9th North American Conference on Industrial Engineering and Operations Management
Washington D.C., USA, June 4-6, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/NA09.20240169
Published: June 4, 2024

Use of the Sugar Cane Bagasse (Saccharum Officinarum) for the Preparation of Biodegradable Food Packages

Gonzalo Dennys Ramos Olortegui and Renzo Martin Barinotto Valencia
University Of Lima
Lima, Peru
20161202@aloe.ulima.edu.pe, 20161813@aloe.ulima.edu.pe

Abstract

Nowadays, sugarcane bagasse is obtained as waste from the sugar industry where it is commonly discarded or burned. Nevertheless, this byproduct contains properties that can be used in the packaging industry. The purpose of this scientific article is to analyze the attributes of small films based on sugarcane bagasse to determine their suitability so that with this data they can produce biodegradable packaging. The most notable results of the tests carried out were the Shore hardness level of 85% of dose 1 and a resistance to elongation of 31.58% of dose 2. With this, added value will be achieved to the sugarcane bagasse since use as raw material in the manufacture of products that provide good to the community. The work carried out has a quantitative approach, descriptive method, and techniques such as observation, documentary analysis and analysis of processes and activities were used.

Keywords

Biopolymers, Agro-industrial wastes, Biodegradable food containers, sugarcane bagasse, Active packaging.

1. Introduction

Currently, millions of tons of plastics are manufactured each year worldwide and both production and consumption are increasing massively (Gupta et al. 2020). Although packaging is essential to preserve the quality and freshness of food, as well as to extend its shelf life, the increase in the production and consumption of conventional food packaging has contributed to an increase in the generation of non-organic packaging waste (Andrade et al. 2022). The rapidly increasing production of plastic, resulting in escalating plastic waste, is surpassing the capabilities of environmental waste management and the capacity of available landfills, thereby exacerbating climate change, which has had negative impacts on the environment and the organisms that inhabit it (Khoaele et al. 2023). It should be noted that there is a considerable demand for food packaging in various industrial areas(El-Sakhawy et al. 2023), but at the same time these conventional plastic containers have certain limitations, the main disadvantage being their long shelf life. Although a small fraction of these materials is recycled (21%), a large proportion (79%) ends up being discarded, causing damage to the environment (Panou and Karabagias 2023). Microplastics have been detected in food worldwide, making human exposure to these contaminants through food unavoidable and potentially posing health risks(Affrald 2024). According to a report, it is estimated that approximately 5 billion pieces of plastic are drifting in the oceans of various nations, from the Arctic to the Antarctic. Given the environmental devastation generated by these plastic materials, sustainable solutions are required as possible alternatives (Yaradoddi et al. 2021).

Expanded polystyrene is one of the most harmful but useful plastics for the manufacture of single-use containers. It is known that it is not a biodegradable material and according to the World Health Organization it has elements that are toxic to human health, such as Bisphenol A, styrene and phthalates, which when in contact with beverages or food at high temperatures have the possibility of being released, causing serious consequences such as reduced fertility, cancer and changes in the central nervous system (Morales et al. 2020). The International Agency for Cancer Research (IARC) determines based on evaluations that styrene monomer is probably carcinogenic (Group 2A). In addition, for this evidence, we worked with high doses in occupational exposure of people and animals by inhalation; the concentration of styrene that has been found in a wide range of foods and beverages gives the following figures:2.6 μg/kg to 163 μg/kg. These numbers depend largely on factors such as temperature, fat concentration, and storage duration (Halim et al. 2024). Any material that can be transferred to food is categorized as an indirect food additive and is subject to legal regulations. According to information provided by the Swedish government in the 2012 "The State of Food and Agriculture Worldwide" report, it was established that bisphenol A will be banned in food packaging intended for children under three years of age from 2013 (Hossam and Fahim 2023). Also; "this packaging material can persist in the environment for long periods of time and can form microplastics or nano plastics"(Sani et al. 2021).

Agricultural waste management has been a major environmental concern, as its negative impact on the environment is considerable when incineration or landfilling is chosen. These circumstances have prompted advances in the food packaging industry, where renewable resources, specifically agri-food waste, and by-products, are explored as more sustainable alternatives (Cristofoli et al. 2023). Therefore, to improve food safety and reduce food waste, packaging materials must be used that have sufficient strength to protect and maintain the product from production until it reaches the final consumers. A relevant alternative is the use of environmentally friendly active packaging whose main function is to control the quality of the product and its sensory characteristics by managing to change its environmental conditions having a positive impact on the environment (Bof et al. 2021). Active packaging with antimicrobial properties can stop the growth of bacteria and extend the shelf life of food products that have been packaged (Srivastava et al. 2024). Furthermore, "The use of biopolymers in these containers proves to be advantageous because they are more biodegradable, sustainable and environmentally friendly than synthetic polymers. Biopolymer-based films can be easily degraded by microorganisms" (Dai et al. 2021). In addition, edible packaging is defined as thin layers of coating or material, this type of packaging is increasingly used today in foods that can be consumed without compromising human health. These containers, functioning as primary packaging, can monitor the water activity of a food and regulate mass transfer in processed foods (Ribeiro et al. 2024).

