International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

Cogon (*Imperata cylindrica*) Grass Cellulose as Reinforcement and Okra (*Abelmoschus esculentus*) Mucilage Plasticizer in the Production of Bioplastic

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***Abstract*— *This study seeks to determine the effects of adding cogon grass cellulose in tapioca starch-based bioplastics. Four various formulations (Mixture 1, Mixture 2, Mixture 3, and Mixture 4) were evaluated for biodegradability, physical, and mechanical properties. Bioplastics were synthesized using tapioca starch, cogon grass cellulose, and okra mucilage. Cogon cellulose underwent delignification, hydrolysis, and bleaching, while okra mucilage was extracted via soaking and heating. Bioplastic films were produced using an inversion method, mixed, heated, molded, and dried. Each formulation underwent ten trials and was assessed for biodegradability, density, water absorption, thickness, tensile strength, and elongation. Mixture 1 exhibited the highest biodegradability at 76.91% due to its lower cellulose content, while Mixture 4 had the highest density at 0.917 g/cm³, lowest water absorption at 14.97, and greatest thickness reduction at 69.50%. Mixture 4 also demonstrated the highest tensile strength at 507.63 kPa and elongation at 7.05%, indicating maximum structural reinforcement at the cost of flexibility. Statistical analyses ANOVA and Kruskal-Wallis tests confirmed significant differences among all formulations. Mixture 4 was identified as optimal in most of categories and mixtures, closely resembling LDPE. Future studies should increase Cogon cellulose concentration for strength, adjust starch/mucilage ratios to reduce water uptake, and explore natural additives for improved biodegradability while maintaining LDPE-like characteristics.*

Keywords— *Bioplastic production, Biodegradable materials, Cellulose reinforcement, Okra mucilage plasticizer, Plant-based bioplastics, Natural polymers, Sustainable materials, Environmental sustainability, Imperata cylindrica (cogon grass), Abelmoschus esculentus (okra).*

I. INTRODUCTION

Reducing excessive plastic usage remains a significant challenge in today's society. As of 2021, global plastic production reached approximately 390.7 million tons (Plastics Europe, 2022). Given that petroleum is the primary raw material for most plastics, these materials pose environmental concerns, often persisting as waste for extended periods. Notably, only about 9% of all plastic waste ever produced has been recycled (United Nations Environment Programme, 2020). Petroleum-based polymers are extensively utilized in product packaging across various markets due to their convenience and waterproof properties.

However, the persistence of plastics presents significant environmental challenges. In 2019, the Philippines were identified as the largest contributor to oceanic plastic waste, accounting for approximately 36.38% of global marine plastic pollution (Earth.Org, 2021). The country's rapidly growing population exacerbates this issue, leading to increased plastic waste generation. These plastics can take years to decompose fully, making their disposal a pressing concern. Developing environmentally friendly alternatives, such as bioplastics, is one approach to mitigating this problem.

Bioplastics are materials that are biodegradable, derived from renewable resources or both (Ernita et al., 2020). They are produced from sources like bacteria, plant cellulose, vegetable oil, and corn starch. Introduced in the 1980s, bioplastics aimed to facilitate the breakdown of commonly discarded plastics in landfills, thereby conserving space. However, the initial goals of bioplastics were not fully realized. Additionally, reducing reliance on petroleum and petrochemicals is a key objective of bioplastics. Contemporary developments include blends of starch-based and petroleum-based plastics (Goodall, 2020).

According to Moosa et al., (2022), bioplastics can be synthesized from various alternative plant-based raw materials, including cellulose, lignin, and starch, as well as animal-based sources raw materials, such lipids and proteins. The majority of bioplastics are produced using starch as their main raw material. Numerous bioplastics derived from starch have previously been created by scientists. Because starch is cheap, readily available, and has a simple extraction procedure, it is a popular raw material for bioplastics (Ernita et al., 2020).

The purpose of this research is to examine the use of affordable plasticizers, such okra mucilage and cogon grass cellulose, in order to improve the mechanical characteristics of bioplastics. By incorporating these natural additives, the research aims to address the challenges associated with starch-based bioplastic production.

