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Water Hyacinth (Eichornia crassipes) Cellulose and Mung Beans (Vigna radiata) Starch as a Composite Plant Bag with Plasticizer Glycerol

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RESEARCH ARTICLE

Abstract

The study developed a composite plant bag using water hyacinth (Eichornia crassipes) cellulose and mung beans (Vigna radiata) starch, with glycerol as plasticizer, aiming to address environmental concerns associated with petrochemical-based bags. Employing a Completely Randomized Design, the study aimed to determine the optimal cellulose-to-starch ratio based on physical and mechanical properties such as tensile strength, elongation, swelling behavior, and biodegradability. Five treatment groups (four experimental cellulose-starch mixtures and one control (pure starch mixture)) were prepared each replicated four times. Evaluations were conducted using one-way Analysis of Variance (ANOVA) to assess differences among the mixtures. Results indicated that the optimal mixture consisted of 80% base mixture and 20% water hyacinth cellulose, which exhibited superior tensile strength (40 MPa), elongation (40%), swelling percentage (0.9), and biodegradability (4.2) compared to the control. The ANOVA results revealed a statistically significant difference among the treatments (F = 15.24, F crit = 3.24, p = 0.0000597), confirming that the addition of water hyacinth cellulose significantly enhanced the composite's physical and mechanical properties. The study concludes that higher concentrations of water hyacinth cellulose can effectively improve the durability and shelf life of bioplastic plant bags, supporting their potential as an eco-friendly alternative to conventional plastics.

Keywords: bioplastic, cellulose-starch blend, water hyacinth, mung bean, glycerol, plant bag

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1 INTRODUCTION

Plastic pollution remains a critical environmental issue worldwide, exacerbated by the extensive use of single-use synthetic plastics. These conventional plastics, composed primarily of petrochemical-based materials, persist in the environment for centuries, contributing significantly to land and marine pollution, hazardous chemical emissions, and threats to wildlife and human health (Gautam et al., 2007;Encinar and González, 2008; Marichelvam et al., 2019). The Philippines, ranked third globally for plastic waste entering oceans, faces an urgent need for sustainable waste management solutions (Biona et al., 2015; Villanueva, 2015).

In response to the mounting plastic crisis, bioplastics have emerged as viable eco-friendly alternatives. Bioplastics are derived from renewable biomass sources and are biodegradable, presenting substantial environmental advantages over traditional plastics. Recognizing this potential, the Philippine government has proposed numerous legislative measures to regulate

and reduce single-use plastic usage (Bulaon-Ducusin, 2018). Initiatives by organizations such as the Department of Science and Technology-Industrial Technology Development Institute (DOST-ITDI) highlight significant advancements in developing biodegradable alternatives, notably starch-based biopolymers that degrade within months and can be seamlessly integrated into agricultural practices (Rodriquez, 2013; Sapp, 2025).

Additionally, natural resources such as starch and cellulose have been extensively studied due to their biodegradability, availability, and cost-effectiveness, making them promising raw materials for bioplastic production. Starch, widely found in numerous plant-based sources, exhibits considerable potential for sustainable packaging solutions (Aranda-García et al., 2015; Vieira et al., 2011). Mung beans (Vigna radiata), known for their nutritional and economic benefits in agriculture, present an untapped resource for industrial bioplastic applications beyond food (Sunnexdesk, 2014; greenconvergence, 2016; Knorr, 2025). Similarly, cellulose derived from water hyacinth (Eichornia crassipes), an invasive aquatic plant prevalent in the Philippines, has demonstrated potential as a sustainable, biodegradable alternative material suitable for textile and packaging applications (Department of Science and Technology, 2014).

