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Banana Bract- Based Bioplastic: A Novel Biodegradable Material with Enhanced Water Retention for Agriculture

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Abstract: The increasing environmental concerns associated with non-biodegradable plastics have accelerated the search for sustainable and eco-friendly alternatives such as bioplastics. The present study focuses on the development and characterization of a biodegradable bioplastic derived from banana bracts (*Musa paradisiaca*), an under-utilized agricultural waste, blended with potato starch. The bioplastic was synthesized using banana bract paste, potato starch, glycerol as a plasticizer, and acetic acid under controlled heating conditions. The prepared films were evaluated through physical, chemical and mechanical analysis. Biodegradability studies revealed complete degradation within 30 days under soil burial conditions, demonstrating its environmentally begin nature. The material exhibited a water absorption capacity of 60% and water retention of 30%, indicating significant hydrophilic properties. Solubility analysis showed higher solubility in sugar solution (38%) and water (30%), suggesting strong interaction with polar solvents. Chemical composition analysis indicated cellulose (46%) as the predominant component, followed by lignin (24%) and hemicellulose (10%), contributing to structural integrity and biodegradability. FTIR analysis confirmed the presence of functional groups such as hydroxyl, carbonyl, and ether linkages, while XRD analysis revealed a semi-crystalline structure. SEM observations showed a porous and heterogeneous surface morphology, facilitating water absorption and microbial degradation. Furthermore, the developed bioplastic was successfully applied as a seedling pot for green gram and fenugreek, exhibiting improved moisture retention compared to conventional plastic pots. Overall, the study demonstrates that banana bract-based bioplastic is a cost-effective, biodegradable, and sustainable alternative for agricultural and eco-friendly packaging applications.

Keywords: *Bioplastic, Banana Bract (Musa paradisiaca), Physical and Chemical Analysis, Sustainable Packaging.*

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I. INTRODUCTION

Plastic has become humans' vital needs as it has a lot of usefulness. The word 'plastic' is originally meant flexible and easily shaped. All over the world around hundreds to thousands of year's people have been using petrochemical based plastics as it is produced in large amounts because it is cheap and easily available. According to Central Pollution Control Board (CPCB) Delhi report (2019-20) the total annual plastic waste generation in India at humungous 3.5 million metric tons per year (Arukan E. B. et al. 2019). India is the fifth highest generator of plastic waste. In the whole world, including the ocean is full of plastic wastes (Thompson R. C. et al. 2009).

People use plastic very often and after use of plastic it is been sent into the garbage and here comes the actual problem that plastic is non-degradable which means plastic cannot be removed from the environment and it releases lots of harmful gases. Plastics can neither be burnt or it can neither be degraded into the soil. Many scientists and the government authorities are very much worried about this problem (Ezgi et al. 2015).

Many studies have been carried out over the century on how to produce manufactured polymers, occasionally natural substance usage such as cellulose, but largely utilizing the plentiful carbon atoms provided by petroleum and other fossil fuels. Engineered plastic composites are comprised of long chains of atoms, arranged in repeating units, frequently any longer than those found in nature (Azieyanti N. A et al. 2020). Plastics are the most common thing used everywhere in the world for packaging, tables, water bottles, many electronic devices etc. Not only is that it also utilized in pharmaceutical products to the advance industry work. So, plastics have been used everywhere and it has led to many problems such as soil infertility, stop up in the water bodies and the worst thing is they are not biodegradable (Bruno. R.M et al. 2011).

Plastic has been named as "Four basic materials" along with steel, wood, and cement. Plastic is not only the major support materials utilizing to make up the deficiencies in the quality and quantity of the traditional materials, but also an indispensable material for technical progress in some fields. About 4% of the annual oil production was directly used in the formation of plastic (Anthony L A et al. 2009 & Thompson R C et al. 2009). A large quantity of synthetic plastic wastes such as plastic mulch, shopping bags, cutlery, and packaging materials are normally directly disposed to the environment after utilization. The total amount of plastic waste is as high as 50 million tons per year in the world. Thus, serious problems in farmland, tourist resorts, coastal ports, and animals (birds, fishes, big wild animals) have been caused. Moreover, the raw material (petroleum) used to prepare plastics is getting declined.

