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Characterization of pineapple peel (*Ananas comosus*) Perolera variety as a potential resource for bioethanol production

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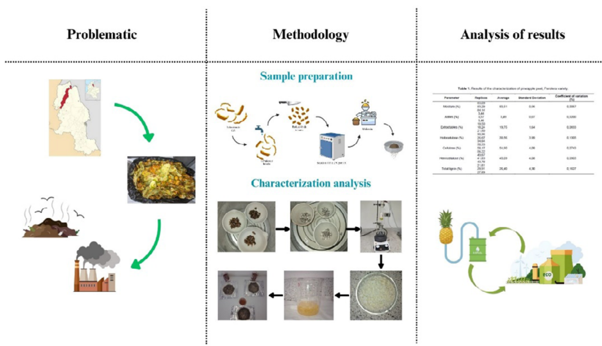
Graphical abstract



Highlights

Pineapple waste, if not managed, generates leachates and pests in the environment.
Lignin can complicate the conversion of cellulose into fermentable sugars.
The high cellulose content in pineapple peel offers great potential for bioethanol production.

Abstract

Pineapple production in Colombia generates around 185,000 tons of waste per year, consisting of peels, residual pulp, stems and leaves. Due to its lignocellulosic nature, pineapple peel shows significant potential to produce bioethanol, leading to the use of this waste. The objective of this research was to characterize the peels of pineapple (*Ananas comosus*) of the Perolera variety, grown in the municipality of Teorama, Catatumbo Region (Norte de Santander), to evaluate its potential for the production of bioethanol. The physical-chemical characterization of the lignocellulosic material was carried out, assessing the percentage of moisture, ash, ethanol-hexane extractables, holocellulose, cellulose, hemicellulose, and lignin soluble and insoluble in acid, each analysis was carried out in triplicate. The most relevant results obtained in the characterization were: 83.51 % moisture, holocellulose, which is made up of cellulose and hemicellulose, with percentages on a dry basis of 54.90 and 45.09 %, respectively, which indicates that a higher cellulose content means a greater amount of glucose, which facilitates the production of reducing sugars through hydrolysis processes. On the other hand, the total lignin content was 26.40 %, which contributes to structural support in the cell wall of pineapple peels, giving it rigidity and permeability. The high lignin content can make the conversion of cellulose into simple sugars difficult, which is why it is suggested to carry out a delignification process so that the cellulose is more susceptible to enzymatic hydrolysis, thus optimizing bioethanol production.

Keywords: *Biofuel; Cellulose; Climate change; Delignification; Enzymatic hydrolysis; Fermentation; Greenhouse gases; Holocellulose; Lignin; Lignocellulosic waste; Organic waste; Reducing sugars.*

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Caracterización de la cáscara de piña (*Ananas comosus*) variedad Perolera como recurso potencial para la producción de bioetanol

Resumen

La producción de piña en Colombia genera alrededor de 185 000 toneladas de residuos al año, constituidos por cáscaras, pulpa residual, tallos y hojas. Por su naturaleza lignocelulósica, la cáscara de piña muestra un potencial significativo para producir bioetanol, conllevando al aprovechamiento de este residuo. El objetivo de esta investigación fue caracterizar las cáscaras de piña (*Ananas comosus*) de la variedad Perolera, cultivada en el municipio de Teorama, Región del Catatumbo (Norte de Santander), con el fin de evaluar su potencial para la producción de bioetanol. Se realizó la caracterización físico-química del material lignocelulósico, evaluando el porcentaje de humedad, cenizas, extraíbles etanol-hexano, holocelulosa, celulosa, hemicelulosa y lignina soluble e insoluble en ácido, cada análisis se realizó por triplicado. Los resultados más relevantes obtenidos en la caracterización fueron: 83,51 % de humedad, la holocelulosa, que está constituida por celulosa y hemicelulosa, con porcentajes en base seca de 54,90 y 45,09 %, respectivamente, lo cual indica que un mayor contenido de celulosa significa una mayor cantidad de glucosa, que facilita la producción de azúcares reductores a través de procesos de hidrólisis. Por otra parte, el contenido total de lignina fue del 26,40 %, la cual contribuye a un soporte estructural en la pared celular de las cáscaras de piña, otorgándole rigidez y permeabilidad. El alto contenido de lignina puede dificultar la conversión de la celulosa en azúcares simples, por esto se sugiere realizar un proceso de deslignificación para que la celulosa sea más susceptible a la hidrólisis enzimática, optimizando así la producción de bioetanol.