This research seeks to implement a new alternative raw material to produce packaging and among the agro-industrial wastes that can help, it is feasible to use sugarcane bagasse, since it is one of the main materials used in the manufacture of biodegradable polymers. "This type of waste is mostly obtained from the sugar industry and has numerous advantages over other residues of agricultural origin making it one of the preferred feedstocks for biorefining" (Dai et al. 2021). Sugarcane bagasse is mainly composed of water and bagasse fiber, which is characterized by its stiffness and frequently used in the derivatives industry. "Sugarcane bagasse contains high levels of phenolic compounds and is cytotoxic to cancer lines inhibiting their cell growth" (Prakash et al. 2021). Finally, bagasse pulp has several advantages compared to conventional plastic containers. For example, they are more environmentally friendly as they are made from renewable resources and can be composted after use. In addition, they are safer for human health as they lack harmful chemicals that can leach into food (Hossam and Fahim 2023).

Nanocellulose (NC), derived from sugarcane bagasse, has gained recognition for its growing application in various areas such as food, healthcare, cosmetics, among others. Its remarkable biodegradability and biological origin make it a valuable material for the manufacture of innovative bioplastics, particularly used in the production of food packaging (Madhavan et al. 2023). "This component has engendered an attractive role as a source of biodegradable plastics by replacing polyethylene due to its abundance, sustainability, great aspect ratio, high tensile strength, stiffness, flexibility, good dynamic mechanical properties" (Reshmy et al. 2021). There are two kinds of nanocellulose: bacterial and plant derived. "Bacterial nanocellulose is a linear, unbranched exopolysaccharide synthesized by some bacteria, consisting solely of β-D-glucopyranose units linked by β-1,4-glycosidic bonds" (Ludwicka et al. 2020). On the other hand, plant nanocellulose is a nanometer-sized component found in plants such as sugarcane and is produced from cellulosic origins by chemical, physical or biological methods such as homogenization and hydrolysis processes (Lu et al. 2020). Peru is a country that produces a large amount of sugar worldwide because there are several lands dedicated to planting and harvesting sugar cane, especially in the north of the country. For this reason, all this waste should be used to manufacture useful products that give an added value helping the environment and the health of the person.

1.1 Objectives

To analyze the attributes of biodegradable films based on sugarcane bagasse in order to propose a prototype design of an ecological packaging for food based on sugar cane bagasse and additives, analyzing its effects on food attributes in comparison with polyethylene (HDPE) packaging, give value to agro-industrial waste such as sugar cane bagasse from the sugar industry, which can be used for different purposes, encourage the use of eco-friendly products and support to reduce the use of packaging and products in general that are not biodegradable and generate a negative impact on the environment and identify the advantages of using biodegradable sugarcane bagasse-based packaging over the conventional packaging used in most food delivery establishments.

2. Literature Review

For our literature review, Panou and Karabagias (2023)argues that biodegradable packaging offers a sustainable solution to the environmental problem of conventional materials and has the potential to reduce costs, improve food preservation and satisfy the preferences of consumers and the food industry. In turn, thanks to the study by Yang et al. (2020), we learned that bio-based nanomaterials, specifically CNF/nisin hybrid nano films developed from sugarcane bagasse nanocellulose and nisin, have antimicrobial properties that make them promise for replacing petroleum-based packaging in preservation food. Hossam and Fahim (2023) notes that the use of bagasse pulp is a promising alternative to produce biodegradable dishes, offering a sustainable solution to the problem of plastic pollution and promoting environmentally responsible practices in sectors such as food packaging and single-use tableware. Frommeyer et al. (2024) highlights in its study the importance of the need to promote the use of ecological packaging in online retail to mitigate its negative environmental impact. Motaleb et al. (2023) indicates that the potential of plant waste to produce composites reinforced with natural fibers, offering a sustainable alternative to environmentally harmful synthetic materials.

