ROPE: Revolutionary Biodegradable Plastic from Orange *(Citrus sinensis (L.) Osbeck)* and Rambutan *(Nephelium lappaceum L.)* Peels

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Abstract— *This study explores the potential of creating biodegradable plastic using cellulose extracted from orange and rambutan peels. With increasing concerns over plastic waste, developing eco-friendly alternatives has become essential. In this research, cellulose from both peels was used to produce bioplastics, and their biodegradability, physical properties (density, water absorption, thickness), and mechanical properties (tensile strength, elongation) were analyzed for three ratios. Bioplastic 1 exhibited the highest density 1.35 g/cm³ and tensile strength 76.46 kPa, indicating a compact, stable structure resistant to deformation. This balanced composition of cellulose from both peels contributes to its high tensile strength, making it a durable, strong candidate for applications requiring structural integrity. Bioplastic 2 high rambutan cellulose content, providing both strength and flexibility. Bioplastic 3 had the highest biodegradability 38.75% and water absorption 24.16% but lower density 1.35 g/cm³, thickness 59%, tensile strength 30.81 kPa. Overall, Bioplastic 1 is the most comparable to LDPE plastics based on these results. Kruskal Wallis test results for all the parameters used show that p = 0.126756942 for biodegradability indicates no significant difference in biodegradation between the samples: BP 1, BP 2, and BP 3. For the physical properties used to test the samples, it shows that there's a significant difference in density and water absorption between the samples, but for their thickness, it indicates a significant difference in thickness between the three samples. The differences in thickness are statistically meaningful, since p = 0.000265 is less than 0.05. For the mechanical properties of these samples, Kruskal-Wallis test (p = 0.0668) shows no statistically significant difference in tensile strength between the samples, while p = 0.0059 shows a significant difference in elongation among the three bioplastics. The results from this study shows that the cellulose of orange and rambutan peels can be used to make a bioplastic. However, it is recommended to develop methods to enhance the production of the product.*

Keywords—*Agricultural use, Alternative materials, Biodegradability, Bioplastic, Orange and Rambutan Peels Cellulose, Biodegradability, Density, Water Absorption, Thickness, Tensile Strength, Elongation, Statistical Analysis, Kruskal-Wallis test, ANOVA.*

I. INTRODUCTION

Plastic pollution is a serious environmental problem due to the overuse and improper disposal of plastic products. Millions of tons of plastic are made annually, and a large amount of it ends up in rivers, seas, and other bodies of water where it endangers human health, ecosystems, and wildlife. Plastics take hundreds of years to break down, which causes garbage to build up and disturb ecosystems as well as enter the food chain. According to the International Union for Conservation of Nature, more than 400 million plastic tons are produced every year for use in a multitude of applications. Plastic makes up at least 80% of all marine waste, which includes everything from surface waters to deep-sea sediments, and at least 14 million tons of it ends up in the ocean every year (IUCN, 2020).

Bioplastics are biodegradable polymers produced from live creatures. These polymers can be broken down in a way that is beneficial to the environment by microorganisms and water in compost piles (Ramadhan & Handayani, 2020). There are three categories for bioplastics. First are the petroleum-based (fossil-based) biodegradable polymers. Second comes bio-petroleum, or bioplastics derived from other source materials and petroleum. Plants and animals-sourced bioplastics are naturally sourced, third in category. Bioplastics have several positive environmental effects that include lowered carbon footprint and green house (GHG) emission, less energy to produce, decreasing permanent waste, increased environmental security, and a potential replacement for petroleum plastics through sustainable means.

Orange peel and rambutan peels are also remarkable for their structures that include pectin, cellulose, and lignin. These play a major role in improving the thermal and mechanical qualities of bioplastics. The orange peels, for example, have proven to be more superior compared to other bioplastic formulations such as starch-gelatin matrices in mechanical functionality. Additionally, the blending with these natural ingredients increases the strength and biodegradability of the end products, hence a future prospective for green packaging and other applications.

