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Synthesis of plantain peel powder-based biofilm

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Abstract

The present study investigated the use of ripe plantain peel powder, crude glycerol, vinegar, egg shell powder and cassava starch as source raw materials for producing plantain peel-based biodegradable biofilm (P-BF). The synthesized biofilm was characterized by chemical test (FTIR, GC-MS, morphology test, water absorption property, biodegradation test, solubility test and swelling test) and mechanical test (ultimate tensile test, flexural, hardness test, % elongation and thermogravimetric analysis). Results showed successful production of P-BF. A non-plantain bioplastic (NP-BF) served as control. The FTIR analysis showed eight functional groups; ether, ethene, amine, carboxylic acid, nitriles, methylene, cyclic ester, primary, secondary and tertiary alcohols common to hydrocarbons. The biodegradation test showed the P-BF degraded at the same pace as NP-BF which degraded on the 6th day of the test. The mechanical test showed P-BF had higher thermal stability and water absorption property compared to the NP-BF. However, P-BF showed lower ultimate tensile test, flexural, hardness test, percentage elongation compared to the NP-BF. Morphology test showed that there was uneven distribution of constituents materials in P-BF compared to the NP-BF which affected its mechanical properties. In conclusion, the study successfully produced plantain peel-based biodegradable biofilm with good mechanical properties, biodegradability, thermal stability, fair water absorption property.

Keywords: Biofilm; Food waste; Plantain peel powder; TGA; Morphology

1. Introduction

Plastics are engineered natural polymers basically made by petroleum derivative based synthetics (petrochemicals). Billions of tonnes of plastics have been generated with more than 79% of them not recycled, but left as waste in the environment [3]. Recycled plastic can cause secondary effects on sullying the item, particularly when it is utilized as a food packaging material because of the presence of specific possibly cancer-causing substances [26]. Burning plastic waste can contaminate the air on the grounds that the smoke created contains dangerous synthetic compounds like dioxin [17]. Furthermore, Polystyrene, the major component in plastics can leach in to water bodies such as oceans, seas and increase the toxicity in water. Aquatic organisms also can mistake the plastic floating on the surface of water for food which can result in death [35].

But, deterioration of plastics in the climate requires several years, and, consequently, leaving plastic waste in the climate or landfill, causing harmful pollution to the earth. Yearly, roughly 13 million tonnes of plastic waste have been tossed by people into the sea, which then hurts marine lives [34].

Bioplastics were developed as an approach to overcome the issue in the early 21st century [36]. They are produced from renewable resources or natural sources like vegetable oil, starch, cellulose, protein, etc. [21]. Utilization of bioplastics has partly replaced the use of conventional plastics in various industrial applications, including packaging

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for food and others, medical instruments, hygiene, and agriculture. In recent developments, bioplastics can be applied in human bodies for medical usage, such as controlled drug delivery systems and therapeutic devices implantation [31]. The European Bioplastic has reported that the production capacity of bioplastics in the year 2022 is 1,075 in 1000 tons, which is expected to increase to approximately 2453 in 1000 tons in the year 2024 [16].

Plantain strips are in many cases disposed of as a loss in landfills, waste and street sides, bringing about natural pollution [8]. The plantain strips make up around 40% of the complete organic product weight and have been viewed as a pontential unrefined component in modern applications particularly agro-based enterprises [20].

Notwithstanding, a lot of research harped on the synthesis of bioplastics from banana strips and cornstarch. However, the current study reports the synthesis and characterization of a biodegradable biofilm from ripe plantain peel powder.

2. Material and methods

The ripe plantain peels (*African Rhino horn species*) were obtained from Buka 9 in Federal University of Technology, Owerri (FUTO) Market, Nigeria (Longitude $6^0$59′E and Latitude $5^0$23′N). The palm oil (produced from the *Elaeis guineensis species*) was purchased from Ihiagwa Market, Nigeria (Longitude $7^0$01′E and Latitude $5^0$24′N). The cassava roots (*TNE 419 species*) were harvested from a farm in FUTO Market (Longitude $6^0$59′E and Latitude $5^0$22′N). The fresh egg shells from chickens of *Leghorn species* were obtained from Lala Meshai Spot in FUTO (Longitude $6^0$59′E and Latitude $5^0$23′N). The pineapple peels (*Abacaxi specie*) were collected from roadside fruit sellers at Ihiagwa Market (Longitude $7^0$01′E and Latitude $5^0$24′N).

2.1. Treatment of materials and production of raw materials

- Plantain peels: the plantain peel powder was produced by sun drying ripe plantain peels for a period of 1 month and grinding into powder according to a modified method of [26].
- Palm oil: Crude glycerol was produced by the saponification method using 100 ml palm oil, 60 % NaOH and 25 g NaCl [41].
- Cassava peels: The cassava root (200g) was washed, peeled and grated using a hand grater. Then, one hundred and fifty milliliter (150ml) of water was added to the mash and stirred. The mash was filtered to obtain a slurry. The starch was prepared at the ratio of 1:1. The slurry was left to stand for 24hours. It was further decanted to obtain the starch. The starch was sun dried for 24h to obtain a fine powder (35g) [27].
- Pineapple peels: The pineapple peels were washed and cut into pieces. It was weighed (500g) and taken into a 1L can. Then, 800ml of water was added, sugar (42g) was added and stirred.
- Eggshells: The eggshell powder was produced by washing, sun drying and grinding fresh egg shells [39].
- Acetic acid (vinegar): The vinegar was produced following the modified method of [13]. It was produced by two-step fermentation, firstly alcoholic fermentation using Saccharomyces cerevisae and secondly, acetic acid fermentation using Acetobaceter aceti.

