**Comparative Biodegradable Plastic Production from Agricultural Wastes**

**ABSTRACT**

Several environmental issues are associated with fossil based plastics. These environmental challenges coupled with the finite nature of fossil fuels is the basis for exploring alternative methods of plastic production. Recently, starch from various sources such as cassava, corn, potatoes, and yam have been used to synthesize bioplastics. This approach is not viable and sustainable because of cases of food shortage across the globe. In this work however, starch obtained from agricultural wastes such as cassava peel and corn cobs was used for bioplastics synthesis. Powdered coconut shells were also used as fillers and its effect on the qualities of the products were examined. Bioplastics was synthesized from starch obtained from cassava peels and corn cobs alone and thereafter 10%, 20%, 30% and 40% (w/w) filler was added differently and its effect on the products was assessed. The tests carried out on the bioplastics include; water retention capacity, biodegradability, water soluble content test, heat resistance test as well Fourier Transformed Infrared Radiation Analysis (FTIR) and Scanning Electron Microscopy (SEM) analysis. In this study it was deduced that bioplastics from cassava peels forms a better product than that from corn cobs andfillers at 20 % w/w formed the best bioplastic composition. As a result, could be used in packaging industries when additives are added in the correct and proper percentage. Industrial adoption of bioplastics should be highly encouraged.

Keywords: bioplastic, agricultural wastes, biodegradable, renewable source

1. **INTRODUCTION**

Plastic is a material made up of a broad array of synthetic and semi-synthetic organic compounds. It is highly valued due to its exceptional versatility, ease of use, and affordability. Plastics are generally large molecular organic polymers, often produced from petrochemical sources derived from fossil fuels (Deepa and Rajeswari 2020; Sharmila, *et al*., 2020). These polymers which are unarguably the mostcommonly used product in every aspect of life has found applications in areas, including containers, packaging, computers, mobile phones and even the medical and automotive companies’ have used plastics for a variety of parts (Nakhil, 2021). This high utility is fostered by their ease of production and handling, as well as light weight in comparison to materials like metals, glass, and ceramics especially when used for packaging (Azsarinka, et al., 2020).

However, due to the growing popularity and increasing use of plastics, there has been an increase in environmental pollution associated. Firstly, since plastics are synthesized from petroleum or crude oil derivatives such as polyethylene, polypropelene among others, it makes it difficult to decompose and this has resulted to accumulation of large volumes of plastic wastes over time (Ghandis*et al*., 2023; Gadissa and Vighneswara, 2021). Secondly, there is a case of release of toxic gases during the burning of these plastics. These gases could be cancerous and has resulted to irritation of the eyes, throat and lungs of humans. These problems caused by petroleum-based plastics and its non-biodegradability has sparked growing curiosity in the sector of bioplastics in recent times (Nakil, 2021; Faseela, 2022).

Furthermore, petrochemicals are not renewable resources and so with every use there is depletion. The search for a sustainable source of plastic is therefore necessary. Bioplastics which are produced from renewable resources are readily decomposed by microorganisms, and represent a new generation of plastics that can reduce reliance on fossil fuels while also minimizing other environmental impacts (Meenakshi*et al*., 2022). Bioplastics can be made from starch, chitosan, cellulose, protein, fibers as well as from other renewable biomass such as agricultural and domestic wastes (Ghendis*et al*, 2023; Desti*et al*., 2023). These biomass can be used to produce bioplastics with similar characteristics as conventional plastics, however, once used and disposed in the environment, they will break down into H₂O and CO₂ through the action of microorganisms (Dasumiati*et al*., 2019; Faseela, 2022).

Starch is considered one of the most promising natural polymers due to its natural biodegradability, abundant availability, and annual renewability. Several studies have been carried out on the production of starch-based bioplastics with cellulose nano fibers (Ghendis*et al*., 2023), however, there have been some few drawback recorded to the use and manufacture of bioplastics from starch. They include; high water retention capacity and low tensile strength. These challenges has necessitated the use of further reinforcements such as the use of additives called fillers to impart specific desired properties on the product(Ghendis*et al*, 2023; Desti*et al*., 2023). These fillers are able to impart mechanical strength, reduce water holding capacity and also improve the texture of the product. Natural products such as egg shells, clay minerals, chitosan, chitin, orange peels and kernel bark have been used in recent research to act as fillers (Mohd, *et al*., 2022). In this work; grounded coconut shells was used as filler during the synthesis of bioplastic from starch obtained from corn cobs and cassava peels. The effects of different concentrations of the coconut shells was examined and determined.

