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Terraplate: Exploring the Potential of Cassava (Manihot esculenta crantz) Peel as Starch and Saw Dust as Filler as an Alternative Bioplastic Plate

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***Abstract*— *This study explores the use of cassava peel starch and wood dust as sustainable components in bioplastic production, aiming to reduce environmental waste and lessen dependence on single-use expanded polystyrene (EPS). Three different formulations were analyzed based on their physical, mechanical, and biodegradable characteristics, focusing on factors like water absorption, tensile strength, elongation, and degradation rate, following recognized commercial standards. Water absorption tests indicated that the third ratio was the most hydrophilic, likely due to the presence of hydroxyl groups. Statistical analysis indicated that the differences in water absorption among the samples were not significant. Mechanical testing revealed that the third ratio had the strongest tensile strength among the formulations, surpassing that of EPS, with statistical tests confirmed a significant difference in strength. However, Ratio Three also showed limited flexibility, as reflected in its low elongation at break, and statistical results suggested that variations in elongation were not statistically significant. Biodegradability assessments demonstrated that Ratio Three had a substantially higher degradation rate compared to EPS, with results indicating a statistically significant difference. Overall, the findings support the viability of cassava peel starch and wood dust in producing biodegradable bioplastic with strong mechanical properties. Despite its higher water absorption, the material's biodegradability and strength make it a promising eco-friendly alternative to EPS. For further enhancement, recommendations include using a dehydrator for even curing, incorporating bamboo wood dust for better aesthetics, and adjusting the starch-to-plasticizer ratio to improve flexibility and durability. Additionally, introducing hydrophobic additives, using a more efficient grinder for starch processing, and applying ceramic coatings can help reduce moisture absorption and improve the material's suitability for food contact applications.*

***Keywords*—*Bioplastic formulations, Bioplastic plate production, Cassava peel starch, Degradation rate, Eco-friendly alternative, Plasticizer, Mechanical properties, Waste management, Water absorption, Wood dust.*

I. Introduction

Global plastic production has vastly risen, exceeding 390 million tons in 2021, reflecting a significant 4% annual growth rate and increasing demand (Plastics Europe, 2022). Since its commercial development in the 1930s and 1940s, plastics have become ubiquitous in consumer markets. Worldwide plastic resin output increased by about 620% between 1975 and 2012, reaching 288 million metric tons (Andrady, 2015). Packaging materials, often discarded immediately, which remains the largest market for plastic resins. In the United States, plastics accounted for a negligible portion of municipal solid waste in 1960, but this figure rose significantly by 2000. By 2005, plastics accounted for at least 10% of solid waste in 58% of countries with available data (Andrady, 2015).

While plastics offer advantages such as durability, versatility, and cost-effectiveness, their dependence on fossil fuels and lack of natural degradation characteristics poses a severe environmental challenge. The accumulation of plastic waste in landfills and oceans, alongside the release of microplastics, has caused significant ecological damage (Jambeck et al., 2015).

Expanded polystyrene (EPS), commonly known as Styrofoam, is a popular type of plastic used for food packaging. Its non-biodegradable nature and difficulty in recycling pose a substantial environmental threat (Evode et al., 2021). Its popularity among small-scale traders and street vendors, due to its waterproof, lightweight, and affordable qualities, further exacerbates this environmental problem (Indarti et al., 2020). The inability of Styrofoam to biodegrade contributes to visual pollution, disrupts ecosystems, and creates health hazards for plants and animals (Kumar et al., 2021). In Bandung, Indonesia, for example, approximately 21,769 tons of Styrofoam waste are generated each month, with only a small fraction (approximately 5,839 tons) being recycled (Fitidarini et al., 2011).

The Philippines generates at least 2.7 million metric tons of plastic waste each year, making it the third-largest plastic polluter worldwide, according to a McKinsey study from 2015 (Braganza, 2017). About 20% of this waste ultimately ends up in marine ecosystems (Ocean Conservancy, 2015). Of the plastic waste polluting the oceans, approximately 74% originates from landfills located near vulnerable waterways, where collected waste has escaped into the environment (World Wildlife Fund, 2018). Additionally, the widespread practice of the "sachet economy" in the Philippines has intensified the plastic pollution problem. In this paradigm, many consumer items are packaged and sold in single-use sachets that are either hard or impossible to recycle (Galarpe et al., 2021; Posadas, 2014). It is estimated that the country consumes nearly 60 billion sachets annually (SEA Circular, 2020; GAIA, 2019).