Despite the recognized advantages of starch-based materials, they often exhibit limitations, such as brittleness and high-water sensitivity. To address these drawbacks, blending starch with cellulose and incorporating glycerol as a plasticizer can significantly improve the mechanical properties and usability of bioplastics. While previous studies have explored starch blends with various natural polymers, comprehensive research examining the combination of mung beans starch with water hyacinth cellulose using glycerol remains limited. This study aims to bridge this gap by evaluating the feasibility of using a composite of mung beans starch and water hyacinth cellulose, plasticized with glycerol, for grow bag applications. The research addresses critical parameters such as tensile strength, elongation, swelling behavior, and biodegradability, thereby contributing to the body of knowledge on sustainable, environmentally friendly materials.

2 METHODOLOGY

2.1 Research Design

The Experimental Research Design was chosen for this study because it provided appropriate means to address the research questions and meet the objectives. Specifically, a Completely Randomized Design (CRD) was employed to evaluate the effects of varying concentrations of water hyacinth cellulose on the properties of composite plant bags made from mung beans starch. The formulation of each treatment was based on a 100 mL mixture, in which incremental amounts of cellulose were incorporated while maintaining a consistent base composition of starch, glycerol, and vinegar.

As shown in Table 1, five set-ups were prepared: one control group (base mixture) and four experimental groups with increasing concentrations of water hyacinth cellulose. The base mixture was composed of 90% mung bean starch, 5% glycerol, and 5% vinegar. For the experimental groups (A, B, C, D), water hyacinth was added at 5%, 10%, 15%, and 20% levels, respectively, replacing equivalent proportions of the base mixture. Each formulation was replicated four times to ensure the validity and reproducibility of the results. This formulation strategy allowed the study to evaluate the impact of varying cellulose content on the biopolymer's strength, flexibility, and biodegradability.

Table 1. The Five Set-ups Used and Treated Under Completely Randomized Design (CRD)

SET UP CODE	PERCENTAGE COMPOSITIONS
Base Mixture	90% mung bean starch, 5% glycerol, 5% vinegar
A	95% base mixture, 5% water hyacinth cellulose
B	90% base mixture, 10% water hyacinth cellulose

C	85% base mixture, 15% water hyacinth cellulose
D	80% base mixture, 20% water hyacinth cellulose

2.2 Data Sources

Data collection was done through primary sources. Primary data source includes the outcome of the researchers' observations from experimental set-ups. During observation, the different characteristics of the bio-based polymer, such as tensile strength, swelling behavior, elongation, and biodegradability was tested and data was recorded. The collected data from the observation were the basis for interpretation of results and formulation of discussions of the present undertaking.

2.3 Instrumentation

After the pilot testing and necessary modifications, observations were conducted to collect data. During the period, the physical and mechanical properties of the bio-based polymers films produced – specifically tensile strength, elongation, swelling behavior, and biodegradability – were measured and monitored without altering environmental conditions such as temperature and humidity.

In testing the bio-based polymer outputs, a combination of natural and chemical components was used. The raw materials included mung beans (for starch extraction), water hyacinth cellulose, glycerol (as plasticizer), distilled water, vinegar (5% acetic acid solution), sodium hydroxide (NaOH 1M), diluted muriatic acid (10% HCl), and 0.5% sodium hypochlorite. The equipment utilized included an electric hot plate, Erlenmeyer flask, graduated cylinder, beaker, stirring rod, laboratory drying oven, Whatman filter paper, mortar and pestle, alcohol lamp, wire gauze, casserole, spatula, blender, aluminum foil, stove, petri dishes, measuring cups and spoons, glass container, molder, mixing bowl, strainer, glove, mask, and a string balance.

2.4 Data Gathering Procedure

2.4.1 Extraction of Starch from Mung Beans

To extract starch, 250 grams of mung beans were soaked in 500 mL of distilled water for 8 to 10 hours at ambient temperature (approximately 25°C), following the modified protocol adapted from Dafader et al. (2011). After soaking, the softened beans were blended with an additional 200 mL of distilled water – just enough to facilitate the breakdown of the beans for efficient starch separation. The mixture was strained through a cheesecloth into a clean container. The remaining solids were blended again with another 200 mL of distilled water, strained a second time, and repeated once more for maximum starch recovery.

