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Potentiality of Banana *(Musa Paradisiaca)* Pseudotallo for The Manufacturing of Biodegradable Polymers

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Abstract

The banana pseudostem, a part of the plant generally wasted after harvest, is revealed as a rich source of starch, a natural polysaccharide. This starch is a promising alternative for the creation of biodegradable polymers, as opposed to conventional polymers that rely on non-renewable resources derived from fossil fuels. The research focuses on analyzing the properties of starch extracted from banana pseudostems, highlighting its resistant starch content and its ability to generate gels and thicken liquids. These characteristics make it an ideal candidate for the production of polymers that can degrade efficiently in the environment, giving rise to products such as disposable cups, plates, bags and cutlery. These products not only represent an environmentally friendly alternative to single-use plastic products, but can also contribute to reducing the accumulation of conventional plastic in ecosystems. This research underscores the importance of sustainably harnessing natural resources to address problems related to plastic pollution and encourage more environmentally friendly practices in the polymer industry.

Keywords: *Banana, Biodegradable Polymers, Residue, Starch, Cellulose.*

1. Introduction

Currently, plastics are of great importance to humanity and its way of life; However, these represent a great source of pollution due to their composition and properties that have a very extensive degradation time of 100 years. On the other hand, the increase in solid waste, specifically plastics, has contributed to environmental pollution due to the fact that these materials are made from non-degradable polymer matrices (Espin, 2021) (Medina *et al.*, 2018).

In the banana industry, 85% corresponds to residues such as: pseudostems, leaves, rachis and peels, being necessary to find alternative uses for these wastes, in addition, it is estimated that from 1000 banana plants 20 to 25 Tn of pseudostems containing 5% starch are generated. (Garcia, 2017)

Currently, this waste generated from agricultural activity decomposes and adheres to the soil, repairing its properties, in addition, part of this waste is used in livestock as fertilizer, or is eliminated so that it does not interfere with agricultural work (Haro *et al.*, 2017). On the other hand, waste from Bananas are not disposed of adequately, they do not have an established final consumer, the lack of information on the capacity to use this plant matter in the region is great, there are no industries that transform this matter and allow the generation of biotechnological processes that give way to innovation and transformation of this organic matter. (Ibarra & Márquez, 2022)

Banana waste serves as a potential source for the production of valuable products, constitutes renewable resources, and provides additional income to agricultural industries (Gupta *et al.*, 2022). The banana pseudostem can be used to obtain chemical and biochemical products, due to its composition of 28.5 to 55% cellulose and 18 to 20% lignin, which gives additional value to this waste. In addition, e (Ibarra &

Márquez, 2022) Due to their characteristics, these wastes are used as raw material for the production of biodegradable polymers (Haro *et al.*, 2017).

The production and use of biodegradable polymers based on the banana pseudostem has a great ecological impact and is of great benefit for the reduction of pollution problems by petroleum-based plastics (Adeniyi *et al.*, 2020). In addition, They generate a new agro-industrial alternative in the region, increasing the economy and improving the quality of life of part of the population. (Cardenas, 2018)

Bioplastics are biodegradable and bio-based polymers, i.e. they can meet both requirements or only one of them, on the one hand, bio-based polymers or biopolymers are defined by IUPAC as macromolecular substances derived from plants, animals or microorganisms (Riba *et al*., 2020).

The artisanal process of making bio-based plastic from the banana pseudostem begins with the weighing of the raw material. Then, it is cut into small pieces that undergo a cleaning process with water. The cleaned pseudostem fragments are crushed and filtered before being dried in an oven. Subsequently, the binder is prepared, which is mixed with the dry fiber and spread evenly on a flat surface (Upegui *et al*, 2022).

The chemical process of bioplastic production begins with the processes of drying, crushing, and grinding the raw material. A basic hydrolysis is then carried out for the breakdown of the components, followed by an acid hydrolysis to dissolve the cellulose. Subsequently, a bleaching and drying process is carried out before the final acetylation is carried out, which culminates in obtaining the cellulose acetate fibers (Aguiar *et al*, 2020).

For all the reasons mentioned above, the objective of the research was to potentiate the banana pseudostem *(Musa paradisiaca)* for the production of biodegradable polymers.

