Evaluation of Biodegradable Nylon from Cassava Starch (Tapioca Starch)

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ABSTRACT

Biodegradable and bio-based plastics currently constitute a small fraction of the overall plastic market. This study aims to scrutinize the feasibility, properties, and environmental impact of producing biodegradable nylon using cassava starch as a raw material. Analysis carried out includes; Solubility, biodegradability, and water adsorption test. The results of the solubility test for the bio plastic derived from cassava starch indicated a slight solubility in water, insolubility in the polar solvent methanol and complete solubility in concentrated sulfuric acid (H_2SO_4) and hydro chloric acid (HCl). The analysis results reveal that the starch-based bio plastic displays a higher capacity for water absorption. Utilizing biodegradable components such as cassava starch, gelatin, and glycerol, a comprehensive performance film was successfully developed. The study demonstrated that bio plastics derived from cassava starch degrade in less than twenty-eight days, suggesting their suitability for application in the packaging industry.

Keywords: Biodegradable, Polymer, Nylon, Cassava, Starch, Bio plastics

INTRODUCTION

Polymers showcase a wide array of material characteristics, ranging from flexibility to rigidity, permeability to impermeability, and hydrophili city to hydrophobi city. These attributes are dictated by the structure of the repeating units constituting polymers, known as monomers [1]. Following the processing of polymeric materials and their formation into final, commercially relevant shapes typically through the application of heat they are termed plastics. Plastics, recognized for being lightweight, versatile, affordable, and exceptionally durable, have permeated various aspects of our daily lives. Plastics are mainly made of carbon, hydrogen, nitrogen, oxygen, chlorine and bromine are used in automobile production, space exploration, irrigation, agriculture, health and other industries [2,3]. Their widespread applications span diverse sectors, including transportation, medicine, agriculture, and households [4,5]. Despite the myriad societal benefits of plastics, a significant proportion is employed in single-use, disposable items such as packaging, contributing to the substantial challenge of managing solid waste globally, given the escalating production of plastics, which has surged seven fold since the mid-1970s [6,7].

Biodegradable and bio-based plastics currently constitute a small fraction of the overall plastic market. In 2020, the global production capacity for biodegradable polymers stood at 1.227 million tonnes, with an additional 0.884 million tonnes for bio-based polymers, accounting for approximately 0.5% of the 360 million tonnes of plastics produced [6,8]. The demand for these environmentally friendly alternatives has risen in recent decades due to the aforementioned challenges, with future projections anticipating further growth in production capacity to an estimated 2.87 million tonnes by 2025 [8].

Biodegradable and bio-based plastics find applications in an expanding range of products, including packaging materials, textiles, hygiene products, consumer goods, and agricultural items [9]. Notably, starch-based bio plastics, sourced from various starches like cassava, wheat, rice, barley, oat, and soy, have gained prominence. Starch-based biofilms possess desirable qualities such as being odourless, tasteless, colourless, non-toxic, and biodegradable.

Tapioca starch, extracted from cassava, exhibits low gelatinization temperatures and comprises two polymers amylose and amylopectin in varying proportions [10]. The high amylopectin content contributes to enhanced binding power in gels, though an excess of amylose may result in reduced gel strength and stickiness [11].

Typical non-biodegradable polymers linger for prolonged periods following disposal, rendering them inappropriate for short-term purposes. This study aims to scrutinize the feasibility, properties, and environmental impact of producing biodegradable nylon using cassava starch as a raw material.

MATERIALS AND METHODS

The raw materials for the preparation of biodegradable plastics include cassava starch, glycerin, gelatin, water and food colour. Raw cassava starch was purchased from the local market Jabi, Abuja, Nigeria. Glycerin, gelatin and food colouring (Green colour) were purchased from Bumsa Plaza, Kubwa Abuja.

Procedure: Biodegradable nylon was manufactured following the methodology outlined by Mroczkowska and Eyre [12, 13]. About 1 g of cassava starch was weighed in a 250 mL beaker and hydrated with 100 mL of distilled water. The starch underwent dissolution through continuous stirring at 60 °C. Subsequently, 1 mL of glycerol and a drop of green food colouring were introduced and mixed into the solution, followed by the dissolution of 5 mL of gelatin. The resulting mixture was stirred until achieving a homogeneous blend, with all components dissolved, following heating between 75 and 80 degrees Celsius. The solution of biodegradable nylon was then poured onto a silicon tray and allowed to air dry for 48 hours in a well-ventilated space. Following this drying period, the biodegradable nylon was extracted from the tray and prepared for further analysis (Solubility test, biodegradability test and water adsorption test). **Figure 1** shows the produced biodegradable nylon.

