Investigation of Cardava Banana Peel (*Musa balbisiana*), Eggshell, and Rice Husk Waste in the Production of Bioplastic

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***Abstract*— *This study investigates the influence of incorporating Cardava banana peel (Musa balbisiana) starch, eggshell waste, and rice husk in the production of bioplastics. Three proportions (Bioplastic 1, Bioplastic 2, and Bioplastic 3) were evaluated in terms of biodegradability, mechanical, and physical properties. The bioplastics were synthesized using a modified heat-and-mold method, combining banana peel starch with powdered eggshell and rice husk as fillers. Each formulation underwent ten trials and was assessed for biodegradability, tensile strength, elongation, density, water absorption, and shrinkage in thickness. Bioplastic 1 exhibited the highest biodegradability at 58.9%, attributed to its higher starch content. Bioplastic 2 recorded the highest tensile strength at 197.10 kPa, while Bioplastic 1 showed the greatest flexibility with an elongation of 4.84%. In terms of density, Bioplastic 1 had the highest at 0.445* g/cm^3*, closely resembling LDPE's density. Bioplastic 3 had the lowest water absorption rate at 53.5%, and Bioplastic 1 showed the least shrinkage in thickness at 67.55%. Statistical analyses using Shapiro-Wilk, Levene's test, One-way ANOVA, and Kruskal-Wallis tests confirmed significant differences in biodegradability, tensile strength, elongation, water absorption, and thickness shrinkage, while density showed no significant difference among groups (*$p = 0.9704$*). Bioplastic 1, composed of 95% banana peel starch, 2.5% eggshell, and 2.5% rice husk, was rated as the most comparable to LDPE and suitable for lightweight, single-use products. The study recommends optimizing the filler processing by improving grinding techniques for a smoother texture and better uniformity in bioplastics. Advanced mixing methods should be employed to ensure consistent filler distribution within the matrix, enhancing overall performance. Exploring additives or alternative formulations can help increase the tensile strength and improve moisture resistance. Additionally, long-term durability tests should be conducted to evaluate bioplastic's performance over time and in varying environmental conditions.*

***Keywords*— *Biodegradability, Bioplastic, Cardava banana peel, Eggshell waste, Rice husk, Tensile strength, Elongation, Density, Water absorption, Heat-and-mold method, Tensile strength, Kruskal-Wallis test, ANOVA*

I. INTRODUCTION

Rising income levels and urbanization have led to higher demand for plastic-packaged goods, resulting in a significant surge in plastic waste generation (Lau et al., 2020). The Philippines ranks as the third-largest producer of plastic waste, generating 2.7 to 5.5 million metric tons annually, with about 20% entering the environment (Schachter & Karasik, 2022). Measures like prohibiting plastic shopping bags on weekends have been put in place in Zamboanga City, which generates 58% of its waste that is not biodegradable (Pio, 2024).

Most commercial plastics come from fossil resources, but bioplastics, derived from renewable sources, offer an eco-friendlier alternative due to their biodegradability (Rosenboom et al., 2022). Although bioplastics have moderate mechanical performance, they are considered more sustainable as they decompose naturally (Attallah et al., 2021). Starch-based bioplastics, particularly, are gaining traction in commercial packaging for being easy to produce, though they have limitations such as poor vapor and oxygen barrier properties (Marichelvam et al., 2019; Siqueira et al., 2021).

This research addresses the plastic waste problem by utilizing starch-rich banana peel waste as a key ingredient for bioplastic production, with eggshell and rice husk waste as fillers, glycerol as a plasticizer, and acetic acid as a solvent. The fillers serve to reinforce the material's mechanical properties, while the plasticizer improves flexibility (Tan et al., 2022). Nanofillers could further enhance these properties (Tan et al., 2022). While banana peel-based bioplastics have lower moisture absorption than other starch-based alternatives, adding fillers like calcium carbonate ($CaCO_3$) improves water resistance and mechanical strength (Taddele, 2019).

However, producing bioplastics from eggshells alone poses challenges, as a large quantity is required for sufficient calcium carbonate (Shafqat, 2021). Introducing rice husk as an additional filler, which provides silica, alongside eggshell's calcium carbonate, can improve structural properties and biodegradability. This dual-filler approach uses two types of agricultural waste, reducing reliance on eggshells while optimizing material performance (Shafqat, 2021; Tan et al., 2022).