Banana *(Musa paradisiaca)*

Bananas are part of the three products with the highest export volume, the taxes generated have registered positive balances in the trade balance, more than 30% of the world banana supply comes from Ecuador, a country highlighted as the main exporter in the world since the beginning of trade exchanges (León *et al.*, 2020).

Bananas (*Paradise Muse*) is grown in the tropical countries of the world, after harvesting 60% of the biomass is wasted, globally 114.08 million tons of waste are produced, which generates environmental problems such as excessive emission of greenhouse gases (Rise up *et al.*, 2021). Ecuador is considered a leader in the production and export of bananas globally, exporting 234.42 million boxes of bananas. (Asociación de Exportadores de Banano del Ecuador, 2022)

Banana agribusiness residues

From the banana plant, the bunches, pseudostems, leaves, rachis, peels of the fruit are released as residues, which are not used efficiently, causing contamination of soils, groundwater, proliferation of bacteria and diseases due to their open decomposition without any control (Haro *et al.*, 2017).

Agro-industrial banana waste is defined as biomass waste from agricultural activities and household waste, this biomass is mainly composed of carbohydrates such as cellulose, hemicellulose and starch, it can be processed in various ways through physical, thermochemical, chemical and biological processes, giving added value to these products such as food, biofuels and energy (Gómez *et al.*, 2021).

Board 1. *Characterization of lignocellulosic biomass*

Residue	Cellulose %	Lignin %	Hemicellulose %
Offshoot	31,26- 69	5- 18,6	18
Leaves	36,3	8,5	27,396
Rachis	30,6	9,85	15,7
Shell	56,55	12,68	29,39
Pseudopetiole	36,98	12,68	32,84

Fountain: Sanchez *et al.*, (2020)

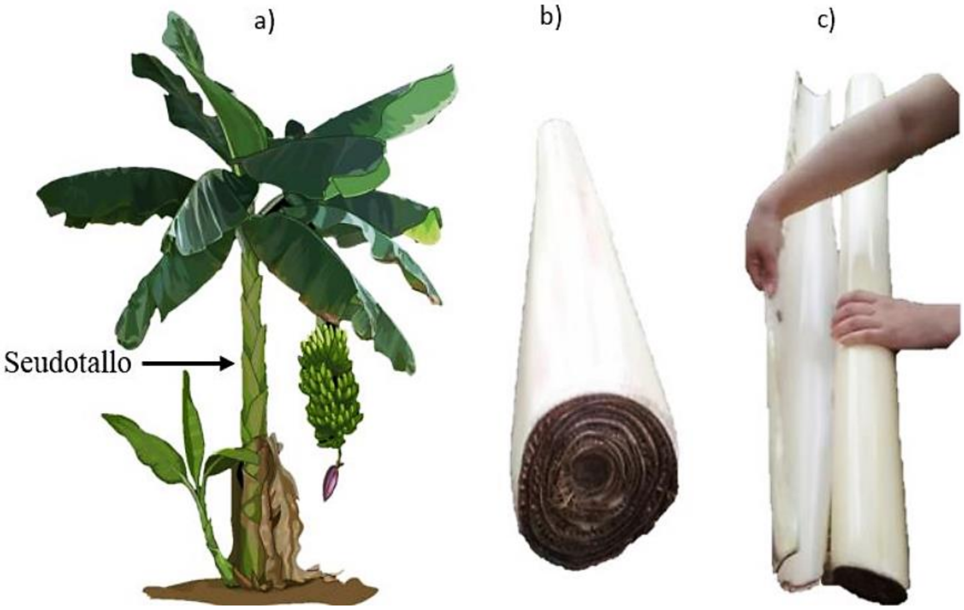
Pseudostem

It is an abundant residue resulting after harvesting the banana bunch (*Musa paradisiaca)* serves as a source of water, nutrients, and organic substances (Domingues *et al.*, 2020). The pseudostem and leaves account for more than 60% of the dry biomass produced in banana plantations, and the pseudostem shows significant amounts of saponins (Murgueitio *et al.*, 2019).

Banana pseudostem fiber is a lignocellulosic bast fiber composed of lignin, hemicellulose, and cellulose in various proportions, as well as minerals, wax, water-soluble compounds, and pectin, which serve as glue to hold the fiber in place (Adeniyi *et al.,* 2020).

Banana pseudostems are used as a raw material to make paper, furniture, and fodder in industrialized countries, in some regions such as India and Malaysia, the tender and fresh core of the banana pseudostem is cooked and consumed, in some studies it is claimed that the banana pseudostem is rich in minerals and nutrients, especially dietary fiber (Bravo *et al.,* 2022).