2.2. Synthesis of biofilms

The non-plantain peel biodegradable biofilm (WP-Bf, control) was produced according to method of [14] whereas the synthesis of plantain powder-based biofilm (P-BF) was done according to a modified method of [14]. The modification was the use of plantain powder.

2.3. Analyses of biofilms

2.3.1. Morphology study

The morphology of the synthesized biofilms was analyzed using a Digital Microscope (BXAW-AX-BC, China) and a Scanning Electron Microscope (SEM; JSM-6360LA; JEOL Ltd., Japan) as described by [21].

2.3.2. Biodegradability test

The biodegradability behaviour test was conducted to determine the biodegradability of bioplastics using compost soil according to the method described by [26].

2.3.3. Water absorption test

The water absorption test evaluates the durability and suitability of bioplastics for moisture or water-related applications. It was conducted according to the method of [26].

2.3.4. Swelling test

Swelling test is generally conducted to check whether developed materials retain the original properties after formation. This was conducted following the procedure of [26].

2.3.5. Mechanical test

The mechanical tests were carried out using the methods of [10, 39] by performing ultimate tensile, flexural, % elongation and hardness tests to the sliced samples. The tensile tests were conducted on a Control Universal Testing Machine at a crosshead speed of 2 kg/min with the load cell of 50 kN. The hardness Shore D tests were conducted by Mitutoyo Shore D hardness tester. Literally, the ultimate tensile test is a measure of the maximum stress a material can withstand without breaking or fallingunder tension. It is a fundamental property used to predict how a material or a component will behave under load. The % Elongation at break is an extension of a material when tested tensile until finally fracture. Flexural strength/bending test refers to how much a material will take before it tears, ruptures, breaks or permanently bends, i.e. yields. This method is used to determine the strength and dimensional changes in the properties of plastics when subjected to tensile, compressive and shear stresses.

2.3.6. Solubility test

Solubility test is carried out to check whether the synthesized biofilm material is sustainable or not. It was conducted as described by [26].

2.3.7. Thermogravimetric analysis

Thermogravimetric analysis is a method used to study the reaction of thermal decomposition [9] between weight change and temperature which are lost due to the effect of temperature on the material [43, 4].The result of the thermal analysis is in the form of a curve called a thermogram. Thermal decomposition is a process of changing the form of a sample into a simpler form [39].The thermal decomposition of biofilm was analyzed using a thermogravimetry (Mettler Toledo TGA/DSC1 simultaneous analyzer). The 10 mg sample of (P-BF) and (N-BF) were heated from 29.92^{0}C (room temperature) to 500^{0}c and 22.17^{0}C (room temperature) to 500^{0}c respectively with a heating rate of 10oC/min in the presence air with a flow rate of 50 mL/min. The thermogravimetric (TG), derivative thermogravimetric (DTG) can identify the thermal decomposition that occurs in biofilm through the loss of weight. It was conducted according to the method described by Okparamma and Muazen, (2013).

2.3.8. Toxicity tests

The toxicity tests on the biofilms and soil containing the biodegraded biofilms were conducted by determining the presence of polycyclic aromatic hydrocarbons (PAHs) in them using GC-FID (Gas chromatographyflame ionization detector, BUCK M910) Buck 530 gas chromatograph equipped with an on – column, automatic injector, Flame Ionization detector, HP 88 capillary column (100m x 0.25µm filmthickness,) CA, USA. It was conducted as described by Hu *et al.*, (2014).

2.4. Statistical Analysis

The obtained data were analysed statistically using Student's *t*- test of significance and analysis of variance (ANOVA). Values were considered significant at $p< 0.05$.

3. Results

3.1. Morphology study

The morphology study of P-Bf shows that there were white patches on the composite, the white patches were identified to be the egg shell powder used as a re-enforcement material. There were also black patches and a ring like substance contributed by the plantain peel.

3.2. Biodegradability test

The results of the degradation (Table 1) shows that P-BF degraded on the 6th day from 2.98g to 2.59g with a percentage weight loss of 13% whereas WP-BF composite degraded on the 6th day from 1.01g to 0.81g with a percentage loss of 20%. However, both composites degraded completely on the 12th day.

3.3. Water absorption test

The water absorption of the synthesized biofilm (Table 2) was carried out at room temperature for 24 hours to obtain the maximum water uptake data. The result of the water absorption test showed that P-BF absorbed less water compared to WP-BF. The results of swelling test showed higher swelling by the P-BF when chloroform was used. However, no change was observed between P-BF and WP-BF when methanol was used.

3.3.1. Swelling test

Table 3 shows the swelling tests of the composites using chloroform and methanol. The results of the swelling test showed a significantly ($p < 0.05$) higher swelling by the P-BF when chloroform was used. However, no significant ($p > 0.05$) change was observed betweenP-BF and WP-BF when methanol was used.

3.4. Mechanical tests

3.4.1. Tensile test

The obtained results showed that the P-BF had less tensile strength compared to the control (WP-BF).

3.4.2. % Elongation

The sample P-BF had higher elongation value than (control) WP-BF. The effect of a measurement of elongation of the break was carried out together with the analysis of tensile strength.

3.4.3. Flexural/ bending test

The result of the flexural test showed that the P-BF had lower flexural strength than the WP-BF.