The combined filtrate was allowed to settle undisturbed for 10 hours in a covered container at room temperature. After settling, the supernatant water was carefully decanted, leaving behind a sediment layer of white starch. This sediment was transferred to a clean, sterilized glass container and sun-dried completely for 24 to 36 hours, depending on weather conditions, until moisture was no longer detectable by touch. The final dried starch yield was recorded and weighed using a digital balance. Yield percentage was calculated based on the formula:

Starch Yield (%) = (Mass of dried starch/Initial mass of mung beans) x 100

The collected starch was placed in an airtight container for use in the formulation of the bio-based polymer composite plant bags.

2.4.2 Extraction of Cellulose from Water Hyacinth

Fresh water hyacinth petioles were thoroughly cleaned to remove debris and surface contaminants, then dried under the sun for 6 hours or in a laboratory drying oven at 90°C. The dried material was blended and sieved to obtain a fine powder. Following the modified protocol from Ginting et

al. (2015), 70 grams of the powdered hyacinth were treated with 100 mL of 1 M sodium hydroxide (NaOH) solution. The mixture was heated and stirred continuously at 80°C for 2 hours to remove hemicellulose and other non-cellulosic components.

After the alkaline treatment, the mixture was filtered using Whatman filter paper and washed thoroughly with distilled water until a neutral pH was achieved. The washed residue was then dried again in the same oven at 90°C for another 6 hours to remove residual moisture.

Subsequently, the dried product was soaked in 50 mL of a 1:5 diluted antimicrobial solution (containing approximately 0.5% sodium hypochlorite) to sterilize the cellulose and prevent breakdown. After soaking, the cellulose was rinsed thoroughly with distilled water and oven-dried at 90°C for 4 hours. The resulting cellulose-rich material was allowed to cool and then stored in a sterilized, airtight amber glass bottle for later use in biopolymer formulation.

2.4.3 Production of the Base Mixture and its Modifications

Based upon the modified procedure outlined by Fathanah et al. (2015), all materials and equipment were properly cleaned and sanitized in a well-organized preparation area. A measured volume of 75 mL of distilled water was poured into a casserole, along with 1 teaspoon (approximately 5 mL) of glycerol, 1 teaspoon (approximately 5 mL) of vinegar (5% acetic acid), and pre-weighed quantities of mung bean starch and water hyacinth cellulose, based on the treatment formulation.

The mixture was continuously stirred over low heat, maintaining a temperature between 70°C to 80°C, until a uniform, viscous consistency was achieved, indicating the gelatinization and dispersion of the polymer matrix. Once all components were fully integrated, the hot biopolymer solution was transferred onto pre-cut aluminum foil and spread evenly using a sterile spatula to achieve a target film thickness of approximately 1.5 mm.

The biopolymer films were then air-dried under sunlight in a clean, dust-free environment for 24 to 36 hours, or until they developed a semi-opaque to transparent appearance. This drying step prepared the films for subsequent mechanical and physical property testing.

2.5 Statistical Treatment of Data

The study used one-way Analysis of Variance (ANOVA) to determine whether there were statistically significant differences among the different treatment groups. Before using the said tools, various formulas were also used.

Tensile strength was determined by elongating the bio- based polymer and measuring the load it carried before breaking. It was calculated by dividing the maximum load by the original cross-sectional area of the bio-based polymer.

$$\text{Tensile Strength (MPa)} = \frac{F\ (\text{kgF})}{A\ (\text{cm}^2)}$$

Where:
F = is the measured load before breaking
A = is the cross-sectional area of the bio-based polymer (width x thickness)

Elongation was the percentage increase in length that occurred before the bioplastic broke under tension.

$$\%\ \text{Elongation} = \left(\frac{L - L_0}{L_0}\right) \times 100\%$$

Where:
L = is the final length of bioplastic before breaking
L_O = is the initial length of bioplastic

Bioplastics were immersed in water for up to 10 minutes. The weight was recorded every 2 minutes.