II. METHODOLOGY

A. Collection of Raw Materials

The raw materials were collected from sources that sell oranges and rambutan like markets and fruit stalls. The orange fruits were bought at Sta. Cruz market and the rambutan fruits were bought from a fruit stall located at Pasonanca by-pass road, Zamboanga City. According to Egbuonu (2016), one point sixty-seven (1.67) kilogram of Citrus sinensis produces one (1) kilogram of peel, one (1) kilogram of peel produces forty-four (44) grams of cellulose. The collected oranges were twenty-five (25) kilograms as needed for the experiment to obtain eight hundred ten (810) grams of orange cellulose. Two-point four (2.4) kilograms of rambutan fruit produces one (1) kilogram of rambutan peels, one (1) kg of rambutan peel produces 75 grams of cellulose according to Albuquerque et al, (2023). Ten (10) kilograms of rambutan fruits were collected to produce eight hundred ten (810) grams of rambutan cellulose.

B. Preparation of Materials

The ingredients that were used include distilled water, vinegar, glycerol, cornstarch, food coloring and peels. The distilled water, vinegar and cornstarch were bought at Cecile's Pharmacy, Divisoria Zamboanga City. While the food coloring was purchased at Yubenco Putik, Zamboanga City and the glycerol was bought from a local bakeshop in town.

C. Extraction of Cellulose from Orange and Rambutan Peels

Before the cellulose extraction, the collected peels were cleaned and washed with running tap water to get rid of dirt and other contaminants. Orange and rambutan peels were ground separately using a grinder then the ground peels were soaked for three (3) hours in an alkaline solution (NaOH) which helps dissolves the hemicellulose and lignin of the peels.

After three (3) hours, the mixture was rinsed with distilled water to neutralize and remove excess alkali. After rinsing the mixture, it was heated these peels with NaOH in a burner and the mixture was stirred occasionally. After one to two (1-2) hours, the mixture was allowed to cool, then it was filtered using a mesh to separate the cellulose and was rinsed with distilled water to eliminate any residual alkali. After rinsing, it was mixed with Zonrox for chlorination to totally remove lignin and the cellulose.

D. Formulation of Reagent Proportions

The following proportions were used for the samples of bioplastic: 1350 mL distilled water, 295.8 mL glycerol, 295.8 mL vinegar, 270 g of cornstarch and 540 g of combined orange and rambutan cellulose with a volume of 600 cubic centimeters of each proportion.

E. Bioplastic Production

The amount of distilled water, vinegar, glycerol, cornstarch and cellulose from orange and rambutan were measured for each bioplastic sample. All components were combined including food coloring (blue for bioplastic 1, yellow for bioplastic 2, and green for bioplastic 3) for its identification. The mixture was cooked on a burner until thick paste without air bubbles is produced. While the mixture is heated to low-medium, it was constantly stirred and was slowly boiled. The total heating was between 10 minutes to 15 minutes. The sticky paste was taken off a pan and was placed in a rectangular shaped molder with 2mm thickness with plastic cover. A firm stick and a plastic cover were used to smoothen the surface of the heated mixture. A toothpick was used to poke any visible bubbles to get rid of them. The same procedure was done to the second and third proportions.

F. Testing

To evaluate the quality and characteristics of the samples of the three (3) proportions, six (6) tests with ten (10) trials were carried out on physical properties such as water absorption, density and thickness; mechanical properties such as tensile strength and elongation; and lastly, on biodegradability test. Each parameter was evaluated ten (10) times.

Since LDPE (Low-Density Polyethylene) plastic is typically utilized for packaging materials, the bioplastics made for the experiment were also contrasted with commercial plastics. Trash bags were utilized to test the LDPE since it is often used. Thirty (30) samples of each proportion were created by evenly cutting the bioplastics into 10 × 10 cm pieces. To prevent bias, the samples required for this production were chosen at random.