1. **MATERIAL AND METHODS**

**2.1 Material**

The materials used for this work include cassava peels obtained from fresh cassava harvested from Loma Linda Layout Extension in Enugu South Local Government Area, Enugu State. Corncobs were purchased from New Market in Enugu North Local Government Area, Enugu State, and coconut shells were collected from coconut bought from Rumodumanya market in ObioakporLocal Government Area of Rivers State. Glycerine, Acetic acid, and Distilled water were also sourced from the Enugu State University of Science and Technology (ESUT) laboratory.

**2.2 Research Design**

The experiment was carried out on ten bioplastic samples, each containing the same mass of starch, glycerin, and distilled water, while the mass of coconut filler varied across samples. Half of the samples were produced using cassava peels, while the other half produced using corn cobs. The cassava peel-based bioplastics were labeled C1, C2, C3, C4, and C5, corresponding to 0%, 10%, 20%, 30%, and 40% weight of cassava peels/ weight of filler, respectively. Likewise, the corn cob-based bioplastics were labeled K1, K2, K3, K4, and K5, corresponding to 0%, 10%, 20%, 30%, and 40% weight of corn cobs/ weight of filler, respectively.

**2.3 Extraction of Starch and Preparation of Coconut Shell Filler**

The collected cassava peels were cut into smaller pieces, weighed, grounded to paste form, dissolved in water, and then filtered. The filtrate was allowed to stand overnight, and was decanted to separate the liquid from the starch at the bottom. The starch was dried and stored for further use. Similarly, the corn cobs, were ground into a powder, dissolved in water, filtered, and the filtrate was left to stand overnight. Afterward, it was decanted, and the starch was collected, dried, and stored in an airtight container for further use.

On the other hand, the coconut shells were sun dried until completely dried. Afterwards they were pounded using ceramic mortar and pestle. The powder was sifted with a micro sieve to obtain the finest coconut shell particles and stored in an airtight container for subsequent usage.

**2.4 Synthesis of Bioplastics**

30 mL distilled water was poured into a beaker and placed on the heating mantle. Thereafter, 10 g of starch was added and allowed to boil for 30 min till complete dissolution of the starch. 2 mL of glycerin (plasticizer) was also added with continued stirring. Furthermore, 1 mL of acetic acid was also added also with constant stirring till a uniform paste was formed. The paste was poured into a mould and allowed to air dry overnight before being sundried till complete dryness.

The above procedure was repeated for four more samples including; 10 % (w/w), 20 % (w/w), 30 % (w/w) and 40 % (w/w) of powdered coconut shells added. The effect of the filler on the physicochemical properties of the bioplastic was evaluated.

**2.5 Characterization of Bioplastics**

**2.5.1 Determination of water holding capacity of bioplastics**

The water absorption capacity of the final product was measured using the standard ASTM D 570 procedure (Gangurde, 2022). This method was used to examine the rate of moisture absorption. A specified mass of the sample was soaked in distilled water for a total of 24 hours, with the bioplastics removed, cleaned, and weighed at 3-hour intervals. The increase in weight as a result of the uptake of water determines the water holding capacity of the bioplastics. Water uptake was calculated using the expression below:

$\% water uptake=\frac{Wet weight-Dry weight }{Dry weight} ×100$ (1)

**2.5.2 Determination of water soluble content of bioplastics**

This test was carried out to determine the water soluble content of the bioplastics. Pre weighed samples were soaked in water for 24 h, afterwards, they were dried for 24 h and weighed to determine the final weight of the samples. The difference in weight gives the amount of water soluble components of the material (Egzi and Bilgen, 2019). The water-soluble content analysis is usually carried out immediately after the water absorption capacity determination analysis.

**2.5.3 Biodegradation test**

Soil burial method was used for this analysis. The pre weighed samples were buried 2-3 cm into compost soil and removed every 3 days for weighing. The reduction in weight shows that biodegradation is occurring. This procedure was continued till complete degradation occurs as shown by the absence of the sample in soil. Water was sprayed on the soil occasionally to increase bacterial action.

**2.5.4 Heat resistance analysis**

This test was carried out to determine the amount of heat the bioplastic can withstand before deforming. The sample is clamped on a retort stand and placed on a heating mantle and allowed to heat till 180 °C. The weight of the sample was checked after every temperature increase of 20 °C, and the percentage weight reduction was calculated using the equation;

$\% heat resistant=\frac{initial weight-final weight }{initial weight} ×100$ (2)

**2.5.6 FTIR analysis**

The samples were analyzed using an FTIR spectrometer (Thermo Scientific Nicolet iS10, Madison, WI) with Omnic software. Measurements were taken in the mid-infrared range of 650–4000 cm⁻¹, using 32 scans at a resolution of 16 cm⁻¹. A background scan was performed to minimize the influence of the air reference spectrum. Before and after each analysis, the ATR crystal was cleaned with acetone p.a., and each sample was scanned three times for replication.

