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Characterization of Cornstarch-Based Bioplastic Reinforced with Three Different Species of Bamboo Shoots

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Abstract The increasing demand for eco-friendly products has led to the development of bioplastics as a substitute for conventional petroleum-based plastics. This study aimed to assess the properties of cornstarch-based bioplastics reinforced with three species of bamboo shoots: *Bambusa vulgaris, Bambusa vulgaris var. striata*, and *Bambusa blumeana*. The properties investigated included tensile strength, water solubility, biodegradability, water absorption, and moisture content. A comparison was also made between the reinforced bioplastics and pure cornstarch bioplastic. The results revealed that the inclusion of shredded bamboo shoots significantly influenced the characteristics of the cornstarch-based bioplastic. Among the tested bioplastics, the one reinforced with *B. vulgaris* exhibited the highest tensile strength (ranging from 2703.37 Pa to 3341.2 Pa), while the unreinforced bioplastic had the lowest strength. Water solubility was lowest in the bioplastic reinforced with *B. vulgaris* (45.52%), and highest in the one reinforced with *B. vulgaris var. striata* (59.58%). The unreinforced bioplastic had the highest biodegradability (63.89%), while the reinforced bioplastic with B. vulgaris had the lowest (36.62%). Furthermore, the bioplastic reinforced with *B. blumeana* exhibited the highest water absorption (157.36%), and the moisture content was 15.56% for *B. blumeana* and 9.39% for *B. vulgaris var. striata*. Statistical analysis revealed no significant differences in water solubility, tensile strength, and moisture content between the various bioplastics. However, significant differences were observed in biodegradability and water absorption. Overall, the cornstarch-based bioplastic reinforced with *B. vulgaris var. striata* demonstrated the most desirable properties, including good tensile strength, high water solubility, good biodegradability, average water absorption, and low moisture content. This study highlights the potential of bioplastics as an environmentally friendly solution, while emphasizing the need for further investigation and improvement in their utilization and ecological qualities.

Keywords: *absorption of water, bamboo shoots, biodegradability, glycerol, moisture content, starch-based bioplastic, tensile strength, water solubility*

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1. Introduction

Plastics are essential to both homes and commercial products in today's generation. Plastic is widely employed in many applications, including handbags, drink containers, toys, food packaging, components and containers, furniture, dress materials, and many more. The most extensive environmental pollution is produced by plastic waste as it is a synthetic material that is made using petroleum-based materials that are difficult to decompose in soil [1]. Due to the advantages such as durability, high tensile strength, and relatively low price of synthetic plastic, plastics are in high demand and remain widely used in food packaging. It is challenging to envision modern life without plastics due to the rapid increase in their creation and use and their increasing utility and significance [2].

Consumption of plastic has quadrupled during the past three decades due to the expansion of emerging markets. From 2000 to 2019, global plastics output increased to 460 million tons. 3.4% of the world's greenhouse gas emissions are caused by plastics [3]. Numerous issues arise as a result of the use of plastic, most notably pollution. Therefore, this research was done to develop an alternative to plastic to minimize the load on our existing waste systems and the environment. This research was conducted to develop environmentally biodegradable plastics and use bamboo shoots that are typically discarded.

Plastics are causing an increasing number of environmental problems, so people are now more interested in making and spreading bioplastics. Plastics are scattered everywhere; it takes years to degrade, so this study would help to resolve this issue. Traditional plastics can take hundreds of years to break down, but biodegradable plastics only take three to six months [4]. This study will help to lessen the waste and create a safe environment. Bamboo shoots can be found anywhere; it is free and often neglected, so the researchers decided to use them.

Plastic has now begun to be developed from natural materials called bioplastics. Bioplastics do emit much less greenhouse gasses than conventional plastics [5]. Bioplastics are developed as an alternative to synthetic plastic as they are considered more environmentally friendly. Bioplastics are derived from renewable resources, and certain bioplastics are biodegradable. Bioplastic has the potential to have a substantially lesser carbon footprint, lower production energy costs, utilize less expensive crude oil, reduce litter, enhance compostability, and become more acceptable to many households [6].

The Philippines is the third-largest contributor to global plastic waste, contributing an estimated 0.75 million metric tons of ocean plastic annually [7]. No manufacturers of biodegradable thermoplastic polymers are present in the Philippines, as far as they know [8]. Polylactic acid (PLA) is a synthetic biodegradable polymer. However, just one local supplier exists. Due to this, this study is keen to develop a bioplastic that could be beneficial to humans and environmentally friendly.

Bamboo shoots are the young, edible bamboo culms that emerge from the ground in various bamboo species. In the Philippines, bamboo shoots are used in cuisine as a vegetable. The bamboo shoot was the primary organ where starch was stored [9]. Researchers have created several bioplastics that are based on starch. Food grains like corn, potato, rice, cassava, and others were used to make the vast majority of these products. In this study, we will explore the feasibility of creating bioplastic from cornstarch and reinforced with bamboo shoots.

Starch is used as a base for making a lot of eco-friendly materials. Polysaccharides make up 75% of all the organic material on Earth. Starch is an essential polysaccharide. Plants make starch and store it in their bodies as a source of energy. Starch can be found in plant seeds, tubers, or roots [10].

