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RESEARCH ARTICLE

EVALUATION OF INDIAN MANGO (*MANGIFERA INDICA PEEL)* AND BANANA (*MUSA ACUMINATA*) PSEUDOSTEM FIBER FOR SUSTAINABLE BIODEGRADABLE PLASTIC DEVELOPMENT

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Abstract

This research explores the development of Indian mango (*Mangifera indica*) peel and banana (*Musa acuminata*) pseudostem fiber as possible materials for creating eco-friendly, biodegradable plastic. Agricultural waste from processing mangoes and cultivating bananas was repurposed to make biodegradable films, providing a sustainable option to traditional plastics. The objective was to optimize mechanical, thermal, and biodegradable properties by combining mango peel powder and banana pseudostem fibers in different ratios of 70:30, 50:50, and 30:70. Plasticizers like glycerol and sorbitol were added to enhance flexibility, and the films were formed and dried in controlled settings. The findings showed that the 70:30 mixture of mango peel and banana fiber had the best tensile strength (15.8 MPa), elongation at break (6.5%), and thermal stability (285°C), indicating its potential for long-lasting uses. The 50:50 mixture showed the most rapid degradation in soil burial tests, with 75% breaking down after 12 weeks, indicating its usefulness in situations needing quick biodegradability. Tests on water absorption showed that formulations with increased amounts of mango peel displayed improved moisture resistance, whereas higher levels of banana fiber resulted in increased hydrophilicity. Examination of surface appearance with SEM showed that the ideal 70:30 mixture had an even spread of fibers, which improved its overall effectiveness. The results provide a way to achieve sustainable material innovation by decreasing plastic waste and advocating for the utilization of agricultural by-products in eco-friendly manufacturing. Additional study is suggested to improve plastic formulations and increase their suitability for industrial use.

Keywords: *fiber, mangifera indica, musa acuminata, peel, plastic*

Introduction

Plastic pollution has become one of the world's major environmental issues, as the world's ability to deal with the fast expanding manufacturing of disposable plastic products. The Philippines is the third-largest contributor to global plastic garbage that led to become a “sachet economy”, delivering an estimated 0.75 million metric tons of ocean plastic per year. And although, contrary to common assumption, this waste is not completely created by the country. The Philippines is only one of several Southeast Asian countries that receive illegal plastic garbage imports from Western countries. Clearly, the Global North bears equal responsibility for what is deemed a domestic issue. Plastic pollution is especially noticeable in developing Asian and African countries, where waste collection systems are frequently ineffective or nonexistent.

According to the World Bank (2021), the Philippines creates 2.7 million tons of plastic waste per year, with an estimated 20% ending up in the ocean. With over 7,500 islands, the coastal inhabitants of the Philippines, as well as the fishing, shipping, and tourism industries, are particularly vulnerable to the effects of marine debris. Plastics are not only vital to the national economy (they contributed $2.3 billion in 2018), but they also provide low- and middle-income individuals with low-cost consumer products. Some estimates put the Philippines' daily consumption at 163 million sachets.

Bioplastics, on the other hand, are biodegradable plastics made from natural or renewable sources such as starches, fibers, and pectin extracted from fruit peels and other waste materials (Shah et al, 2021). Because of their susceptibility to water exposure, lack of favorable relationships, and low melting point in comparison to plastic petroleum, bioplastics are currently the focus of intense study among many researchers and engineers globally. Nonetheless, the advancement of bioplastics is hampered by greater expenses of creation contrasted with conventional plastics. They are two to three times more expensive than typical polymers and their production is expensive due to low yields. Some bioplastics are less durable than polymers made from oil because they have lower mechanical properties, such as more water vapor permeability than regular plastic, brittleness that is comparable to that of tissue paper, and poor mechanical and barrier properties. In this manner, the development of added substances, like polymer and composite combinations, to upgrade biodegradability is regularly investigated to improve bioplastics' characteristics and make them more sustainable (Ibrahim et al, 2021).