3.4.4. Hardness test

The hardness tests of the produced biofilm indicated that the thickness did not affect the hardness of the material.

3.4.5. Solubility test

Table 5 shows the result for solubility test of the synthesized biodegradable plastics. The result shows that P-BF was partially soluble in acetone and sulphuric acid while NP-BF was completely soluble in acetone but partially soluble in sulphuric acid. Similarly, P-BF was completely soluble in ethyl alcohol while NP-BF was insoluble in ethyl alcohol. Furthermore, the result showed that P-BF showed less engorgement compared to NP-BF.

3.5. Thermogravimetric analysis

Fig 3 shows TGA (thermogravimetric analysis). First step decomposition occurred at the temperature of 29.92^{0}C - 137^{0}C for 12min.About 14.75% of the material was decomposed leaving 85.32% of the composite. About 14.75% of the material was decomposed leaving 85.32% of the composite. Consequently, 4.12% of the composite was decomposed at the temperature of 137^{0}C- 203.02^{0}C for 25 min. whereas 81.10% of the composite was left. Third step decomposition occurred at a temperature of 203.02^{0}C- 331.04^{0}C for 16 min. About 27.38% of the composite was decomposed remaining 53.75%. Fig 4 shows TGA (thermogravimetric analysis) of NP-BF. First step decomposition occurred at the temperature of 22.17^{0}C - 139.95^{0}C for 12min. About 11.9% of the material was decomposed leaving 88% of the composite. Consequently, second step decomposition took place in which 8.1% of the composite was decomposed at the temperature of 139.95^{0}C - 213^{0}C for 25 min. whereas 79% of the composite was left. Thereafter, third step decomposition occurred at a temperature of 213 ^{0}C-366^{0}C for 16 min. About 48% of the composite was decomposed remaining 32% of the composite. Stage 4 is the last stage of the thermal decomposition process in biofilm that occurred at 366°C-500°C for 23 min.

Fig 5 shows the thermogravimetric analysis of P-BF and NP-BF. As the temperature increased to 100^{o}C, the biofilms decomposed causing the weight of the biofilms to decrease until it got to a steady value at 200^{o}C where both graphs merged. Further increase in temperature up to 500^{o}C, the P-BF decomposed slightly causing a slight drop in the graph compared to the control (NP-BF) which decomposed drastically with a heavy drop in the graph. The P-BF decomposed slightly compared to NP-BF having 85% of material left while 88% of NP-BF was left after decomposition at the same temperature.

3.6. Toxicity test

Table 6 shows PAH contents of egg shell powder. Nine compounds were identified in the egg shell powder by GC-FID of which dibenzy(a,h)pyrene was identified to have the highest concentration followed by benzo(k)fluoranthene and phenanthrene. Other compounds were detected in substantial amounts such as pyrenes, acenaphthylene, 1_2Benzanthracene, benzo(c) chrysene, benzo(a)pyrene and benzo(g_h_i)perylene.

Similarly, Table 7 shows PAH contents of glycerol. Eight compounds were identified with the most prevailing polycyclic aromatic compounds as 1_2 benzanthracene, fluoranthene, benzo [a] pyrene and pyrene. The rest of the compounds occurred in minimal quantities; for instance, benzo[e]pyrene (0.10%), phenanthrene (0.70 %) and perylene (0.04 %).

Table 8 shows PAH contents of vinegar. Seven compounds were identified; the most abundant compounds being benzo[e]pyrene, 1_2 benzanthracene (pyrene, phenanthrene and benzo[g_h_i]perylene. Other compounds identified in trace amounts were anthracene and fluoranthene.

Table 9 shows PAH contents of cassava starch. Four compounds were identified; the most prevailing compound was identified as 1_2 benzanthracene while other compounds occurred in minimal amounts; benzo[k]fluoranthene, pyrene and benzo[g_h_i]perylene.

Table 10 shows the PAH contents of the soil that contained the synthesized biodegraded biofilms. The result showed 15 PAH compounds including; napthalene , acenapthylene, acenaphthene, fluorene, phenanthracene, anthracene, fluoranthene, pyrene, benzo(a) anthracene, chrysene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1_2_3)pyrene, benzo(a_h)anthracene and benzo(a_h)perylene. Napthalene mean concentration in the soil P (0.11±0.00 mg/kg) and soil W (0.11±0.00 mg/kg) were found to be significantly lower compared to the control (0.21 ± 0.00 mg/kg). Acenaphthylene in soil P and soil W were lower when compared to the control. Likewise, acenaphthene in soil P and soil W were found to be lower compared to the control. Furthermore, anthracene (concentration in soil P and W were found to be lower compared to the control. However, fluorene concentration in soil P and soil W showed no significant difference compared to the control. Furthermore, fluoranthene concentration in soils P and W were lower compared to the control. Likewise, phenanthracene concentrations in soil P and soil W were lower compared to the control. On the other hand, pyrene concentrations in soil P and soil W were higher compared to the control. Benzo(a) anthracene concentration in soil P was higher compared to the control. While benzo(a) anthracene in soil W showed no significant difference compared to the control. On the other hand, chrysene concentrations in soil P and soil W were significantly lower compared to the control. Benzo(a)pyrene concentrations in soil P and soil W were lower compared to the control. Likewise, benzo(a_h)anthracene concentration in soil P was higher compared to the control. Whereas benzo(a_h)anthracene concentration in soil W did not differ with that of the control. Indeno(1_2_3)pyrene concentrations in soil P and soil W were lower compared to the control. The benzo(a_h)perylene concentrations in soil P and soil W were lower compared to the control. The result of the toxicity test also indicated that PAHs in soil P such as napthalene, acenapthylene, acenaphthene, fluorene, phenanthracene, anthracene, fluoranthene, benzo(a) anthracene, ,benzo(k)fluoranthene,benzo(a)pyrene, indeno(1_2_3)pyrene, benzo(a_h)anthracene and benzo(a_h)perylene were lower compared to the control with exception of chrysene and pyrene which were found to be higher compared to the control. Additionally, acenapthylene were found to be the highest while flourene showed no significant difference. Likewise the PAH compounds in soil W such as napthalene, acenapthylene, phenanthracene, anthracene, fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1_2_3)pyrene, benzo(a_h)anthracene and benzo(a_h)perylene were found to be lower compared to the control with exception of pyrene which were higher compared to the control. Furthermore, acenaphthene, fluorine, benzo(a) anthracene did not differ with that of the control.