Swelling percentage was calculated as:

$$\% \text{ Swelling} = \left(\frac{W - W_0}{W_0}\right) \times 100\%$$

Where:
W_O = is the initial sample weight
W = is the final sample weight

Biodegradability Test. In accordance with the modified experimental procedure described by Ginting et al. (2015), with modifications, 2 cm × 2 cm bioplastic film samples were placed in sterile Petri dishes and treated with 20 mL of a 1:5 diluted antibacterial solution (containing 0.5% sodium hypochlorite). The samples were incubated at room temperature (25–28°C), and degradation indicators such as thinning, discoloration, and tearing, were monitored at 30-minute intervals over a total duration of 150 minutes. These observations were used to assess the comparative biodegradability of each formulation.

ANOVA was appropriate for comparing the means of more than two groups (five in this case) for each property measured. It evaluated the effects of varying concentrations of cellulose on tensile strength, elongation, swelling behavior, and biodegradability.

$$F = \frac{MS_B}{MS_W}$$

Where: F = is the ANOVA statistic
MS_B = is the mean sum of squares between groups
MS_B = is the mean sum of squares within groups

3 RESULTS AND DISCUSSION

3.1 Percentage composition of the variables that has the best mixture to produce a bio-based plant bag

All the different percentage composition of the variables conducted in this study successfully produced composite plant bags, as the output formed a homogeneous system comparable to commercially available ones. However, they differed in both external and internal attributes as the amount of cellulose was varied in the mixtures, indicating deviations in compatibility levels (SeniChev and Tereshatov, 2012). Specifically, their physical and mechanical properties as decreased shown in Table 2.

Table 2. Elongation of the Different Mixtures

MIXTURE	INITIAL LENGTH	FINAL LENGTH	ELONGATION	RANK
A	10 cm	11 cm	1 cm (10%)	5
B	10 cm	13 cm	2 cm (30%)	3
C	10 cm	13.5 cm	3.5 cm (35%)	2
D	10 cm	14 cm	4 cm (40%)	1
BASE	10 cm	11 cm	1 cm (10%)	5

Results showed that Mixture D exhibited the highest tensile strength at 40 MPa while base mixture had the lowest tensile strength with 7.14 MPa. This indicated that the incorporation of water hyacinth cellulose significantly enhanced the tensile strength compared to the base formulation. The proper proportion of cellulose contributed to the improved structural integrity of the composite material. These findings were supported by previous studies conducted by Dafader et al. (2011), Ashori and Bahrami (2014), Fathanah et al. (2015), Ginting et al. (2015), and Hasan et al. (2018), which highlighted the strengthening effects of cellulose when blended with biopolymer matrices.

3.2 Swelling Behavior

The swelling behavior was measured by calculating the percentage increase in the weight of the films using a digital weighing scale. The composites were immersed in water for up to 10 minutes, during which their swelling behavior was observed. The increase in weight of the composite films indicated the amount of water absorbed, which was reflected as the swelling percentage.

Table 3 illustrates that the swelling percentages increased over time in all samples. Notably, Mixture A only showed a marked increase in weight after 10 minutes, while Mixtures B, C, D, and the base mixture began to absorb water within just 2 minutes of soaking. As the cellulose concentration in the mixtures increased, the overall swelling percentages tended to decrease, suggesting that higher cellulose content reduced water uptake.