Figure 1. *Pseudostem*



Fountain: Huaman *et al.,* (2020)

Note: The graph shows the whole banana plant and the waste generated: **a.** Whole banana plant; **B and C.** pseudostem.

Pseudostem characterization

It is the main waste in banana production and this material is only used as fertilizer, since at an industrial level it has not had any use or application, the banana pseudostem is considered a soft wood, and is mainly made up of cellulose, hemicellulose, lignin and starch. (Jimenes, 2017)

On the other hand Ezeh & Agu (2022), studied banana pseudostem fibers and determined that these fibers are 60 to 65% cellulose, 6 to 19% hemicellulose, 5 to 10% lignin, 3 to 5% pectin, 1% ash, and 3 to 6% extractives.

However, compounds are not perfect, they have their disadvantages in terms of mechanical inconsistency, water absorption; therefore, poor compatibility with the resin. These deficiencies can be overcome by pre-treating the fibers with physical and chemical techniques that modify the surface, such as xylan and alkali treatments. (Barrera, 2022)

Board 2. *Chemical Composition of Banana Pseudostem*

Components	mg/100 g Dry Peel
Ash	28,3
Coal	38,3
Hydrogen	3,88
Sulfur	0,58
Lignin	5,2
Cellulose	35,3
Hemicellulose	24,9

Source: Alzate *et al.,* (2021)

Bioplastics

A bio-based plastic is a type of plastic that is made from renewable biological resources. These types of plastic are considered more environmentally friendly and sustainable, as they reduce dependence on fossil fuels and decrease greenhouse gas emissions during their manufacture. In addition, some of these bio-based plastics may also be biodegradable, meaning they break down more quickly compared to traditional plastics, reducing their impact on the environment. (Garzón & Gil, 2023)(Armingol, 2020)

Types of bioplastics

Bioplastics are plastics that are made from renewable resources, such as plants, algae, or microorganisms. Listed below are the types of bioplastics:

- Polyhydroxyalkanoates (PHAs): These bioplastics are generated by microorganisms using renewable carbon sources. They are biodegradable and compatible with living organisms, making them ideal for applications in the medical industry and packaging (Guancha *et al*, 2022).
- Polylactic acid (PLA): PLA is a bioplastic obtained from starch from corn, sugarcane, or other crops. It is biodegradable and is used in the manufacture of packaging, textiles and medical products. (Campana & Guerrero, 2018)
- Green polyethylene (PE): Green polyethylene is produced from ethanol derived from sugarcane. It has similar properties and applications to conventional polyethylene, but has a lower environmental impact due to its renewable origin (Pereira *et al*, 2020)

Starch

Starch is a natural polymer composed of glucose units, it is an amalgam of two similar polysaccharides: amylose, with a linear structure, and amylopectin, which has a branched structure (Upegui *et al*, 2022). It acts as the main nutrient reserve in plants and, in terms of abundance, is the second most common carbohydrate in nature after cellulose. Its water-retaining property allows it to form gels and thicken liquids.(Garzón & Gil, 2023)

The starch present in the native banana exhibits a high resistant starch content, ranging from 65% to 98%. In addition, the starch extracted from bananas contains a moisture content ranging from 6.83% to 14.00%, with an ash content that is in the range of 0.03% to 2.08% (Herlina *et al*, 2022).

Process of obtaining starch from the pseudostem

The process for obtaining starch from the pseudostem of the banana plant involves several stages, ranging from the extraction of the plant material to the obtaining of pure starch:

- Pseudostem extraction: The banana pseudostem is separated from the plant and cut into small pieces for easy processing [1].
    - Washing and defibering: The pseudostem pieces are washed to remove impurities and then undergo a defibering process, whereby the fibers are separated from the plant material.
    - Maceration: The shredded pieces undergo a maceration process, where they are immersed in hot water to soften the material and allow the release of starch.
    - Separation of solids and liquids: After maceration, the solids (pseudostem residues) are separated from the liquid (mixture of water and starch) by filtration or sedimentation.
    - Decanting and washing: The liquid containing the starch is allowed to sit to allow the starch particles to settle to the bottom of the container. The supernatant water and impurities are then removed by repeated washing.
    - Drying: The starch obtained is dried to remove moisture and obtain a powdered product. This can be achieved by air drying, vacuum drying, or spray drying techniques (Herlina *et al*, 2022).