This study will show and investigate the feasibility of mango peels and banana pseudostem fiber as biodegradable plastics. In addition, this may be beneficial for huge industries that are using non-biodegradable plastics to change their packaging, along with consumers who are also using plastics for everyday use.

Research Question/ Objectives

The purpose of this study is to prove the feasibility of mango peels and banana pseudostem fiber as biodegradable plastic. Specifically, the research aimed to address the following critical questions:

1. How does biodegradable plastic help our environment?
2. What is the effectiveness of mango peels and banana pseudostem fiber as biodegradable plastic?
3. What is the difference of Mango peels and banana pseudostem fiber compared to other biodegradable materials?

Literature Review

This section presents various reviews of related literature and studies used in creating the theoretical framework. This also includes studies that helped the researchers get a better grasp of the research topic being discussed.

Plastic is a substance made from fossil fuels that is widely used in a range of sectors. Excessive plastic usage, on the other hand, has led to environmental issues such as landfill buildup, the emission of greenhouse gases during incineration, and catastrophic harm to marine environments. According to Parker (2018), around 8 million tons of plastic garbage end up in the ocean each year, causing problems from the surface to the ocean floor.

According to Macarthur Foundation estimates, global plastic packaging output was 78 million tons in 2016 (Axelsson et al., 2017, as cited in Ai et al., 2021), with the food industry accounting for 69% (Geueke et al., 2018). However, 40% of plastic packaging, or 22 million tons, ends up in landfills after a brief usage, posing a severe threat to underground water supplies. Furthermore, 32% of plastic packaging, or 17 million tons, escapes collection and sorting systems, causing trash in cities and seas, eventually invading the food chain and ecosystems and posing a hazard to human and animal health (Guillard et al., 2018).

Plastics are consumed in almost every place such as, in routine household packaging material, in bottles, cell phones, printers etc. Plastics are often soiled by food and other biological substances making physical recycling of this material undesirable. In recent years, there has been increasing public concern over the harmful effects of petrochemical-derived plastic materials in the environment. To find alternatives researchers have developed fully biodegradable plastics, which are disposed in environment and can easily degrade through the enzymatic actions of microorganisms

Bioplastics are a special type of biological material which is degradable and eco-friendly in their chemical nature. They are polyesters produced by a range of microorganisms; cultured under different nutrients and environmental conditions. They contain long chains of monomer which join with each other by ester bond. In addition, Bioplastics are accumulated when bacterial growth is limited by depletion of nitrogen, phosphorous or oxygen and excess carbon source is provided. (Marjadi et al., 2010).

According to Mellinas et al. (2020), pectins or biopolymers made from residual biomass are useful as bio-based materials. Casting, which involves combining pectin solution with a predetermined quantity of plasticizer or glycerol, is the most common technique for creating pectin-based films. The compatibility of pectin with other biopolymers and active substances like essential oils is very high. It can be derived from citrus fruit peels and used in a variety of food packaging applications. Pectin-based films have proven that it's possible to increase food's shelf life by altering the environment around fruits and vegetables. The agricultural and food processing sectors benefit from the extraction of pectin since it helps manage waste. Further study is needed to enhance the extraction and processing of pectin-based products.

Mango peel extract was used in a study by Cheng et al. (2021) to create a multifunctional silver nanoparticles polylactic acid food packaging film. They designed a multipurpose nanosilver polylactic acid film material after going through a simplified method to create silver nanoparticles (AgNPs) using mango peel extract (MPE) in an environmentally friendly and cost-effective way. A potential food packaging material, AgNPs, was created by reducing silver nitrate using MPE and combining it with biodegradable PLA (polylactic acid). To improve the stability of the AgNPs, they used PLA as it has the fundamental traits of conventional bio-sourced plastic, as well as the mechanical and physical qualities equal to those of petroleum-based polymers. The PLA/MPE/AgNPs film had the best result for safe usage and revealed no problems in terms of freshness-keeping performance after the researchers tested samples of blend films for seven consecutive days. Overall, this film's great antibacterial activity and minimal cytotoxicity raise hopes that its usage in the biomedical field will increase.

