como combustible Study of the energy potential of pelletized Ecuadorian rice husk for use as fuel', 2020. [Online]. Available: https://revistas.ug.edu.ec/index.php/iqd

[22] S. J. y G. C. Ríos Inés, 'BiocombustiblesSolidos', Biocombustibles solidos, solución al calenta-miento global, vol. 68, Oct. 2017.

[23] F. J. Velasco-Sarria, C. R. Forero, I. Adánez-Rubio, A. Abad, and J. Adánez, 'Assessment of low-cost oxygen carrier in South-western Colombia, and its use in the in-situ gasification chemical looping combustion technology,' Fuel, vol. 218, pp. 417–424, Apr. 2018, doi: 10.1016/j.fuel.2017.11.078.

[24] S. Peña, C. Forero, and F. Velasco, 'Bibliometric study of the combustion of cane cutting waste (RAC) in the capture of carbon dioxide,' SN Appl Sci, vol. 4, no. 5, 2022, doi: 10.1007/s42452-022-05009-9.

[25] J. Serrano, W. Mejía, J. Ortiz, A. Sánchez, and S. Zalamea, 'Determination of the Potential Electric Generation from Biomass in Ecuador', 2017. [Online]. Available: http://data.worldbank.org

[26] J. J. Santos-Lema and C. A. Silva-Arroyo, Obtención de nanocelulosa a partir de la cascarilla de arroz mediante hidrólisis ácida. 2019. [Online]. Available: http://186.101.98.14/bitstream/redug/40057/1/401-1370 - obtenc nanocelulosa a partir cas-carilla arroz mediante hidrólisis ácida.pdf

[27] S. Perez, I. Silva, G. Penueña, and S. Cardona, 'Evaluación De Biocombustibles E Hidro-carburos Del Petróleo (Gasolina Y Diesel) En Un Suelo: Proceso De Transporte Y Biorre-mediación', Revista EIA, vol. 12, no. 1, pp. 21–46, 2015, doi: 10.24050/reia.v1i1.704.

[28] R. R. Philippine, S. E. Martiniano, A. K. Chandel, W. de Carvalho, and S. S. da Silva, 'Pre-treatment of Sugarcane Bagasse from Cane Hybrids: Effects on Chemical Composition and 2G Sugars Recovery', Waste Biomass Valorization, vol. 10, no. 6, pp. 1561–1570, 2019, doi: 10.1007/s12649-017-0162-0.

[29] H. P. Castillo, D. A. Mendoza, and M. P. Caballero, 'Análisis de las propiedades fisico-químicas de gasolina y diesel mexicanos reformulados con Etanol Analysis of Physico-chemical Properties of Mexican Gasoline and Diesel Reformulated with Ethanol', Ingenie-ría Investigación y Tecnología, vol. XIII, no. número 3, pp. 293–306, 2017, [Online]. Available: http://www.scielo.org.mx/pdf/iit/v13n3/v13n3a4.pdf

[30] D. Lesme-Jaén, René; Garcia-Faure, Luis; Oliva-Ruiz, Luis; Pajarín-Rodríguez, Juan; Revi-lla - Suarez, 'Gasificación de biomasa para la generación de electricidad con motores de combustión interna. Eficiencia del proceso', Tecnologí¬a Química, vol. 36, no. 2, pp. 161–172, 2016, doi: 10.1590/2224-6185.2016.2.

[31] A. Cornejo et al., ‘Pretreatment and enzymatic hydrolysis for the efficient production of glucose and furfural from wheat straw, pine, and poplar chips,’ Bioresour Technol, vol. 288, Sep. 2019, doi 10.1016/j.biortech.2019.121583.

[32] C. Chandler et al., ‘HIDRÓLISIS ÁCIDA DILUIDA EN DOS ETAPAS DE BAGAZO DE CAÑA DE AZÚCAR PARA LA PRODUCCIÓN DE AZÚCARES FERMENTABLES’, Multi-ciencias, vol. 12, no. 3, pp. 245–253, 2012, [Online]. Available: https://www.redalyc.org/articulo.oa?id=90426810002

[33] I. Jesús, D. Artigas, A. D. Concepción, A. J. R. Piñero, and A. A. Álvarez, ‘Briquetas energe-ticas con aserrín y corteza de pino’, Ingeniería Energética, vol. XLI, pp. 1–6, 2020.

[34] Duque Jhonathan, ‘DESARROLLO Y EVALUACIÓN ENERGÉTICA DE UN SISTEMA PARA COMPACTACIÓN DE RESIDUOS DE COSECHA DE CAÑA DE AZÚCAR (RAC)’, 2021.

[35] Golato Marcos et al., ‘Estudio preliminar del aprovechamiento del RAC’, 2019.

[36] P. A. Meléndez Hernández, J. U. Hernández Beltrán, H. Hernandez Escoto, and R. Morales Rodriguez, ‘ANÁLISIS DEL PRETRATAMIENTO DE RESIDUOS LIGNOCELULÓSICOS PARA LA PRODUCCIÓN DE BIOCOMBUSTIBLES Y BIOPRODUCTOS DE ALTO VALOR AGREGADO’, JÓVENES EN LA CIENCIA, vol. 1, no. 2, pp. 534–538, 2015, [Online]. Avail-able: http://www.jovenesenlaciencia.ugto.mx/index.php/jovenesenlaciencia/article/view/416

[37] F. Velázquez, ‘Cambio climático y protocolo de Kioto. Ciencia y estrategias: Compromisos para España’, Rev Esp Salud Publica, vol. 79, no. 2, pp. 191–201, 2015, doi: 10.1590/s1135-57272005000200007.

[38] P. D. L. C. Martínez Nodal, E. Rosa Domínguez, I. Rodrigué Rico, and J. Leiva Mas, ‘CA-RACTERIZACIÓN FÍSICO QUÍMICA DEL BAGAZO DE CAÑA NATURAL UTILIZADO COMO BIOSORBENTE EN LA REMOCIÓN DE HIDROCARBUROS EN AGUA’, ICIDCA. SOBRE LOS DERIVADOS DE LA CAÑA DE AZÚCAR, vol. 51, no. 2, pp. 35–39, 2017, [On-line]. Available: www.redalyc.org/articulo.oa?id=223154251006

[39] L. Leiva-Giraldo, D. F. Vinasco-Maca, and J. M. Barraza-Burgos, ‘BIOMASA: ESTADO DEL ARTE PARA APLICACIÓN’.