In the Zamboanga Peninsula, similar to other parts of the Philippines, solid waste management continues to be a major environmental issue. The Department of Environment and Natural Resources 9 (DENR-9) has identified solid waste management as a critical concern both in the region and nationwide (DENR IX, 2022). In Zamboanga City, the third-largest and sixth-most populous city in the Philippines, a significant challenge in waste management is the lack of cooperation from the public and waste generators in adhering to collection schedules, which has resulted in uncollected waste accumulating in public spaces.

The global plastic pollution crisis demands urgent action. In countries like the Philippines, particularly in cities such as Zamboanga, the detrimental effects of plastic waste on the environment and society are starkly evident. The widespread use of non-biodegradable materials like expanded polystyrene has intensified these problems, emphasizing the critical need for sustainable alternatives.

Environmental concerns over plastic waste have driven research into sustainable bioplastics. The peel of cassava, a starchy agricultural waste, has potential for the creation of biodegradable plastics (Pulungan et al., 2020; Fong & Othman, 2022). Similarly, wood dust serves as an effective filler in bioplastics, enhancing mechanical properties while maintaining biodegradability, making it a promising alternative for sustainable packaging solutions (Sulaiman et al., 2013). Exploring the potential of biodegradable materials like cassava peel and wood byproduct like wood dust to produce bioplastics is essential for mitigating the plastic waste crisis and protecting the environment for future generations.

II. Methodology

A. Gathering of Raw Materials

The raw materials were sourced from the cassava vendor at Barangay Lubigan, Zamboanga City, where the Lubigan Cassava Farmers Association produced grated cassava, locally known as pangi, that discards cassava peel, and the wood dust, a byproduct from coconut lumber, was outsourced from the DL Hardware and Construction Supply, located at MCLL Highway, Putik, Zamboanga City, and other lumber dealers in Zamboanga City. The collected cassava peels were cut into 1x1 cm pieces, dried, and ground into a fine powder. The powder was then mixed with distilled water to form a suspension, which was stirred for 30 minutes to release starch granules. To optimize starch recovery, the fibrous residue was re-suspended in water after the slurry was filtered and collected. After being dried in an oven at 50°C for 24 hours, the wet starch precipitate was ground into a fine powder. Additionally, the collected sawdust was thoroughly sieved several times to ensure that no foreign object was included. Furthermore, the distilled water and vinegar were sourced from Putik Flea Market, while glycerol was obtained from Watsons at KCC Mall de Zamboanga.

B. Preparation of Raw Materials

In this study, three distinct formulations were prepared to determine the optimal ratio of cassava peel starch to wood dust for the development of bioplastic plates. The ratios investigated were 1:1, 1:2, and 2:1, respectively. Each formulation was uniformly combined with 180 milliliters of distilled water, 10 milliliters of vinegar, and 10 milliliters of glycerol to ensure consistency in all other components of the mixture. The cassava peel starch and wood dust were the only variables altered in terms of quantity, thereby isolating their influence on the properties of the resulting bioplastic. This approach allowed for a systematic evaluation of the effect of varying filler-to-binder ratios on the performance characteristics of the bioplastic, facilitating the identification of the most suitable composition for practical application.

C. Preparation of the Bioplastic Mixtures

The preparation of the bioplastic sample mixture involved weighing cassava peel starch and wood dust according to their required ratio by weight. Three mixtures were prepared, namely Ratio 1:1 (90g Cassava Peel Starch, 90g Wood Dust), Ratio 1:2 (60g Cassava Peel Starch, 120g Wood Dust), and Ratio 2:1 (120g Cassava Peel Starch, 60g Wood Dust). The bioplastics were tested according to the standard test methods and criteria, which include the physical, mechanical, and biodegradable properties of the bioplastics, testing their water absorption, tensile strength, elongation, and degradation rate.

D. Production of Bioplastic

The quantities of the materials were meticulously measured to guarantee the quality of the bioplastic plate production. The ingredients were combined and mixed thoroughly, followed by cooking each ratio on a burner until a thick consistency is attained, ensuring no bubbles form that could compromise the product's quality. The mixture was stirred continuously under low heat, as illustrated in Figure 3.9. The heating process lasted for 5-10 minutes.

Figure 1. The bioplastic mixture of three (3) different ratios.

E. Oven-drying of Bioplastic

The three bioplastic mixtures were prepared for the curing process, which was carried out using an oven-drying method. Each mixture was placed in a mold and subjected to controlled heating in a laboratory oven at a constant temperature of 100°C for a duration of 3 hours. This curing process was essential not only for removing excess moisture from the bioplastic mixture but also for ensuring proper solidification and structural integrity of the final product.