Banana plants (Musa spp.) contain a high concentration of natural fibre. It is a commonly grown fruit crop in tropical and subtropical regions, particularly in India. Banana plants produce a large amount of biomass during cultivation and harvest, which includes pseudostems, leaves, and bracts. Banana bract, which is part of the banana inflorescence, contains valuable biopolymers such as cellulose, lignin, hemicellulose, and pectin, every one of which can be used to make bioplastics. Cellulose and lignocellulosic materials are important building blocks for film-forming bioplastics because of their structural strength, biodegradability, and ability to form hydrogen bonds with other molecules. In a country like India, where agricultural waste is plentiful but underutilized, this idea could serve as a model for rural entrepreneurship and decentralized bioplastic production. Earlier study had shown that the banana plant and its various parts, such as the pseudostem and banana peel, may be used to manufacture bioplastic. By utilizing the natural resources found in banana plantations, it may be possible to establish small-scale units that produce biodegradable materials, thereby supporting livelihoods while reducing plastic pollution.

To overcome such a big problem the researches have worked a lot with obtaining different methods and finally brought a solution to it that is the bioplastic. Bioplastic are the plastics which are acquired from the renewable biomass sources like starch, vegetable oils, fats and microbial communities. Bio plastics were procured from sugar derivatives like starch, cellulose, lactic acid etc. Bioplastic are the biodegradable substances that come from the renewable sources and can be helpful to reduce the plastic waste which affects the planet and also leads to many in appropriate gases which also affects the existence (Anggun et al. 2018). Bioplastic is a type of plastic made from biomass materials. Biomass normally refers to a union of microorganisms, which mainly contains macromolecules including starch, cellulose, protein, etc. The biodegradability of bioplastic has become an important feature for its application (Shrivastav A 2013).

Bioplastic is the best replaceable of petrochemical plastic. There are many different types of bioplastics such as Polyacetic acid (PLA), Poly-3-hydroxybutyrate (PHB) which is considered as consumption and leads to biodegradation in less volume. PLA Production of all bioplastics results in lowering the carbon dioxide emissions compared to the other conventional plastics (Melissa et al. 2014). Due to these advantages of bioplastic, researchers and engineers try to promote its production and application. Nowadays, the main obstacle to the growth of the bioplastic market is its high production cost. Bioplastic products are still rare and struggling to gain a massive production (Brockhaus S 2016).

Bioplastics and bio composites are emerging as sustainable materials that have potential to meet or exceed the functional performance of petroleum-based plastics (Grewell et al.,2014) and there is a broad range of properties that can be achieved by blending and compounding these bio-based materials (Madbouly et al., 2014). Using this ecologically acceptable plastic instead of regular ones provides a number of benefits: degradability, minimization of the using of the non-renewable energy sources among them (Atiwesh G et al. 2021). Researchers are working with many biopolymers, biobased products and now a day's they are even using the biowaste like potato starch, corn starch, banana starch, newspaper waste, rice straw, cotton, jute, hemp etc. Plant and animal withdrawn the proteins like casein, collagen, gelatine and lipids which include cross link between the triglycerides (Logeshwaran V et al. 2020).

The aim for developing bioplastic is that it will simply disintegrate and biodegrade if accidentally emitted into the environment. Aside from that, bioplastics are less expensive, disintegrate more quickly and can work as fertilizer after decomposition, contributing no pollution to the environment.

Previous studies on banana-based bioplastics primarily utilized the banana peel, whereas our study is the first to develop bioplastic using the banana bract. The present study research to formulate the bioplastic from banana bract and blended with potato starch. The prepared bioplastic films were evaluated for mechanical and physical properties such as durability, flexibility and water absorption. Biodegradability tests were also carried out to observe the decomposition. Furthermore, to develop the bioplastic into the potential application products alternate to synthetic bioplastic. Continuous research in this field can lead to the development of innovative and commercially viable eco-friendly products.