Moreover, starch has beneficial thermoplastic qualities and is biodegradable. According to the Ecosystems and Research and Development Bureau in Bukidnon, *Bambusa blumeana* (Kawayang Tinik), *Bambusa vulgaris var. striata* (Yellow bamboo), and *Bambusa vulgaris* (Kauayan killing) are widespread around Bukidnon. These three bamboo species often have bamboo shoots, even though it is not the season for them. *B. blumeana* is a tropical, grouping bamboo species native to Indonesia and is now widespread throughout Southeast Asia, the Philippines, and southern China. The Painted Bamboo, or *B. vulgaris var. strata*, is a medium-sized clumping bamboo native to China and the Indochina region. Previously, this species was known as *B. striata*. In the tropics, it is one of the most popular ornamental bamboo to grow [11]. *B. vulgaris* is a clump-forming, evergreen, erect bamboo that can reach heights of 15-20 meters [12]. The *B. vulgaris var. striata*, *B. vulgaris*, and *B. blumeana* bamboo shoots used in this study all have a little bitter, rough flavor, which is why they are used to have their significance even though people rarely consume these [13].

Furthermore, this research aimed to determine the characteristics of cornstarch-based bioplastics reinforced with three different species of bamboo shoots. This study sought to determine whether this would help resolve the rising plastic pollution problem. This study investigated whether cornstarch-based bioplastics reinforced with bamboo shoots are a suitable alternative to plastic. The researchers were conducting this study because traditional plastic is non-biodegradable. It harms the environment, and they want to produce a readily available alternative bioplastic. This study aimed to analyze the characteristics of bioplastic as an alternative to traditional plastic.

2. Methodology Research Design

This study employed a research and development research design as it seeks to develop a new product that can benefit the environment. The research and development method is a method used to produce a certain product and test its effectiveness of the product. Experimental development is the systematic application of knowledge gained through research and practical experience to produce new products or processes or improve existing products or processes [14]. This study utilized a quantitative research design since it collects data from the physical properties' characterization. This study is an empirical study of the characterization of cornstarch-based bioplastics reinforced with three different species of bamboo shoots. The researchers were doing manual testing on the bioplastic's quality, adopting the method of other researchers.

Experimental research was undertaken scientifically since it is the most systematic study design available. It involved testing a theory or attempting to demonstrate it through experiments. In addition, this study attempts to demonstrate how experiments are created and assessed from a researcher's standpoint. This study looked into the characteristics of bioplastic derived from cornstarch and reinforced with bamboo shoots.

2.1. Preparation and Collection of Data

Bamboo shoots of the three different species were collected in the nearby bamboo clumps on the houses of the study participants located at Alanib, Lantapan, Bukidnon, and Managok, Malaybalay City, Bukidnon. The glycerol was used as a plasticizer, and the bamboo shoots were then specified by the Ecosystems Research and Development Bureau in Malaybalay City, Bukidnon. Moreover, each bioplastic was tested three times in each test to ensure reliability of the results.

2.2. Preparation of Bamboo Shoots

The bamboo shoots were washed and cleaned to extract the starch. Bamboo shoots will be ground with purified water in an industrial blender. The mixture was filtered, and the solid residue was placed into a separate container. The procedure is repeated until additional starchy water is obtained. The mixture was given 5 minutes to settle in a container to confirm that starchy water from the bamboo shoots was collected. After that, the mixture was mixed to finally obtain starchy water from each bamboo shoots specie [15]. The shredded bamboo shoots were sun-dried until it is completely dry.

2.3. Mixing Procedure and Control Mixed Design

Following the method, four tablespoons of water were added to a pan, followed by one tablespoon of cornstarch, which was then stirred until the cornstarch was completely dissolved. Following that, one teaspoon of vinegar and one teaspoon of glycerol was added and thoroughly combined. After thoroughly incorporating all ingredients, the heat was turned on to medium-low, and the mixture was agitated until a toothpaste-like consistency was achieved [16]. The heat was then removed, and adds fiber and in this study, 2.5 grams of dried shredded bamboo shoots were added [17].

2.4. Casting Method

Bioplastics were produced through the casting process. The cooked mixture was spread into an aluminum foil tray. The cooked mixture was kept in the mold for at least 2 hours to allow it to completely dry at room temperature. To finish the bioplastic's healing process, it was treated once more in a hot air oven for at least 24 hours at 85°C [18]. The bioplastic was then be allowed to cool and fully solidify before being removed from the aluminum foil tray mold.

2.5. Test Analysis

This research involved five (5) different types of testing, including tensile strength, water solubility, biodegradability, water absorption, and moisture content.

(a) Tensile Test

A participant flattens and molds bioplastic samples created from the three types of bamboo shoots into dumbbell shapes. There were two tables used, and they were placed four to five inches apart. The ends of the bioplastic material in the form of a dumbbell were punctured with holes. Each dumbbell-shaped bioplastic sample has markings on its neck on the opposite ends. This will enable the researchers to gauge the bioplastic sample's maximum stretch as force is applied. A participant measures and records each dumbbell-shaped bioplastic's width and height from its neck region. The metal rod was taped to the table along with a ruler, allowing the bioplastic samples to hang freely between the spaces between the tables. The force meter was then attached to the opposite end of the bioplastic samples. A tripod with a camera was then put up 3 feet away from the table, capturing the top of the dumbbell-shaped bioplastic and the bottom section of the force meter. As the recording begins, a participant pulls down the force meter until the dumbbell-shaped bioplastic breaks. This method allows the researchers to determine the time, stretch distance, and force needed to break the dumbbell-shaped bioplastic [19]. The overall tensile strength of the samples was then calculated using the formula, ultimate force divided by cross-sectional area. To get the cross-sectional area, the researchers multiplied the dumbbell-shaped bioplastics' thickness, width, and height.

