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Production and Characterization of Biodegradable Plastics from Water Yam Peel Starch and Rubber Seed Oil

Osagie, O.F.[1*], Oriji, O.G.[2] & Okorosaye-Orubite, K.[3]
[1]Department of Chemistry, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria
[2,3]Department of Pure and Industrial Chemistry, University of Port Harcourt, Port Harcourt, Nigeria
[*]Corresponding Author Email: omons.osagie@ust.edu.ng

ABSTRACT
Packaging waste forms a significant part of municipal solid waste and has caused increasing environmental concern. This research investigates the potential of producing bioplastics using the starch from water yam peels and epoxidized rubber seed oil. The starch and epoxidized rubber seed oil with additives were copolymerized to form the bioplastic. Analysis of the starch were: moisture content (10.08±0.42%), ash content (0.175±0.010%). amylase (26.93±0.01%) and amylopectin (73.07±0.10%). Physicochemical analysis of the epoxidized rubber seed oil were pH (6.50±0.01), specific gravity (0.97±0.24), viscosity (12.30±0.20 poise) acid value (22.62±0.01 mgKOH/g) and iodine value (158.51±0.03 mgI_2/g). The bioplastic was subsequently produced by copolymerization of the epoxidized rubber seed oil and water yam peels starch. The tensile strengths of both bioplastic and the control were 20.54N/mm^2 and 12.28N/mm^2 respectively. Also, the results showed that the bioplastic had a poor resistance in acidic and water media, good resistance in basic, and alcoholic media. The biodegradability test results showed that weight loss was more evident in loamy soil whereas no change was observed for the control.

Keywords:
Starch,
Epoxidized,
Bioplastic,
Weight loss,
Chemical resistance

INTRODUCTION

Plastic has transformed everyday human life and is playing a crucial role in influencing every aspect of life. Though, the majority of the plastics are petroleum based which dominates everywhere due to their excellent versatility, mechanical and barrier properties (Salgado et al., 2025). Unmanaged plastic contributes to air and water pollution (Onah et al., 2025). Despite of plentiful advantages of petroleum-based plastics; they are big threats to the environment due to their exceptional resistance to biodegradation (Sanyang et al., 2015).

Packaging waste forms a significant part of municipal solid waste and has caused increasing environmental concern, resulting in the strengthening of various regulations aimed at reducing the amount generated among other materials (Dametres et al., 2023). A wide range of oil-based polymers is currently used or in combination of more than one material as composites. Most of these packaging materials enter municipal waste stream at the end of their service life (Jain et al., 2010)

Since plastics cannot be degraded by natural processes in a short period of time, they are left as 'plastic waste' causing environmental problems. The methods normally used to destroy other types of waste such as burning and burying are not suitable for plastic destruction. When some types of plastics are burnt, they can release dangerous gases to the atmosphere while burying plastics in soil cannot destroy plastics because they are not biodegradable. Degradation at high temperature, such as in pyrolysis (burning) tends to cause emission of toxic fumes. Plastic accumulation in the environment thus creates tremendous problems for the world, presently and in the future. (Demetres et al., 2023),

Plastics are made from oil-based polymers mixed with additives such as fillers, plasticizers, and lubricants that are difficult to decompose. Due to the wide variety of processes, recycling plastics is complex, and some of the recycled products available are generally of poor quality (Ragadhita et al., 2022). The plastics disposed of in landfills emit about 253 g carbon dioxide (CO_2) per kg, while ignition discharges 673–4605 g kg^{-1} of CO_2 . (Behera et al., 2022) This incineration practice leads to enormous greenhouse gas emissions, which contribute to global warming. It is assessed that polythene would debase only 0.5% even after 100 years (Ragadhita et al., 2022). Its degradation essentially relies upon temperature, light, oxygen, and dampness accessibility (Bhuyar et al., 2019). Also, partial combustion of plastics releases carbon monoxide (CO) and other hazardous gas directly into the environment,

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thereby polluting the environment (Behera et al., 2022). The development of bioplastics has focused on starch, which is available abundantly in nature. The potential for bioplastic development is immense because the raw material is available in the environment. The bioplastics have been reported by authors in which they were processed from great range sources, such as cassava (Ezeoha & Ezewanne 2013). The present study utilized the water yam (*Dioscorea alata*) as the raw material with some considerations. Nigeria is among the largest water yam producing country in the world with production capacity in 2014, reaching 29 million tons, meanwhile based on the Jabeen report in 2015, and the world capacity attained at 267.0 Million Tons. The huge availability of water yam peel waste can provide a sustainable resource for the production of bioplastic.