**2.5.7 SEM determination**

The samples were examined using a Scanning Electron Microscope (SEM) (JEOL JSM-7600F) equipped with In Touch Scope software. The bioplastic sample was attached to an SEM stub using double-sided carbon tape and sputter-coated with a thin layer of gold to improve conductivity. The SEM chamber was evacuated to high vacuum, and the beam voltage was set to 15 kV. Using the BSD Full detector, the image was acquired by scanning the sample surface, capturing compositional contrast based on atomic number differences. Image processing was done to adjust contrast and brightness for clarity.

1. **RESULTS AND DISCUSSION**

**3.1 Physical Properties of Cassava Peel and Corn Cobs Bioplastics**

As shown in table 1, the physical appearance of bioplastics synthesized from cassava peel is brown and translucent, while the bioplastic synthesized from corn cobs appeared to be fragile, soft, and easily breakable compared to their cassava peels counterparts. The incorporation of filler enhanced the tensile strength of the cassava peels product, as shown in samples C2 to C4, the strength of the material decreased when the filler exceeded 30 %. C5 gave a soft, low strength, low cohesion material that easily breaks on handling. On the other hand, the addition of filler didn’t show any improvement in the tensile strength of the corn cobs products. According to Fong and Othman (2022), starch granules are composed of amylose and amylopectin. A higher amylose content in starch tends to reduce gel strength and stickiness, whereas a high amylopectin content indicates a greater binding capacity. From the physical properties observed, starch obtained from corn cobs has a higher amylose content while that from cassava peel have a higher amylopectin content (Fong and Othman, 2022).

**Table 1. Physical properties of bioplastics**

|  |  |  |
| --- | --- | --- |
| **S/N** | **Weight % of filler (%)** | **Remarks** |
| C1 | 0 | Flexible, shiny, brownish, translucent and soft  |
| C2 | 10 | Hard, rough, translucent, brownish and thick |
| C3 | 20 | Hard, coerce, thick, compact, brownish and translucent |
| C4 | 30 | Hard and strong, coerce, thick, translucent, brownish |
| C5 | 40 | Coerce, brittle, low cohesion and translucent, brownish |
| K1 | 0 | Grayish colour, soft, thin, and easily breakable material |
| K2 | 10 | Grayish colour, soft, flexible and low tensile strength material |
| K3 | 20 | Grayish, strong, hard, rigid material |
| K4 | 30 | Grayish colour, rigid, translucent, coerce  |
| K5 | 40 | Grayish colour, rigid, low strength, soft, and easily breakable |

**3.2 Water Holding Capacity**

The water holding capacity test for bioplastic samples is conducted to evaluate their ability to retain moisture, which is crucial for assessing their performance and stability in humid or wet environments. As shown in Fig 1,bioplastics synthesized from cassava peel without the addition of filler (C1) has higher water retention capacity of 64.00 % (3.28g final weight from 2g soaked in water for 24h).Addition of 10 % w/w filler to the products (C2) reduced the water holding capacity of the bioplastics. This is because the filler can fill the pores present in the bioplastics, thereby reducing the rate of water absorption (Norhafezah and Muhammad, 2018). Further increase in the percentage of the filler to more than 30% had a detrimental effect on the bioplastic as it will lead to saturation and super saturation of the product thereby limiting the binding effect of the plasticizer (Manasiet al., 2018). For this amount of filler to be effective, more volumes of plasticizer will be needed.

Corn cob bioplastics on the other hand showed higher water absorption ability. Fig 2 showed that, the water retention capacity of the product without the filler (K1) was 74.50 % (3.49g final weight from 2g soaked in water for 24h) this was because corn cobs naturally absorbs water easily. The incorporation of 10% filler material into the product decreased the water holding capacity to 58%. However, beyond this amount there is less cohesion between the molecules due to saturation and super saturation which also resulted in the scattering of the product when dissolved in water for more than 6 h. This indicates that with a higher amount of filler, the plasticizer will be unable to hold the molecules together leading to breakage and subsequent scattering when dissolved in water for too long (Thu & Aye, 2020). Therefore, to increase the strength and cohesion of the bioplastic with a high percentage of filler or other additives, the quantity of glycerol should be re-evaluated to account for the amount of filler to be utilized.