4. Discussion

The morphology study of NP-BF (figures 1-2) showed that the constituent materials in the NP-BF composite were more evenly distributed compared to that of the P-BF composite; which reflected in their mechanical properties [28].

Biodegradability tests (Table 1) evaluated how easily bioplastics break down in the environment. In order to evaluate the sustainability and environmental impact of bioplastics, these tests evaluate the rate of degradation and ecological integration. They also provide insights into the mechanisms of deterioration and help determine their suitability for specific applications. The degradation studies (soil burial test) conducted was helpful in preparation of environmental friendly product which is derived from natural polymers; they can be reused in bio-compost preparation. The versatility of bioplastic plays key role in green applications (May *et al*., 2019). This implied that P-BF was biodegradable but less degradable compared to NP-BF which degraded faster.

Water - resistant property is an important characteristics of synthetic plastic. The water absorption test (Table 2) evaluated the durability and suitability of the biofilms for moisture or water-related applications. Water resistance is an important characteristic in determining a suitable source for biofilm. This test provides insights into the material's resistance to water infiltration and its dimensional changes or expansion when exposed to moisture [34]. The water absorption of the synthesized biofilm was carried out at room temperature for 24 hours to obtain the maximum water uptake data. The result of the water absorption test showed that P-BF absorbed less water compared to NP-BF. The films were determined to have a water uptake percentage more of than 50% because biopolymers are hydrophilic in nature [7].

In addition to the interactions between water molecules and the hydroxyl groups in starch structures, the plasticization of biopolymer with glycerol plays a significant role in this research.

Because glycerol is a hydrophilic low molecular carbohydrate, its molecular weight and number of hydroxyl groups determine how much water it can absorb. Glycerol has three carbons attached to their backbone with one hydroxyl group attached to each carbon which causes the molecules to bind to the highest amount of water corresponding to the weight portion [35]. Increasing sizes of hydroxyl group concentration-centre in biocomposite matrix increases the water absorption of the film [8]. The results got were in line with the research conducted by [35]

The results of the swelling test showed that P-BF swelled more when chloroform was used but did not differ when methanol was used. This was in line with the research conducted by [35].

The tensile strength (Table 4) was conducted to determine the maximum load that a material can withstand before it breaks [41]. Smaller tensile strength indicates that the material can easily deform in plastic behavior [22]. This could be due to the higher degree of homogeneity of biofilm constituent molecules in WP-BF compared to P-BP; causing the distribution of biofilm constituent molecules to be consistently distributed. On the contrary, the P-BF had a smaller degree of homogeneity, making an uneven distribution of bioplastic constituent molecules [4] due to the fibres in the plantain peels which greatly influenced the tensile strength. Furthermore, the added plasticizer (glycerol) strongly influenced the tensile strength of biofilms. The tensile strength of biofilms will be lower when the concentration is higher. This is due to the decrease in hydrogen bonds that occurred in the biofilm, thereby increasing flexibility [4]. Therefore, the tensile strength of the biofilm gets smaller. Besides that, the resulting biofilm was softer and

more flexible. However, the plantain powder-based biofilm met the required standard value for tensile strength which is between 1-10 mpa [4].

The elongation of break test is carried out to determine the magnitude of the increase in the length of a polymer before finally breaking up. The value of % elongation test showed the ability of the biofilm to elongate. This property depends on the type of biofilm formation materials which may have affected the cohesion properties of the biofilm's bioplastic structure.

The P-BF had higher elongation value than (control) NP-BF; indicating that the NP-BF could hold its shape better than the P-BF under the same elongation. But, higher elongation value meant that the biofilm was more deformable. This unique deformation behavior is likely due to the uneven distribution of bioplastics constituent molecules inside P-BF. Indeed, this may have reduced the strong intermolecular interactions between starch molecules (due to the longer hydrogen bonding) [11]. The percentage of elongation of a biofilm is good if the value is more than 50% and bad if the value is less than 10% [11]. Additionally, the NP-BF met the required standard value of percentage elongation which is between 10-20% [11]. The P-BF showed lower percentage elongation below the standard value probably due to the uneven distribution of the constituent molecules in it [8]. The result of the flexural test showed that the P-BF had a lower flexural strength than NP-BF because the constituents materials in the biofilm were not uniformly distributed ; influenced by the plantain peel powder fibres [8, 23].

The results from the mechanical test of the synthesized composites showed that the P-BF had a lower tensile, percentage elongation as well as hardness compared to NP-BF (the control). The mechanical performance in P-BF was likely due to the inhomogeneity of the constituent molecules in the composite which is due to the presence of the plantain peels [8].