The increase of bioplastic quality was the addition of biopolymers such as glycerol and sorbitol. The addition of glycerol provides a higher solubility in plastic films than sorbitol. Bioplastics made from cassava starch and glycerol plasticizers are transparent, bright, homogeneous, flexible, and easy to handle (Ezeoha & Ezewanne 2013).

Based on the reference survey as described by Obunwo et al., (2020), the preparation and characterization of plastic films synthesized with a combination of epoxidized rubber seed oil + water yam peels starch + glycerol + water are needed to be studied and analyzed. Bioplastics were characterized by assessment of their physico-mechanical properties, Chemical resistance and biodegradability in different soil type through soil burial method

MATERIALS AND METHODS

The rubber seeds were collected from rubber plantation at Omagwa whereas the water yam peels were collected from waste receptacle in Aluu both in Ikwere Local Government Area of Rivers State. The water tuber peels were washed thoroughly, diced carefully to smaller cubes and blended. The blended water yam peels was then mixed with water to form slurry which was sieved in order to separate the starch granules extract from the water yam peels residue. The slurry was allowed to stand for 1 h and the excess water was decanted. The slurry was stirred again and sieved, followed by quick water washing which was used to get rid of any residue left in the bowl. The starch slurry was then transferred to aluminium foils and put in an oven for 1 h

The rubber seeds on the other were dehulled, cleaned and dried under the sun for about 5 h after which the seeds were transferred into the oven to heat at 105 ℃ for 1h in order to remove moisture. The dried seeds were allowed to cool and then ground to paste which was stored in an air tight container. The oil extracted from the seeds was extracted using n-hexane solvent for 168 h in order to ensure maximum separation. Finally, the mixture was filtered

To epoxidize the rubber seed oil, glacial acetic acid 15.0 g, and rubber seed oil (RSO) 60.0 g, were charged into a 250-mL reaction flask and the reaction mixture was maintained at 10 °C. 30% hydrogen peroxide (66.1g) equilibrated at 10 °C, was added drop wise under continuous stirring for 1 h. Thereafter, the reactor temperature was raised and maintained at 60 °C for 8h under magnetic stirring. The aliquots of the reaction mixture were cooled to 40 °C temperature. The oil was extracted with ethyl acetate, separated and washed with a brine solution (5% wt NaCl) until acid free and dried over sodium sulphate. The epoxidized oil was concentrated by removing the solvent in vacuo at 60 °C. The resulting epoxidized rubber seed oil (ERSO) was characterized using standard method (AOCS, 1990).

The physical characteristics of the starch such including the pH, gelatinization temperature and proximate composition including the moisture content, ash content, swelling power, swelling volume and solubility were determined following the AOAC guidelines (AOAC, 1990).

Characterization of Epoxidized Rubber seed oil The parameters measured with accompanying devices include;

pH: pH meter:		Benchtop pH Meter	Seven Compact S220	Mettler Toledo	Switzerland
Colour: Tintometer	Lovibond	PFXi-195/2	Tintometer GmbH (Lovibond®)	Germany	
Odour: Olfactometer	Dynamic Olfactometer	GmbH Germany			
Density: (Pycnometer)		25 mL Gay-Lussac Pycnometer	Borosil Glass Works Ltd.	India	
Viscosity: Viscometer	Digital Rotational	DV2T	AMETEK Brookfield	United States	
Refractive index: Refractometer	Digital Refractometer	PAL-1	ATAGO Co., Ltd.	Japan.	

