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MangFILM: Development of Mango (*Mangifera indica L.*) Seed as Starch Source of Bioplastic Mulch Film with Dried Guyabano (*Annona muricata L.*) Leaves and Additives as an Alternative to Traditional Mulch Film

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Abstract— *This study presents the formulation of bioplastic mulch films made from varying ratios of dried guyabano leaves and mango seed starch, highlighting their potential as sustainable alternatives to traditional plastics. Ratio three stood out as the best among the three ratios, outperforming other ratios in some parameters. Ratio three demonstrated the highest average moisture retention, with Levene Test confirming equal variances and Shapiro-Wilk Test indicating significant deviation from normality. A Kruskal-Wallis test revealed no significant differences in moisture retention among the ratios. In impact resistance, Ratio three achieved an average of a specific value, with significant differences confirmed by Kruskal-Wallis testing. However, its tensile strength was only a specific value, falling below the required threshold, with Levene Test showing equal variances and significant deviation from normality. For percent elongation, Ratio three had the highest at a specific percentage, but no significant differences were observed among groups. Its biodegradability averaged a specific value, surpassing the effective threshold, with significant differences indicated by ANOVA. A t-test revealed no significant difference in overall performance between bioplastic and traditional mulch films, suggesting that bioplastic mulch films can serve as viable alternatives. Recommendations for enhancing bioplastic mulch films include refining mango seed starch, testing various beeswax concentrations, conducting water absorption tests, and exploring alternative materials to improve mechanical properties for agricultural use.*

Keywords—*Agricultural use, Alternative materials, Biodegradability, Bioplastic, Guyabano leaves, Impact resistance, Soil moisture retention, Mango seed starch, Statistical analysis, Tensile strength, Kruskal-Wallis test, ANOVA.*

I. Introduction

As cities expand rapidly and the dependence on plastic continues to rise, managing plastic waste has become a critical challenge that impacts everyone around the world. In places where waste management systems are not up to par or completely absent, plastic waste is often poorly handled, resulting in pollution that harms oceans and waterways. This mismanaged plastic waste (MPW) is a major contributor to ocean pollution, with approximately 360,000 metric tons of ocean plastic waste entering the seas each year. This situation is exacerbated by ineffective waste management systems and high population density, which together create substantial environmental challenges (Cipan, 2023). A crucial finding in a study by Cipan (2023) highlights the necessity of implementing targeted strategies and advanced technologies to address plastic waste and improve waste management practices. An essential starting point in this effort is the reduction of single-use plastics. While individual actions to minimize plastic consumption are important, there is also an urgent need for comprehensive policy changes, such as the prohibition of single-use plastics, to achieve a significant reduction in plastic waste.

To better understand the broader implications of plastic pollution, it is essential to examine specific sources, particularly within agricultural practices like the use of plastic mulch films. These films play a significant role in boosting crop yields around the world. However, they also contribute notably to both microplastic and microplastic pollution in agricultural soils during degradation periods and the difficulties associated with their disposal (Salama & Geyer, 2023). In the Philippines, where waste generation rates are among the highest globally, the improper disposal of these films exacerbates an already critical waste management issue (RTS, 2024). The widespread use of non-biodegradable plastic mulch films in agriculture raises pressing concerns about environmental sustainability. Their persistence in the soil and the lack of effective disposal options can result in accumulating plastic waste. Moreover, plastic production and its accumulation in the environment are increasing at an alarming rate, driven by indiscriminate usage, insufficient recycling efforts, and the deposition of waste in landfills (Kumar et al., 2021).