For the biodegradability test, 10 cm by 10 cm strips were cut from three (3) proportions and one (1) LPDE plastic bag (Madden, 2020) for testing, after which it was weighed, put on a sizable plastic cover, and buried at a depth of 8 cm (Rahman et al., 2019). They were buried eight (8) centimeters deep for the biodegradability test.

The physical properties of the material were also tested which includes the density, water absorption, and percentage shrinkage. Each sample was weighed using a digital scale to record its initial weight before testing In calculating the density, the mass of the sample was divided by its volume. The mass of these samples was obtained by using a digital scale and its volume by displacement method. In measuring its volume, the beaker was filled with 200 ml of water. Using the submerged samples from the density test, they were continuously submerged for 24 hours. The thickness of the bioplastic was measured using a digital caliper for accuracy based on the air-dried samples.

The ASTM D412 test method is commonly used to evaluate the tensile properties of rubber, elastomers, and similar materials, including bioplastics. However, this research only used a manual testing where digital spring scale and binder clips were used to pull the samples to measure the applied force.

It's important to comprehend how a bioplastic product reacts to tensile pressures and how far it can stretch before breaking in order to evaluate its performance in various applications. The percentage elongation of the bioplastic sample measures how much the sample stretches before breaking. This test gives important information about the material's capacity to deform under stress by determining how much a bioplastic can stretch before breaking. High elongation percentages are frequently a sign of a bioplastic's increased resilience and ability to withstand mechanical stress without breaking, which makes them more appropriate for practical applications.

G. Formulas

Biodegradability property

The degradation rate of the material was calculated using the fomula shown, where the sample's initial weight (w1) was determined by weighing prior to its burial in the ground, and the sample's final weight (w2) was determined upon its unearthing one week later.

$$\text{Biodegradability (\%)} = \frac{W_1 - W_2}{W_1} x\ 100 \quad (1)$$

Physical property

The mass and volume of the sample was measured, and the density of bioplastics was calculated using the following formula:

$$p = \frac{m}{v} \quad (2)$$

In order to evaluate the water absorption capacity, bioplastic samples were weighed after being immersed in water for a predetermined amount of time and is calculated using this formula:

$$\text{Water Absorption (\%)} = \frac{W_t - W_0}{W_0} x\ 100 \quad (3)$$

The shrinkage percentage of the sample was calculated from the difference of the original thickness and the final thickness of the sample. The percentage shrinkage in thickness of an object were calculated using the following formula, where it needs to obtain the initial thickness of bioplastic in a liquid state and the final thickness when it is totally dried.

$$\text{Shrinkage (\%)} = \frac{\text{Original Thickness - Final Thickness}}{\text{Original Thickness}} x\ 100 \quad (4)$$

Mechanical property

For the tensile strength of the sample, two binder clips were used on both ends of the bioplastic, with one clip fastened to the specimen in place and another clip being used to hold the spring scale's hook. The scale was pulled slowly until the sample breaks. For accurate data, the process for this test was recorded through a video. The following formula was used to calculate the tensile strength of the sample:

$$\text{Tensile Strength} = \frac{\text{Maximum Load}}{\text{Original Cross-Sectional Area}} \quad (5)$$

The percentage elongation of the bioplastic sample measures how much the sample stretches before breaking and was computed using this formula:

$$\text{Elongation (\%)} = \frac{\text{Final Length- Original Length}}{\text{Original Length}} \quad (6)$$

To guarantee that the results are accurate, ten trials were conducted for each parameter. The characteristics of the Low-Density Polyethylene kind of plastic bag were contrasted with the results of the biodegradability, physical tests and mechanical tests. The testing findings served as the basis for the interpretation and data analysis. The data were evaluated for normality using Shapiro-Wilk Test before applying parametric or nonparametric statistical methods for test of significance at α= 5% and p= 0.05 in order to compare the quality of this study. For normal and homogenous variance data, one-way ANOVA and Kruskal=Wallis were used.