Banana peel, rich in starch, cellulose, and biopolymers, combined with rice husk's high cellulose content and eggshell's CaCOs, offers promising potential for producing bioplastics with improved chemical, physical, and mechanical properties. Currently, no studies exist on using Cardava banana peel (Musa balbisiana), eggshell, and rice husk waste together for bioplastic production, highlighting a gap for further research.

II. METHODOLOGY

A. Collection of Raw Materials

The raw materials for the bioplastic—Cardava banana peel (*Musa balbisiana*), eggshell waste, and rice husk—were sourced locally in Zamboanga City. The Cardava banana peels were collected from households in Barangay Ayala, while eggshell waste and rice husk were obtained from households and a rice mill in Tulungatung. All raw materials were cleaned and prepared before further processing.

B. *Preparation of Materials*

The Cardava banana peels were soaked in 0.2M sodium metabisulfite for 45 minutes, then boiled in distilled water and blended into a uniform paste. Eggshells were cleaned, dried at 85°C for 5 hours, and ground into powder. Rice husks were also dried at 85°C for 5 hours and ground into a fine powder. Both fillers were sieved for uniformity. Other ingredients used included distilled water, vinegar, glycerol (as plasticizer), and food coloring.

C. *Extraction and Formulation of Bioplastic*

To prepare the starch solution, 12.5 g, 12.1 g, and 11.8 g of banana peel paste were dissolved in varying volumes of distilled water. Each formulation also included 7.3 mL of vinegar and 7.3 mL of glycerol. Eggshell and rice husk powders were added according to three different ratios. The mixture was stirred and heated at 220°C until a thick paste formed.

D. *Molding and Drying Process*

The cooked paste was transferred into rectangular molding pans (32.5 × 22.5 cm, 2 mm thick) lined with parchment paper. Food coloring was added to distinguish each formulation: red for Bioplastic 1, blue for Bioplastic 2, and yellow for Bioplastic 3. The mixtures were oven-dried at 105°C for 30 minutes and cooled to room temperature to solidify.

E. *Trials and Proportions*

Three bioplastic samples were produced using varying proportions of starch and natural fillers. Bioplastic 1 consisted of 95% banana peel starch, 2.5% eggshell, and 2.5% rice husk. Bioplastic 2 contained 92% banana peel starch, 4% eggshell, and 4% rice husk, while Bioplastic 3 was formulated with 90% banana peel starch, 5% eggshell, and 5% rice husk. These ratios were designed to evaluate the effect of increasing filler content on the mechanical, physical, and biodegradable properties of the bioplastics.

F. *Characterization of Bioplastic*

The bioplastics produced from Cardava banana peel, eggshell, and rice husk waste were evaluated through six key tests to assess their biodegradability, mechanical, and physical properties. Each test was conducted in ten trials for each of the three formulations.

The Biodegradability Test used the soil burial method, adapted from Madden (2020), to determine the percentage of weight loss after a 7-day period. The samples were buried at an 8 cm depth, and weight loss was calculated by comparing initial and final weights.

Mechanical properties included the Tensile Strength Test, which followed the ASTM D412 standard, using a spring scale to measure the force required to break the specimen. The Percentage Elongation Test recorded the change in length before and after the sample was stretched until rupture, using video analysis to obtain precise measurements.

Physical properties were analyzed through the Density Test, conducted via the displacement method, where the sample's mass was divided by its volume based on the change in water level. The Water Absorption Test involved immersing bioplastic samples in water for 24 hours and recording the difference in weight before and after soaking. Lastly, the Shrinkage in Thickness Test measured the reduction in sample thickness after oven-drying, using a digital caliper for accurate readings.

G. *Formula*s

Physical properties

To determine the water absorption of a bioplastic sample, the percentage increase in weight due to water uptake was calculated. In the formula, W_w is the wet weight of the sample after soaking, and W_d is the dry weight before soaking.

$$\text{Water Absorption (\%)} = \frac{W_w - W_d}{W_d} \times 100 \tag{1}$$

The shrinkage in thickness was measured to evaluate the dimensional stability of the bioplastic after drying. T_0 is the initial thickness before drying, and T_f is the final thickness after drying.

$$\text{Shrinkage in Thickness (\%)} = \frac{T_0 - T_f}{T_0} \times 100 \tag{2}$$

To compute density, the sample's mass was divided by its volume using water displacement. In this equation, m represents the mass of the sample in grams, and V is the volume in cubic centimeters.