Furthermore, the central purpose of the work was to create a valuable product that was biodegradable and suitable for environmentally friendly packaging. Carboxymethyl cellulose (CMC) obtained from agricultural waste was chosen to reduce the production costs of the films, since commercial CMC is expensive. The evaluation of the physical and chemical properties of the developed films confirmed their usefulness for packaging, their biodegradation capacity, and their harmony with the environmental environment (Yaradoddi et al. 2020). In turn, El-Sakhawy et al. (2023) emphasizes the development of biodegradable packaging using carboxymethylcellulose (CMC) derived from sugarcane bagasse and extracts from mandarin and melon peels, which show outstanding antimicrobial properties against Gram-positive, Gram-negative bacteria and pathogenic yeasts, representing a sustainable solution for food packaging. For their part, Patil et al. (2023) underlines the importance of research into a biodegradable composite from cellulose and natural resins, which shows favorable mechanical properties and significant degradation under soil conditions, suggesting its potential as a rigid packaging material with low environmental impact. Finally, Madhavan et al. (2023) highlights the development of biodegradable packaging using nanocellulose, derived from curry leaves and sugarcane bagasse, with antibacterial and biocompatible properties, offering a sustainable and safe alternative for food packaging.

3. Methods

For this study, biodegradable films based on sugarcane bagasse were produced. The samples with their respective doses were elaborated at “Laboratorio Sistema de Servicios y Análisis Químicos S.A.C. SLAB” for a period of 15 days. The bagasse pulp, the fundamental raw material for the process, was obtained from a local market in Lima. Also, the process included 3 key steps covering pretreatment, extraction of the fiber from the bagasse and the elaboration of the films, following each of these steps 6 samples were manufactured (2 doses per sample) shown in Figure N°4 and the dimensions for the doses are in 25 x 30 cm.

Materials and Machinery:

Sugarcane Bagasse

It is the solid lignocellulosic residue left after the extraction of sugarcane juice. It was collected from the local supplier of sugar cane juice in the city of Lima, Peru. The amount used was 0.75 g for dose 1, 1.5 g for dose 2 and 2 g for dose 3.

Sodium Hydroxide (NaOH)

Caustic soda, which is sodium hydroxide, is used in the creation of biodegradable films due to its chemical properties and its ability to regulate the pH in the solutions used during the process. In summary, sodium hydroxide plays a crucial role in the manufacture of biodegradable films by simplifying material handling, regulating pH and promoting the chemical reactions essential to achieve a high-level end product.

Distilled water

Distilled water functions as a solvent that allows the mixing and dissolution of the ingredients used. In addition, its action as a diluent helps to control the viscosity of the solutions during manufacturing, thus facilitating the homogenization of the components and ensuring an even distribution of materials. On the other hand, it can help to neutralize the pH.

Compound solution (vinegar + NaCl)

It is primarily used as a treatment solution for the purpose of sugarcane bagasse fiber extraction.

Glycerol

Glycerol, when used as a plasticizer in biodegradable films, gives them flexibility and malleability, which is essential for them to conform to different shapes and surfaces, thus improving their versatility in different uses. The essential role of glycerol in the manufacture of biodegradable films lies in improving their mechanical characteristics, increasing their flexibility and resistance, regulating humidity, and enhancing their decomposition in the environment.

Sorbitol

Sorbitol acts as a plasticizer that can absorb moisture from the environment. This can be beneficial in some applications where moisture control is required in films.

Methodology by test

Once the films have been elaborated, several tests are carried out on them, which will help to see in which attributes they can excel over the others and thus be able to conclude which dose used is the most adequate to elaborate eco-friendly packaging for foodstuffs. Each test was carried out in a scientific laboratory which were given under various systems of standards such as ASTM, NTP and ISO to ensure the quality of the tests performed on each film. It should be noted that each test used a different method for biodegradability, physical and water absorption tests.

Tensile Strength and Elongation

The standard test method for tensile properties of plastics ASTM D638 was used; it consists of describing the procedures for performing uniaxial tensile tests on samples of plastic materials, where a tensile force is applied gradually until the sample breaks. During the test, data such as the maximum force applied, the elongation or deformation of the specimen, and other parameters that allow determining the tensile strength are recorded.

Determination of Shore Hardness

This test was performed under the standards of NTP 311.253:1982 Plastics: Determination of hardness. Shore method. 1st Edition which measures the resistance to penetration of an indenter on the surface of the samples to be able to analyze the durability of the bioplastic material.

Determination of water absorption

ASTM D570 standard for the determination of water absorption in plastic materials was used for the determination of water absorption. The method consists of exposing the films to a certain temperature and humidity as indicated in the standard for a certain period and analyzing the change in mass with respect to the initial mass.

Biodegradability Analysis

To know if the films are biodegradable, they were subjected to several tests to determine the degree of degradation, potential biodegradability, and impact on the environment. Three tests were performed to evaluate the above-mentioned characteristics:

Infrared Spectroscopy Characterization Test (FTIR-ATR).

This test will help to evaluate the molecular structure and the degree of degradation of each sample under ASTM E1252-98 (2021). Item 9. Standard practice for general techniques for obtaining infrared spectra for qualitative FTIR ATR analysis the following equipment was used to carry out this test:
- Infrared Spectrophotometer
- Test Range: Wavenumber Range 380 cm-1 to 4000 cm-1
- Reference Method: ASTM E1252 Standard practice for general techniques for obtaining infrared spectra for qualitative FTIR analysis.