III. Result and Discussion

This chapter highlights the potential of bioplastics as an eco-friendly alternative to conventional plastics, reducing plastic waste and promoting sustainability, while also addressing the need for further optimization in their properties to match the performance of traditional plastics.

The main polymer that was used in producing a starch-based bioplastic was the cellulose of the raw materials which are the orange and rambutan peels. In order to enhance the properties and ability to process, two kinds of cellulose were combined and were mixed with cornstarch as an additive to improve its quality.

- Bioplastic 1 - have a glossy surface, which enhances their aesthetic appeal and potential for use in packaging applications. It also has wrinkled edges.
- Bioplastic 2- is thinner compared to bioplastics 1 and 3. It is composed of 30% orange peels and 70% rambutan peels. According to Soberanes et al. (2022), the lesser the presence of orange peel means that the overall strength and ability to form a thicker network are reduced. The higher percentage of rambutan, which contains different polymer compositions, can lead to inconsistent bonding and a more porous structure, decreasing the overall thickness and sturdiness of the bioplastic (Hugo et al., 2024). This bioplastic also have a glossy surface and also has a kind of rough texture.
- Bioplastic 3- have a little glossy surface and is thicker than the bioplastics 1 and 2. In the study of Espinoza et al. (2018), it was stated that the synergetic effects of the cellulose and pectin present in orange peel help create a stronger bond when supported by more orange peel.

LDPE (Low-Density Polyethylene) and bioplastics have quite different material characteristics and environmental effects. Bioplastics are biodegradable and an environmentally beneficial substitute for petroleum-based plastics since they are derived from renewable resources like cornstarch, sugarcane, or algae. In contrast to LDPE, they often exhibit lower tensile strength and elongation rates, rendering them more rigid and susceptible to breaking under stress unless specifically designed for flexibility. Bioplastics, on the other hand, are less harmful to the environment, but they are usually more expensive to produce and may not currently have the same mechanical qualities as LDPE in many applications.

TABLE 1. Biodegradability Rate of Bioplastic 1, 2, 3, and LDPE

Biodegradability	Rate
Bioplastic 1	32.50%
Bioplastic 2	28.86%
Bioplastic 3	38.75%
LDPE	0%

After 7 days underground, bioplastics showed signs of degradation—color changes, tearing, and in some cases, disappearance. Bioplastics 1 (BP 1) and 3 (BP 3) degraded more than Bioplastic 2 (BP 2). BP 3 degraded the fastest due to high orange peel content, which is rich in pectin and cellulose. BP 2, which had more rambutan peel (higher lignin/tannin), degraded the slowest. Statistical Analysis (Kruskal-Wallis, p = 0.127): No statistically significant difference in biodegradability across the samples.

TABLE 2. Density of Bioplastic 1, 2, 3, and LDPE

Density	Average
Bioplastic 1	2.06 g/cm³
Bioplastic 2	1.49 g/cm³
Bioplastic 3	1.35 g/cm³
LDPE	0.92 g/cm³

BP 1 (equal mix of orange and rambutan peels) had the best structural integrity and density. BP 3 (more orange peel) was fibrous and less dense. BP 2 (more rambutan peel) was looser in structure. Statistical Analysis: Kruskal-Wallis test showed significant differences in density (p = 0.00013).

TABLE 3. Water Absorption of Bioplastic 1, 2, 3, and LDPE

Water Absorption	Average
Bioplastic 1	23.17%
Bioplastic 2	15.62%
Bioplastic 3	24.16%
LDPE	0%

Higher orange peel content (in BP 3) increases water absorption due to pectin. Rambutan peels (in BP 2) reduce water absorption due to higher lignin/cellulose content. Statistical Analysis: No significant difference (p = 0.056) between the groups in terms of water absorption.