The solubility test (Table 5) determined the persistence of the biofilms after being immersed in different solvents. It is the main properties to check whether the synthesized bioplastic material is sustainable or not. If the bioplastic material possesses the property of less or zero engorgement property, that can be considered as excellent material with stability as characteristic features [31].

The thermogravimetric tests (figures 3-5) showed reduction weight was caused by the release of moisture or water.

The first stage of the thermal decomposition process is caused by the evaporation of the water at this point, and the very light volatile matter compounds have also been lost [46]. Stage 2 is the process of releasing volatile matter [29].Stage 3 is the phase that follows the volatile as matter in the samples being released. The fixed carbon content of the biofilm was relatively low, i.e. 32% (b/b). In this stage, the charcoal is flammable as it is surrounded by volatile matter and oxygen diffused on the surface of the charcoal, which burn the charcoal and volatile matter simultaneously. This stage occurs after the release of volatile matter which leaves or forms carbon [46].

Reduction weight was caused by the release of moisture or water. In this stage, the very light volatile matter compounds were also lost and the initial stage of the thermal decomposition process occurs due to evaporation of the water [10]. Stage 4 does not produce ash, since the composite was almost completely decomposed remaining 11.9% residue.

The thermogravimetric metric analysis of P-BF and NP-BF (Fig. 5) showed that as the temperature increased to 100^{o}C, the biofilms decomposed causing the weight of the biofilms to decrease until it got to a steady value where both graphs merged. At this point, there was loss of moisture content in the material. With further increase in temperature, the P-BF decomposed slightly causing a slight drop in the graph compared to the control (NP-BF) which decomposed drastically with a heavy drop in the graph. This could be due to the plantain peels in the P-BF which is the only material absent in the NP-BF. This therefore implied that the plantain peel based biofilm can withstand high temperatures of up to 500^{o}C [8].

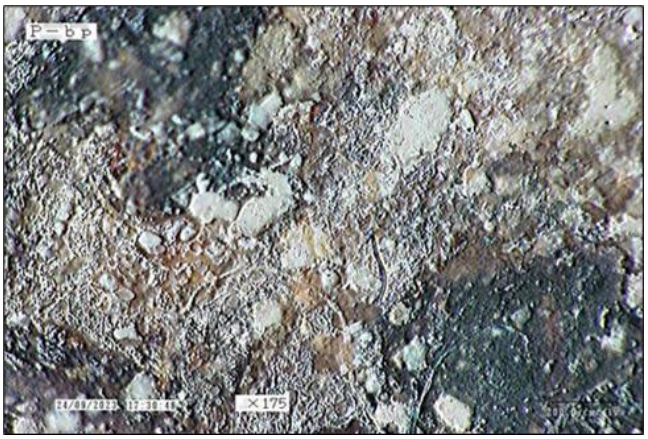

Figure 1 Micrograph of P-BF (×175)

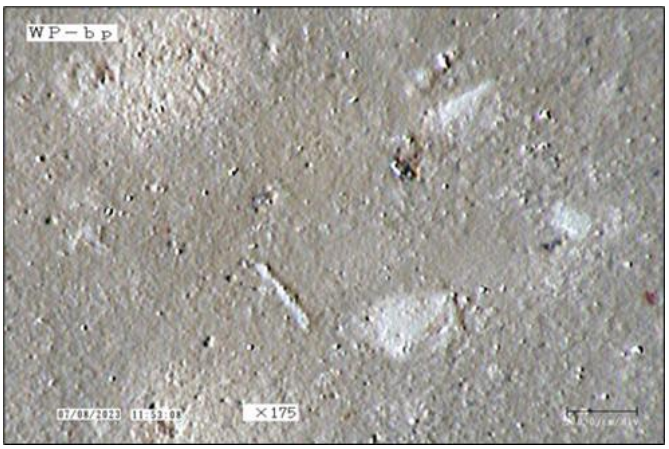

Figure 2 Micrograph of NP-BF (×175)

The toxicity tests (Tables 6-10) showed that according to EC Regulations Commission (2011), BaP and PAH4 (Benzo(a)Pyrene, Chrysene, Benzo(b)Fluoranthene and Benzo(a)Anthracene) are used as markers for assessing toxicity level of PAHs in food. The BaP in the egg shell powder and BaA exceeded the maximum acceptable limit of PAHs in plant based powders which is 0.01mg/kg[2, 18]. The International Agency for Cancer Research classifies Bap as a group 1

agent which are carcinogenic to humans and BaA as group 2 agent which is termed as probable carcinogen [20]. The BaP as well as 1_2 Benzanthracene detected in glycerol but exceeded the maximum acceptable limit of PAHs in vegetable oils and fat which is 0.002mg/kg [2, 18]. The International Agency for Cancer Research classifies BaP as a group 1 agent which are carcinogenic to humans [23].