Nomativa to obtain bioplastic

The regulations applied in the production of bioplastics may vary by country or region, however, there are certain widely recognized international regulations that establish the criteria for the biodegradability and compostability of these materials. Some of these standards include:

- EN 13432: This European regulation defines the requirements that compostable containers and packaging must meet in terms of biodegradability and disintegration. It establishes the criteria necessary for these materials to be able to be composted effectively under controlled industrial conditions.(Adapt , 2020)

- EN 14995: European standard, focuses on compostable plastics and sets the standards for biodegradability and disintegration in a home composting environment. Products that meet this standard are suitable for home composting.(Adapt , 2020)
- ISO 17088: At the international level, ISO 17088 provides guidelines for assessing the biodegradability and disintegration of plastics in soil. It defines test methods and acceptance criteria for biodegradable materials in terrestrial environments.(Ministerio de Ambiente - Remar, 2020)

It is important to note that these regulations focus exclusively on the biodegradability and compostability of bioplastics, without addressing other aspects such as toxicity or general environmental impact. In addition, it is important to note that each country or region may have its own additional regulations and standards

Enzymes & Food Additives

Banana stem residues have been valorized in the bioassisted production of enzymes such as laccase, different oxidases and also endoglucanases, in banana waste as a solid fermentation substrate, *Pleurotus ostreatus* and *P. sajor-caju* microorganisms were used to produce lignolytic and cellulolytic enzymes such as laccase, lignin peroxidase, xylanase, endo-1,4-β-D-glucanase (CMCase), and exo-1, 4-β-D-glucanase, which showed comparable levels of enzyme activities and production patterns (Anwar *et al.*, 2018).

Leaf biomass was found to be an appropriate substrate compared to pseudostems for enzyme production (Redondo *et al.*, 2020). Banana peel extracts have been studied as antioxidants in fresh orange juices and the free radical scavenging capacity has been found to be increased by adding banana peel extracts to juice formulations (Ortiz *et al.*, 2017).

Polymers in bananas

Starch is stored in plants as granules or solid particles consisting of two biopolymers, amylose and amylopectin, the granules can range in size from a few microns to 15 or more microns.(Garcia, 2017)

The starch that is obtained from agricultural and plant waste is used to produce biodegradable polymers and can be mixed with bioplastics, which produces a decomposition for the generation of useful organic fertilizer for the soil. It must be considered that the addition of this type of natural polymers in dosage with other synthetic polymers causes an increase in the degradability of the polymer matrix and that, in some cases, such as the combination of starch by 30% with low-density polyethylene, has caused the matrix to be considered as a partially biodegradable material (Rodríguez & Orrego, 2016) (Salcedo *et al.*, 2016).