TABLE 4. Thickness of Bioplastic 1, 2, 3, and LDPE

Thickness	Average
Bioplastic 1	0.73 mm (63.5% shrinkage, **most shrinkage**)
Bioplastic 2	0.82 mm (59.5%)
Bioplastic 3	0.82 mm (59%, **least shrinkage**)
LDPE	0.05 mm (baseline)

BP 1's balanced composition gave it higher structural integrity. Excessive orange peel (BP 3) reduced thickness retention due to brittleness. Statistical Analysis: Kruskal-Wallis test indicated a significant difference in thickness across samples (p = 0.00027).

TABLE 5. Tensile Strength of Bioplastic 1, 2, 3, and LDPE

Tensile Strength	Average
Bioplastic 1	76.46 kPa
Bioplastic 2	44.59 kPa
Bioplastic 3	30.81 kPa
LDPE	6958.13 kPa

BP1's balance of flexibility (pectin in orange) and rigidity (lignin/cellulose in rambutan) creates a strong and stable material. BP3's high orange content increases softness and reduces tensile resistance. BP2 is rigid but less flexible, leading to moderate strength. Statistical Analysis using Kruskal-Wallis Test shows that there is no statistically significant difference between the tensile strengths of BP1, BP2, and BP3 since p= 0.0668.

TABLE 6. Elongation Rate of Bioplastic 1, 2, 3, and LDPE

Percentage Elongation	Average
Bioplastic 1	5.11%
Bioplastic 2	3.56%
Bioplastic 3	3.75%.
LDPE	7.79%

BP1's even composition provides optimal flexibility and strength. BP2's higher rambutan content leads to more rigidity and less stretchability. BP3's excess orange content reduces rigidity, resulting in brittleness. The Kruskal-Wallis Test result shows that p = 0.0059 and it is an indication that there is a significant difference in elongation between bioplastic samples.

TABLE 7. Overall ranking of bioplastics based on performance parameters

Properties	BP 1	BP 2	BP 3	LDPE
Biodegradability	2	3	4	1
Density	1	2	3	4
Water Absorption	2	3	1	4
Thickness	4	3	2	1
Tensile Strength	3	2	1	4
Elongation	3	1	2	4
Total:	**15**	**14**	**13**	**18**

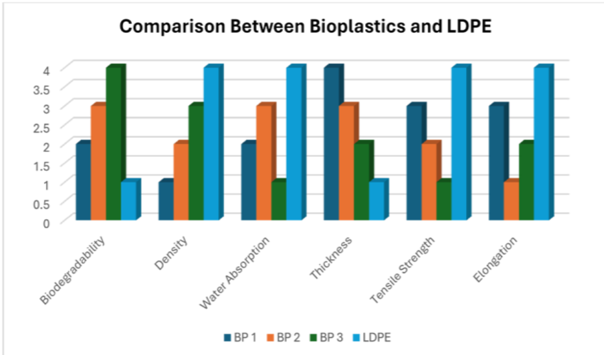

Fig. 1. Chart for the Comparison of Bioplastics and LDPE plastic

Table 7 shows the ranking of the bioplastics. LDPE achieved the highest total score of 18, followed by BP 1 with 15, BP 2 with 14, and BP 3 with the lowest score. Based on the score scale presented in Table 4.14, LDPE falls within the very satisfactory range of 17–21, compared to the other bioplastics produced. The bioplastics are classified as satisfactory, as it suggests satisfactory summation range of 12-16.

Figure 1 shows the graphical comparison of the bioplastics and LDPE plastic, BP 1 performs best in thickness, while BP 3 biodegrades faster compared to other BP and LDPE. Both of these bioplastics provides a satisfying result in different properties. BP 1 is best for its biodegradability, density and tensile strength. While BP 2 is only best for its two properties which are thickness and elongation rate. Therefore, BP 1 is useful as an alternative for the conventional plastic. This innovative approach not only addresses pressing environmental concerns but also leverages agricultural resources efficiently, highlighting the potential for bioplastics to play a crucial role in reducing plastic pollution and promoting sustainable material practices.