Palabras clave: *Azúcares reductores; Biocombustible; Cambio climático; Celulosa; Deslignificación; Fermentación; Gases de efecto invernadero; Hidrólisis enzimática; Holocelulosa; Lignina; Residuos lignocelulósicos; Residuos orgánicos.*

Caracterização da casca de abacaxi (*Ananas comosus*) variedade Perolera como recurso potencial para produção de bioetanol

Resumo

A produção de abacaxi na Colômbia gera cerca de 185 mil toneladas de resíduos por ano, compostos por cascas, polpa residual, caules e folhas. Devido à sua natureza lignocelulósica, a casca do abacaxi apresenta potencial significativo para a produção de bioetanol, levando ao aproveitamento desse resíduo. O objetivo desta pesquisa foi caracterizar as cascas de abacaxi (*Ananas comosus*) da variedade Perolera, cultivado no município de Teorama, região de Catatumbo (Norte de Santander), a fim de avaliar seu potencial para a produção de bioetanol. Foi realizada a caracterização físico-química do material lignocelulósico, avaliando o percentual de umidade, cinzas, extraíveis etanol-hexano, holocelulose, celulose, hemicelulose e lignina solúveis e insolúveis em ácido, cada análise foi realizada em triplicata. Os resultados mais relevantes obtidos na caracterização foram: 83,51 % de umidade, holocelulose, que é composta por celulose e hemicelulose, com percentuais em base seca de 54,90 e 45,09 %, respectivamente, o que indica que maior teor de celulose significa maior quantidade de glicose, o que facilita a produção de açúcares redutores através de processos de hidrólise. Por outro lado, o teor total de lignina foi de 26,40 %, o que contribui para sustentação estrutural na parede celular da casca do abacaxi, conferindo-lhe rigidez e permeabilidade. O alto teor de lignina pode dificultar a conversão da celulose em açúcares simples, por isso se sugere a realização de um processo de deslignificação para que a celulose fique mais suscetível à hidrólise enzimática, otimizando assim a produção de bioetanol.

Palavras-chave: *Açúcares redutores; Biocombustíveis; Celulose; Deslignificação; Fermentação; Gases de efeito estufa; Hidrólise enzimática; Holocelulose; Lignina; Mudanças climáticas; Resíduos lignocelulósicos; Resíduos orgânicos.*

Introduction

Pineapple is one of the crops that generates the most organic waste, which is highly problematic for farmers, since for each hectare of pineapple there are between 200 and 250 tons of organic waste, which has not been properly managed, so the possibility arises of using it and adding added value that benefits all the actors related to the economy generated by pineapple [1]. Of the total mass of the pineapple, the pulp constitutes about 30-45 % and the remaining 55-70 % represents waste (crown, core, peels, and fruit trimmings); therefore, an increase in pineapple production leads to an increase in waste generation, since only the pulp is consumed and inappropriate components of the fruit are eliminated [2].

Pineapple production and processing generates by-products such as stubble, crowns, skin, and core, as well as damaged fruits. Despite their potential, these by-products are often discarded or burned, releasing methane and CO_2, contributing to climate change, water and soil pollution, and affecting local biodiversity [3]. Pineapple, being 100 % usable, offers multiple uses for its by-products, although most efforts are focused on its fresh consumption. The pulp (33 %) is used for juices and food; the core (6 %) provides sugars for drinks, vinegar, and concentrates; the leaves and stems (20 %) are a source of fiber and carbon for fermentation; and the peels (41 %) contain sugars useful in the production of methane, ethanol, and hydrogen [4,5].

Pineapple production in Colombia generates around 185,000 tons of waste per year, consisting of peels, residual pulp, stems, and leaves [6]. Proper management of these wastes is necessary to avoid adverse environmental effects such as leaching, bad odors, greenhouse gas emissions, and insect proliferation [7]. When pineapple is processed to obtain derivatives, such as jams, concentrates, or canned products, approximately 50 % of the fruit is discarded as waste, mainly composed of the peels and core of the pineapple [8]. Due to its lignocellulosic nature, pineapple peel shows a significant potential to produce bioethanol, leading to the use of this waste [9].