F. Testing of Bioplastic

The testing phase was conducted to assess the quality and effectiveness of the testing samples. Data obtained from (10) ten trials of the (3) three proportions were analyzed, focusing on (3) three essential properties: physical property (water absorption), mechanical property (tensile strength and elongation), and biodegradability (degradation rate).

The primary objective of the experimental approach of this study is to manufacture bioplastic for comparison with the disposable styro-plate commonly used as food packaging in the market. These disposable plates are prevalent and convenient for use, to also determine which of the ratio proportions used in the bioplastic closely resembled the properties of the styro-plates for practical applications.

Physical Properties

Water Absorption

The bioplastic plate's water absorption characteristics were assessed using a physical property test in accordance with the ASTM D570 standard. The samples were 50.8 mm in diameter and 3.2 mm thick. The test involved immersing a representative sample in distilled water for 24 hours, then extracting, drying, and recording the weight gained. The weight acquired was then subtracted from the starting weight, divided by the plate's starting weight, and multiplied by 100. This test provided valuable insights into the bioplastic's resistance to water absorption, which is crucial for applications involving liquid exposure.

$$\%Water\ Absorption = \left(\frac{Wet\ weight - Dry\ weight}{Dry\ weight}\right) \times 100\% \qquad (1)$$

Mechanical Properties

The objective of the experiment is to measure the tensile strength and elongation of a plastic sample by subjecting it to a regulated tensile force. The specimen is prepared like a dumbbell, and the test measures the maximum force a material can endure before yielding or breaking under tension.

Tensile Strength

The ASTM D638 standard was used to determine the tensile strength of a bioplastic plate sample. The test involved applying a tensile force until it breaks, with the maximum load representing the force applied at the point of failure and the cross-sectional area referring to the sample's area before the test. This quantitative measure of the bioplastic's resistance to tensile stress is crucial for evaluating its durability and structural integrity. The formula for calculating the tensile strength (TS), where Fmax is the recorded total mass and A is the cross-sectional area of the sample.

$$TS = \frac{F_{max}}{A} \qquad (2)$$

Elongation

Elongation was measured the extent of stretching the material was able to withstand before breaking, illustrating its ductility. The material's ductility increases with its elongation value. Elongation is calculated as the percent change in the length of a test specimen gauge section before and after a tensile test. From the testing made for tensile strength, the elongation was determined. Percentage elongation was calculated using the formula, where the final length was subtracted from the initial length and were then divided by the initial length of the bioplastic sample and then multiplied by 100%.

$$\%Elongation = \left(\frac{final\ lenght - initial\ length}{initial\ length}\right) \times 100\% \qquad (3)$$

Biodegradability

Degradation Rate

The experiment investigated the biodegradability of three samples, each cut into 2.5x2.5 cm (1x1 in.) strips. The samples were buried in compost soil at a depth of 7.5 cm in a controlled environment maintained at a temperature of 37°C, simulating mesophilic conditions. Visual changes in color, texture, and weight were documented over time. After the experiment, the samples were removed, cleaned of soil, and weighed to assess weight loss, which indicated the extent of biodegradation. This analysis compared the biodegradation rates of the samples with different starch ratios, aiming to determine the optimal starch composition for producing biodegradable plastic plates. The weight loss of the sample was used to determine its degradation rate. The weight of the sample prior to the test was used as the initial sample weight (Wo), and the weight following the test was used as the final weight (Wf), with the degradation rate calculated by multiplying the weight loss by 100%

$$Weight\ Loss = \left(\frac{w_o - w_f}{w_o}\right) \times 100\% \qquad (3)$$

G. Data Analysis and Interpretation

This study aimed to explore the characteristics of bioplastic plates made from cassava peel starch and wood dust, focusing on their physical properties, mechanical properties, and biodegradability. To analyze the data, the Shapiro-Wilk test was first employed to evaluate the normality of the data distribution, while Levene’s Test assessed the homogeneity of variances across groups. A p-value greater than 0.05 indicated that the data met the assumptions of normality and homogeneity, whereas a p-value less than 0.05 suggested deviations from normality. If the data was normally distributed, an ANOVA test was conducted to identify significant differences in the ratios of cassava peel starch to wood dust among groups, with a p-value below 0.05 indicating significant differences. In cases where normality was not achieved, non-parametric tests like the Kruskal-Wallis test were used, or data transformation techniques were applied to meet normality requirements.