Conventional plastics made from petroleum can be effectively replaced with biodegradable materials, such as starch. Starch is not only readily available but also both effective and biodegradable, making it a great substitute for traditional plastics. It’s used in any different fields, like food, packaging, and medicine. Bioplastics often utilize starch as the primary raw material, benefitting from its abundance and renewability as a natural polymer (Rendón-Villabos et al., 2022). The development and research of starch-based bioplastics offer a promising avenue to replace petroleum-based plastics. One such interesting bioplastic feedstock is mango (*Mangifera indica L.*) seeds, which make up approximately 17-22% of the fruit. Normally discarded as waste once the fruit has been eaten, these seeds, together with the peel, are a cheap and readily accessible source for starch extraction (Admase et al., 2022). Utilizing the mango seeds for their significant starch content offers a promising alternative for bioplastic production. Additionally, incorporating dried guyabano (*Annona muricata L.*) leaves, which are also abundant in the Philippines, can enhance the mechanical strength of the bioplastic. These leaves possess antimicrobial properties that may reduce the decay rate of the bioplastic, aligning with the study's goal of extending the lifespan of bioplastic mulch films while providing added benefits for agricultural applications. Furthermore, adding glycerol as a plasticizer in the formulation can improve the flexibility of the bioplastic mulch films. However, the varying amounts of glycerol have an influence on the mechanical performance of the final product.

Bioplastic mulch films made from mango seed starch present an innovative agricultural solution by repurposing waste. However, there is a research gap regarding dried guyabano (*Annona muricata L.*) leaves, which are high in cellulose and could enhance bioplastic strength. Their benefits and use as a filler remain unexplored. Addressing this could lead to more sustainable bioplastic mulch solutions and advance agricultural innovation.

II. METHODOLOGY

A. Collection of Raw Materials

The raw materials for the bioplastic, specifically mango (*Mangifera indica L.*) seed waste and guyabano (*Annona muricata L.*) leaves, were sourced from the researcher's backyard, local fruit stands, and public markets.

The extraction yield of mango seeds was found to be 53.89% (De Souza et al., 2021). Therefore, two hundred (200) grams of mango seeds can produce approximately one hundred and ten (110) grams of starch. The guyabano leaves were oven-dried at a temperature of 50°-65°C for (50) fifty minutes (Nhi et al., 2020).

B. Preparation of Materials

The other key ingredients utilized included distilled water, glycerol, and beeswax. Glycerol was purchased from KCC Watsons, and beeswax was acquired online. Distilled water was obtained from a local convenience store. The materials and equipment necessary for starch extraction from mango seeds comprised a blender, distilled water, a strainer with sieve no.80, and cheesecloth with a ratio of 2:1 for water to mango seeds. To produce the bioplastic, the following items were used: a pan, a stirrer, three (3) 1m x 1m molds made from plain sheets, a grinder, a strainer with sieve no.80, measuring cups, and a burner.

C. Extraction of Starch from Mango Seeds

The extraction of starch from mango seeds involved several key steps. The collected mango seeds were washed with tap water to remove impurities. The seeds were manually separated from the hull to extract the kernels and soaked in water for 6 to 8 hours to soften the seeds and facilitate starch extraction. After soaking, the seeds were drained and blended into a paste using a blender. This paste was mixed with distilled water and blended again to release the starch granules and create a smooth slurry.

The starch-containing liquid was filtered through cheesecloth to separate it from the insoluble fiber and proteins. The liquid was allowed to settle overnight for twelve hours. The upper layer of liquid starch was decanted, and the white material settled at the bottom was collected, rinsed with distilled water to clean it, and allowed to settle once more for six hours with 0.1 M sodium chloride ($NaCl$) (Shahrim et al., 2018). The collected starch was dried for 24 hours at 45°C using an oven dryer (Nguyen et al., 2022) before being collected as mango seed starch. The dried starch was sieved to obtain fine starch.

D. Formulation and Drying of Bioplastic Mulch Film

To formulate the bioplastic mulch film from mango seed, the materials were combined in a pan and the burner was set to low heat. The mixture was continuously stirred for about 5 to 7 minutes until it reached a slurry (paste-like) consistency and appeared cloudy. In the first three minutes of cooking, the mixture began to develop a sticky consistency. The stirring continued until the mixture slowly boiled, ensuring that no bubbles formed so that it lay smoothly in the mold. The mixture was poured into a sheet and was evenly spread.