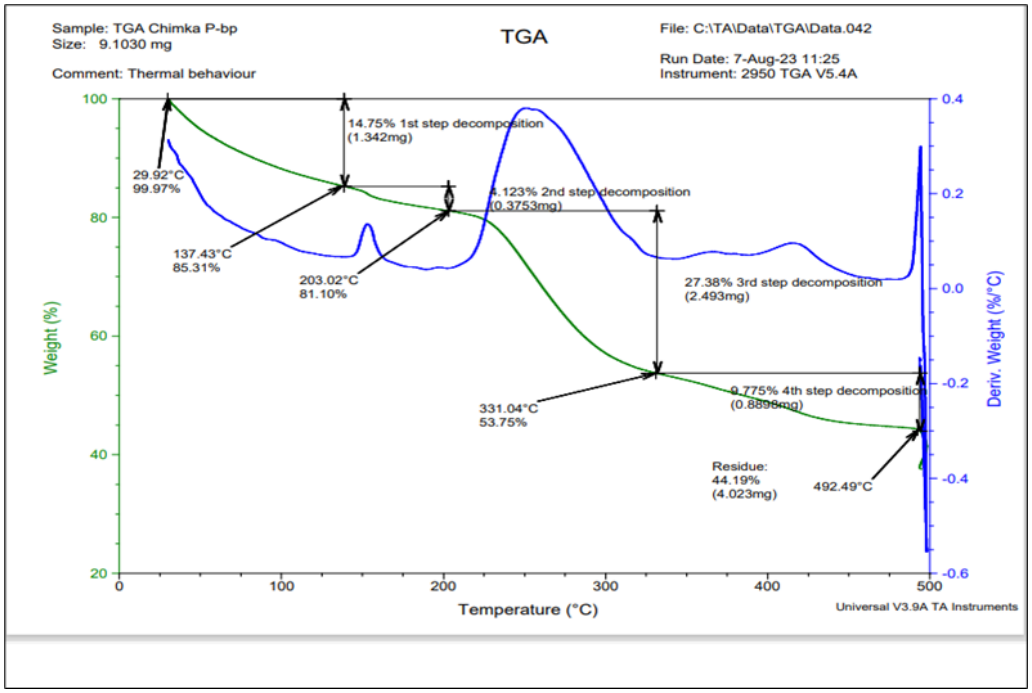

Figure 3 Thermogravimetric analysis of P-BF

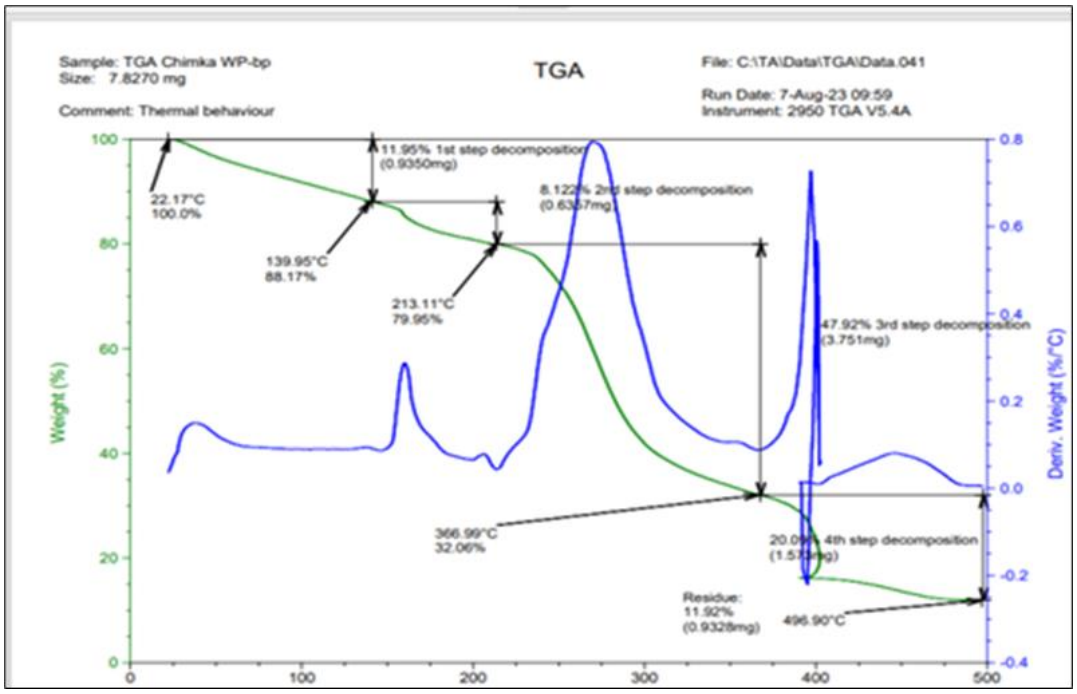

Figure 4 Thermogravimetric analysis of WP-BF

The 1_2 Benzanthracene in the vinegar exceeded the maximum acceptable limit of PAHs in food which is 0.002mg/kg [2, 18]. The International agency for Cancer Research classifies BaA as a group 2 agent which are probably carcinogenic

to human [23]. The 1_2 benzanthracene and benzo(b)fluoranthine are used as a marker for assessing PAHs in food. There levels that were found in the cassava starch exceeded the maximum acceptable limit of PAHs in plant based powders which is 0.01mg/kg [2, 18]. The International agency for Cancer Research classifies BaP as a group 1 agent which are carcinogenic to humans and BaA as group 2 agent termed probable carcinogen [23]. The PAHs are among the pollutants that are considered ubiquitous in the environment [23].