Table 3. Swelling Behavior vs. Time Soaked in Water

MIXTURE	INITIAL WEIGHT	2 minutes	4 minutes	6 minutes	8 minutes	10 minutes
A	0.30 g	0.60 g	0.60 g	0.60 g	0.60 g	0.70 g
B	0.30 g	0.60 g	0.70 g	0.70 g	0.70 g	0.70 g
C	0.30 g	0.60 g	0.70 g	0.70 g	0.70 g	0.70 g
D	0.30 g	0.70 g	0.70 g	0.70 g	0.90 g	0.90 g
BASE	0.30 g	0.40 g	0.40 g	0.50 g	0.50 g	0.40 g

Table 4 summarizes the swelling behavior of the different bioplastic mixtures after 10 minutes of immersion in water. Mixture D exhibited the highest swelling behavior, with a final average weight of 0.78 g and a swelling value of 0.90 g, earning the top rank (1). Mixtures B and C both showed moderate swelling, each with an average final weight of 0.68 g and a swelling value of 0.70 g, sharing a rank of 3.5. Mixture A demonstrated a slightly lower swelling capacity, with a final weight of 0.64 g and a swelling value of 0.60 g, ranking 2nd. The base mixture had the lowest swelling behavior, with only 0.50 g swelling and a final average weight of 0.44 g, ranking last (5). This pattern aligns with the observations of Thapa and Narain (2016) and Ribba et al. (2017), who reported that starch-based polymers are particularly sensitive to moisture because water can easily penetrate their molecular structure during the swelling process.

Table 4. Swelling Behavior of the Different Mixtures

MIXTURE	INITIAL WEIGHT	AVERAGE FINAL WEIGHT AFTER 10 MINUTES	SWELLING BEHAVIOR	RANK
A	0.30 g	0.64 g	0.60 g	2
B	0.30 g	0.68 g	0.70 g	3.5
C	0.30 g	0.68 g	0.70 g	3.5
D	0.30 g	0.78 g	0.90 g	1
BASE	0.30 g	0.44 g	0.50 g	5

3.3 Biodegradability

The biodegradability test was conducted at favorable temperature and humidity conditions. The composite films were cut into 2cm by 2cm and placed into petri dishes along with 20 mL microbial solution. The degradation processes were monitored every 30 seconds, and the data were transcribed. The observation lasted for 150 minutes. Changes in thickness, decolorization and tearing apart of the samples were recorded.

Table 5. Weighted Mean of the Observations for Biodegradability

MIXTURE	Thickness (Visibility)	Decolorization	Tearing apart of the Sample
A	3.00	3.00	2.50
B	3.30	3.50	3.30
C	2.30	2.70	2.30
D	4.20	4.20	4.20
BASE	2.00	2.30	1.80

The result revealed that the base mixture showed a pronounced reduction in thickness, dissolving first among all samples. In contrast, Mixture D demonstrated superior resistance to degradation, indicating the protective effect of increased cellulose content. These results are consistent with the observations of Ribba et al. (2017), who noted that starch's hydrophilic nature renders it more vulnerable to moisture and rapid breakdown. Furthermore, the minimal decolorization observed across all mixtures indicated a high degree of compatibility between the blended polymers. In terms of brittleness, Mixture D attained the highest weighted mean score of 4.20 highlighting its improved structural integrity compared to the other formulations.

3.4 Summary of Physical and Mechanical Properties of Bioplastic Mixtures

Table 6 revealed that the incorporation of water hyacinth cellulose in the bioplastic mixtures significantly improved their physical and mechanical properties compared to the base mixture.

Table 6. Summary of Physical and Mechanical Properties of Bioplastic Mixtures

MIXTURE	TENSILE STRENGTH	ELONGATION	SWELLING BEHAVIOR	BIODEGRADABILITY
A	14.29	1.00	0.60	2.50
B	17.00	2.00	0.70	3.30
C	30.00	3.50	0.70	2.30
D	30.00	4.00	0.90	4.20
Base	7.14	1.00	0.50	1.80

Among all the formulations, Mixture D demonstrated the most favorable results, with the highest tensile strength (30 MPa), elongation (4.00), swelling behavior (0.90), and biodegradability (4.20). Mixture C also achieved high tensile strength and relatively good elongation, though its biodegradability was slightly lower than Mixture D. Mixtures A and B showed moderate improvements in all properties compared to the base, but their performance did not reach that of Mixtures C and D. In contrast, the base mixture consistently registered the lowest values across all categories, emphasizing the positive impact of adding cellulose.