Treatment of the raw material of the pseudostems

Obtaining starch from banana pseudo-stems

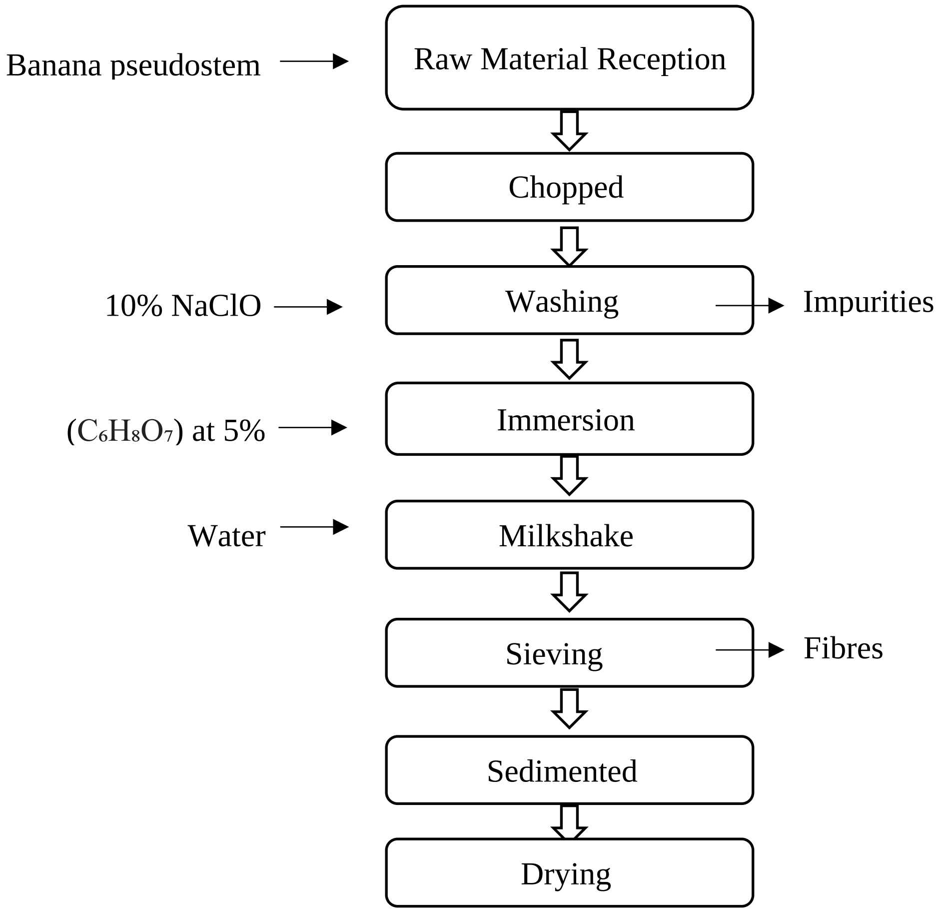
Jimenes (2017), describes the process of obtaining starch, where the banana pseudostem is crushed to obtain small pieces of 3 to 5 cm, then washed with 10% NaClO and left to rest in a solution $C_6H_8O_7$ at 5% for 4 h.

Figure 2. *Chopped banana pseudo-stem*

Fountain: Jimenes, (2017)

Subsequently, the soaked samples are liquefied for 5 min with a water ratio of 1:1, then they are sifted in a 355 µm sieve allowing the starch to pass through stopping the fibers, the acquired liquid is left to rest for 3 hours in ice, then it settles for 15 h. Finally, the sediment (starch) obtained is dried at room temperature.

Figure 3. *Flow Chart of Obtaining Starch from Pseudostem*



Technological processes of the extraction of natural polymers from bananas

There are currently different methods for the extraction of starch and cellulose, including chemical, physical, wet and enzymatic extraction. Having favorable returns in each of the cases

Board 3 *Polymer Extraction Methods*

Extraction Methods	Starch	Cellulose	Lignin	Reference
Chemical	Yes	Yes	Yes	(Canché *et al.*, 2005)
Physical	Yes	Yes	Yes	(Cobona & Antezana, 2007)
Moist	Yes	Yes	---	(Benavides, 2014)
Enzymatic	----	---	Yes	(Blanco, 2012)

Each of the extraction processes must be carried out in a specific way, in the case of chemical extraction the presence of solvents is necessary, which produces polluting residues, for physical extraction, machines such as presses or electric mills, sieves, among others, in wet extraction mainly water is used, equipment such as industrial blenders and presses, finally in the extraction via enzymatic way microorganisms are used microorganisms that produce specific enzymes for a certain treatment, it should be noted that only the waste that is generated and not handled properly is polluting.

Starch Extraction

Astudillo & Sanchez (2019), mention the existence of Two important methods for starch extraction: the dry method and the wet method, the dry extraction method allows 49.62% of the starch to be extracted from the banana pulp, while the wet method allows 56.76% to be extracted.

Gelatinization

Starch granules are insoluble in cold water, but they swell when heated in an aqueous medium, initially the swelling is reversible and the optical properties of the granule are not lost; however, when a certain temperature is reached, the swelling becomes irreversible affecting the structure of the granule (Agurto *et al.*, 2022). This process is known as gelatinization and occurs over a temperature range, as the granules have different resistance due to their composition and degree of crystallinity (Salgado *et al.*, 2019).

Retrodegradation

The development of the structure and crystallinity of starch gels in a short time is dominated by the gelation and crystallization of amylose, increases in the modulus of elasticity of the gels during storage are linked to the crystallization of amylopectin, increasing the rigidity of the granules and reinforcing the amylose matrix (Agurto *et al.*, 2022).

These processes are grouped under the term retrogradation and affect the texture, digestibility and consumer acceptance of starch-based products (Villaroel *et al.*, 2018).