Given the current need to promote sustainable practices that transform industrial waste into renewable and environmentally friendly resources, this study proposes an alternative for the processing of pineapple peels of the Perolera variety produced in the municipality of Teorama; this approach not only addresses local problems, such as the accumulation of agricultural waste but also contributes to the global challenges of reducing dependence on fossil fuels through the production of bioethanol, a renewable energy resource. The municipality of Teorama is located in the western part of the Norte de Santander department, being one of the 11 municipalities that make up the Catatumbo region. Regarding agricultural production, in 2022 it stood out with a total of 85 hectares dedicated to the cultivation and production of pineapple. This extension of land generated a production of 1,275 tons of pineapple, consolidating Teorama as the second municipality with the highest production yield in the department, only surpassed by San Calixto [10]. The Perolera variety of pineapple stands out as the most representative cultivated product of Teorama, granting recognition to the municipality, both for the quality and the quantity of products derived from it.

One of the main applications of bioethanol is as a biofuel, as it is the most relevant renewable fuel due to its beneficial environmental impact. It is currently produced mainly from biomass, particularly lignocellulosic biomass. Therefore, bioethanol can be a potential alternative to conventional fuels currently used due to its important characteristics such as energy security, waste utilization and environmental sustainability [11,12]. Due to the excessive use of fossil fuels and as a consequence of global warming and climate change, the transition towards cleaner and renewable energy sources such as bioethanol and biodiesel has been promoted. Research has been conducted on the production of ethanol from lignocellulosic materials, due to their low cost and abundance [13]. Ethanol, obtained by fermentation of sugars, cellulose or starch, has various applications, such as biofuel in the automotive industry and in the manufacture of medicines, cosmetics and chemical products [14].

In response, a global energy alternative is being sought, with bioethanol being a promising option. This biofuel, produced by fermentation, contains 35 % oxygen that facilitates more efficient combustion, reducing polluting emissions. Furthermore, its eco-friendly nature makes it ideal for applications in the industrial, energy and transportation sectors, especially when obtained from agricultural waste [15]. The objective of this study is to characterize the cellulose, hemicellulose and lignin content in pineapple peels (*Ananas comosus*) of the Perolera variety, grown in the municipality of Teorama, Catatumbo region, and to evaluate its suitability as a raw material for the production of bioethanol, thus offering a sustainable solution for the management of waste from the pineapple industry; this variety was chosen because it is typical of the region and represents an abundant source of waste. Furthermore, although studies have been carried out on other pineapple varieties, the Perolera variety has been less explored in terms of its potential for bioethanol production. This study proposes the hypothesis that the pineapple peel of the Perolera variety, with its high cellulose content, represents an under-exploited resource for the production of bioethanol.

Materials and methods

Sample preparation

For the development of the research, approximately 1 kg of pineapple peel of the Perolera variety were collected, provided by the company "Tortas El Buen Sabor" located in the municipality of Teorama, Norte de Santander. The pineapple peels were immediately refrigerated at 4 °C for preservation until processing. Subsequently, the peels were conditioned for characterization, which included selection, cleaning and manual cutting to reduce their size, as shown in Figure 1.

Physicochemical characterization of pineapple peels

Moisture determination

The moisture percentage of the pineapple peel was determined, which was carried out using the gravimetric method of moisture determination NTC 287 [16]. Porcelain capsules were used, previously dried in an oven at 103 ± 2 °C for 1 hour, then allowed to cool in a desiccator for 30 to 45 min and weighed (m_1). In the previously dried capsules, samples of pineapple peel cut into small pieces of size 0.3 and 0.5 cm were weighed, of 10.0371, 10.0620 and 10.0790 g, respectively (m_2); the above was subjected to heating in an oven at 103 ± 2 °C for 1 hour, after which time the capsules with the samples were placed to cool in the desiccator for 30 to 45 min and weighed (m_3). The drying process was repeated until the mass difference between two consecutive weighings was less than 0.0050 g, thus ensuring that the sample reached a constant mass [17]. Figure 2 shows the pineapple peel samples after drying, obtaining constant mass after four hours in the oven.

Figure 1. Manual washing and cutting of pineapple peel.

Figure 2. Pineapple peels obtained after the drying process.