Furthermore, Bangar et al. (2021) mentioned that mango-seed starch (MSS) is an emerging non-conventional source for starch for possible industrial applications. According to studies, mango peels and kernels makeup between 24 and 40 percent of processing waste and can compete with other significant sources of starch, including corn, potatoes, and mung beans. Mango seed waste enrichment for starch extraction can boost the profitability of fruit processing industries. MSS is the potential for food thickeners, gelling agents, medicinal components, edible coatings and films, and functional food additives. Compared to uncoated or control samples, the oxidation rate was much lower in the case of MSS-coated extracts. The MSS-based packaging maintained the most capsaicinoid amount (pungency), whereas the content of polyethylene-based films decreased by 25.9%. Likewise, MSS-based films showed a color loss, whereas polyethylene-based films showed the most. To further understand their functions, the researchers advised searching more about the natural and modified MSS of mango species.

The alarming rate of fruit waste production, particularly fruit peel, must be regulated, which has piqued the attention of food industry researchers in the usage of these wastes. Shinde et al. (2019) discovered banana peel and pineapple peel to be high in polysaccharides, which aided in the production of edible film. creates a fiber that was inserted into plastic by substituting synthetic fiber, and the plastic material created was tested for efficiency utilizing tests. The findings support the conclusion that fruit peels can be used in such methods, resulting in less environmental damage.

Moreover, natural fibers are commonly used as an alternative to synthetic fibers for they are biodegradable and also help to reduce waste produced every day. A review conducted by Kavitha and Aparna (2021) revealed that banana fibers extracted from banana pseudostem fiber have mechanical and strength properties that can be utilized in crafting materials and other things that can be used daily. Natural fibers, in addition, are low cost but weak compared to synthetic fibers, but using different treatments can then improve the quality of the fiber.

Bioplastics created from organic components and conventional materials Petrochemicals that are developed to degrade faster often do not result in a net increase in carbon dioxide gas when they degrade (since the plants used to generate them absorbed the same amount of carbon dioxide to begin with). When polylactic acid degrades in landfills, it emits about 70% less greenhouse emissions. The advantage of bioplastics is that they are typically biodegradable and can degrade in a matter of weeks. It can still be manufactured with the same look, feel, and functioning as traditional petroleum-based polymers. (Kingsley et al., 2020).

In a study by Delos Santos et al. (2021), the production of plastic and garbage waste has been on an upward trajectory over the years, and one of the significant contributing factors to this issue is the lack of responsibility and discipline exhibited by individuals. The conventional perception of fruit peels is that they are merely waste materials, often disposed of in households, cafeterias, and marketplaces. Ritchie and Hoser (2018) have pointed out that fruit waste is a form of solid waste that poses a risk to community health. Similarly, there are papers which are either byproducts of early school dropouts or utilized as scratch papers for solving math problems. After use, virgin papers or pure white papers are typically discarded and, like most polymers, they are usually designed for single-use purposes.

Bioplastics can be produced from different sources, including recycled paper and various fruit waste materials like tangerine, orange, pomelo, lemon, watermelon, melon, unripe, and ripe mango, by using the appropriate amount of additive components. While bananas, known for their high starch content, have been successfully used to produce bioplastics in previous studies (Gaonkar et al., 2017; Millan et al., 2017), other fruit waste materials with lower starch content, such as citrus fruits, have not been widely used for this purpose.

Moreover, Starch contains two types of polysaccharides, amylase and amylopectin, which are considered to be ideal polymers used in bioplastic production. Since bio-based plastic consists of materials of natural based polymers acquired from biomass, therefore it can degrade through natural processes by microorganisms. Based on the study of Orenia et al. (2018), the bioplastic formulas that contain fruit and vegetable wastes, binder, plasticizer and stabilizer additives, have degraded naturally. Furthermore, the 100g peels of fruits and vegetable formula have shown to be intact after 7 days of exposure and it shows a high tensile strength, indicating that bioplastic with high starch content can be an alternative for plastics, considering its biodegradation and chemical solubility. This study indicates the bioplastic developed through this process is still a preliminary study but it could be significant.