3.5 Significant Difference Between the Best and Base Mixture

Table 7 revealed key insights into how varying the composition affects physical and mechanical properties.

Table 7. Significant Difference Between the Best and Base Mixture

Groups	Count	Sum	Average	Variance
Tensile strength	5	98.43	19.686	101.62268

Elongation	5	11.50	2.30	1.950
Swelling behavior	5	3.40	0.68	0.022
Biodegradability	5	14.10	2.82	0.887

Tensile strength, with an average of 19.686 MPa and a high variance of 101.62, demonstrated the greatest variability, indicating that strength was highly sensitive to the proportions of cellulose added to the mixtures. In contrast, elongation averaged 2.3% with a variance of 1.95, reflecting a more consistent ability of the samples to stretch before breaking. Swelling behavior showed remarkable stability, averaging 0.68 with a very low variance of 0.022, suggesting that all formulations absorbed water at similar rates. Likewise, biodegradability was consistent across groups, with an average score of 2.82 and a variance of 0.887, implying that changes in cellulose content had only modest effects on this property.

The ANOVA table presented in Table 8 shows the statistical comparison of physical and mechanical properties (tensile strength, elongation, swelling behavior, and biodegradability) across different bioplastic mixtures.

Table 8. Analysis of Variance (ANOVA) Summary for the Physical and Mechanical Properties of Bioplastic Mixtures

Source of Variation	SS	df	MS	F	p-value	F crit
Between Groups	1194.2967	3	398.09891	15.240908	5.97E-05	3.2388715
Within Groups	417.92672	16	26.12042			
Total	1612.2235	19				

The computed F-value of 15.24 was much greater than the F critical value of 3.24, and the p-value was significantly less than 0.05 ($p = 0.0000597054$). This indicated that there were statistically significant differences among the groups. Thus, the addition of water hyacinth cellulose had a significant impact on the physical and mechanical properties of the bioplastic films, confirming the effectiveness of the experimental treatments.

3.6 Major Findings

Based on the results of the study, several key findings were identified. All formulations successfully produced homogenous, commercially comparable plant bags; however, their physical and mechanical properties varied as the cellulose content increased. Among the mixtures tested, Mixture D, which consisted of 80% base material and 20% cellulose, yielded the best results. It achieved the highest tensile strength at 40 MPa, the greatest elongation at 40%, and the maximum swelling at 0.90 g, while also demonstrating improved biodegradability and durability. In contrast, the base mixture exhibited the lowest performance across all measured properties, highlighting the beneficial impact of adding water hyacinth cellulose. Statistical analysis using ANOVA revealed significant differences among the mixtures ($F = 15.24$, $p < 0.00006$), confirming that higher cellulose content significantly enhanced the bioplastic's strength, flexibility, water absorption, and resistance to degradation.

4 CONCLUSIONS AND RECOMMENDATION

The incorporation of water hyacinth cellulose into mung bean starch-based bioplastic significantly enhanced the physical and mechanical properties of the resulting plant bags, including tensile strength, elongation, swelling behavior, and biodegradability. Mixture D, which contained 80% base mixture and 20% water hyacinth cellulose, was identified as the optimal formulation. It demonstrated superior strength, flexibility, and resistance to degradation compared to the other mixtures and the base formulation. Statistical analysis confirmed that the differences between the

mixtures were highly significant, indicating that adjusting the cellulose content has a substantial impact on the performance of bioplastic films.

It is recommended to investigate alternative natural plasticizers and additives to further enhance the properties of bioplastics. Future studies should also focus on refining the optimal formulation ratios and conducting field trials to evaluate the performance and biodegradability of the bioplastics under real-world conditions. Additionally, performing life cycle and cost-benefit analyses is encouraged to assess the environmental impact and economic feasibility of large-scale bioplastic production.

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