II. METHODOLOGY

A. Collection and Extraction of Cogon Grass Cellulose

The cogon grass powder is first treated with a sodium hydroxide solution to break down its lignin, a complex organic compound, in a process called delignification. The resulting mixture is then filtered and washed to remove impurities, before being dried to a constant weight. Next, the delignified

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product is treated with hydrochloric acid to further break down its components in a process called hydrolysis. The mixture is filtered and washed again to remove any remaining impurities. Finally, the residue is bleached to remove any remaining impurities, washed, and dried to produce a fine powder, ready for use in bioplastic production.

B. Extraction of Okra Mucilage

The extraction of okra mucilage begins with the selection of fresh okra fruits. The okra fruits are then washed and crushed to release the mucilage, which is then mixed with water to create a mucilage solution. The mixture is allowed to settle, letting the contaminants break free from the mucilage. The supernatant is then filtered and centrifuged to remove any remaining impurities, resulting in a clear and viscous okra mucilage extract.

C. Bioplastic Film Making

Tapioca starch and distilled water are first combined to create the base mixture. To this, okra mucilage is added, which acts as a natural plasticizer, improving the flexibility and binding properties of the film. The mixture is then stirred thoroughly to ensure uniformity. Following this, cellulose extracted from cogon grass is added to reinforce the film and enhance its structural strength. After the mixing stage, four different formulations—referred to as Mixture 1 (3:3:10), Mixture 2 (5:3:10), Mixture 3 (7:3:10), and Mixture 4 (9:3:10)—are prepared, with the ratios representing the proportions of tapioca starch, okra mucilage, and cogon grass cellulose, respectively. These different mixtures allow for the evaluation of how varying ingredient ratios affect the film's properties.

D. Molding of Bioplastic Film

Casting the mixtures into film form by pouring them into molds or onto surfaces, followed by a drying process to remove moisture and solidify the bioplastic films. Once the films are formed, they undergo a series of analyses to assess their properties.

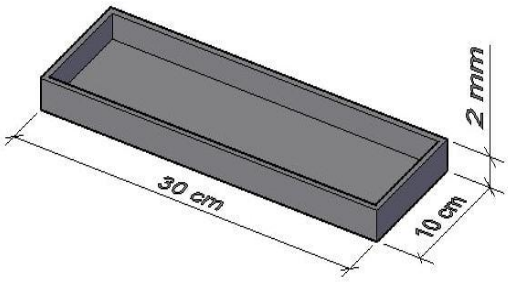

Figure 1. The bioplastic mold used during the experiment

E. Bioplastic Test Analysis

To evaluate the efficacy and efficiency of the bioplastic samples, the acquired data were carefully analyzed using four different proportions of cogon grass cellulose and okra mucilage extract. Each formulation was subjected to a series of tests to assess its physical, mechanical, and biodegradability properties. Ten trials were conducted for each testing to ensure statistical reliability and consistency in the results. The Low-Density Polyethylene (LDPE) plastic, which was widely used for packaging materials like plastic bags and shrink wrap and was ideal for many applications requiring a flexible material due to its softness and malleability, was compared with the bioplastics generated from this experiment. Additionally, to ascertain which of the dimensions were appropriate for this kind of plastic, plastic bags were utilized for the LDPE tests since they were commonly used.

Physical Analysis

Density Test

In this study, the method conducted by Darnie et al., (2014) was adapted. The mass (m) of the bioplastic was weighed. The measured bioplastic was then placed into the measuring cup, which was filled with up to 5 ml of distilled water, for a total of 10 ml. After 15 minutes, the new water volume (V) was recorded to calculate the actual bioplastic volume by finding the difference between the initial and final water volumes. The formula for this calculation is shown as:

$$\rho = \frac{m}{v} \tag{1}$$

Water Absorption Test

The water absorption procedure followed the method outlined by Tamiogy et al. (2019). The weight of the initial bioplastic to be test was weighed, and then put into a beaker filled with water. After 10 seconds, the bioplastic was removed and weighed. The process was repeated until the weight of the bioplastic remained constant. The water absorbed was calculated by:

$$\text{Air (\%)} = \frac{W - W_o}{W_o} \times 100 \tag{2}$$

Thickness

Thickness is the perpendicular distance between the two outer surfaces of materials. The tapioca starch-based bioplastic with cogon grass cellulose and okra mucilage thickness was measured using a micrometer. The measurement was taken directly by holding the work piece between the stylus and the anvil.