$$\text{Density (g/cm}^3) = \frac{m}{V} \tag{3}$$

Mechanical properties

The tensile strength (TS) of each bioplastic sample was determined by dividing the maximum applied force by the product of the specimen's width and thickness. In the equation, F is the maximum force in newtons (N), W is the width in millimeters (mm), and t is the thickness in millimeters (mm).

$$\text{TS} = \frac{F}{W \cdot t} \tag{4}$$

The elongation percentage measures how much the material can stretch before breaking. In this formula, L_0 is the initial length of the sample, and L_f is the final length after stretching.

$$\text{Elongation (\%)} = \frac{L_f - L_0}{L_0} \times 100 \tag{5}$$

Biological property

To evaluate biodegradability, the percentage of weight loss after soil burial was calculated. Here, W_0 is the initial sample weight, and W_f is the final weight after 7 days of burial.

$$\text{Biodegradability}\ (\%) = \frac{W_0 - W_f}{W_0} \times 100 \tag{6}$$

III. RESULT AND DISCUSSION

This section presents the results of an investigation into the properties of bioplastics formulated from Cardava banana peel (*Musa balbisiana*), eggshell, and rice husk waste at varying proportions of 95:2.5:2.5, 92:4:4, and 90:5:5. The focus is on their biodegradability, mechanical properties—including tensile strength and percentage elongation—and physical characteristics such as density, water absorption, and thickness shrinkage. The findings reveal significant differences in biodegradability and mechanical performance among the different bioplastics, which are critical for assessing their potential applications in sustainable materials. The following subsections will detail the specific properties measured and provide a comparative analysis with Low-Density Polyethylene (LDPE) plastic.

TABLE 1. Ranks of Bioplastics

Properties	Bioplastic 1	Bioplastic 2	Bioplastic 3	LDPE
Biodegradability	4	3	2	1
Tensile	1	3	2	4
Elongation	3	2	1	4
Density	3	2	1	4
Water Absorption	1	2	3	4
Thickness	3	2	1	4
Total	**15**	**14**	**10**	**21**

TABLE 2. Score Scale and Description

Classification	Description
Poor	It suggests a poor summation with a range of 0-6.
Unsatisfactory	It suggests an unsatisfactory summation with a range of 7-12.
Satisfactory	It suggests a satisfactory summation with a range of 13-18.
Very satisfactory	It suggests a very satisfactory summation with a range of 19-24.

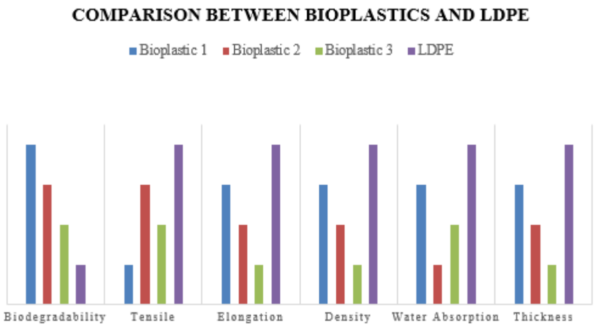

Fig. 1. Chart for Comparison of Bioplastics and LDPE

Table 1 depicts the ranks of bioplastics, while Table 2 shows the score scale and description. Table 1 indicates that LDPE has a score of 21, reflecting satisfactory properties. Bioplastics 1 and 2 scored 15 and 14, respectively, which also suggests satisfactory performance. In contrast, bioplastic 3, with a score of 10, indicates unsatisfactory properties. Of all the bioplastics, bioplastic 1 is the most similar to LDPE. Figure 1 provides a graphical representation of the scores for each treatment, allowing for a direct comparison between the bioplastics and LDPE.

TABLE 3. Summary of Results

Parameter	Bioplastic 1	Bioplastic 2	Bioplastic 3	LDPE (Plastic)
Biodegradability (%)	58.9	37.4	28.0	0
Tensile Strength (kPa)	176.31	**197.10**	187.09	**3487.61**
Elongation (%)	**4.84**	4.33	2.89	**13.40**
Density (g/cm³)	**0.445**	0.42	0.41	0.92
Water Absorption (%)	**74.2**	60.6	**53.5**	~0.01
Shrinkage in Thickness (%)	**67.55**	69.7	**78.25**	N/A

The performance of the bioplastic samples was evaluated based on six parameters: biodegradability, tensile strength, elongation, density, water absorption, and shrinkage in thickness. Each parameter demonstrated distinct trends depending on the proportion of banana peel starch and fillers used in the formulation.