Volatile Solids Test

The volatile solids test helps, through the amount of volatile material in the sample, to indicate the potential biodegradability. It consists of heating the sample to a specific temperature according to ISO 3451-1: 2019

Determination of volatile solids to remove the volatile components and to be able to measure the mass of residual solids.

Determination of Metal Content:
This test consists of measuring the content of various metals in the sample which can affect biodegradability and their toxicity in the environment. The Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES) method was used for this analysis.

Experimental Procedure for Bioplastic Elaboration:

Sugarcane bagasse pretreatment
In this brief stage, the bagasse (2 kg) is taken to the drying area to eliminate the humidity and after that it is pulverized until obtaining fine fibers of sugar cane bagasse where 100 grams were extracted for the elaboration of 6 films of measures 25 cm x 30 cm.

Fiber extraction from sugarcane bagasse
1. First, 100 g of fine bagasse powder was treated with 1000 mL of 1M NaOH solution for one hour with constant stirring at room temperature. Subsequently, the treated bagasse solution was washed and filtered using distilled water until a neutral pH was obtained.
2. The extracted fiber was dried in the oven at 50 °C for 24 h.
3. Then, 100 g of the dried fiber was bleached by stirring with an 800 mL solution containing 4 mL of vinegar and 12 g of NaCl on the hot plate for two hours at 70 °C.
4. The procedure continued with filtration and washing of the resulting product using distilled water to neutralize the pH.
5. The bleached fiber was dried in the oven at 50 °C for 24 h. The bleaching treatment was performed to remove lignin.
6. This bleaching process allowed the fibers to be less susceptible to UV rays and humidity, which was considered a factor for the degradation process.
7. The dried and bleached fibers were saved for later use after the milling and sieving procedures.

Production of bioplastics (03 Doses)
1. They were prepared with a mass of Cane Bagasse powder, 1 ml of glycerol, 40 mL of distilled water and 0.5 g of sorbitol.
2. All ingredients were mixed in a 250 mL beaker and stirred on the hot plate for 30 minutes until the water evaporated and the solution began to become sticky.
3. The mixture was then poured and spread on a glass plate to produce a plastic based on Cane Bagasse Fiber.
4. This bioclastic film was dried in an oven for two hours at 50 °C and then remained at room temperature for approximately three days until reaching constant weight. This bioplastic film is labeled as Dose #1 sample. 5.
5. For the doses, the weight of sugarcane bagasse fiber was taken as follows: Dose N°1 (0.75 g), Dose N°2 (1.50 g) and Dose N°3 (2.00 g).

4. Data Collection

Regarding the collection of the most important data, it was taken from the tests that were carried out on the biodegradable films to determine if the characteristics analyzed are viable for the manufacture of containers. With respect to tensile strength, 1.94 Mpa, 1.77 Mpa and 1.37 Mpa were determined for doses 1, 2 and 3 respectively. The elongation resistance data were 31.22% for dose 1, 31.58% for dose 2 and 27.74% for dose 3. In addition, another attribute analyzed was 85%, 78.5% and 72.5% in the shore hardness category. In water absorption, 45.5%, 44.3% and 41.2% were obtained respectively. Finally, in the biodegradability test we were able to determine through the 3 different tests carried out that it is eco-friendly since the values that were obtained are within the theoretical ranges, whether for the tests of volatile solids, heavy metals and functional groups.

5. Results and Discussion

5.1. Numerical Results

Once the bioplastic films of each dose (1, 2 and 3) were prepared, the tests were carried out, which will allow us to identify which of the doses has the best physical and biodegradable characteristics. The methodology used was the following according to the trial to be analyzed:

5.1.1. Tensile strength and elongation

The results obtained from the tensile strength and elongation test using the ASTM D638 standard help determine how much force can be applied to the bioplastic material before it stretches irreparably and/or breaks. As can be seen in the tables and graphs of this test, there is a dose that on average had better results, which is dose 1 that presents the least amount of fine bagasse with an average tensile strength of 1,937 Mpa and a resistance to average elongation of 31.22%, followed by doses 2 and 3 respectively, so there is a tendency to see better results when the dose has a greater amount of additives in its formulation for this type of physical-mechanical tests in bioplastics. Therefore, it can be interpreted that reducing the amount of natural input in a biomaterial helps to improve both tensile strength and elongation because there is a greater presence of additives in the mixture that allow the bioplastic to have a more widespread distribution. uniform load and that can deform uniformly before reaching its breaking point.