Mechanical Analysis

Tensile Strength

The tensile strength was carried out with the test object drawn in two directions so that the length increased and the diameter shrank. The ASTM D412 standard test method was used to determine the tensile characteristics of rubber and rubber-like materials like bioplastics. The amounts of load and length increase were recorded during the test. In this test, a digital spring scale and binder clips were used to pull the samples and measure the force. This was followed by cutting the testing sample into a dumbbell shape, which was then placed between the tensile grips. The test was initiated at a speed of 0.00847 m/s and stopped after the sample broke.

The material's tensile strength was a measurement of the maximum stress it could withstand when stretched or pulled before necking occurred. It was computed using the formula shown, where F is the force required to break, W is the width, and t is the thickness of the sample.

$$TS = \frac{F}{W.t} \quad (3)$$

Percent Elongation Test

The percent elongation was calculated by comparing the length of the film at break with the length of the film before being pulled by the tensile strength elongation tester. The mathematical percent elongation was calculated using the Elongation Formula:

$$(\%) = [(L_1 - L_0)/L_0] \text{ x } 100\% \quad (4)$$

Biodegradability Test

The biodegradability of the samples was assessed by subjecting them to controlled environmental conditions, monitoring their degradation rate over time. This analysis helped determine the sustainability and potential environmental impact of the bioplastics. The four (4) proportions and one LDPE plastic bag were cut into strips measuring approximately 10 cm by 10 cm for the biodegradability test (Madden, 2020). The samples were weighed and placed on a plastic cover of the same size before being buried in the ground at a depth of 8 cm (Robert & Iyer, 2019). The four samples were uncovered and cleaned after a week, and their visual appearance was observed along with any indications of biodegradation. Visual variations in the product's weight, texture, color, and appearance were noted.

The following method was used to compute the rate of material degradation: the sample's initial weight was determined before it was buried, and the sample's final weight was determined after it was uncovered after a week.

$$Degradation\ rate = \frac{Initial\ weight - Final\ weight \text{ x } 100\%}{Initial\ weight} \quad (5)$$

F. Data Analysis and Interpretation

The study conducted ten (10) trials for each property (physical, mechanical, and biodegradability) across four formulations of cogon grass cellulose and okra mucilage extract in bioplastics. Statistical analyses, including the Shapiro-Wilk test for normality, Levene's test for homogeneity, and one-way ANOVA, were performed to assess differences among formulations. If significant differences were found, post-hoc tests like Tukey's HSD identified which formulations varied. Key properties such as tensile strength, elongation, density, water absorption, thickness, and biodegradability were analyzed to determine the most effective formulation. Additionally, the physical and mechanical properties of these bioplastics were compared with those of Low-Density Polyethylene (LDPE) plastic bags. Descriptive and inferential statistical tests ensured reliable results, and one-way ANOVA determined significant differences among formulations, contributing to the development of sustainable bioplastic alternatives.

III. RESULT AND DISCUSSION

The bioplastic made in this study contained starch as its primary component, which was extracted from the starch of tapioca. The two starches were combined to change and increase the starch molecules' qualities and processing capabilities. Properties such as mechanical, physical and biodegradability may be obtained by testing. The characteristics of starch-based bioplastic can be altered during formulation and processing to meet the requirements of specific applications.

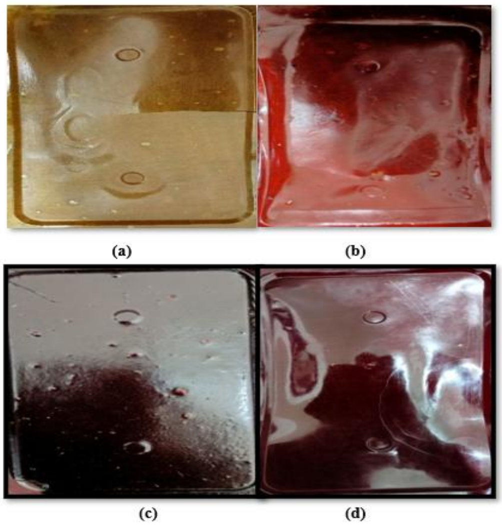

Figure 2. Tapioca Starch-based Bioplastics with Cogon Grass Cellulose and Okra Mucilage as Plasticizer: (a) Mixture 1, (b) Mixture 2, (c) Mixture 3, (d) Mixture 4