Ash determination

The ash content was determined using NTC 1886 [18]. Dry samples of 1.6904, 1.7046 and 1.7108 g, respectively, used in the determination of total moisture, were added to previously weighed crucibles and taken to the muffle where the temperature was gradually raised to 550 °C for 1 hour; this temperature was selected to ensure complete combustion of organic matter, while avoiding sintering of inorganic components in the ashes. They were covered with an aluminum sheet, allowed to cool in the desiccator and the mass of the ashes was determined; Figure 3 shows the ash content obtained from pineapple peels, visually evidencing the low residue after combustion, suggesting a high purity of the sample.

Figure 3. Ashes obtained from pineapple peels.

Determination of extractables

Extractables are materials soluble in water and organic solvents, which generally represent a small fraction of the plant. With the determination of extractables, condensed tannins, resins, waxes, fats, chlorophylls, carotenoids and some proportions of gums can be removed. For the determination of extractables, the methodology of the TAPPI 204 cm-97 standard is followed [19]. 7.5009, 7.5013 and 7.5020 g of dried pineapple peel were weighed, ground and sieved through No. 40 mesh. These samples were placed in respective cellulose thimbles and subjected to Soxhlet extraction as can be seen in Figure 4. A mixture of 170 mL of hexane and 130 mL of ethanol was used as a solvent and the temperature was adjusted to recirculate the solvent. After 12 complete extractions, the samples without extractables were transferred to tared capsules and dried at 105 °C for 4 hours to remove residual solvents. They were then cooled in a desiccator for 30 minutes before the sample was weighed. This process ensures an accurate measurement of the dry weight, free of extracts, guaranteeing the accuracy of the results [17].

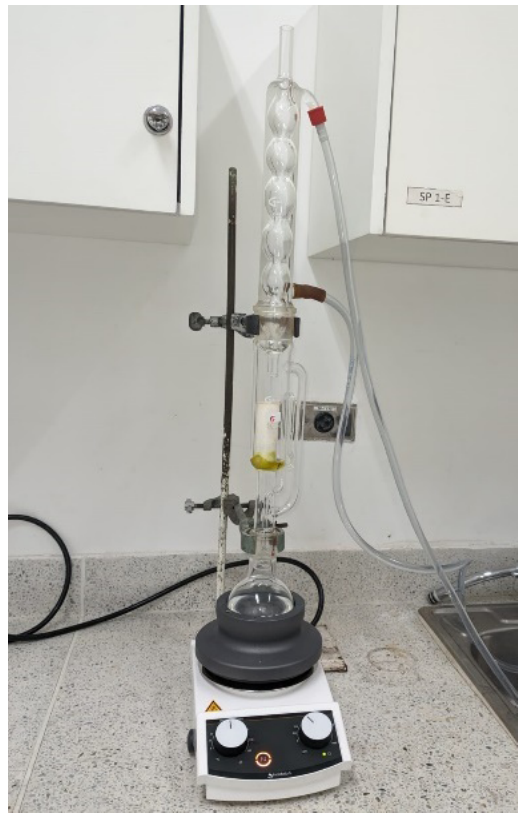

Figure 4. Soxhlet assembly for removal of extractables.

Determination of holocellulose

Holocellulose is the total polysaccharide fraction present in lignocellulosic biomass, composed of the combination of cellulose and hemicelluloses. These polymers are closely associated and serve as structural support to the cell wall [20]. The determination of holocellulose was carried out using the methodology of the ASTM D-1104 standard [21]. 2.5003, 2.5009 and 2.5010 g of samples free of extractables were weighed and added to respective Erlenmeyer flasks and treated with 80 mL of distilled water, 0.5 mL of glacial acetic acid and 1 g of sodium chlorite 25 %w placed in a water bath at a temperature between 70-80 °C, then the Erlenmeyer flasks were capped and left to rest for 1 hour. After time, an additional 0.5 mL of glacial acetic acid and 1 g of 25 %w sodium chlorite were added and it was left to rest again for 1 hour. The process was repeated until it was observed that the residue that was initially yellow became white. During preliminary trials, sodium chlorite concentration and acidic conditions were optimized to selectively remove lignin and hemicellulose, without degrading cellulose. To stop the reaction, the Erlenmeyer flasks were placed in an ice bath until the temperature reached 10 °C. Figure 5 shows the contents of each Erlenmeyer flask, which was filtered, washed with distilled water and subjected to a drying process at 105 °C until reaching a constant mass. The mass of the final residue corresponds to the holocellulose of each sample [17].