The average tensile strength and elongation strength obtained were 1.68 Mpa and 30% respectively; considering that a biodegradable film is being analyzed to use that same composition for food packaging, the calculated tensile strength could be adequate due to the nature of the base material since sugarcane bagasse has limited mechanical properties compared to other materials. Therefore, coming from that raw material the calculated tensile strength and elongation are reasonable for this bioplastic. Yang et al. (2020) found that the tensile strength and elongation of their samples are hovering around 45.79 Mpa and 6.53%. We can see that in our research it has a higher percentage of elongation which indicates that the material can stretch more before breaking; however, our tensile strength is low making it not withstand higher tensile forces before yielding or breaking (Table 1-Table 3).

Table 1. Tensile strength results

Laboratory Code	Parameter	Unit	Test Tube Number	Results	Average
Sample N°1	Tensile strength	Mpa	1	1.921	1.937
			2	1.984	
			3	1.908	
			4	1.944	
			5	1.928	
Sample N°2	Tensile strength	Mpa	1	1.782	1.759
			2	1.797	
			3	1.718	
			4	1.794	
			5	1.704	
Sample N°3	Tensile strength	Mpa	1	1.341	1.370
			2	1.384	
			3	1.372	
			4	1.367	
			5	1.385	

Table 2. Elongation resistance results

Laboratory Code	Parameter	Unit	Test Tube Number	Results	Average
Sample N°1	Elongation resistance	%	1	30.8	31.22
			2	32.5	
			3	31.2	
			4	30.1	
			5	31.5	
Sample N°2	Elongation resistance	%	1	30.5	31.58
			2	32.6	
			3	31.8	
			4	32.5	
			5	30.5	
Sample N°3	Elongation resistance	%	1	28.5	27.74
			2	28.9	
			3	24.9	
			4	27.5	
			5	28.9	

5.1.2. Determination of Shore Hardness

During the Shore Hardness analysis of the films, it is observed that there is a continuous decrease in hardness as the amount of sugarcane bagasse increases. Dose 1, with 0.75 grams of bagasse, recorded a hardness of 85 HA, followed by the second dose with 1.5 grams of bagasse and a hardness of 78.5 HA, and finally the third dose with 2 grams of bagasse and a hardness of 72.5 HA. The findings argue that this happens due to the high flexibility since, since bagasse is a fibrous material, it can imply a lower resistance to penetration and therefore it will have a lower shore hardness. Another feasible reason is that bagasse can introduce porosity to the films, which reduces their density and compaction, key factors for hardness.

After the Shore hardness test, the average data obtained was 78.6 HA, which is considered adequate in the packaging category, which means that our samples have an optimum resistance to deformation under compression and pressure loads. Therefore, when making an eco-friendly food packaging from sugarcane bagasse, a rigid material product would be obtained. It was dose 1 that obtained the best result in the shore test, this may be since it is the dose that contains the least amount of bagasse in the mixture and therefore the greater the presence of additives, the better hardness properties were obtained (Table 3).

Table 3. Hardness Shore Results

Laboratory Code	Parameter	Unit	LCM	Results (*)
Sample 1	Hardness Shore	HA	0.01	85.00
Sample 2		HA	0.01	78.50
Sample 3		HA	0.01	72.50

5.1.3. Determination of Water Absorption

In the water absorption test, it was determined that dose 1 had 45.5%, followed by dose 2 with 44.3% and finally dose 3 with 41.2%. For the 3 doses there is a very high rate of water absorption during its measurement in the bioplastics. This high % is interpreted negatively since it can impact the integrity of the container, weakening its structure and causing losses of strength and rigidity, deformities, and possible breakages. Excess water absorption also means that the food to be stored is affected to such an extent that an environment conducive to the growth of bacteria is created. To counteract the high %, it is recommended to add waterproofing and/or moisture-absorbing additives that help reduce humidity without affecting the other properties of the bioplastic. For example, polylactic acid (PLA) or Carnauba Wax (natural wax).

The results obtained in the test to determine water absorption using ASTM D570 indicate that the 3 doses analyzed show a high % absorption and therefore would imply that in case the food container meets a liquid, the structure of the container and also the contents could be affected. In view of this dilemma, it can be considered as an opportunity for improvement to reanalyze the composition of the doses to add or replace a new additive that helps to reduce the high absorption % that is being presented in the current doses without affecting the other characteristics such as hardness, resistance and biodegradability. Motaleb et al. (2023) tell us that the chemical product WR (water repellent) was applied to the surface of the reinforcing nonwovens forming a thin coating that prevents water from penetrating inside the fiber. Therefore, the overall hydrophobicity of the composites was significantly improved (Table 4).

Table 4. Results of Absorption Water

Laboratory Code	Parameter	Unidad	LCM	Results (*)
Sample 1	Water Absorption	%	0.01	45.50
Sample 2		%	0.01	44.30
Sample 3		%	0.01	41.20

Note (*) Average of the 4 results.