(b) Water Solubility Test

Before being placed in a beaker of 50 ml distilled water at room temperature for 24 hours, bioplastic samples were dried at room temperature for 2 hours and then in an oven at 85°C for 24 hours to allow measuring their dry weight (W1). The bioplastic residue was recovered after 24 hours by filtering the water, dried once more for 2 hours at room temperature, and then for 24 hours in an oven set to 85°C. The residue was then weighed to determine the final weight (W2). The following formula was used to determine the solubility [20]:

$$Solubility\ in\ Water\,(\%) = \frac{(w_1 - w_2)}{W_1} X100 \qquad (1)$$

(c) Biodegradability test

For the Biodegradability test, bioplastic samples were weighed to measure the initial weight (W1). The samples were buried under 2 cm of moist garden soil in a plastic container and stored at room temperature for five days. The soil was maintained moist for five days, following which the bioplastic residue was collected, washed with water, dried at room temperature for 2 hours, and in an oven at 85°C for 24 hours, and then weighed again to determine the final weight (W2). The biodegradability was calculated using the following formula [21]:

$$Biodegradability\,(\%) = \frac{(w_1 - w_2)}{W_1} X100 \qquad (2)$$

(d) Absorption of Water Test

The bioplastics' water absorption was determined using a slightly modified version of ASTM D570-98. Before being placed in a beaker with 50 ml of distilled water at room temperature for 24 hours, bioplastic samples were dried for 2 hours at room temperature and then for 24 hours in an oven set to 85 °C to measure their dry weight (W1). The bioplastic was retrieved after 24 hours by filtering the water, and its weight was then calculated to determine its ultimate weight (W2). The following formula was used to calculate water absorption [22]:

$$Water\ Absorption\,(\%) = \frac{(w_1 - w_2)}{W_1} X100 \qquad (3)$$

(e) Moisture Content Test

A sample of bioplastic was weighed to determine its initial weight (W1). The samples were dried at room temperature for 2 hours and in an oven at 85C for 24 hours. Once more, the samples were weighed to get the final weight (W2). The formula shown below was subsequently used to calculate the moisture content [20]:

$$Moisture\ Content\,(\%) = \frac{(w_1 - w_2)}{W_1} X100 \qquad (4)$$

2.6. Statistical Treatment of Data

The results from each experimental group were analyzed, and all results were shown as the mean and standard deviation for each bioplastic made from bamboo shoots of different species and with different characteristics. The one-way analysis of variance (ANOVA) was used to evaluate all data. Furthermore, the p-value was compared to the standardized value, which is equal to a significance level of 0.05, to establish whether the result would reject the null hypothesis.

3. Results and Discussion

(a) Tensile Strength

Table 1. Summary of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Tensile Strength Data

Groups	N	Mean (Pa) and Standard Deviation
Cornstarch-based bioplastic reinforced with *B. blumeana*	3	2736.66 ± 150.09
Cornstarch-based bioplastic reinforced with *B. vulgaris*	3	3341.20 ± 244.55
Cornstarch-based bioplastic reinforced with *B. vulgaris var. striata*	3	2978.01 ± 516.54
Cornstarch-based bioplastic	3	2703.37 ± 434.54

Table 1 presents the characterization of the corn starch-based bioplastic reinforced with three different species of bamboo shoots in terms of tensile strength. Based on the data displayed above, cornstarch-based bioplastic reinforced with *B. vulgaris* has the strongest tensile strength or can withstand a larger amount of pulling force. In contrast, cornstarch-based bioplastic without any reinforcement has the lowest tensile strength. The tensile strength varied between 2703.37 Pa and 3341.2 Pa.

In this study, the bioplastic has a strength between 2 to 2.5 N. In getting the tensile strength, we get the plastic's cross-sectional area; after that, we solve for the tensile strength force load divided by the cross-sectional area. Based on the results, it is concluded that the bioplastic reinforced with bamboo shoots has a better tensile than those that are not reinforced. As described, reinforcing agents are added to bioplastics to improve their mechanical characteristics and broaden their potential applications [23]. The final mechanical properties of bioplastics were significantly influenced by choice of reinforcement, aspect ratio, filler loading, and surface treatment used.

The bioplastic with a potato starch foundation was calculated to have the maximum strength, at 3.37 N/mm, 0.98 N/mm stronger than cornstarch, and 2.18 N/mm stronger than wheat starch, this is according to a study published in the journal [24]. To completely tear down a banana peel bioplastic containing acacia seed extract takes an average of 2.2867 N, but a banana plastic without extract requires an average of 1.6333 N [25].

(b) Water Solubility

Table 2. Summary of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Water Solubility Data

Groups	N	Mean (%) and Standard Deviation
Cornstarch-based bioplastic reinforced with *B. blumeana*	3	54.20 ± 15.55
Cornstarch-based bioplastic reinforced with *B. vulgaris*	3	45.52 ± 10.87
Cornstarch-based bioplastic reinforced with *B. vulgaris var. striata*	3	59.58 ± 9.38
Cornstarch-based bioplastic	3	55.86 ± 10.02

Table 2 illustrates the characterization of the corn starch-based bioplastic reinforced with three different species of bamboo shoots in terms of water solubility. According to the data, cornstarch-based bioplastic reinforced with *B. vulgaris* has the lowest water solubility. In contrast, cornstarch-based bioplastic reinforced with *B. vulgaris var. striata* has the highest. The water solubility varied between 45.52 and 59.58 %. Compared to other studies, the water solubility of starch-based bioplastics from jackfruit seed plasticized with glycerol ranged from 16.42 to 23.26 percent, whereas the water solubility of cornstarch-based bioplastics with and without reinforcement with three different species of bamboo shoots was higher [26].

The reinforcement of *B. vulgaris* in bioplastic reduces water solubility due to the presence of insoluble bamboo shoot fibers, which contain nonfermentable cellulose and fermentable hemicelluloses [27]. It is possible that *B. vulgaris* shoots are among the bamboo shoots that exhibit insolubility, whereas the other two species of bamboo shoots exhibit higher solubility related to their solubility characteristics.