Others are acid value, iodine value, and saponification value which were measured according to AOAC, (2020) guidelines.
The production of the bioplastic was based on the formulated recipe according to the composition shown in Table 1.

Table 1: Formulation of the bioplastics

Recipe		Quantity (g)
Starch		105.00
Water		120.00
Epoxidized rubber seed oil		40.50
Glycerol		10.50

The weighed water and starch were first mixed and boiled, using a hot plate at 100 ºC, until a sticky paste was formed. After removing the starch-water mixture from the hot plate, the rest of the materials were then added and mixed, the mixture was later passed through a roll-mill with a temperature of 120 ºC. It was then compressed, using a compressor with a temperature of 130 ºC for seven minutes. The products were later removed from the compressor and kept in an open pan. The bioplastics were later cut into strips of (100mm x 23 mm) dimension for analysis.

Characterization of bio-plastic the bioplastic produced was characterized using methods described by Obunwo et al., (2020) and its characteristics compared with the characteristics of polyethylene which served as the control. Properties determined included: clarity and transparency, tensile strength, water uptake, heat and chemical resistance, as well as biodegradability of the samples

RESULTS AND DISCUSSION

Table 2: Physicochemical characteristics of water yam peels starch

Parameter	Mean Values	
pH	5.80±0.05	
Gelatinization Temperature (℃)	79.00±0.01	
Moisture Content (%)	10.08±0.42	
Ash Content (%)	0.18±0.010	
Swelling Volume (ml)	10.80±0.008	
Swelling power (g)	27.60±0.91	
Solubility (%)	13.08±0.70	
Amylose (%)	26.93±0.01	
Amylopectin (%)	73.07±0.10	

The physicochemical characteristics of the water yam peels starch are presented in Table 2. The Swelling power (27.60±0.91 g), Amylose and Amylopectin content (26.93±0.01% and 73.07±0.10 %) respectively. Gelatinization temperature (79.0±0.01 ⁰C), Solubility (13.08±0.70 %), are in agreement with the ranges (2.29-34.10 g), (60.20-84.56 g) (69.4℃-81.4℃), (0.22-15.68%), reported in literature (Wickramasinghe et al., 2009; Wioletta et al., 2012 and Mweta et al., 2015). Moisture content (10.08±0.42 %) is almost similar to the result (10.25 %) found by Omotoso et al. (2015) while ash content (0.175± 0.010%) is low when compared with result (0.55%) reported by Omotoso et al. (2015).

Table 3: Physicochemical characteristics of the epoxidized rubber seed oil

Parameters	Rubber seed oil
Colour	Golden yellow
Odour	Unpleasant
pH	6.50±0.01
Specific Gravity	0.97±0.24
Melting Point (℃)	44.0±0.1
Viscosity (poise)	12.30±0.20
Refractive Index	1.42±0.01
Acid Value (mgKOH/g)	22.62±0.01
Iodine Value (mgI_2/g)	158.51±0.03
Saponification Value (mgKOH/g)	202.40±0.03

The golden yellow colour obtained was different from the dark brown colour observed by Rubber Research Institute of Nigeria. The specific gravity (0.97), refractive index (1.42) and melting point (44 ºC) were in-line with the results and ranges (0.916, 1.3-1.6, and 45-48℃) obtained by (Aigbodion & Bakare 2005; Kovo & Bawa 2007 and Asuquo et al., 2012). Acid value (22.62 mg/KOH) and iodine value (158.51 mgI_2 /g) values were higher than values obtained for pure oil (0.51mg/KOH) and palm oil (52mg/g) by Ascherio & Willet (1997) and Onyeike & Ascheru (2002). The saponification value (202.42 mgKOH/g) and viscosity (12.23 poise) the values are close to the values reported by Abdullah & Salimon, (2009) and Asuquo et al., (2012) which are 182 ± 0.27 mgKOH/g and 119 ± 0.27 mgKOH/g. respectively.