5.1.4. Results of Biodegradable Analysis

By means of the FTIR characterization test of the 3 samples, characteristic peaks of OH, CH, CC, COC were identified, indicative of the presence of cellulose in the material. According to Table 1 of Annex III of Supreme Decree No. 025-2021-PRODUCE, the sample is classified as biodegradable. In addition, the results of volatile solids indicate that the evaluated sample complies with the requirement established for the content of volatile solids, as specified in point 5.1.1 of the Characterization (NTP 900.080 - 2015) of Chapter II of the same Supreme Decree. Likewise, the results of heavy metals and other substances show that the evaluated sample complies with the requirement established in Table 2, referring to the concentration of metals and other substances, as established in point 5.1.1 of the Characterization (NTP 900.080 - 2015) of Chapter II of Supreme Decree No. 025-2021-PRODUCE. Since these tests allow determining if the bioplastic film is biodegradable, only 2 results can be obtained: Yes or No, and as can be seen in the 3 doses, all of them comply with the requirements to be considered biodegradable materials according to Supreme Decree N° 025-2021-PRODUCE.

Three tests were carried out on the doses in which their composition was analyzed to determine whether the sugarcane bagasse-based compound is biodegradable, which resulted in the 3 doses being identified as a class of material called Biodegradable, therefore this characteristic would be an added value in comparison with the common containers that are being used in various restaurants to minimize costs, which, by not being able to degrade over time, would be contaminating the environment. Although it is true that these tests do not determine how long it will take for the material to decompose, they can assure us that the analyzed doses present a composition of materials with the capacity to degrade, therefore we would be talking about the fact that the inputs used, together with the sugarcane bagasse, can form an eco-friendly product (Table 5- Table 13).

Table 5. Identification Of Functional Groups Sample N°1

Vibration Type	Functional group	Theoretical Range (CM-1)	Experimental Result (CM-1)
Tension Vibration Band	"-O-H "	3400-3200	3317
Tension Vibration Band	"-C-H "	2990-2800	2874
Tension Vibration Band	"-O-H, C=C "	1640-1400	1603
Tension Vibration Band	"-C-O-C"	1200-980	1026
Tension Vibration Band	"-C-H "	900-800	891

Table 6. Results Of Volatile Solids Sample N°1

Laboratory Code	**Parameter**	**Unit**	**Minimum Limit 900,080-2015 DS N°025-2021-PRODUCE**	**Results**
SAMPLE N°1	Volatile Solids	%	50	90.58

Table 7. Results For Heavy Metals and Other Substances Sample 1

Laboratory Code	**Parameter**	**Unit**	**LCM**	**Minimum Limit 900,080-2015 DS N°025-2021-PRODUCE**	**Results**
SAMPLE N°1	Arsenic, As	mg/kg	2.67	5	<2.67
	Cadmium, Cd	mg/kg	0.33	0.5	<0.33
	Chromium, Cr	mg/kg	1.33	50	<1.34
	Copper, Cu	mg/kg	1.00	50	4.15
	Mercury, Hg	mg/kg	0.50	0.5	<0.50
	Molybdenum, Mo	mg/kg	1.00	1	<1.33
	Nickel, Ni	mg/kg	1.67	25	1.78
	Lead, Pb	mg/kg	3.33	50	6.44
	Selenium, Se	mg/kg	0.50	0.75	<6.67
	Zinc, Zn	mg/kg	0.67	150	15.75
	Fluorine, F	mg/kg	0.10	100	<0.10

Table 8. Identification Of Functional Groups Sample N°2

Vibration Type	**Functional group**	**Theoretical Range (CM-1)**	**Experimental Result (CM-1)**
Tension Vibration Band	"-O-H "	3400-3200	3318
Tension Vibration Band	"-C-H "	2990-2800	2877
Tension Vibration Band	"-O-H, C=C "	1640-1400	1608
Tension Vibration Band	"-C-O-C"	1200-980	1028
Tension Vibration Band	"-C-H "	900-800	892

Table 9. Results Of Volatile Solids Sample N°2

Laboratory Code	**Parameter**	**Unit**	**Minimum Limit 900,080-2015 DS N°025-2021-PRODUCE**	**Results**
SAMPLE N°2	Volatile Solids	%	50	84.68

Table 10. Results For Heavy Metals and Other Substances Sample 2

Laboratory Code	**Parameter**	**Unit**	**LCM**	**Minimum Limit 900,080-2015 DS N°025-2021-PRODUCE**	**Results**
SAMPLE N°2	Arsenic, As	mg/kg	2.67	5	<2.67
	Cadmium, Cd	mg/kg	0.33	0.5	<0.33
	Chromium, Cr	mg/kg	1.33	50	<1.34
	Copper, Cu	mg/kg	1.00	50	3.24
	Mercury, Hg	mg/kg	0.50	0.5	<0.50
	Molybdenum, Mo	mg/kg	1.00	1	<1.33
	Nickel, Ni	mg/kg	1.67	25	3.69
	Lead, Pb	mg/kg	3.33	50	4.68
	Selenium, Se	mg/kg	0.50	0.75	<6.67
	Zinc, Zn	mg/kg	0.67	150	15.26
	Fluorine, F	mg/kg	0.10	100	<0.10