Bio-based Figure 2 shows the bioplastics made from cogon grass cellulose, okra mucilage extract and tapioca starch. The production of tapioca starch-based bioplastic films with the addition of cogon grass cellulose and okra mucilage as plasticizer aimed to determine which mixture its physical and mechanical properties as well as the biodegradability. The results show that based on the physical and mechanical properties test conducted the optimum concentration of cogon grass cellulose and okra mucilage in the making of starch-based bioplastic is at concentration of 9 grams of cellulose, 3 grams of okra mucilage extract and 10 grams of tapioca starch.

TABLE 1. Overall Ranking of the Comparison between the Experimental Bioplastics and LDPE in terms of its tested parameters

Properties	Mixture 1	Mixture 2	Mixture 3	Mixture 4	LDPE
Density	4	3	2	1	5
Water Absorption	1	2	3	4	5
Thickness	1	2	3	4	5
Tensile	1	2	3	4	5
Elongation	1	2	3	4	5
Biodegradability	5	4	3	2	1
Total Average	**2.17**	**2.50**	**2.83**	**3.17**	**4.33**

Note: 1 = Poor 2 = Fair
3 = Good 4 = Very Good

The features of LDPE and bioplastics based on tapioca starch, cellulose from cogon grass, and okra mucilage as a plasticizer are investigated in this study, emphasizing both their benefits and drawbacks. Table 4.13 shows the ranking of the bioplastics based on the summation of ranks in each property. The rankings are as follows: Mixture 1 has a total rank of 2.17, Mixture 2 has a total rank of 2.50, Mixture 3 has a total rank of 2.83, and Mixture 4 has a total rank of 3.17, and lastly, LDPE with a total rank of 4.33. This ranking reflects how closely each mixture and LDPE performs in terms of various properties. Mixture 4 shows the most similar characteristics between LDPE plastic in the study, indicating that Mixture 4 is the closest in performance to LDPE. In contrast, Mixture 1 ranks the lowest, highlighting its relatively lower similarity to LDPE in the properties examined.

IV. CONCLUSION

The study successfully developed tapioca starch-based bioplastics using cogon grass cellulose and okra mucilage as key components, with the objective of identifying the optimal formulation by evaluating their biodegradability, physical, and mechanical properties. The research revealed that Mixture 1 had the highest biodegradability rate at 76.912%, while Mixture 4 had the lowest at 68.64778%, indicating greater microbial resistance due to higher cellulose content. ANOVA analysis confirmed significant differences in degradation rates among the formulations ($p = 0.033833$). In terms of physical properties, Mixture 1 exhibited the lowest density at 0.629 g/cm^3, and Mixture 4 had the highest at 0.917 g/cm^3, with the Kruskal-Wallis test showing significant variation ($p = 0.002336$), confirming that cellulose increases density. Mixture 4 also had the lowest water absorption rate of 14.97% ($p = 0.001430$), indicating enhanced moisture resistance, and it showed the least shrinkage in thickness at 69.50%, confirmed by an ANOVA test ($p = 0.025168$). Mechanically, Mixture 4 displayed the highest tensile strength among the bioplastics at 507.6319 kPa, although it remained lower than commercial LDPE plastic, which measured at 2136.766 kPa. The Kruskal-Wallis test for tensile strength showed significant differences ($p = 0.0000670$). Mixture 4 also demonstrated the greatest percent elongation at 7.051%, indicating superior flexibility, with a significant p-value of 0.000107. These results underscore that higher cellulose content contributes positively to both strength and flexibility. Overall, Mixture 4, composed of 9 grams of cogon grass cellulose, 3 grams of okra mucilage, and 10 grams of tapioca starch, was identified as the optimal formulation. When compared to LDPE, the bioplastics were less durable in terms of tensile strength, elongation, water absorption, and moisture resistance. However, LDPE exhibited 0% biodegradability, whereas the bioplastics, particularly Mixture 1, demonstrated substantial degradation—up to 76.91% in just seven days. Although bioplastics showed greater variation in density and thickness, Mixture 4 stood out with the highest density and the lowest water absorption. While not as mechanically robust as LDPE, the bioplastics provide a viable, sustainable, and biodegradable alternative for single-use applications.

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