Application of biopolymers

Biopolymers can be used and classified in a variety of applications, including drug release, bioremediation, food packaging, and enzymatic catalysis. (Bernadette & Flórez, 2020)

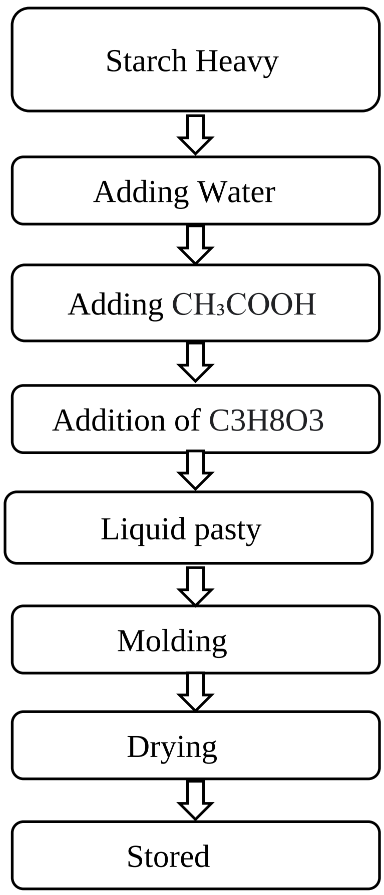
Characteristics of products from biopolymers

Biodegradable polymers have the property of degrading through the enzymatic action of microorganisms such as bacteria, fungi and algae, mainly producing CO2, CH4, water, biomass and other substances that are not harmful to the environment, being extracted from nature, such as cellulose, starch and proteins (Rodríguez *et al.*, 2021).

Process of making biodegradable material

Garcia (2017), describes the process of making biodegradable polymers: **a. Heavy starch** (5 g of banana pseudostem starch is weighed); **B. Adding Water** (55 mL of water is added); **C. Addition of acetic acid** (CH_3COOH); **D. Addition of glycerol** (then the temperature is raised to 55 °C and C3H8O3 is added in order to give elasticity to the product); **E. Liquid pasty** (finally, it is raised to 75 °C until it acquires a pasty-liquid consistency); **f. Molding** (They are placed in a glass mold and brought to a stove at 69 °C for 24 h); **g. Stored.**

Figure 4. *Flow Chart of Biodegradable Material Processing*



Biopolymers based on banana pseudostem (*Musa paradisiaca)*

The banana pseudostem (*Musa paradisiaca)* is one of the strongest natural fibers in the world, it is a biodegradable material, composed mainly of cellulose, hemicelluloses and lignin and its rotation capacity, fineness and tensile strength are analyzed factors that determine the quality of the fibers obtained (Aguiar *et al.*, 2020).

Board 4.

Physicochemical properties of banana residue

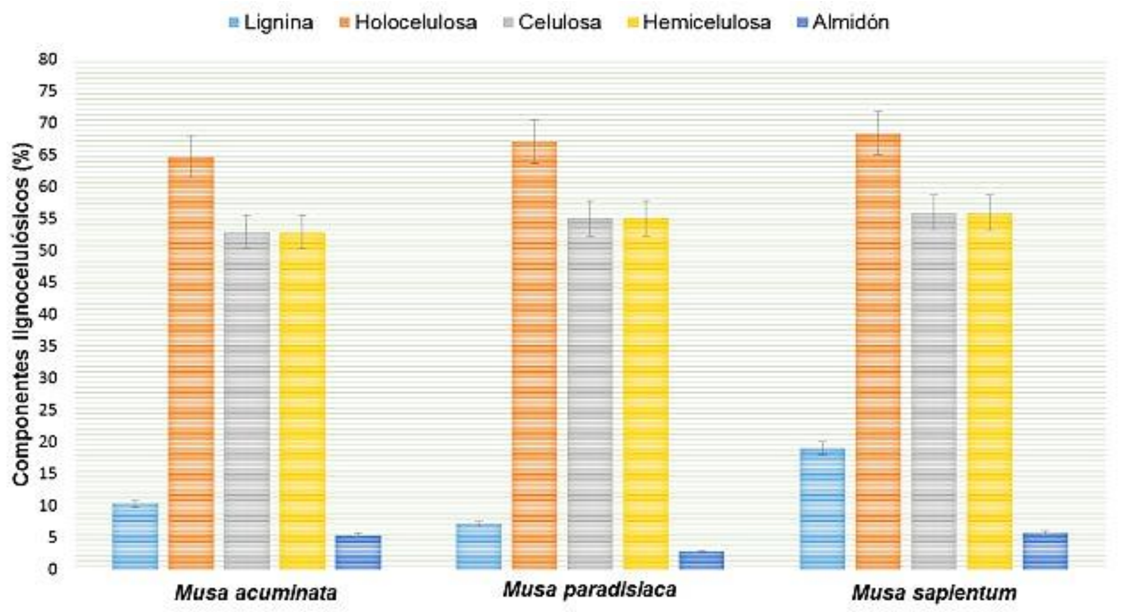
Waste	Ash	Humidity	pH	Density	Thickness
Rachis	6 %	11 %	8,74 %	10132.325 g/m3	0.1375 mm
Shell	1 %	11,60 %	7,84 %	19753.086 g/m3	0.0416 mm
Pseudostem	2 %	11,60 %	8,12 %	13610.586 g/m3	0.145 mm