A study concluded that biodegradable plastic film is highly soluble in water and produces no harmful byproducts when dissolved in water [28]. And this supports the study's conclusion that it has a high-water solubility, as it is not harmful to the environment. Furthermore, it is stated that despite the fact that bioplastics are derived from organic carbohydrates, they do not degrade in water like other organic materials [29]. The event has a relatively straightforward explanation: Bioplastics are fermented and combined with chemicals to form polymers and monomers. Therefore, bioplastic's water solubility is not 100 percent, as it requires a great deal of consistent heat for weeks and months to begin degrading effectively.

(c) Biodegradability

Table 3. Summary of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Biodegradability Data

Groups	N	Mean (%) and Standard Deviation
Cornstarch-based bioplastic reinforced with *B. blumeana*	3	39.76 ± 6.91
Cornstarch-based bioplastic reinforced with *B. vulgaris*	3	36.62 ± 1.59
Cornstarch-based bioplastic reinforced with *B. vulgaris var. striata*	3	44.07 ± 5.78
Cornstarch-based bioplastic	3	63.89 ± 4.82

Table 3 depicts the characterization of the cornstarch-based bioplastic reinforced with three different species of bamboo shoots in terms of biodegradability. This table indicates that the cornstarch-based bioplastic without reinforcement has the highest percentage (63.89%), while the one reinforced with *B. vulgaris* has the lowest percentage (36.62%) in biodegradability. These results conclude that bioplastic with reinforcement has low biodegradability compared to bioplastic without reinforcement. According to the study, the weight loss and degradation rate of starch-based plastic films were observed to be accelerated (within a week) when subjected to buried in soil, and degradation of nearly 95% was observed and it was revealed that the rate of degradation increased as the starch dosage was increased. In this study, the biodegradability of the 2cm by 2 cm film in 5 days ranged from 36.62 to 63.89% [30].

As per the findings of some researchers, the bamboo fiber film underwent complete degradation in soil within 70 days [31]. Furthermore, the bioplastic reinforced with three distinct species demonstrates reduced biodegradability compared to the unreinforced bioplastic, as the degradation of bamboo shoot fiber is a time-consuming process.

They concluded that plastics derived from starch, a natural source, would undergo complete degradation within 60 days [32]. In contrast, plastics containing biodegradable additives would necessitate a longer duration for degradation. That is why in this research, bioplastic has a high biodegradability rate. It is indicated that the biodegradability of starch-based bioplastic with reinforcement varies depending on the soil use since some soil enhanced biodegradability along the lower portion because that area is more easily attacked by microorganisms [33].

(d) Absorption of Water

Table 4. Summary of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Water Absorption Data

Groups	N	Mean (%) and Standard Deviation
Cornstarch-based bioplastic reinforced with *B. blumeana*	3	157.36 ± 4.53
Cornstarch-based bioplastic reinforced with *B. vulgaris*	3	119.02 ± 5.79
Cornstarch-based bioplastic reinforced with *B. vulgaris var. striata*	3	142.99 ± 17.07
Cornstarch-based bioplastic	3	86.66 ± 2.24

As shown in the table, the bioplastic reinforced with *B. blumeana* had the highest average water absorption (157.36%). The bioplastic absorbed the least amount of water (86.66% on average) without any reinforcement. Overall, the data indicate that some species of bamboo can increase the water absorption of cornstarch-based bioplastics, with the effect varying depending on the species employed. Furthermore, because the dried, shredded bamboo shoots absorb water, the reinforced bioplastic has a high-water absorption rate. It is found that the water absorption capacity of several types of bioplastics varied from 40% to 320%, which is similar to this study. The current study yielded a range of water absorption values from 86.66 to 157.36% [34].

Moreover, most starch-based bioplastics have poor water-related properties, such as high-water absorption and moisture content [35]. No wonder the corn starch-based bioplastic with and without reinforcement from three different species of bamboo shoots has high water absorption.

(e) Moisture Content

Table 5. Summary of the Characterization of Corn Starch-based Bioplastics with and without Reinforcement in terms of Moisture Content Data

Groups	N	Mean (%) and Standard Deviation
Cornstarch-based bioplastic reinforced with *B. blumeana*	3	15.56 ± 5.09
Cornstarch-based bioplastic reinforced with *B. vulgaris*	3	12.99 ± 2.18
Cornstarch-based bioplastic reinforced with *B. vulgaris var. striata*	3	9.39 ± 0.53
Cornstarch-based bioplastic	3	14.35 ± 7.13

Table 5 shows the moisture content of different types of cornstarch-based bioplastics. The moisture content of each type of bioplastic has been measured three times. It can be observed that the average moisture content of the cornstarch-based bioplastic reinforced with *B. blumeana* is 15.56%. The cornstarch-based bioplastic reinforced with *B. vulgaris* has an average moisture content of 12.99%. The cornstarch-based bioplastic reinforced with *B. vulgaris var. striata* has the lowest average moisture content of 9.39%. Finally, the cornstarch-based bioplastic without any reinforcement has an average moisture content of 14.35%. It can be concluded that the addition of bamboo reinforcements decreases the moisture content of the cornstarch-based bioplastic. The moisture content of bioplastic made from cornstarch, both with and without reinforcement, displays a range of 9.39% to 15.56%.

Comparably to the study by other researchers, starch-based bioplastic has a moisture content of 6.62-11.85% which is higher but closely similar to the results of this research [36]. Bioplastic samples containing glycerol had a high moisture content [18] because glycerol contains a hydroxyl group attracted to water molecules, allowing them to form hydrogen bonds and incorporate water into the structure [37].

They concluded that the moisture content of starch-based bioplastic ranges from 13.21% to 17.59% [38]. Compared to the results of this study, the moisture content ranged from 9.39% to 15.56%, indicating a lower moisture content.