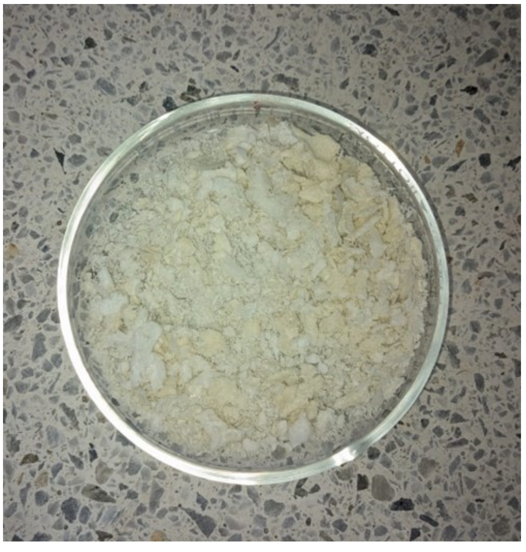

Figure 5. Holocellulose obtained from pineapple peels after drying.

Determination of cellulose and hemicellulose

Cellulose is one of the most abundant renewable natural polymers, since it makes up the majority of terrestrial biomass and is a structural component of plants [22]. The determination of cellulose was carried out following the methodology of the ASTM D1103-55 T standard [23]. 1.0000, 1.0002 and 1.0002 g of each holocellulose sample obtained in the previous analysis were weighed and reacted with 25 mL of 17.5 %w/v sodium hydroxide solution for 45 min as seen in Figure 6, then diluted with 30 mL of distilled water, shaken and allowed to settle. The fiber suspension was filtered under vacuum, washing with a mixture of 25 mL of 17.5 %w/v sodium hydroxide solution and 30 mL of distilled water. 15 mL of 10 %v acetic acid was added for 5 min while continuing to apply vacuum, the neutralized α-cellulose was washed with distilled water. The samples obtained were dried at 105 °C for 4 hours and transferred to a desiccator for 30 min. Finally, the cellulose obtained was weighed. Hemicelluloses, on the other hand, are short branched heterogeneous polymers composed of pentoses, hexoses and different types of uronic acids [20]; the hemicellulose content is obtained by the difference between the cellulose obtained and its holocellulose content [17].

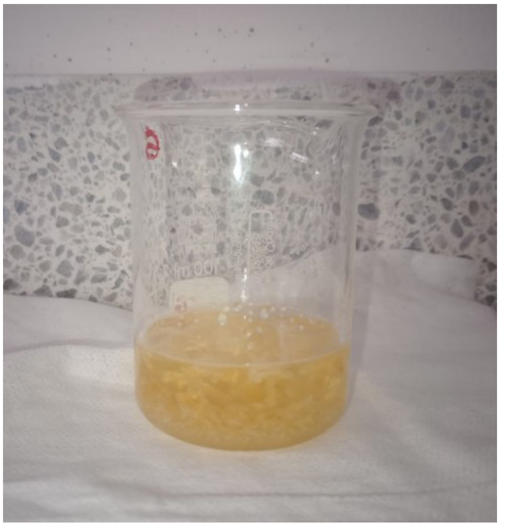

Figure 6. Obtaining cellulose through the reaction of holocellulose with 17.5 % (m/v) NaOH.

Determination of acid-insoluble lignin and acid-soluble lignin

Lignin, the second most abundant natural polymer on the planet, is the main renewable source of aromatic compounds. Its chemical structure is based on three repetitive units: coumaryl (H), guaiacyl (G) and syringyl (S), derived from the monolignols p-coumaric, coniferyl and sinalpylic [24].

The determination of acid-insoluble lignin was carried out using the methodology of the TAPPI standard reaffirmation of T 222 om-02 [25]. The total lignin content is the sum of the content of soluble acids and insoluble acids.