E. Trials and Proportions

There were three samples produced during this experiment, each with different proportions of mango seed starch and dried guyabano leaves according to the specified ratios. For Ratio 1 (1:1), equal amounts of mango seed starch and dried guyabano leaves were incorporated. In Ratio 2 (1:2.5), a smaller amount of dried guyabano leaves was combined with a larger amount of mango seed starch. Lastly, in Ratio 3 (1:5), an even smaller amount of dried guyabano leaves was mixed with a significantly larger amount of mango seed starch.

F. Characterization of Bioplastic

The methodology for testing the bioplastic mulch film encompasses several key assessments. The Water Vapor Transmission Test, based on ASTM E96, measures the movement of water vapor through materials using an upright cup method with solid desiccant and liquid water setups to determine the water vapor transmission rate. The UV Resistance Test, following ISO 4892-3, simulates weathering effects by exposing the material to UV light in a controlled environment to assess its durability against sunlight.

The Chemical Resistance Test, guided by ASTM D543, evaluates the bioplastic's resistance to chemicals, such as pesticides, by immersing samples in chemical solutions for 24 hours and observing any mass changes and physical alterations. The Soil Temperature and Moisture Retention Test measures the film's effectiveness in retaining soil moisture and regulating temperature, which impacts plant growth by monitoring soil temperature and moisture levels before and after film application.

Regarding physical characteristics, the Thickness and Uniformity Test, conducted according to ASTM D6988, focuses on the material's thickness and uniformity. For mechanical properties, the Tear Resistance Test follows ISO 6383-2 to measure the force required to extend a tear in the film, while the Impact Resistance Test adheres to ASTM D1709, providing guidelines for determining the impact resistance of plastic films. The Tensile Strength Test, according to ASTM D638, assesses the force needed to stretch the bioplastic until it breaks, and the Percent Elongation Test measures how much the material can stretch before breaking.

The Biodegradability Test utilizes EN 17033 to determine the rate of aerobic biodegradation in soil through a soil burial method, assessing the weight loss of buried samples over time. This comprehensive testing framework ensures that the bioplastic mulch films are effectively evaluated for their intended agricultural applications.

G. *Formulas*

Physical property

The water vapor transmission rate is a standard procedure used to measure the rate at which water vapor passes through a material, it can be calculated using this formula, WVTR is the water vapor transmission rate (g/m²·day). ΔW is the change in weight of the desiccant or water cup (grams), A is the area of sample (m^2) and t is the time exposure (days) It is usually expressed in grams per square meter per day (g/m²·day).

$$WVTR = \frac{\Delta W}{A \times t} \quad (1)$$

The UV resistance test was used in this study to indicate degradation of the sample films due to UV exposure. Its weight loss was calculated using the following formula obtain the weight loss.

$$Weight\ loss = initial\ weight - final\ weight \quad (2)$$

To effectively measure and determine soil moisture percentage after conducting the Soil temperature and moisture retention test, the formula below was used.

$$Soil\ moisture\ percentage(\%) = \frac{W_{wet} - W_{dry}}{W_{dry}} \times 100\% \quad (3)$$

To determine the thickness of the specimens after conducting the Thickness and uniformity test, the arithmetic mean was calculated using this formula:

$$T = \frac{t_0 \mp t_1 \mp t_2 \mp t_3 \mp t_4}{5} \quad (4)$$

Where *t* represents all the points of the specimen to be tested.

Mechanical property

The Tear resistance of materials is often measured using specific formulas and test methods. The tear resistance σ, is calculated as follows:

$$\sigma = \frac{F_t}{d} \times 100\% \quad (5)$$

where F_t is the average tearing force in N, and d is the thickness of the specimens in mm.

To assess the specimen's ability to withstand sudden forces or impacts without failing, the following calculation was used to get the total penetration energy (W_t), expressed in Joules (J) for Impact resistance test.

$$W_t = m \times g \times H_o \quad (6)$$

Where m is the mass of the striker (kg), g is the acceleration due to gravity, and H_0 is the height of the fall (meters).