Bioplastic films produced with dialdehyde starch solution (due to their low moisture content) may protect food integrity more effectively than bioplastic films produced with silica solution [36].

(a) Tensile Strength

Table 6. Analysis of Variance of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Tensile Strength

Source of Variation	SS	df	MS	F	P-value
Between Groups	779249.70	3.00	259749.90	1.93	0.20
Within Groups	1076912.53	8.00	134614.07		
Total	1856162.23	11.00			

In Table 6, the F-value is 1.93, which is lower than the F-crit (4.07), and this means that there is no significant difference in the water solubility of the cornstarch-based bioplastics with or without reinforcement. Looking at the P-value of 0.20, we can conclude that there is no significant difference between the means of the groups at the 0.05 significance level. Therefore, we fail to reject the null hypothesis that the means of the groups are equal.

It is observed that the bioplastic is so brittle. This research reveals that the incorporation of bamboo shoots as reinforcement in bioplastic materials results in reduced flexibility compared to unreinforced bioplastics. It is found that the decrease in tensile strength due to glycerol is caused by the reduction of intermolecular hydrogen, which may additionally decrease the intermolecular attraction between adjacent polymer chains [39]. This reduces bioplastics' tensile strength and stiffness, resulting in a reduction in tensile strength.

According to [40], bamboo shoots are rich in fiber. However, as identified, the treatment of these fibers reinforces them, thereby restricting molecular movements and resulting in a bioplastic that is less flexible and stiffer [23]. Due to a weak interface and detrimental stress concentration, natural fillers like bamboo flour (BF) have a negative impact on the tensile strength of bioplastic with PLA [41]. But they concluded in their study that bamboo flour has a good effect on the other mechanical properties of bioplastics.

(b) Water Solubility

Table 7. Analysis of Variance of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Water Solubility

Source of Variation	SS	df	MS	F	P-value
Between Groups	319.31	3.00	106.44	0.78	0.54
Within Groups	1,096.84	8.00	137.10		
Total	1,416.14	11.00			

Table 7 illustrates the difference in water solubility between bioplastics made from cornstarch with and without reinforcement. The F-value is 0.78, which is lower than the F-crit (4.07), and this means that there is no significant difference in the water solubility of the cornstarch-based bioplastics with or without reinforcement. Additionally, given that the P-value is 0.54, higher than the P-alpha level of 0.05, the null hypothesis cannot be rejected. In conclusion, no significant differences exist in the water solubility of the bioplastic produced. Thus, it means that the null hypothesis failed to reject.

Despite the insolubility of certain fibers found in bamboo shoots, the statistical analysis of variance (ANOVA) reveals no significant difference exists in the water solubility of reinforced bioplastics that are not. In terms of their water solubility, all of them exhibit identical characteristics, thereby concluding the analysis. Furthermore, there is no significant difference between them as they contain an equivalent quantity of glycerol, which shows a solubility value that is almost complete, allowing it to dissolve entirely in water [42].

Since the bioplastic made has higher water solubility, the bioplastic films indicate their suitability for various packaging applications, including the packaging of colorants, soaps, and cleansers [43]. Also, films with higher solubility can be used to make garbage bags, laundry bags, and retail bags.

(c) Biodegradability

Table 8. Analysis of Variance of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Biodegradability

Source of Variation	SS	df	MS	F	P-value
Between Groups	1,351.63	3.00	450.54	16.88	0.000805
Within Groups	213.54	8.00	26.69		
Total	1,565.18	11.00			

The analysis of variance (ANOVA) findings for the biodegradability characterization of cornstarch-based bioplastics are shown in Table 8. The F-statistic in this instance is 16.88. The P-value indicates the probability of getting the observed F-statistic or a more extreme number if the null hypothesis is true. The null hypothesis is firmly rejected by the P-value for this ANOVA, which is 0.000805, which is less than the usual significance level of 0.05. The F-value is 16.88, and the fact that it is higher than the critical F-value (4.07) indicates that the bioplastics differ significantly. In terms of biodegradability, the null hypothesis is therefore rejected.

There is a significant difference in biodegradability between bioplastics due to the presence of factors such as exposure conditions, pH, temperature, moisture, bio-surfactant, enzyme, and microbial strain [44]. Although the same soil source is used in the biodegradability test of bioplastics, the moisture and pH of the soil in each test container may not be equal. This could be why the results of the biodegradability test are varied.

(d) Absorption of Water

Table 9. Analysis of Variance of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Absorption of Water

Source of Variation	SS	df	MS	F	P-value
Between Groups	8,602.34	3.00	2,867.45	32.72	0.000077
Within Groups	701.04	8.00	87.63		
Total	9303.38	11			

The findings of the ANOVA comparing the bioplastics in terms of water absorption are displayed in Table 9. The p-value is 0.000077, which is below the 0.05 level of significance. Since there is a significant difference in water absorption across the groups of bioplastics, it rejects the null hypothesis and comes to that conclusion. According to the ANOVA results, there is a significant difference in the amount of water absorbed by the various groups of cornstarch-based bioplastics with or without reinforcement, with a high F-value and a very low p-value. Additionally, the F-value (32.72) is higher than the critical F-value (4.07), supporting the rejection of the null hypothesis.

There is a significant difference between the water absorption of bioplastics with and without reinforcement since bamboo shoots absorb water. In line with the research conducted by some researchers, it has been observed that bamboo fibers exhibit a remarkably high-water absorption capacity, ranging from 742.8% to 775.4% [45]. In that case, the bioplastic reinforced with bamboo shoot, which has fiber, has high water absorption, given that the bamboo itself already has high water absorption. That alone supports the fact that there is a significant difference.