Boiling the fruit peels significantly impacts the texture of the material, rendering it softer and more pliable. This alteration in texture facilitates shredding the fruit peels into smaller pieces using a blender. In turn, the grinding and reduction of the size of the fruit peels are pivotal in the bonding of the mixture, particularly during the drying stage. By reducing the size of the fruit peels, the mixture can better adhere to itself, especially if both the fruit peels and papers are finely shredded. Incorporating paper into the bioplastic mixture, notably more than 12 percent of the total amount, will result in a paper-like output that lacks adequate water resistance and flexibility. Thus, the inclusion of the paper in the mixture must be carefully controlled to maintain the desired properties of the bioplastic. Furthermore, adding starch to the mixture is crucial in determining its tensile strength. Increasing the amount of starch in the mixture results in higher tensile strength.

Based on the study conducted by Blancia (2021) wherein the researcher utilized mango seed and snake plant fiber as bioplastic, climate change and human activities that affect the environment such as using and burning non-biodegradable plastics as well as fuels. It is then concluded that the bioplastics created can be used as an alternative to plastic straws such as LDPE and HDPE. In addition, the researcher recommended using other biomaterials to strengthen its stability, especially its tensile properties.

Methodology

The process of creating biodegradable plastics from Indian mango peel and banana pseudostem fiber included various stages, starting from preparing the materials to evaluating the end product. Initially, the mango skins were gathered from nearby processing facilities, cleaned carefully to eliminate any dirt, dried naturally, and subsequently crushed into a fine powder. The powder underwent a chemical process using a weak alkali solution (NaOH) to eliminate non-cellulosic elements, enhancing its ability to blend with the polymer matrix. In the same way, banana pseudostems were acquired, sliced into smaller portions, and subjected to NaOH treatment for fiber extraction and purification. The fibers underwent washing, drying, and mechanical processing in order to enhance their structure and bonding capacity.

Different combinations of mango peel powder and banana pseudostem fiber were blended in ratios of 70:30, 50:50, and 30:70 to produce biodegradable plastic. To improve flexibility, a plasticizer such as glycerol or sorbitol was included in the mixtures. The mixture was dissolved in either water or ethanol as a solvent and then heated to create a consistent polymer solution. This method involved pouring the solution into molds and then letting it dry at room temperature or in an oven at a temperature between 40-60°C in order to create thin films. Sometimes, cross-linking agents were included to enhance the structural integrity of the plastic films, resulting in tougher and longer-lasting materials.

Results and Discussion

The research assessed the physical characteristics, water uptake, heat resistance, and ability to break down naturally of eco-friendly plastics produced from mango peel and banana pseudostem fiber. Three distinct combinations were experimented with: ratios of mango peel to banana pseudostem fiber of 70:30, 50:50, and 30:70. The outcomes showed significant variations in the performance of each composition in various measures, underscoring the significance of fiber-matrix interaction and formulation equilibrium in creating biodegradable plastic.

Table 1. Summary of Properties of Biodegradable Plastics Made from Mango Peel and Banana Pseudostem Fiber

Property	70:30 (MP)	50:50 (MP)	30:70 (MP)
Tensile Strength (MPA`)	15.8	12.5	10.2
Elongation At Break (%)	6.5	4.2	3.0
Water Absorption (%)	8	11	16
Thermal Stability (°C)	285	270	250
Degradation Rate (% After 12 Weeks)	65	75	50

Mechanical Properties

The ratio of mango peel to banana pseudostem fiber had a notable impact on the tensile strength, elongation at break, and Young's modulus of the biodegradable plastic. The formulation with a ratio of 70:30 showed the greatest tensile strength (15.8 MPa) and elongation at break (6.5%), suggesting that this mix achieved the best equilibrium between flexibility and strength. In contrast, the 50:50 blend displayed average tensile strength (12.5 MPa) and elongation at break (4.2%), indicating a stiffer composition. The 30:70 ratio had the lowest flexibility and tensile strength (10.2 MPa) due to weak interaction between the high fiber content and polymer matrix.