Table 11. Identification Of Functional Groups Sample N°3

Vibration Type	**Functional group**	**Theoretical Range (CM-1)**	**Experimental Result (CM-1)**
Tension Vibration Band	"-O-H "	3400-3200	3315
Tension Vibration Band	"-C-H "	2990-2800	2879
Tension Vibration Band	"-O-H, C=C "	1640-1400	1605
Tension Vibration Band	"-C-O-C"	1200-980	1027
Tension Vibration Band	"-C-H "	900-800	895

Table 12. Results Of Volatile Solids Sample N°3

Laboratory Code	**Parameter**	**Unit**	**Minimum Limit 900,080-2015 DS N°025-2021-PRODUCE**	**Results**
SAMPLE N°3	Volatile Solids	%	50	82.61

Table 13. Results For Heavy Metals and Other Substances Sample 3

Laboratory Code	**Parameter**	**Unit**	**LCM**	**Minimum Limit 900,080-2015 DS N°025-2021-PRODUCE**	**Results**
SAMPLE N°3	Arsenic, As	mg/kg	2.67	5	<2.67
	Cadmium, Cd	mg/kg	0.33	0.5	<0.33
	Chromium, Cr	mg/kg	1.33	50	<1.34
	Copper, Cu	mg/kg	1.00	50	2.03
	Mercury, Hg	mg/kg	0.50	0.5	<0.50
	Molybdenum, Mo	mg/kg	1.00	1	<1.33
	Nickel, Ni	mg/kg	1.67	25	3.48
	Lead, Pb	mg/kg	3.33	50	5.69
	Selenium, Se	mg/kg	0.50	0.75	<6.67
	Zinc, Zn	mg/kg	0.67	150	12.16
	Fluorine, F	mg/kg	0.10	100	<0.10

5.2. Graphical Results

By the FTIR characterization test of sample 1 (Figure 1), a spectrum and characteristic peaks of OH, CH, CC, COC were obtained, which would belong to a material that is formed by cellulose (Table 5).

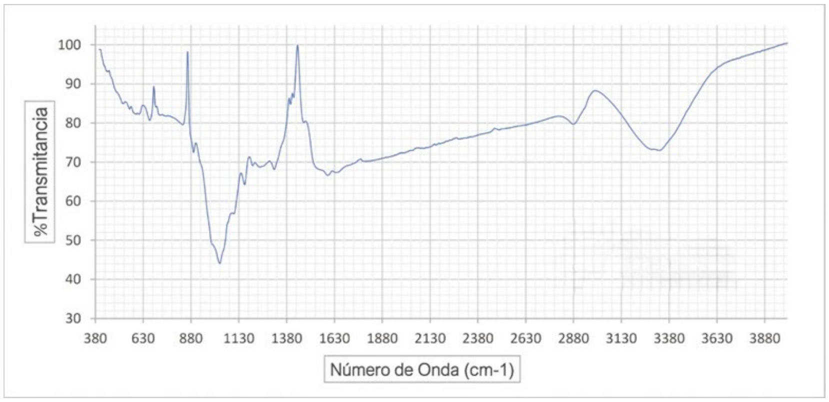

Figure 1. Infrared Spectrum of the Sample 1

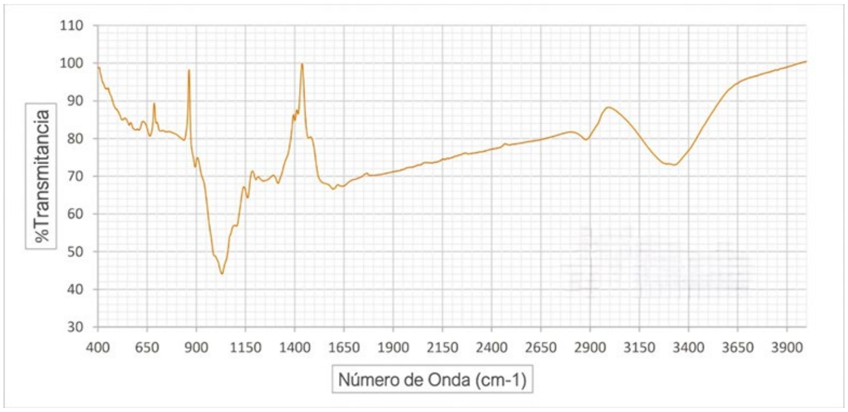

Figure 2. Infrared Spectrum of the Sample 2

By the FTIR characterization test of sample 2 (Figure 2), a spectrum and characteristic peaks of OH, CH, CC, COC were obtained, which would belong to a material that is formed by cellulose (Table 8).