III. Result and Discussion

The table provides a comprehensive ranking of bioplastic samples, Ratio 1, Ratio 2, and Ratio 3, produced in varying proportions. Each sample was evaluated across multiple parameters to determine their overall performance and identify the most efficient proportion of the bioplastic. The ranking system used assigns rank 1 to the highest-performing sample, rank 2 to the sample with moderate performance, and rank 3 to the lowest-performing sample for each parameter. This

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systematic ranking helped to pinpoint the standout ratio, offering insights into which proportion yields the most desirable properties for the bioplastic.

TABLE 1. Overall Ranking of Bioplastic Plate Ratios Based on Performance Parameters

Parameter	Ranks		
	Ratio 1	Ratio 2	Ratio 3
Water Absorption	2	1	3
Tensile Strength	2	3	1
Elongation	2	3	1
Degradation Rate	2	3	1
Average	2	2.5	1.5
Final Rank	2nd	3rd	1st

Note: 1- being the highest; 2- being the moderate; and 3- being the lowest.

This study aimed to investigate the characteristics of bioplastic plates made from cassava peel starch and wood dust, focusing on their physical properties, mechanical properties, and biodegradability. The Shapiro-Wilk test and Levene's Test were used to assess normality and homogeneity of data distribution. ANOVA was conducted to determine significant differences in the ratios of cassava peel starch to wood dust across different groups or conditions. Non-parametric tests like Kruskal-Wallis test were used for analyzing data with skewed distributions.

The analysis provided valuable insights into the performance of the three groups across different parameters: Water Absorption, Tensile Strength, Elongation, and Degradation Rate. Ratio 3 consistently performed well across the parameters, with the highest rank for Tensile Strength, Elongation, and Biodegradability. Ratio 1 demonstrated slightly lower performance in Water Absorption, Tensile Strength and Elongation, and Biodegradability, ranking second overall. Ratio 3 had mixed performance, achieving the top rank in Water Absorption but consistently lower ranks in other critical parameters.

The results highlight the importance of multi-parameter optimization in evaluating the effectiveness of different ratios. The consistent performance of Ratio 3 across parameters makes it the most versatile and robust choice, while the specific strengths of Ratio 1 and Ratio 2 could make them suitable for niche applications where those particular properties are prioritized. The rankings provide a clear and actionable framework for selecting the most appropriate ratio based on the desired application and performance criteria.

Research indicates that increasing starch content in bioplastics generally enhances mechanical properties and biodegradability, improving tensile strength and elongation. Kaolin demonstrates superior water absorption, tensile strength, and biodegradability compared to alternatives like microcrystalline cellulose and chitosan.

The table presented below shows the overall ranking of all the samples (Mixture 1, Mixture 2, and Mixture 3) used in developing an alternative briquette. The results were obtained after evaluating all the samples according to their parameters and standards. The scoring is from 1 to 3, 1 being the lowest and 3 being the highest.

This study examines the performance of bioplastic made with the Ratio 3 formulation compared to commercially available expanded polystyrene. It evaluates functional parameters like water absorption, tensile strength, elongation, and degradation rate to identify performance differences. The comparison aims to determine bioplastic's strengths and limitations in various applications, offering insights into its sustainability as a sustainable alternative.

TABLE 2. Summary of All Results of Comparisons Between Bioplastic (Ratio 3) and Commercial Expanded Polystyrene

Parameters	Standard Criteria	Bioplastic Plate (Ratio 3)	Commercial EPS
Water Absorption	Water absorption levels ranging from 10% ≤	Failed	Passed
Tensile Strength	Range of tensile strength: 10 MPa	Failed	Failed
Elongation	Range of elongation: 5-10%	Failed	Failed
Degradation Rate	Approximately 25-30% within 10 days	Passed	Failed

The bioplastic (Ratio 3) and commercial EPS showed significant differences in water absorption properties. The bioplastic had an average water absorption of 43.479%, exceeding the ASTM D570 standard's threshold of 10%. This led to its classification as "Failed" under the standard. The commercial EPS had an average water absorption of only 5%, passing the ASTM D570 threshold. The bioplastic's high water absorption rate suggests potential limitations in moisture-sensitive applications, highlighting the need for further material optimization to improve water resistance in bioplastic formulations.