Acid-insoluble lignin

0.5001, 0.5005 and 0.5003 g of dried pineapple peel were taken, previously ground and sieved through a No. 40 sieve, free of extractables and with known moisture. The fiber samples were subjected to acid hydrolysis with 5 mL of 72 %w H_2SO_4 at 30 °C for 1 hour. They were then diluted with distilled water until obtaining a H_2SO_4 concentration of 4 %w, placed in a water bath for 1 hour at 110 °C, allowed to cool and rest. After acid hydrolysis, the suspension was filtered through a pre-weighed glass fiber filter, which was then washed with distilled water until it reached a neutral pH. The filter containing the retained residue was dried to constant mass for the quantification of acid-insoluble lignin. The filtrate was directly used for the analysis of acid-soluble lignin. Figure 7 shows the dried acid-insoluble lignin extracted after the acid hydrolysis, filtering and drying processes together with the hydrolysate obtained.

Figure 7. Dried acid-insoluble lignin together with the hydrolyzate obtained.

Acid-soluble lignin

Figure 8 shows the filtered solution of the hydrolysate, which was used for the determination of acid-soluble lignin. This analysis was performed following the methodology of LAP-004 [26]. Using the BioMateTM 3S – Thermo SCIENTIFIC UV-Vis spectrophotometer, the absorbance at 205 nm of the hydrolyzate obtained during the determination of acid-insoluble lignin was measured. For the blank, a solution of 4 %w H_2SO_4 was prepared. Finally, the average of several absorbance measurements was determined [27].

Figure 8. Hydrolyzate obtained in the analysis of acid-insoluble lignin.

Results and discussion

Sample preparation

Initial conditioning included sorting, cleaning, and manual cutting, followed by grinding in a fixed disc mill and sieved through No. 40 mesh, which guaranteed uniformity of particle size. These steps ensure that samples are free of contaminants and adequately prepared for the physical-chemical characterization of pineapple peels, improving the accuracy, reproducibility, and efficiency of the analyses.

Physicochemical characterization of pineapple peels

Characterization of the pineapple peel of the Perolera variety revealed a moisture content of 83.51 %, an ash content of 3.49 %, an extractable content of 19.75 % and a significant presence of holocellulose (30.56 %), cellulose (54.90 %) and lignin (26.40 %). These findings suggest a high potential for bioethanol production given the substantial cellulose content.

The characterization tests described in the methodology were carried out in triplicate and the results obtained are presented in Table 1.

Table 1. Results of the characterization of pineapple peel, Perolera variety.

Parameter (%w)	Replicas	Average	Standard Deviation	Coefficient of variation (%)
Moisture*	83.09	83.51	0.56	0.0067
	83.29			
	84.14			
Ashes**	3.44	3.49	0.07	0.0200
	3.57			
	3.46			
Extractables**	19.50	19.75	1.64	0.0833
	18.24			
	21.50			
Hollocelulose**	30.36	30.56	3.99	0.1305
	26.67			
	34.64			
Cellulose**	50.33	54.90	4.08	0.0743
	58.17			
	56.22			
Hemicellulose**	49.67	45.09	4.08	0.0905
	41.83			
	43.78			
Total lignin**	21.61	26.40	4.30	0.1627
	29.91			
	27.69			

*Wet mass basis
**Dry mass basis

Determination of the percentage of moisture in the pineapple peel sample, in accordance with the NTC 287 standard, revealed that the fiber on a wet basis contains 83.51 % moisture on average. This value is close to that reported by Lobo & Paull *et al*. [28], which is 82.7 % moisture, which is very close considering that it is another type of pineapple variety. A high moisture content in pineapple peels indicates that the sample is composed mainly of water, which is characteristic of fresh organic materials. This high percentage of humidity can generate some challenges in subsequent processes, such as alterations during storage, since it favors the proliferation of microorganisms that could cause decomposition. However, moisture content can also be beneficial as it facilitates the extraction of soluble compounds, such as sugars, which can be used in subsequent analyses [29]. It is important to determine the moisture content before carrying out the other analyses, as this avoids possible problems due to changes during the chemical treatments necessary to quantify each component [27]. Pre-drying would have modified the apparent composition of the Perolera variety pineapple peels, altering the percentages of the components measured, mainly due to the elimination of moisture and, to a lesser extent, to possible losses of soluble or degradable compounds. This highlights the importance of performing the analyses directly on fresh peels to reflect their composition in their natural state [30].

Regarding the ash value obtained in the analysis of 3.49 % and contrasting it with the literature, it is a value quite close to the value determined by Owoeye *et al.* [31] of 3.78 %. The results were normalized without considering the ashes, which allowed an accurate assessment of the organic components without the ashes affecting the values of the subsequent analyses performed.