(e) Moisture Content

Table 10. Analysis of Variance of the Characterization of Cornstarch-based Bioplastics with and without Reinforcement in terms of Moisture Content

Source of Variation	SS	df	MS	F	P-value
Between Groups	64.04	3.00	21.35	1.04	0.42
Within Groups	163.50	8.00	20.44		
Total	227.53	11.00			

The F-value in this table is 1.04, less than the critical F-value of 4.07 at a significance level of 0.05. Therefore, the null hypothesis that no significant difference exists between the means of moisture content in the four groups cannot be rejected. The P-value of 0.42 exceeds the significance level of 0.05. This further supports the conclusion that the means are similar. Based on the ANOVA results presented in Table 10, there is no significant difference between the moisture content of the four tested groups of cornstarch-based bioplastics.

It has been demonstrated that starch-based bioplastics are extremely sensitive to moisture absorption, which can result in a decrease in their mechanical properties [46]. The study demonstrates that the inclusion of glycerol results in a reduction in the moisture absorption capacity of bioplastic, leading to a decrease in moisture content [47]. This finding suggests that the moisture content of each bioplastic is not significantly different, as they contain an equal amount of glycerol.

4. Conclusion

Based on the findings of the study about the physical properties of cornstarch-based bioplastic reinforced with three different kinds of bamboo shoots, namely *B. vulgaris*, *B. blumeana*, and *B. vulgaris var. striata*. Bamboo shoots significantly increased the bioplastic's mechanical qualities, particularly tensile strength. Furthermore, the inclusion of bamboo shoots affected the physical qualities of the bioplastic. Among the four groups of bioplastics tested for their water solubility, cornstarch-based bioplastic reinforced with *B. vulgaris* has the lowest water solubility, whereas corn starch-based bioplastic reinforced with *B. vulgaris* var. striata has the highest. For the bioplastic's biodegradability, it is observed that the cornstarch-based bioplastic without reinforcement has the highest percentage, while the one reinforced with *B. vulgaris* has the lowest percentage. In terms of the bioplastic's absorption of water, this study observed that the bioplastic reinforced with *B. blumeana* had the highest average water absorption. The bioplastic absorbed the least amount of water without any reinforcement. For the bioplastic's moisture content, this study concluded that the cornstarch-based bioplastic reinforced with *B. blumeana* has the highest moisture content. In contrast, the cornstarch-based bioplastic reinforced with *B. vulgaris var. striata* has the lowest average moisture content. Shredded bamboo shoots improved the bioplastic's mechanical qualities and physical properties, including water solubility, biodegradability, water absorption, and moisture content. It is observed that excessively thick, shrinking would shatter the flattened viscous biopolymer layer. Hand leveling the viscous bioplastic in the tray before drying created uneven specimen thickness. Due to the specimens' minute air bubbles and uneven thickness, the bioplastics' mechanical properties may be higher.

The study proves that bioplastics can substitute conventional plastics. However, the study also found areas for improvement, including energy consumption and production costs, as well as the need for more research to improve bioplastics' physical properties, particularly in preventing casting cracking. The ANOVA results for tensile strength and water solubility showed that there was no significant difference between cornstarch-based bioplastics with and without reinforcement. However, the ANOVA results for biodegradability indicated a significant difference among the bioplastics. Similarly, there was a significant difference in water absorption across the different groups of cornstarch-based bioplastics. Conversely, the ANOVA results for moisture content revealed no significant difference among the four tested groups. Bioplastics differed in biodegradability and water absorption but not in water solubility, tensile strength, and moisture content.

In conclusion, based on the characterization of bioplastics, the cornstarch-bioplastic reinforced with *B. vulgaris var. striata* has the best characteristic of bioplastic, which has good tensile strength, high water solubility, good biodegradability, average water absorption, and low moisture content. Furthermore, the research demonstrates the significance of applying into consideration multiple factors such as exposure conditions, pH levels, and microbial species when evaluating the biodegradability of materials. In general, bioplastics hold the potential as a viable solution to the escalating ecological concerns associated with traditional plastics. However, further investigation and enhancement are necessary to improve their utilization and environmentally friendly quality.

5. Recommendations

For the enhancement of this research, the researchers would recommend the following:

The starch content of each species of bamboo shoot needs to be tested to further know its characteristics and compound for the reliability of the results since it can affect the physical properties of bioplastics.

The bioplastic curing process needs to be studied and researched well because it has been observed that while curing the bioplastic, it cracks. Therefore, it needs further studies on how to avoid cracking during the making of bioplastics.

The bioplastics thickness and physical properties such as color, texture, and etc. are needed to be tested for more reliable and appealing bioplastic to consumers.

It is also essential to use varying amount of shredded bamboo shoot in reinforcing the bioplastic to know the best amount to use. It is also best to use varying concentrations of glycerol in the making of bioplastics since, in previous studies, it was found that it affects the physical properties of bioplastics. By varying the concentrations of glycerol, it can be determined how much glycerol to use when making the best bioplastics.

It is also observed that bamboo shoot pulp can be used in the production of paper since it contains a lot of fiber, as stated in past research.

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References

[1] Evode, N., Qamar, S. A., Bilal, M., Barceló, D., & Iqbal, H. M. N. (2021). Plastic waste and its management strategies for environmental sustainability. Case Studies in Chemical and Environmental Engineering, 4(4), 100142.

[2] Fridovich-Keil, J. L. (2019). Bioplastic. In Encyclopædia Britannica. https://www.britannica.com/technology/bioplastic.

[3] OECD. (2022). Plastic pollution is growing relentlessly as waste management and recycling fall short, says OECD. OECD. https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

[4] Gammage, E. (2021). How long does it take for plastic to biodegrade? Save Money Cut Carbon. https://www.savemoneycutcarbon.com/learn-save/how-long-does-it-take-for-plastic-to-biodegrade/.