Tensile strength tests on bioplastic and commercial EPS revealed that both materials failed under stress, indicating their inadequacy for demanding structural applications. Bioplastic had a higher tensile strength of 0.853MPa, while EPS had a slightly lower strength of 0.359 MPa. Both materials failed under stress, indicating that while bioplastic has marginally higher strength than EPS, its performance under tensile stress is still inadequate. EPS, with a lower tensile strength, is notably weaker than bioplastic due to its lightweight and brittle nature, often used for insulation rather than structural strength. Both materials failed under test conditions, reinforcing the notion that it is not designed to withstand significant tensile forces. Bioplastic outperforms EPS slightly in terms of tensile strength, but both materials fall short of the expected performance from plastics. The failure of both materials suggests that while bioplastics offer an eco-friendly alternative to EPS, the mechanical properties, particularly tensile strength, need further optimization for use in applications. EPS, commonly used in packaging and insulation, demonstrates typical behavior for a material for tensile strength. Both materials are suitable for low mechanical stress applications, but alternative solutions may be necessary for greater durability and strength.

The elongation results of bioplastic and commercial EPS under tensile stress show that bioplastic has a lower elongation than expected, with an average of 1%, which is lower than the ASTM D638 standard's reference value of 10%. This suggests that bioplastic may lack the necessary ductility for certain applications, such as packaging or structural components. Commercial EPS has an average elongation of 3%, slightly lower than bioplastic, but also has limited elongation and flexibility. The ratio of elongation values between the two materials is relatively close, suggesting that bioplastic does not significantly outperform EPS in terms of flexibility. Both materials fail under stress before reaching the standard elongation values of 10%, suggesting they are not well-suited for applications requiring high elasticity or elongation. Future research could explore modifications to these materials, such as blending with additives or reinforcing with fibers, to improve their mechanical properties and broader usability.

The bioplastic's degradation rate is far higher than that of commercial EPS, which has a degradation rate of 0%, because it is a very biodegradable substance. This indicates that bioplastics have a potential to reduce long-term environmental impact, as they break down more rapidly under environmental conditions. Unlike EPS, which can remain in the environment for hundreds of years, bioplastics decompose over time, making them a more sustainable alternative. The bioplastic's 72.4% degradation rate makes it a more sustainable alternative to EPS, emphasizing the need for increased use of biodegradable materials, especially in industries that heavily rely on single-use plastics. This comparison underscores the importance of adopting environmentally friendly alternatives to mitigate the ecological footprint of materials like EPS.

The comparison between bioplastic (Ratio 3) and Commercial EPS highlights key differences. The bioplastic failed the Water Absorption, Tensile Strength, and Elongation, but passed the Degradation Rate, while the commercial EPS passed Water Absorption Test, but fails in all three tests. Overall, the commercial EPS and bioplastic performed well in critical performance areas.

IV. Conclusion

Among the tested formulations, Bioplastic Ratio 3, which consists of a 2:1 ratio of starch to wood dust, proved to be the most promising due to its enhanced properties, largely attributed to the higher starch content acting as the matrix and wood dust serving as a reinforcing filler. The physical, mechanical, and biodegradability evaluations, along with statistical analyses, provided a comprehensive understanding of its performance. In terms of physical properties, Ratio 3 exhibited an average water absorption rate of 43.479%, significantly higher than commercial expanded polystyrene (EPS) at 5%, but the ANOVA test ($p = 0.5197$, $\eta^2 = 0.047$) indicated no statistically significant differences across groups, suggesting variations were likely random. For the mechanical property, Ratio 3 demonstrated an average tensile strength of 0.853 MPa, outperforming commercial EPS at 0.359 MPa, with a Kruskal-Wallis H test ($H = 17.81$, $p < 0.001$, $\eta^2 = 0.59$) confirming significant differences between ratios. However, elongation remained a weakness, with Ratio 3 showing only 1%, far below the ASTM D638 standard of 10%, and statistical tests (Kruskal-Wallis $p = 0.1835$) indicating no significant differences in flexibility among samples. In terms of biodegradability, the bioplastic had a high degradation rate of 72.4%, significantly outperforming EPS at 0%. The ANOVA ($F = 5.48$, $p = 0.01003$, $\eta^2 = 0.29$) confirmed meaningful differences in degradation rates across the ratios. When compared to commercial EPS, Ratio 3 bioplastic showed notable advantages in mechanical strength and biodegradability, although it underperformed in moisture resistance and flexibility, indicating the need for further formulation enhancements. Overall, Bioplastic Ratio 3 offers a viable, more sustainable alternative to EPS for disposable applications, especially where biodegradability and mechanical performance are prioritized over water resistance.

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