Fountain: Calero *et al.*, (2020)

In the study conducted by Calero *et al.*, (2020), determined that the biodegradable pseudostem containers acquired a thickness of 0.041 mm thick, which they concluded that the product is the optimal result of biodegradable packaging.

The figure shows the content of lignin, cellulose, hemicellulose, starch of the banana pseudostem, where the following percentages are detailed.

Figure 5. *Lignocellulosic and starch components present in banana pseudostem*



Fountain: Jimenes, (2017)

The figure shows a high percentage of cellulose with 52.69%, lignin with 17.61%, hemicellulose with 52.69%, starch with 5.38%. Gogoi *et al.*, (2014), reported in their research the following results in banana pseudostem, cellulose 55.06%, hemicellulose 2.66%, starch 2.89%.

According to Delgado & Vidal (2021), reveals the physical properties of a biodegradable banana pseudostem starch plastic:

Humidity: Rosales, mentions that the maximum percentage of moisture that a bioplastic must have is 22%, this prevents the possible growth of fungi and yeasts which can deteriorate the product, the research carried out by (2016)Garcia (2017), found a moisture content of 9.36% in the biodegradable polymer acquired from banana pseudostems.

Thickness: The NTE INEN 2542 standard establishes the requirements that plastic sheets must meet, which must be 0.2 mm thick.

Tensile Strength: Camarillo conducted a study of tensile strength in the biodegradable polymer, where it was 21.19 N, when compared to a common plastic the tensile strength is 48.26 N.(2023)

Biodegradability: Different authors state that the biodegradable polymer degrades up to 75% in 30 days, depending on the percentage of glycerin and oily acid used in the production (Mesa, 2016).

This waste is used to manufacture eco-friendly products, such as disposable cups and plates, offering a sustainable alternative to single-use plastics. These products stand out for their rapid biodegradability, which is completed in less than a year (Haro et al., 2017).

In addition, bags are produced with a significantly shorter degradation time than conventional bags. These bags vary in size, ranging from 14 to 45 cm in length and 8 to 23 cm in width, with a load capacity of up to 4 kg. This approach seeks to provide benefits to both the environment and society by offering useful and eco-friendly products that contribute to reducing pollution problems associated with the use of plastics (Upegui et al., 2022).

Finally, disposable cutlery is produced in an attractive matte black shade, made from a biopolymer extracted from the cellulose of the banana pseudostem, a by-product of harvesting. These products are biodegradable and their use helps prevent the accumulation of traditional plastic in ecosystems (Villamar et al., 2020)."

4. Conclusion

The proper use of the residues of the banana pseudo-stems avoids the contamination and proliferation of bacteria that affect the rest of the plantations, leaving irreparable damage to them. Bioplastics made from banana pseudostem starch present an alternative to replace synthetic plastics.

In this study, the use of residues from banana pseudo-stems is documented, as we currently know the great problem is the excessive generation of waste that, when not properly managed, ends up disposed of in open dumps, in ravines, causing environmental problems such as soil and water contamination, as well as problems of harmful fauna that are the cause of diseases that affect public health.

After the proper processing of banana waste, it is concluded that biodegradable polymers can be offered to the Ecuadorian market to replace synthetic ones, since production costs are lower because they are produced by abundant vegetable waste in the country, and in this way be able to contribute to the care of the environment and local and sustainable development of the country.

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