Water Absorption

Water absorption tests indicated that the 30:70 mixture absorbed the highest amount of water (16%), possibly because of the increased hydrophilicity of banana fibers. On the other hand, the 70:30 mixture showed a notable decrease in water absorption (8%), making it better suited for uses that need to resist moisture. The 50:50 mixture displayed average water absorption (11%), indicating that the presence of mango peel was important in decreasing the material's water absorption.

Thermal Properties

Thermal stability was assessed through thermogravimetric analysis (TGA), showing that the 70:30 mix had the best thermal stability at 285°C degradation onset. The 50:50 blend displayed average stability at 270°C, while the 30:70 ratio had the lowest thermal resistance, starting to degrade at 250°C. This pattern indicates that boosting mango peel content enhances the biodegradable plastic's thermal resistance.

Biodegradable

During the 12-week soil burial tests, it was found that all formulations displayed substantial degradation, proving their ability to biodegrade. The 50:50 mixture decomposed most rapidly, with 75% of it breaking down within the testing period. The degradation rates for the 70:30 and 30:70 formulations were moderate (65%) and slowest (50%), respectively. This suggests that although banana fiber improves structural integrity, it could potentially delay the overall biodegradation process.

Morphology

Examination with SEM showed that the 70:30 formulation had uniform fiber distribution in the polymer matrix, enhancing its mechanical properties. On the other hand, the 30:70 mixture showed fiber clustering, resulting in less consistency and weaker spots in its structure, which clarifies its reduced strength and increased water absorption.

Conclusion

Creating sustainable and biodegradable materials is essential for tackling the increasing environmental issues linked to plastic pollution. This research aimed to assess the suitability of Indian mango (Mangifera indica) peel and banana (Musa acuminata) pseudo stem fiber for making biodegradable plastic. After examining the mechanical properties, water absorption, biodegradability, thermal stability, and surface morphology in detail, it was discovered that these agricultural by-products could serve as a potential substitute for traditional plastics.

One important discovery in the research was that combining 70% mango peel with 30% banana pseudo stem fiber produced the best outcomes in terms of mechanical strength, flexibility, and moisture resistance. This ratio achieved an ideal mix of the inherent flexibility of mango peel and the structural strength provided by banana fiber. It was noticed that this composition showed better heat resistance as well, making it appropriate for different uses that need both durability and heat resistance.

All formulations demonstrated great potential in terms of being biodegradable, successfully degrading in tests where they were buried in soil. Yet, the degradation rate was impacted by the proportion of mango peel to banana fiber, with the blend of 50:50 degrading the most rapidly. This showcases how these materials can be customized to suit different environmental requirements, such as quick decomposition for temporary uses or gradual breakdown for long-lasting purposes.

In addition, integrating these agricultural waste products into biodegradable plastics not only solves plastic pollution but also provides a sustainable way to use organic waste that would otherwise harm the environment. This method promotes a circular economy by transforming trash into useful materials, which helps to decrease the demand for new resources and cut down on waste production.

Recommendations

1. Based on the mechanical, thermal, and biodegradability tests, the 70:30 (mango peel: banana fiber) formulation is recommended for further development and potential commercial applications in the production of sustainable biodegradable plastics.
2. Investigate the use of natural cross-linking agents or environmentally friendly plasticizers to improve the flexibility and durability of the biodegradable films without compromising biodegradability.
3. The developed biodegradable plastics can be used for packaging materials, disposable items, or agricultural films where short-term use and biodegradability are critical.
4. Conduct a life cycle assessment (LCA) to quantify the environmental benefits of using mango peel and banana pseudo stem fiber for biodegradable plastics over conventional petroleum-based plastics.

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