[5] Cho, R. (2017). The Truth About Bioplastics. State of the Planet. https://news.climate.columbia.edu/2017/12/13/the-truth-about-bioplastics/#:~:text=Bioplastics%20do%20produce%20significantly%20fewer.

[6] Goodall, C. (2011). Carbon Commentary. Carbon Commentary. https://www.carboncommentary.com/blog/2011/09/02/bioplastics-an-important-component-of-global-sustainability.

[7] Guevarra, S. (2022). The Face of Plastic | News. Ateneo de Manila University. https://www.ateneo.edu/news/2022/07/18/face-plastic.

[8] Bulaon-Ducusin, G. (2018). DOST-developed biodegradable substitute to synthetic plastics offers opportunity for plastic manufacturers. Stii.dost.gov.ph. https://stii.dost.gov.ph/808-dost-developed-biodegradable-substitute-to-synthetic-plastics-offers-opportunity-for-plastic-manufacturers.

[9] Zhang, J., Ma, R., Ding, X., Huang, M., Shen, K., Zhao, S., Xiao, Z., & Xiu, C. (2021). Association among starch storage, metabolism, related genes and growth of Moso bamboo (Phyllostachys heterocycla) shoots. BMC Plant Biology, 21(1).

[10] Gadhave, R. V., Das, A., Mahanwar, P. A., & Gadekar, P. T. (2018). Starch Based Bio-Plastics: The Future of Sustainable Packaging. Open Journal of Polymer Chemistry, 08(02), 21-33.

[11] Schroder, S. (2011). Bambusa vulgaris "Vittata" - Painted Bamboo. Guadua Bamboo. https://www.guaduabamboo.com/blog/bambusa-vulgaris-vittata.

[12] Akhtar, J., & Patowary, L. (2022). Bambusa vulgaris: A comprehensive review of its traditional uses, phytochemicals and pharmacological activities. Sciences of Phytochemistry, 1(2), 11-21.

[13] Darmawan, U., & Sutiyono. (2021). Analysis of financial feasibility of cultivation of bambu ampel kuning (Bambusa vulgaris var. striata) as a bamboo shoot resource. IOP Conference Series: Earth and Environmental Science, 917(1), 012044.

[14] OECD. (2015). Concepts and definitions for identifying R&D. https://www.oecd-ilibrary.org/docserver/9789264239012-4-en.pdf?expires=1680010772&id=id&accname=guest&checksum=BAF5347BCB7D8C2A5B6A11286FE40FCB#:~:text=2.24%20There%20are%20three%20types%20of%20r%26d%3A&text=basic%20research%20%E2%97%8F%20applied%20research%20%E2%97%8F%20experimental%20development.

[15] Tun, T. Y., & Mar, A. A. (2022). Preparation and Characterization of Starch Based Bioplastic Film from Dent Corn. Meral.edu.mm. https://meral.edu.mm/record/5651/files/Preparation%20and%20Characterization%20of%20Starch%20Based%20Bioplastic%20Film.pdf.

[16] Smitley, D. (2019). Curiosity Guide #506 Bioplastics. https://mediad.publicbroadcasting.net/p/wkar/files/506-stem-design-a-bioplastic-sculpture-curiosityguide.pdf.

[17] Jethoo, A. S. (2019). Effect of fiber reinforcement on tensile strength and flexibility of corn starch-based bioplastic. IOP Conference Series: Materials Science and Engineering, 652, 012035.

[18] Shafqat, A., Al-Zaqri, N., Tahir, A., & Alsalme, A. (2021). Synthesis and characterization of starch based bioplastics using varying plant-based ingredients, plasticizers and natural fillers. Saudi Journal of Biological Sciences, 28(3), 1739-1749.

[19] Amino Labs. (2023). Analyzing Bioplastics: Tensile strength test part 1. Www.youtube.com. https://www.youtube.com/watch?v=OxG3fMnq72M.

[20] Sanyang, M. L. (2016). Effect of plasticizer type and concentration on physical properties of biodegradable films based on sugar palm (arenga pinnata) starch for food packaging. SpringerLink. https://link.springer.com/article/10.1007/s13197-015-2009-7?error=cookies_not_supported&code=c1590aa8-f9b1-4b21-92a2-3b553e8e1665.

[21] Tan, Z. (2016). Physical and Degradable Properties of Mulching Films Prepared from Natural Fibers and Biodegradable Polymers. MDPI. https://www.mdpi.com/2076-3417/6/5/147.

[22] Sujuthi, M., & Liew. (2016). Properties of Bioplastic Sheets Made from Different Types of Starch Incorporated With Recycled Newspaper Pulp. Transactions on Science and Technology, 3(1-2), 257-264.

[23] Boey, J. Y., Lee, C. K., & Tay, G. S. (2022). Factors Affecting Mechanical Properties of Reinforced Bioplastics: A Review. *Polymers*, *14*(18), 3737.

[24] Future Science Leaders. (2022). Comparing the Tensile Strength of Starch Bases in Biodegradable Plastic Alternatives." www.futurescienceleaders.com/blog/2022/06/comparing-the-tensile-strength-of-starch-bases-in-biodegradable-plastic-alternatives/.

[25] Mesina, Raine Cassandra T., et al. "Enhancing Durability of Banana Peel Bio-Plastic Using Acacia (Samanea Saman) Seed Extract." *Ascendens Asia Journal of Multidisciplinary Research Abstracts*, vol. 3, no. 2O, 18 Jan. 2019, ojs.aaresearchindex.com/index.php/AAJMRA/article/view/11991#:~:text=Each%20sample%20underwent%20three%20trials. Accessed 13 May 2023.