**Fig. 1. Water holding capacity of cassava peels bioplastic**

**Fig. 2. Water holding capacity of corn cobs bioplastic**

**3.3Water Soluble Content of Bioplastics**

This test was used to determine the amount of water soluble matter present in the product after dissolution for 24 h. This test was usually preceded by the water holding capacity test and the weight loss after drying gives the mass of material soluble in water. From the results obtained, C1 and K1 contains about 8.55 % (1.83g final mass from 2g soaked in water) and 13.45 % (1.73g final mass from 2g soaked in water) water soluble content respectively, while the addition of fillers as indicated in C2 and C3 depicted a reduction to about 6.50 % water soluble content. Other results, obtained for corn cob bioplastic as indicated in K2 and K3 showed that increasing the concentration of filler resulted to reduction in water soluble matter. This isdue to the non dissolving nature of the fillers in water over the period of time in consideration. In contrast to the above result, the solubility content of product with higher concentration of filler(C4, C5,K4 and K5) could not be determined because they were already scattered upon dissolution even before 24 h.

**Fig. 3. Water soluble content of cassava peels bioplastic**

**Fig 4. Water soluble content of corn cobs Bioplastic**

**3.4 Biodegradability of the Bioplastics**

Biodegradation is the breakdown of complex materials by the action of microorganisms under certain conditions (Fatima, 2017; Fong and Othman, 2021). The biodegradability of cassava peel and corn cob bioplastics as indicated in Figures 5 and 6 showed that there was a massive decrease in the mass of cassava peel and corn cobs bioplastics (C1 and K1) after 12 days (reduction from 5 g to about 3g). Complete biodegradation however occurred after 18 days and by 21 days, it had turned to compost soil. The addition of filler however increased the time of biodegradation. Significant weight reduction started after 18 days in C2, C3, K2 and K3 and it took between 24 to 27 days for complete biodegradation to occur in these samples. Higher amount of filler such as 30 % and 40 % used in C4, C5, K4 and K4 showed the slowest rate of degradation; which will take over 30 days to completely degrade. This illustrates the slow rate of biodegradation of coconut shells. Coconut shells are tough, fibrous, and contain a high lignin content. Lignin, a complex organic polymer, renders the shell highly resistant to microbial decomposition (Norhafezah and Muhammad, 2018; Praveen).

**Fig .5. Biodegradability of cassava peel bioplastic after 30 days**

**Fig. 6. Biodegradability of corn cobs bioplastic after 30 days**

**3.5 Heat resistance of the Bioplastics**

The result of heat resistance analysis shown in Figures 7 and 8, indicated that it took about 1000C for the cassava peel bioplastic to start deforming and about 160 0C to turn completely to ash (100% mass reduction of bioplastic). This value was slightly lower in the case of corn cob bioplastics whose deformation started at about 80 0C and completely turned to ash at 140 0C. Addition of filler in form of coconut shells increased the time for deformation. It took about 120 0Cfor deformation to occur while complete ash formation was observed at about 180 0C. This implies that bioplastics synthesized from corn cobs and cassava peels can be used to store substances at temperature below 100 0C, above this temperature leaching could occur which could cause harm when used for consumable products.

**Fig. 7. The heat resistance analysis on cassava peels bioplastic**

**Fig. 8. The heat resistance analysis on corn cobs bioplastic**

1. **CONCLUSION**

Recently, biodegradable plastics have emerged as one of the most innovative materials in the polymer packaging industry. This research focuses on the synthesis and characterization of natural polymeric materials. Since many countries around the world are struggling with food shortage and environmental pollution, producing bioplastics from agricultural waste such as cassava peel is a viable alternative to fossil fuel based plastics. This study confirms that wastes from food or agriculture could be used for bioplastic production to reduce the overdependence on fossil based plastics and also ensure a cleaner environment.

In this study it can be deduced that bioplastics from cassava peels forms a better product than those from corn cobs and could be used in packaging industries when additives are added in the correct and proper proportion. High water absorption ability which has been limiting the use of bioplastics in recent times can be reduced by using efficient additives such as fillers from coconut shell. Also, fillers at 20 % w/w formed the best bioplastic, above which could result to lower cohesive forces and poor tensile strength of the product. More additives will therefore require more volume of plasticizer to enable better cohesion and stronger intermolecular forces of attraction between the various feed stocks. More also, the problem of degradation of bioplastics will be solved from bioplastics synthesized from cassava peel and corn cob because from the result obtained, complete biodegradation occurred within 18 to 21 days while the addition of filler will reduce the rate of degradation and increase the time needed for complete degradation to over 30 days. The more the amount of filler, the more the time it will take for complete biodegradation to occur.

The FTIR analysis showed the presence of O-H group of alcohol or phenol, carboxylic, amide and alkyl functional groups in the synthesized bioplastics. As a result, the presence of 1,2,3- tri substituted organic compound was suspected.

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