Tensile strength represents the maximum strength a material can withstand in tension before it breaks or fractures. Using the following formula, where *F* (expressed in N) is the maximum force applied to the specimen during the tensile test and *A* (expressed in m^2) is the area cross-sectional area of the test specimen. It is usually expressed in MPa.

$$Tensile\ strength = \frac{F}{A} \quad (7)$$

The elongation test measures the ability of a material to stretch or deform under tensile forces before it breaks or fails. It quantifies the material's ductility or plasticity, which is its ability to undergo plastic deformation without fracturing. It is calculated using a formula, where the initial gauge and final gauge is recorded.

$$\%elongation = \frac{L_f - L_o}{L_o} \times 100\% \quad (8)$$

Biological property

The weight loss of the sample was measured by weighing samples before the test for the initial sample weight (W_o) and its final weight (W_f) after the test. Percent weight loss was calculated with the following equation.

$$\%weight\ loss = \frac{W_o - W_f}{W_o} \times 100\% \quad (9)$$

III. Result and Discussion

This study evaluated the data from the formulation and testing of bioplastic mulch films to identify viable mixture ratios of dried guyabano leaves and mango seed starch. By examining their physical, mechanical, and biological properties, the research provided insights into effective mixtures for sustainable mulch films, contributing to the understanding of bioplastics in agricultural applications and their role in promoting environmentally friendly practices.

TABLE 1. Overall ranking of bioplastic mulch film ratios based on performance parameters

Parameters	Ranking		
	Ratio 1	Ratio 2	Ratio 3
Water vapor transmission rate	3	1	2
UV resistance test	3	1	2
Chemical resistance test	2	1	1
Soil temperature and moisture retention	3	2	1
Thickness and uniformity test	3	1	2
Tear resistance test	3	1	2
Impact resistance test	3	2	1
Tensile strength	2	3	1
Percent elongation	2	3	1
Biodegradability rate	3	2	1
Average	**2.7**	**1.7**	**1.4**
Final rank	**3**	**2**	**1**

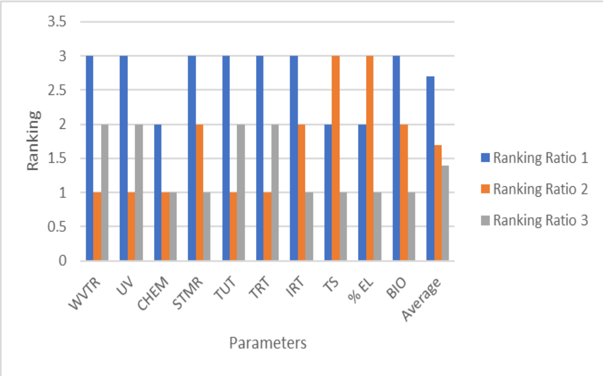

Fig. 1. Visual comparison of the ranking of ratios 1, 2, and 3

Table 1 represents the ranking of bioplastic mulch film based on the ratios of 1, 2, and 3, with one (1) being the highest rank and three (3) the lowest rank. These evaluations are based on different parameters necessary for evaluating the bioplastic mulch film. The overall ranking table evaluates three bioplastic mulch film ratios 1, 2, and 3 across various performance parameters. Ratio 2 consistently ranks highest in key areas such as water vapor transmission, UV resistance, and chemical resistance, showcasing its effectiveness in managing moisture and environmental challenges. Meanwhile, ratio 3 also performs well, particularly in soil temperature and moisture retention, impact resistance, tensile strength, and biodegradability, reflecting its strong structural integrity and sustainability features. Notably, both ratios 2 and 3 achieve an equal number of rank one (1) scores in several parameters; however, Ratio 3's overall mean rank of 1.4 positions it as the top performer among the three. Ratio 1 ranks last, with an average score of 2.7, indicating it may not be suitable for applications requiring high durability and flexibility. Overall, although ratio 2 is effective, ratio 3 higher average rank highlights its strengths, particularly in environmentally sustainable applications.