IV. Conclusion

As an environmentally friendly and sustainable alternative of conventional plastics, this research has shed a significant insight into the bioplastics' potential. These are the following findings on the experiment conducted for this research:

A. Biodegradability Test:

BP 3 decomposes faster than BP 1 and BP 2, with higher cellulose content from orange peel enhancing biodegradability by promoting microbial activity and moisture retention. Kruskal Wallis test results (p=0.126756942) show no significant difference in biodegradation between the samples: BP 1 (32.50%), BP 2 (28.86%), and BP 3 (38.75%). The differences in biodegradability are due to varying celluloPPse proportions from orange and rambutan peels.

B. Physical Properties:

- *Density:* BP 1 (2.06 g/cm³) has the highest density among the bioplastics. The interaction between cellulose from different peels forms a more compact structure, resisting deformation. Kruskal Wallis test results ($p = 0.000132123$) show a significant difference in density between the samples: BP 1 (2.06 g/cm³), BP 2 (1.49 g/cm³), and BP 3 (1.35 g/cm³).
- Water Absorption: BP 3 (24.15%), with 70% orange peels and 30% rambutan peels, has the highest water absorption due to the higher hydrophilicity from the orange peel content. Orange peels increase water absorption, while rambutan peels, with lower cellulose, reduce it. Kruskal-Wallis analysis ($p = 0.0559$) shows no statistically significant difference in water absorption among the three bioplastics: BP 1 (23.17%), BP 2 (15.62%), and BP 3 (24.16%). The differences are not strong enough to be statistically meaningful.
- Thickness: BP 2 shows the greatest reduction in thickness due to the dominant presence of rambutan cellulose (70%), which strengthens the structure but reduces thickness as the solvent evaporates. The higher thickness in BP 2 suggests that rambutan peels contribute more to bioplastic thickness due to their high fiber and lignin content. KruskalWallis analysis ($p = 0.000265$) indicates a significant difference in thickness between the three samples: BP 1 (59.5%), BP 2 (63.5%), and BP 3 (59%). The differences in thickness are statistically meaningful.

C. Mechanical Properties:

- *Tensile Strength:* Equal proportions of peels show higher tensile strength due to optimal molecular cross-linking and a balanced polymer network. BP 1 (50% orange, 50% rambutan) has the highest tensile strength (76.46 kPa) due to the balance of rigidity (lignin, cellulose) and flexibility (pectin). BP 3 (70% orange, 30% rambutan) has the lowest tensile strength (30.81 kPa) due to excess pectin, making it softer. BP 2 (30% orange, 70% rambutan) is strong but more rigid. Kruskal-Wallis test ($p = 0.0668$) shows no statistically significant difference in tensile strength between the samples: BP 1 (76.46 kPa), BP 2 (44.59 kPa), and BP 3 (30.81 kPa). The differences are not statistically meaningful.
- *Elongation:* BP 2 has the highest elongation (3.75%) due to its balanced composition of rambutan and orange peel, offering both strength and flexibility. BP 3 (1.06%) has the lowest elongation because its high pectin content makes it brittle. BP 2 falls between, with some rigidity from rambutan but not as much as BP 3. Kruskal-Wallis analysis ($p = 0.0059$) shows a significant difference in elongation among the three bioplastics.

The ideal proportions to use in producing bioplastics as an alternative for conventional plastics is 50% orange peels and 50% rambutan peels. It was concluded that the BP 1 has the highest satisfactory classification followed by the BP 2 based on the results from the tests conducted in this study.

D. Comparison:

When compared to LDPE plastic, the three bioplastics (BP 1, BP 2, and BP 3) show varying performance. BP 1 (50% orange peels, 50% rambutan peels) ranked first, offering the best tensile strength and elongation, making it a strong, flexible, eco-friendly alternative to LDPE. BP 2 (30% orange, 70% rambutan) ranked second excelling in biodegradability, thickness and water absorption, suitable for flexible packaging but not as strong as BP 1 or LDPE. BP 3 (70% orange, 30% rambutan) ranked last, underperforming in both strength and flexibility, making it less suitable for most applications compared to BP 1 and BP 2.

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