Figure 1: Produced Biodegradable Nylon

Solubility Test

The dry film mass was precisely weighed and documented. The samples were submerged in the solutions (acidic, organic and water) in the beaker for six hours. The solutions are:

1. Hydrochloric acid (HCl)
2. Sulphuric acid (H_2SO_4)
3. Methanol (CH_3OH)
4. Water (H_2O).

After six hours, the film's remaining sections were filtered, and after drying in a hot air oven at 110 ^{0}C, a final fixed weight was determined. A suitable water solubility range for glycerol is between 18% and 25%. Calculations to determine the amount of total soluble materials (%) was carried out using equation 1:

$$W_s(\%) = \frac{W_i - W_f}{W_i} \quad x\,100 \quad (1)$$

Where;

W_S= solubility in water

W_i = initial weight

W_f= final weight

(A) Biodegradable nylon submerged into their respective solution

(B) Biodegradable nylon after six hours in the solutions

Figure 2**:** Stages of the solubility test

Biodegradability Test

A small amount of moisture that was discovered around the roots of wealthy plants was collected and kept in a 600 mL beaker. Two samples-one at the upper layer and the other at the lower layer were buried in the soil for one week. The specimen's weight was recorded both before and after the test. The equation used to measure the results of the biodegradability test was:

$$Weight\ Loss(\%) = \frac{W_i - W}{W_i} \quad x\ 100 \qquad (2)$$

Where;

W_i = weight of a sample (before the test)

W = weight of a sample (after the test)

(a) Nylon before Soil Burial Test (b) Biodegradable nylon buried in the soil (c) Nylon film after one Week

Figure 3: Soil Burial Test for Biodegradable Nylon

Water Absorption Test

Two of the produced biodegradable nylon of varying weights were collected for the water adsorption test. The samples' original weight was noted. The samples were then put into a beaker with 60 ml of water and kept there at room temperature for twenty-four hours. After that, the samples were removed from the water and cleaned. The following formula was used to determine the amount of water taken in:

$$Water\ adsorption = \frac{W_w - W_d}{W_w} \quad x\ 100 \qquad (3)$$

Where;

Ww = Wet weight

Wd = Dry weight

RESULTS AND DISCUSSION

A solubility assessment (as shown in **Figure 2**) was conducted to examine the influence of different solvents on the synthesized bio plastic. The results of the solubility test for the bio plastic derived from cassava starch indicated a slight solubility in water, thereby enhancing its suitability as a bio plastic. However, for applications demanding enhanced product integrity and water resistance, achieving water insolubility is essential. Notably, the bio plastic demonstrated insolubility in the polar solvent methanol, as evidenced in **Table 1**

It exhibited complete solubility in concentrated sulfuric acid (H_2SO_4) and hydrochloric acid (HCl) at a concentration of 100%.

Table 1: Solubility Test

Solvents	**Initial weight (Wi) (g)**	**Final weight (Wf) (g)**	**Solubility (%)**
Methanol (CH_3OH)	0.686	0.669	2.48
Water (H_2O)	0.514	0.344	33.07
Hydrochloric Acid (conc.) (HCl)	0.812	0.00	100
Sulfuric Acid (conc.) (H_2SO_4)	0.638	0.00	100

The samples were measured to calculate the percent weight reduction after one week of soil burial test. Cassava starch and gelatin mixture were found to have lost 100% of their weight after being buried at the upper layer for one week as shown in **Table 2**. Additionally, 98% of the second sample that was buried on the lower layer was found. Over fairly short periods, these materials disintegrate and are released into the environment. Cassava starch and gelatin-based biodegradable nylon showed a greater level of bio degradation based on the amount of weight loss.

Table 2: Biodegradable test

Sample burial	**Before weight (Wi) (g)**	**After weight (W) (g)**	**Weight loss (%)**
Upper Layer	0.606	0.000	100
Lower Layer	0.598	0.011	98

To determine the water absorptivity of the material, a water absorption test was performed. The inherent hydrophili city of starch is identified as the primary factor contributing to water absorption. Two samples of different weights were gathered for the water adsorption test (as shown in stage 3 **Figure 3**). The initial sample exhibited a dry weight of 0.513 g and a moist weight of 1.892 g. Subsequently, a second sample, weighing 72.09 g when wet and 0.341 g when dry, was collected, as outlined in **Table 3**. The analysis results reveal that the starch-based bio plastic displays a higher capacity for water absorption.

Table 3: Water absorption test

Dry weight (W_d) (g)	**Wet weight (Ww) (g)**	**Uptake (%)**
0.513	1.892	72.89
0.341	1.125	72.09

CONCLUSIONS

The study demonstrated that bio plastics derived from cassava starch degrade in less than twenty-eight days, suggesting their suitability for application in the packaging industry. While exploring their mechanical properties is crucial for diverse industrial applications, it was observed that a commercial bio plastic failed to decompose within the specified time frame. Given the global expansion of bio plastic usage, it is imperative to establish criteria ensuring the sustainability of materials labeled as “biodegradable.” In conclusion, there is a pressing need for a new guide addressing the manufacturing, utilization, and disposal of bio plastics worldwide.

As an environmentally friendly and biodegradable alternative to traditional plastics, the bio plastics produced in this study offer an effective means to mitigate plastic emissions. The starch-based film developed here, with its outstanding performance, holds promise for eco-friendly food packaging applications.

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Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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