They may be released by naturally occurring processes like biomass combustion, volcanic eruptions, and diagenetic processes [23]. The results of the present study also showed that the control soil had higher mean concentration of PAH compounds compared to the soil samples that contained the degraded biofilm. This seemed to suggest that the biofilms may have adsorbed some PAHs. However, the concentrations of the PAHs reported in the present study were lower than the 1.00 mg/kg recommended for soil cleanup by the Department of Petroleum Resources, Nigeria [15]. Similarly, PAH values in the present study were within the allowed limits of 1.00 mg/kg, 1500.00 µg/kg and 5.00 mg/kg stipulated guidelines for soil cleanup by Denmark, Netherlands, and Australia, respectively [5, 16]

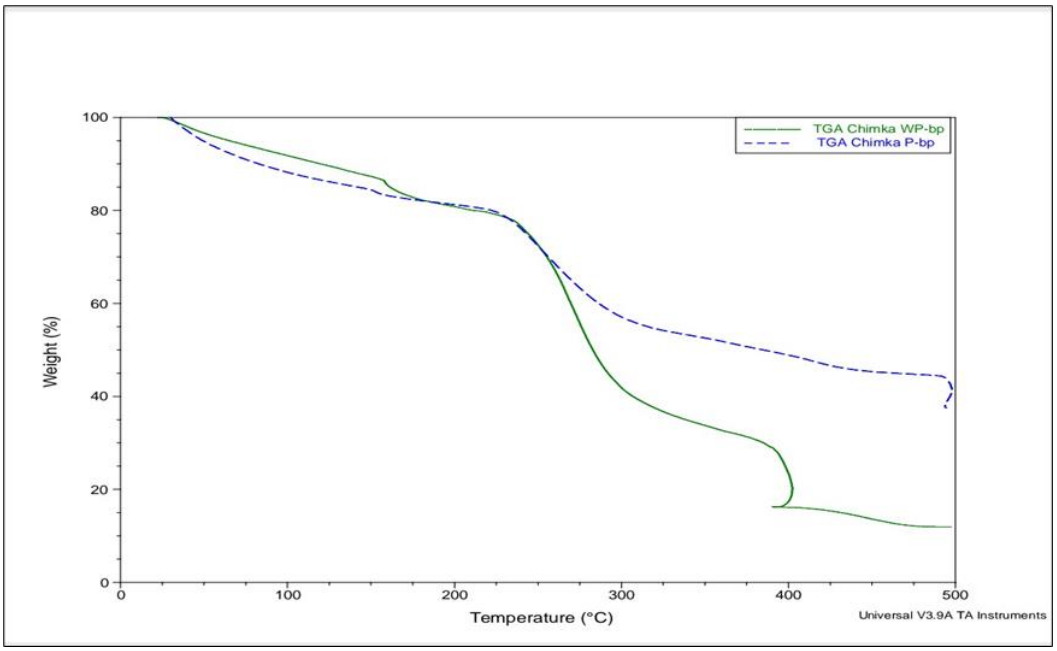

Figure 5 Thermogravimetric analysis of biofilms

Table 1 Biodegradability test of biofilms

Sample	Day 0 wt (g)	Day 6 wt (g)	Day 12 wt (g)	Difference(g)	% Weight loss	Mean± STD
P-Bf	2.98	2.59	0	0.13	13	0.13±.017[b]
NP-Bf	1.01	0.81	0	0.19	20	0.19±.02[a]

Results are presented as mean±SD (n=6). Mean values with different superscript letters are statistically significantly ($p<0.05$) different. P-BF=: plantain peel based biofilm; N-BF: without/ non plantain peel based biofilm.

Table 2 Water absorption analyses of the biofilms

Sample	Initial wt (g)	Final wt (g)	Difference (g)	% Water uptake	MEAN±SD
P-BF	1.09	1.73	0.28	37	0.31±.04[a]
	1.64	2.10	0.28	28	
	1.44	1.85	0.28	28	
Average				31	

NP-BF	0.46	0.79	0.72	72	0.46±0.19[b]
	0.79	1.04	0.32	32	
	0.51	0.69	0.35	35	
Average				46	

Results are presented as mean ± SD (n=6) of triplicate determinations. Mean values with different superscript letters are statistically significantly ($p<0.05$) different. P-BF= plantain peel biofilm, NP-BF = without or non- plantain peel biofilm.

Table 3 Results of swelling test of biofilms

Sample	**Initial wt (g)**	**Final wt (g)**	**Weight gain (g)**	**Initial wt (g)**	**Final wt (g)**	**Weight gain (g)**	**Mean±SD**
Methanol							
P-BF	2.01	2.10	0.10	2.02	2.12	0.10	0.10±0.00[b]
N-BF	2.02	2.12	0.10	2.01	2.13	0.12	0.10± 0.01
Chloroform							
P-BF	2.00	2.05	0.05	2.00	2.04	0.04	0.04±0.00[a]
N-BF	2.00	2.02	0.02	2.00	2.02	0.02	0.02±0.00

Results are presented as mean ± SD (n=6). Mean values with different superscript letters [a] are considered statistically significantly ($p<0.05$) different. P-BF = plantain peel based biofilm; NP-BF = without/ non plantain peel based biofilm.

Table 4 Mechanical indices of biofilms

(Nmm^2)	**P-BF**	**NP-BF**	**Standard value**
Tensile strength	2.87±0.02[b]	5.45±0.02[a]	1-10 (Nmm^2)
Hardness ShoreD	22.00±1.78[b]	49.00±1.78[a]	
%Elongation	6.29±0.01[b]	13.85±0.03[a]	10-20%.
Flexural strenght	0.41±0.01[b]	1.56±0.02[a]	1-8 (Nmm^2)

Results are presented as mean±SD (n=6). Mean values with different superscript letters are statistically significantly ($p<0.05$) different.