TABLE 2. Summary of all average results of comparisons between bioplastic mulch film (Ratio 3) and traditional mulch film

Parameters	Bioplastic mulch film (Ratio 3)	Commercial mulch film
Water vapor transmission rate	$470.37 g/m^2 day$	$3.8 g/m^2 day$
UV resistance test	31 %	10 %
Soil temperature and moisture retention	19.87 %	20 %
Thickness and uniformity test	0.032 mm	0.03 mm
Tear resistance test	$94.176 N/mm$	$490.5 N/mm$
Impact resistance test	50 % passed	50 % passed
Tensile strength	0.000512 MPa	0.00162955 MPa
Percent elongation	21 %	54 %
Biodegradability rate	47.50 %	0 %

The data analysis in Table 2 was conducted using SPSS provided insights into two groups. Group 1 (Bioplastic mulch film) had an average score of 81.55, while Group 2 (Traditional mulch film) scored lower at 69.81. Both groups exhibited significant variability in their scores, with standard deviations of 148.67 for Group 1 and a higher 159.16 for Group 2. This suggests that although Group 1 generally performed better, there was considerable fluctuation in scores within both groups. The standard error means, at 49.56 for Group 1 and 53.05 for Group 2, further emphasize the precision of these average scores.

TABLE 3. Independent test samples

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Score	Equal variances assumed	0.006	0.941	0.162	16	0.874	11.73521	72.59770	-142.165504	165.63546
	Equal variances not assumed			0.162	15.926	0.874	11.73521	72.59770	-142.223305	165.69347

The SPSS results in Table 3 show no significant difference in scores between the two groups. Levene's Test suggests that the variances are equal (F = 0.006, Sig. = 0.941). The t-test reveals a t-value of 0.162 with 16 degrees of freedom and a p-value of 0.874, indicating that the average scores are similar. While Group 1 (Bioplastic mulch film) has a higher average score of about 11.74 points compared to Group 2 (Traditional mulch film), the large standard error of 72.60 indicates considerable variability in the data. The 95% confidence interval for the mean difference ranges from -142.17 to 165.64, which includes zero, reinforcing that this difference is not statistically significant. These findings suggest that both groups performed almost equally.

IV. Conclusion

The study assessed the physical, mechanical, and biological properties of bioplastic mulch films made from different ratios of dried guyabano leaves and starch. In terms of physical properties, water vapor transmission rates (WVTR) varied, with Ratio 1 being least effective at moisture control, while Ratio 2 was the most effective. UV resistance tests showed that Ratio 2 had the lowest weight loss due to UV exposure, indicating better durability. Chemical tests revealed Ratio 1 was highly reactive, while Ratios 2 and 3 maintained clarity, making them more suitable for chemical exposure. Soil moisture retention was highest in Ratio 3, followed by Ratio 2, highlighting their effectiveness in moisture management. Mechanical properties showed that Ratio 2 had the highest tear resistance, while Ratio 3 excelled in impact resistance and elongation but fell short of the necessary tensile strength threshold. Finally, biodegradability tests indicated that Ratio 1 had the highest biodegradability, followed by Ratio 2 and Ratio 3. The evaluation of bioplastic mulch films highlighted Ratio 3, consisting of 1 part dried guyabano leaves to 5 parts mango seed starch, as a successful formulation in several important areas. It demonstrated good performance in chemical resistance, soil temperature and moisture retention, thickness and uniformity, impact resistance, percent elongation, and biodegradability rate. These strengths indicate its potential for effective use in agricultural applications. While Ratio 3 has notable advantages, further improvements could enhance its overall effectiveness in other critical parameters.

The comparison between bioplastic mulch film (Ratio 3) and traditional mulch film reveals several key findings. The bioplastic film exhibits a significantly higher water vapor transmission rate and better UV resistance, suggesting enhanced moisture management and protection against degradation. While both films effectively maintain soil moisture levels, the bioplastic film has lower tear resistance and tensile strength, indicating potential durability issues for certain applications. However, its biodegradability rate of 47.50% offers a significant environmental benefit compared to non-biodegradable traditional films. Statistical tests confirmed no significant differences between the two groups, with a t-value of 0.162 and a p-value of 0.874. Overall, while the bioplastic mulch film shows promise for sustainability and moisture retention, improvements in its physical properties are necessary for better practical use in agriculture. To enhance the bioplastic mulch film, recommendations include refining mango seed starch, experimenting with different concentrations of beeswax, conducting water absorption tests, and investigating alternative materials to improve its mechanical properties for agricultural applications.

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