In terms of biodegradability, Bioplastic 1 showed the highest percentage weight loss at 58.9%, indicating the most effective degradation over the 7-day soil burial period. This result is attributed to its high starch content and lower filler ratio, making it more susceptible to microbial attack. Bioplastic 2 and Bioplastic 3 followed with biodegradability rates of 37.4% and 28.0%, respectively. In contrast, the conventional plastic low-density polyethylene (LDPE) exhibited 0% biodegradability, highlighting the environmental advantage of the starch-based alternatives.

The mechanical property results revealed that Bioplastic 2 had the highest tensile strength at 197.10 kPa, suggesting that its balanced starch-to-filler ratio contributed to a more structurally reinforced matrix. Bioplastic 3 followed closely with 187.09 kPa, while Bioplastic 1 had a slightly lower strength at 176.31 kPa. However, LDPE far outperformed all bioplastics with a tensile strength of 3487.61 kPa, underscoring the industrial durability of petroleum-based plastics.

For elongation, which measures the flexibility of the material, Bioplastic 1 showed the highest value at 4.84%, followed by Bioplastic 2 at 4.33%, and Bioplastic 3 at 2.89%. The trend suggests that higher starch content enhances elasticity, while increased filler content reduces flexibility. LDPE, as expected, exhibited superior flexibility with an elongation of 13.40%.

Density measurements indicated that Bioplastic 1 had the highest density among the bioplastics at 0.445 g/cm³, followed by Bioplastic 2 at 0.42 g/cm³ and Bioplastic 3 at 0.41 g/cm³. Although all three bioplastics showed significantly lower densities than LDPE (0.92 g/cm³), the relatively higher density of Bioplastic 1 suggests better compactness, which may influence performance in applications requiring moderate strength and structural integrity.

Water absorption results showed a decreasing trend with increasing filler content. Bioplastic 1 absorbed the most water at 74.2%, which can be explained by the hydrophilic nature of starch. Bioplastic 2 and Bioplastic 3 absorbed 60.6% and 53.5% water, respectively. The lower water uptake of Bioplastic 3 indicates improved resistance to moisture, a result of higher filler composition. In comparison, LDPE absorbed negligible moisture (around 0.01%), a characteristic feature of synthetic plastics.

Lastly, the shrinkage in thickness, which assesses dimensional stability during drying, was least observed in Bioplastic 1 (67.55%), followed by Bioplastic 2 (69.7%) and Bioplastic 3 (78.25%). This suggests that lower filler content results in reduced shrinkage, offering better consistency in product shape and thickness. The trend indicates that while fillers enhance strength and moisture resistance, they may also contribute to greater dimensional changes upon drying.

IV. CONCLUSION

This study explored the potential of bioplastics made from Cardava banana peel starch, eggshell, and rice husk as sustainable alternatives to conventional petroleum-based plastics. Among the three bioplastic formulations tested, Bioplastic 1—comprising 95% banana peel starch and 5% fillers (2.5% eggshell and 2.5% rice husk)—exhibited the most favorable overall performance in terms of biodegradability and flexibility. It demonstrated the highest biodegradation rate at 58.9%, confirming its rapid breakdown in soil compared to LDPE, which showed 0% degradation. Bioplastic 1 also recorded the highest elongation percentage (4.84%) and the highest density among the bioplastics (0.445 g/cm^3), values that are closer to the physical characteristics of LDPE.

Meanwhile, Bioplastic 2, formulated with 92% starch and 8% fillers, yielded the highest tensile strength at 197.10 kPa, suggesting better mechanical reinforcement. Bioplastic 3, with the highest filler content (10%), had the lowest water absorption (53.5%) and the highest shrinkage in thickness (78.25%), indicating improved moisture resistance but reduced dimensional stability.

Statistical analyses confirmed significant differences in biodegradability, tensile strength, elongation, water absorption, and shrinkage in thickness across the bioplastics, with p-values below the 0.05 threshold. Only density showed no statistically significant difference, indicating that filler variation had little effect on this property.

Overall, the study confirms that bioplastics made from agricultural waste materials can provide promising eco-friendly alternatives to conventional plastics. While they currently do not match LDPE in terms of tensile strength and water resistance, their biodegradability, sustainability, and potential for further enhancement through formulation optimization make them viable for single-use or lightweight applications.

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