Table 5 Solubility test for biofilms

Sample	**Solvent**	**Insoluble**	**Partially soluble**	**Completely soluble**
P-BF	Acetone	-	+	-
NP-BF	Acetone	-	-	+
P-BF	Sulphuric acid	-	+	-
NP-BF	Sulphuric acid	-	+	-
P-BF	Ethyl alcohol	-	+	-
NP-BF	Ethyl alcohol	+	-	-

P-BF = plantain peel powder-based biofilm; NP-BF = without plantain peel powder-based biofilm + = Positive; - = Negative

Table 6 PAH contents of egg shell powder

Component	Concentration (mg/ml)	% Concentration	Permissible limit (mg/kg)EUNo835/2011
Pyrenees	1.07	7.54	0.03
Benz(k)fluoranthene	2.13	15.01	0.2
Acenaphthylene	1.52	10.75	0.6
Phenanthrene	2.09	14.74	0.9
Dibenzy(a,h)pyrene	2.87	20.26	0.3
1_2Benzanthracene	0.96	6.81	0.06
Benzo(a)pyrene	0.64	4.52	0.02
Benzo(g_h_i)perylene	1.80	12.72	0.01
Benzo (c) chrysene	1.07	7.54	0.01
Total	14.2034		

Table 7 PAH contents of glycerol

Component	Concentration (mg/ml)	% Concentration	Permissible limit (mg/kg) EURegNo835/2011
Benzo [a] pyrene	0.42	13.60	0.05
Perylene	0.001	0.04	0.05
Fluoranthene	0.76	24.54	0.05
1_2 Benzanthracene	1.38	44.23	0.06
Phenanthrene	0.02	0.70	0.9
Dibenzyl[a_h]anthracene	0.20	6.50	0.06
Benzo[e]pyrene	0.003	0.10	0.01
Pyrene	0.32	10.25	0.03
Total	3.12		

Table 8 PAH contents of vinegar

Component	Concentration (mg/ml)	% Concentration	Permissible limit (mg/kg)EURegNo835/2011
Fluoranthene	0.14	4.83	0.05
1_2 Benzanthracene	0.42	13.92	0.06
Phenanthrene	0.32	10.46	0.9
Anthracene	0.09	3.13	0.06
Benzo[e]pyrene	1.38	44.86	0.01
Pyrene	0.41	13.49	0.03
Benzo[g_h_i]perylene	0.28	9.29	0.01
Total	3.08		

Table 9 PAH contents of cassava starch

Component	Concentration (mg/ml)	% Concentration	Toxic limit (mg/kg) EUReg No 835/2011
Pyrene	0.48	21.00	0.03
1_2 Benzanthracene	0.99	43.29	0.06
Benzo[g_h_i]perylene	0.32	14.20	0.04
Benzo[k]Fluoranthene	0.49	21.46	0.01
Total	2.28		

Table 10 PAH contents of soil containing biodegraded biofilm

PAHs	soil C	soil P	soil W
Napthalene	0.21 ± 0.00^{b}	0.11±0.00^{a}	0.11±0.01^{a}
Acenapthylene	1.55± 0.23^{b}	0.43 ± 0.15^{a}	0.22±0.00^{a}
Acenaphthene	0.51 ± 0.03^{a}	0.15 ± 0.00^{b}	0.60 ±0.48^{a}
Fluorene	0.43± 0.01^{a}	0.37 ±0.07^{a}	0.37± 0.07^{a}
Phenanthracene	0.67± 0.24^{a}	0.27 ± 0.07^{a}	0.27± 0.21^{a}
Anthracene	0.66± 0.12^{b}	0.22 ± 0.00^{a}	0.11±0.00^{a}
Fluoranthene	0.61±0.05^{a}	0.28 ±0.03^{b}	0.12±0.02^{c}
Pyrene	0.02± 0.00^{a}	0.27± 0.00^{b}	0.09± 0.0^{c}
Benzo(a) anthracene	0.11 ±0.00^{a}	0.22 ± 0.00^{b}	0.10 ± 0.00^{c}
Chrysene	0.40 ±0.27^{b}	0.03 ± 0.00^{a}	0.21±0.01^{a}
Benzo(k)fluoranthene	0.51±0.03^{a}	0.22± 0.00^{b}	0.09 ± 0.02^{c}
Benzo(a)pyrene	0.43±0.12^{a}	0.11±0.00^{b}	0.09±0.02^{c}
Indeno(1_2_3)pyrene	0.36±0.00^{b}	0.18± 0.08^{a}	0.11±0.00^{a}
Benzo(a_h)anthracene	0.61±0.03^{b}	0.21±0.08^{a}	0.09±0.00^{a}
Benzo(a_h)perylene	0.52±0.04^{b}	0.27±0.08^{a}	0.17±0.03^{a}

Results are presented as mean±SD (n=2) of triplicate determinations. Mean values with the different superscript $^{a,b \text{ or } a,b,c}$ are considered statistically significant ($p<0.05$). Soil c; control, soil p; soil with p-bp, soil W; soil with w-bp.

Recommended limit for PAHS in the soil : 1mg/kg and 1mg/kg, 1500 µg/kg, and 5 mg/kg[14,15].

5. Conclusion.

In the course of the research, ripe plantain peels were initially processed using aqeous solvent. However, the biofilm produced was fragile with holes and it decayed in 48h. The result of the study showed that powdered plantain peel gives better biofilm which are eco-friendly and thermally stable. Furthermore, the result showed that a non-toxic biofilm can be produced from waste plantain peels.

Compliance with ethical standards

Disclosure of conflict of interest

We declare that no conflict of interest.

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