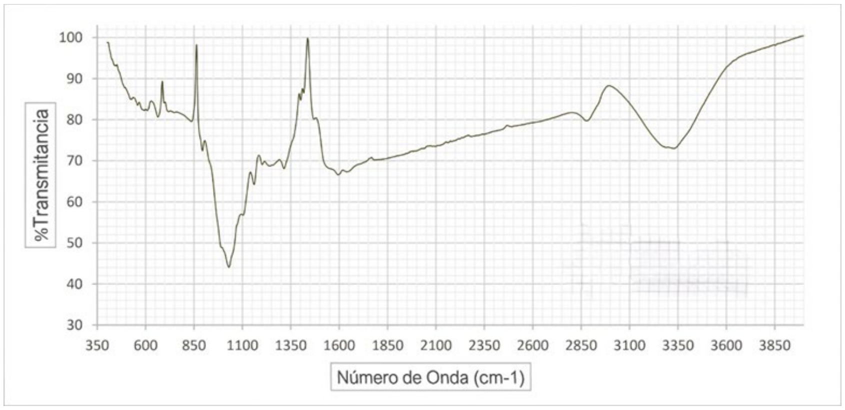

Figure 3. Infrared Spectrum of the Sample 3

By the FTIR characterization test of sample 3 (Figure 3), a spectrum and characteristic peaks of OH, CH, CC, COC were obtained, which would belong to a material that is formed by cellulose (Table 11).

5.3 Proposed Improvements

To achieve a film with more promising attributes, it is recommended to make improvements in the Shore hardness, water absorption and tensile strength and elongation tests. With these improvement proposals, the objective of being a functional material to produce biodegradable packaging will be achieved. Firstly, obtaining a lower water absorption percentage is vital for the films; to obtain it, a chemical modification process would have to be carried out on the raw material (sugarcane bagasse). We can opt for hydrophilization through a fatty acid treatment, which would help a lot since this process will seek to bind the hydrophobic hydrocarbon chains to the cellulose fiber, creating a barrier that repels water. Likewise, although it is true to improve hardness and tensile strength there are quite a few alternatives, but what we need to obtain is something that can be economical and that does not affect the biodegradability of the product, so rigid and cross-linking additives are ruled out. Instead, we can opt for the addition of more rigid organic compounds in the composition such as polyhydroxyalkanoates. For example, PHB AND PHBO in the appropriate proportions will provide the necessary help to improve this function.

6. Conclusion

The use of sugarcane bagasse, as an agro-industrial waste, is a viable option for the manufacture of food containers having the same or similar properties as expanded polystyrene containers; in addition, being an agricultural waste, it does not require complex technology for its production at an industrial level. Also, thanks to the use of sugarcane bagasse in the manufacture of the container, we can speak of an eco-friendly product that will be accepted by the public because it helps to care for the environment.

The tests of physical mechanical properties in bioplastics of the 3 doses helped to verify the strengths and weaknesses of each one compared to a conventional food packaging. However, there are characteristics that can be improved to obtain a quality product that can compete in the market. With respect to the tensile strength and elongation test, good results were obtained, but we believe that the tensile strength can be improved with the help of additives and the use of reinforcing agents of natural origin. A high % of water absorption was also observed in the 3 doses, which can be detrimental depending on the type of food to be stored. To avoid this drawback, the use of additives or agents that help to reduce the high absorption that was obtained is suggested.

It was demonstrated that our films in all their doses successfully fulfilled the biodegradability test, since the data obtained are within the theoretical ranges of each test. With this, a future elaboration of containers using bagasse fiber and chemical additives would encourage the use of biodegradable containers since they will not generate a negative impact on the planet and at the same time fulfill the same function as a conventional polystyrene-based food container.

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Biographies

Renzo Martin Barinotto Valencia has a bachelor's degree in industrial engineering from the University of Lima, with a specialization in Process Management obtained at Centrum PUCP. He has 2 years of experience in the commercial area in the retail and telecommunications sectors. During my academic training, I have acquired solid knowledge in the design, analysis, and optimization of industrial and commercial processes, focused on improving efficiency and productivity in various organizations. His specialization in Process Management has allowed him to delve into advanced modeling and continuous improvement techniques, applying methodologies such as Lean Manufacturing and Six Sigma.

Gonzalo Dennys Ramos Olortegui is an industrial engineering graduate from the university of lima. He has experience in the electric power sector where he gained experience in tracking and analyzing data, preparing reports, and supervising field work in a global energy company. He is currently pursuing a diploma course in operations and logistics management as he wishes to expand his knowledge and apply for a better position in the production sector. Together with his colleague he is preparing a report on the utilization of waste for the generation of bioplastic food containers which is expected to help reduce the environmental pollution caused by plastic materials.