Table 4: Comparative study between the produced bioplastic and the control (commercial plastic)

Parameter	Bioplastic	Control Sample
Clarity	Slightly Clear	Extremely Clear
Transparency	Semi-Transparent	Transparent
Thickness (mm)	0.085±0.027	0.040±0.100
Flammability (sec)	342.00±3.54	205.00±0.10

Tensile strength (N/mm^2)	12.28±3.54	11.22±1.50

Table 5: **Result of chemical resistance and air test.**

Solvent	**Bioplastic**	**Control**
Ethanol	A, C, D	A, C, D
HCl	E, G	E, G
NaOH	B, D	B, D
NaCl	B, D	B, D,
Air	A	A
Water	B, E	B, E

A: No change in dimension; B: Change in dimension; C: Wrinkle; D: Not dissolved in the solution;E: Dissolved in the solution; F: Not absorbed in the solution; G: Absorbed in the solution

Table 6: % weight loss of wild water yam bioplastics (WYPP)

Time (week)	**Sandy Soil**	**Clay Soil**	**Loamy Soil**
1	3.6	3.04	6.42
2	5.2	4.29	8.21
3	7.12	5.18	10.15
4	9.25	6.06	13.36
5	12.70	6.40	19.57

Table 7: Rate of biodegradability of polyethylene control using different soil samples weekly for 5 weeks

Time (week)	Sandy Soil	Clay Soil	Loamy Soil
1	0.00	0.00	0.00
2	0.00	0.00	0.00
3	0.01	0.00	0.01
4	0.01	0.00	0.02
5	0.02	0.01	0.02

Tensile strength (Tables 4-5) performed on the bioplastic and polyethylene control sample were 12.28 N/mm^2 and 11.22± N/mm^2 respectively. The higher value obtained for the bioplastic can be attributed to the epoxidized rubber seed oil and glycerol used to improve the mechanical properties while the value of the control sample was found to be lower. More can be done however to improve the quality of the bioplastics. For flammability test, all the samples burnt completely, however, the control sample took shorter time.

For the chemical resistance and air test performed on the samples, it was observed that the strong acid (HCl) had serious effects on the bioplastic but had no effect on the control sample. In the case of the strong base (NaOH), instead of being dissolved in the liquid, the bioplastic sample was absorbed. The base had no effect on the control sample. When exposed to air, no significant change was observed for both the bioplastic samples and the control samples. When dissolved in ethanol, there was no change in dimension of the samples implying that it did not dissolve. However, it was observed that ethanol made the bioplastic samples brittle, hence they broke easily. The bioplastic samples dissolved in water, unlike the control sample where there was no effect at all.

The results from the biodegradability tests as shown in table 6 using three different soil types (sandy, loamy and clay) showed that there was significant weight loss and reduction in size of the bioplastic samples when buried for 5 weeks. Also, from table 6, it can be deduced that weight loss and reduction in size was more evident in loamy soil when compared to clay soil and sandy soil. The three different soil samples had no effect on the control sample (Table 7). This biodegradability trend was also observed by Obunwo et al., (2020). The weight loss could be as a result of micro-organisms in the soil that decomposed the starch and other components used in the production of the bioplastics.

CONCLUSION

The production of biodegradable plastics using rubber seed oil and water yam peels starch also demonstrates a sustainable and environmentally friendly alternative to conventional petroleum-based plastics. The study shows that these locally available agricultural materials possess suitable starch and oil properties that can be utilized in the development of biodegradable polymer films. Rubber seed oil acts as a plasticizer and improves flexibility, while the starch obtained from water yam starch provides the structural matrix for the bioplastic. It is recommended that further research should be carried out to improve the mechanical strength, water resistance, and durability of the biodegradable plastics through blending with other natural polymers or additives. Optimization of production conditions such as starch-to-oil ratio, temperature, and drying methods is recommended to enhance the quality and performance of the bioplastic.

Conflict of interest

I wish to state that there is no conflict of interest concerning the manuscript titled 'Production and Characterization of Biodegradable Plastics from Water Yam Peel Starch and Rubber Seed Oil.

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