[26] Santana, R. F., Bonomo, R. C. F., Gandolfi, O. R. R., Rodrigues, L. B., Santos, L. S., dos Santos Pires, A. C., de Oliveira, C. P., da Costa Ilhéu Fontan, R., & Veloso, C. M. (2018). Characterization of starch-based bioplastics from jackfruit seed plasticized with glycerol. Journal of Food Science and Technology, 55(1), 278-286.

[27] Li, X., Guo, J., Ji, K., & Zhang, P. (2016). Bamboo shoot fiber prevents obesity in mice by modulating the gut microbiota. *Scientific Reports*, *6*(1).

[28] Diane. (2019). *What are the benefits of biodegradable water soluble plastic film?* Soltec Development. https://www.soltec-development.com/en/benefits-biodegradable-water-soluble-plastic-film/.

[29] Lui, R. (2020). *Does Bioplastic Dissolve in Water? | Sparkoncept | Biodegradable plastic products*. Sparkoncept. https://sparkoncept.com/does-bioplastic-dissolve-in-water/#:~:text=Despite%20having%20been%20sources%20from.

[30] Folino, A., Karageorgiou, A., Calabrò, P. S., & Komilis, D. (2020). Biodegradation of Wasted Bioplastics in Natural and Industrial Environments: A Review. *Sustainability*, *12*(15), 6030.

[31] Jiang, H., Wang, G., Chen, F., Chen, X., & Wei, X. (2022). Degradation Characteristics of Environment-Friendly Bamboo Fiber Lunch Box Buried in the Soil. *Forests*, *13*(7), 1008.

[32] Mohee, R., & Unmar, G. (2007). Determining biodegradability of plastic materials under controlled and natural composting environments. *Waste Management*, *27*(11), 1486-1493.

[33] Ochi, S. (2011). Durability of Starch Based Biodegradable Plastics Reinforced with Manila Hemp Fibers. *Materials*, *4*(3), 457-468.

[34] Jones, A., Zeller, M., & Sharma, S. (2013). Thermal, mechanical, and moisture absorption properties of egg white protein bioplastics with natural rubber and glycerol. Progress in Biomaterials, 2(1), 12.

[35] Castillo, L. A., López, O. V., García, M. A., Barbosa, S. E., & Villar, M. A. (2019). *Crystalline morphology of thermoplastic starch/talc nanocomposites induced by thermal processing. Heliyon, 5(6).* https://www.cell.com/heliyon/fulltext/S2405-8440(18)37977-5?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com %2Fretrieve%2Fpii%2FS2405844018379775%3Fshowall%3Dtrue.

[36] Oluwasina, O. O., Akinyele, B. P., Olusegun, S. J., Oluwasina, O. O., & Mohallem, N. D. S. (2021). Evaluation of the effects of additives on the properties of starch-based bioplastic film. SN Applied Sciences, 3(4).

[37] Cerqueira, M. A., Souza, B. W. S., Teixeira, J. A., & Vicente, A. A. (2012). Effect of glycerol and corn oil on physicochemical properties of polysaccharide films - A comparative study. Food Hydrocolloids, 27(1), 175-184.

[38] Spada, J. C., Silva, E. M., & Tessaro, I. C. (2014). Production and characterization of pinhão starch biofilms. Revista Brasileira de Ciências Agrárias - Brazilian Journal of Agricultural Sciences, 9(3), 365-369.

[39] Fauziyah, S. N., Mubarak, A. S., & Pujiastuti, D. Y. (2021). Application of glycerol on bioplastic based carrageenan waste cellulose on biodegradability and mechanical properties bioplastic. IOP Conference Series: Earth and Environmental Science, 679(1), 012005.

[40] Chongtham, N., Bisht, M. S., & Haorongbam, S. (2011). Nutritional Properties of Bamboo Shoots: Potential and Prospects for Utilization as a Health Food. Comprehensive Reviews in Food Science and Food Safety, 10(3), 153-168.

[41] Baek, B.-S., Park, J.-W., Lee, B.-H., & Kim, H.-J. (2013). Development and Application of Green Composites: Using Coffee Ground and Bamboo Flour. Journal of Polymers and the Environment, 21(3), 702-709.

[42] Saiful, Helwati, H., Saleha, S., & Iqbalsyah, T. M. (2019). Development of bioplastic from wheat Janeng starch for food packaging. IOP Conference Series: Materials Science and Engineering, 523, 012015.

[43] Marichelvam, M. K., Manimaran, P., Sanjay, M. R., Siengchin, S., Geetha, M., Kandakodeeswaran, K., Boonyasopon, P., & Gorbatyuk, S. (2022). Extraction and development of starch-based bioplastics from Prosopis Juliflora Plant: Eco-friendly and sustainability aspects. Current Research in Green and Sustainable Chemistry, 5, 100296.

[44] Khan, Amna & Majeed, Tanveer. (2019). BIODEGRADATION OF SYNTHETIC AND NATURAL PLASTICS BY MICROORGANISMS: A MINI REVIEW. 1. 180-184.

[45] Kanayama, M., & Kawamura, S. (2019). Effect of Waste Bamboo Fiber Addition on Mechanical Properties of Soil. Open Journal of Civil Engineering, 09(03), 173-184.

[46] Avérous, L. (2008). Monomers, Polymers and Composites from Renewable Resources || Polylactic Acid: Synthesis, Properties and Applications. 433-450.

[47] Gujar, S., Pandel, B., & Jethoo, A. (2014). Effect of Plasticizer on Mechanical and Moisture Absorption Properties of Eco-friendly Corn Starch-based Bioplastic Nature Environment and Pollution Technology An International Quarterly Scientific Journal Original Research Paper. Neptjournal, 13, 425-428.