Regarding the percentage of extractables (19.75 %), a large proportion of these are present in the sample, and the determined value is above

that reported by Garay & Peña [17] (18.23 %); the extractables correspond mainly to proteins, vitamins, lipids, minerals, chlorophyll and secondary structural components of the material such as terpenes, resins, phenols and some low molecular weight carbohydrates that are extracted with the help of solvents.
For its part, the 30.56 % holocellulose contained in pineapple peel is close to the estimate mentioned by Sukruansuwan and Napathorn [32], of 36.8 %. Holocellulose is made up of cellulose and hemicellulose. The percentage of cellulose and hemicellulose.
As seen in Table 1, the average content of cellulose and hemicellulose is 54.90 and 45.09 %, respectively, these values are close to those reported by Garay & Peña [17], who obtained 65.89 % of cellulose and 34.11 % of hemicellulose, in pineapple peels of the MD2 variety. As indicated by these authors, the content of initial sugars such as cellulose and hemicellulose are present in a greater proportion, which indicates that it is useful for a microorganism with the ability to hydrolyze this type of sugars, to convert them into simpler sugars susceptible to being fermented. The average holocellulose content present in pineapple peels of the Perolera variety is 30.56 %. The total mass of holocellulose is composed of cellulose and hemicellulose, therefore, it follows that in 1 g of holocellulose, 0.549 g represents cellulose and 0.4509 g corresponds to hemicellulose, which is equivalent to 18.15 and 13.77 %, respectively, of the total holocellulose sample.
According to what was reported by Echeverría Narváez [33], there is no main method applicable for the quantitative determination of lignin in lignocellulosic materials. They point out that over the years numerous methods have been developed and modified to quantify the amount of lignin in plant tissues. The analysis was performed in triplicate on the extractable samples obtained previously.
The 26.40 % average total lignin found in the analyzes carried out for characterization is slightly lower than that reported by Morales Vázquez [9], who obtained 27.13 % lignin. As described by Garay & Peña [17], not all bonds are available to attract moisture, which contributes to pineapple peels presenting a structural support in the cell wall which gives rigidity and permeability to water, offering a degradation stability. On the other hand, Ramírez & Reyes [27] mention that a high amount of lignin is not favorable for the production of bioethanol, which is why they suggest carrying out delignification to carry out enzymatic hydrolysis and thus be able to obtain high conversion yields of complex substrates into simple sugars such as glucose.
According to the results obtained, pineapple peels of the Perolera variety represent a raw material with high potential for the production of bioethanol, thanks to its high content of cellulose and hemicellulose. In the municipality of Teorama, these residues have not been used and are often disposed of uncontrollably, generating environmental problems such as waste accumulation and pollution. The use of these peels could reduce these impacts, promoting the sustainable use of agricultural waste. In addition, it would encourage local job creation, strengthening the regional economy and promoting greater energy autonomy through the production of second-generation bioethanol. However, to implement this process on a large scale, challenges such as pretreatment costs and the improvement of collection and processing infrastructure would need to be overcome. This sustainable approach has the potential to transform an environmental problem into an economic and energy opportunity for the Catatumbo region.

Conclusions

The physical-chemical characterization of pineapple peels (*Ananas comosus*) of the Perolera variety was carried out, determining percentages of 83.51 % humidity, 3.49 % ash, 19.75 % extractables, 30.56 % holocellulose, 54.90 % cellulose, 45.09 % hemicellulose and 26.40 % total lignin. This high lignin content suggests the need for thermal pretreatments and delignification processes, such as ultrasound, to optimize the conversion into bioethanol. These findings support the potential of this residue for bioenergy applications, promoting a sustainable model that takes advantage of agricultural waste, generates local employment and fosters a circular economy. Future research is recommended to explore innovative pretreatment methods to improve cellulose extraction, study the viability of large-scale bioethanol production, and promote circular economy models that include local communities.
Based on the analyses carried out, the results obtained and the review of the literature, it is concluded that the pineapple peel (*Ananas comosus*) of the Perolera variety has great potential for the production of bioethanol. This

use is economically viable due to the abundant biomass available in the municipality of Teorama, which is currently not used or given added value. Its use would not only contribute to solving environmental problems derived from the inadequate management of this waste, but would also boost the local economy and promote a sustainable development model.

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