II. MATERIALS AND METHODS

- *Sample Collections*

The banana bracts (*Musa paradisiaca)* were collected from different local markets in Coimbatore city, Tamil Nadu, India. The freshly collected bracts were free from visible damage and decay and only healthy bracts were selected for further processing.

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➢ *Sample Preparation*

Take 150 g of banana bracts that were washed with distilled water. Cut it into small pieces and put it in a 500ml beaker. Soak the pieces in a beaker containing citric acid solution and let it rest for 30 minutes. Decant the citric acid from the banana bract. Add 500 ml of distilled water and transfer the bract into another beaker. Boil the banana bract for 30 minutes and remove the distilled water from it. Place the banana bract on the butter paper and put it in an oven at 60° C for 30 minutes for drying. After drying, the sample was ground in the mixer. Now blend it and make a thick paste of it and weigh 30 g of the paste.

➢ *Extraction of Potato Starch*

- *Procedure:*

The potatoes (6kg) were washed properly with distilled water to remove all the impurities present on them. The potatoes were grated with the help of a grater, and after that, they were ground in the mixer grinder to make a semi-solid thick paste. The semi-solid paste of potato is then filtered. The filtrate is kept separate in a beaker to rest for 1 hr. After the rest time, it was observed that all the starch had settled at the bottom of the beaker. This Starch is filtered and dried. After the continuous repetition of the above procedure, we got 20 g of starch. Keep it aside for blending.

➢ *Preparation of Bioplastic*

- *Procedure:*

A clean 500 ml beaker was taken and into 30 g of thick paste prepared form oven-dried banana bracts. Then 20g of pre-extracted dried potato starch was added to the beaker. These two materials served as the primary polymer sources for the composite bioplastic. The mixture was blended using a glass rod and distilled water was added dropwise while mixing to obtain a uniform paste. After proper mixing, 10 ml of glycerol was added as a plasticizer to improve the flexibility of the bioplastic. Subsequently, 20 ml of vinegar was added to the mixture and stirred well for a few minutes. Then 2 to 3 ml of 0.5M hydrochloric acid (HCl) was added dropwise to the mixture while stirring continuously. Finally, 50 ml of distilled water was added to the beaker to form a uniform slurry. The beaker containing the slurry was placed on a heating plate, and the temperature was maintained at approximately 80° C (medium heat). During heating, the mixture was continuously stirred using a glass rod or magnetic stirrer to prevent settling and ensure uniform heat distribution. Heating and stirring were continued until the mixture became a gel-like, semi-transparent, and viscous material. This change indicated proper polymer blending and partial gelatinization, making the material suitable for casting and molding into bioplastic sheets.

III. PHYSICAL ANALYSIS

➢ *Biodegradability Test*

The biodegradability of the prepared bioplastic film was evaluated using the soil burial method. Small pieces of the dried bioplastic film measuring approximately 2 × 2 cm were cut and used for the experiment. The samples were buried in garden soil at a depth of about 5 cm in a container and maintained under room temperature conditions. Soil moisture was maintained by periodically sprinkling water to simulate natural environmental conditions. The samples were removed at regular intervals on the 7th, 15th, and 30th days. After removal, the bioplastic film was carefully cleaned and examined for physical changes such as surface erosion, structural damage, and partial degradation, indicating the biodegradability of the prepared bioplastic film.

➢ *Water Absorption Test*

The water absorption capacity of the bioplastic film was determined using a gravimetric method. Pre-weighed dried bioplastic sample (0.1g) were immersed in distilled water at room temperature and kept for a fixed period of 24 hours. After soaking, the films were removed and gently blotted with filter paper to remove excess surface water. The wet weight of the samples was immediately measured using an electronic balance. The percentage of water absorption was calculated by comparing the initial dry weight with the final wet weight of the sample.

$$\text{Water Absorption (\%)} = (W_2 – W_1) / W_1 \times 100$$

➢ *Water Retention Test*

The water retention ability of the bioplastic film was analyzed by measuring the amount of water retained after absorption. Initially, dried bioplastic samples were weighed and soaked in distilled water for 24 hours. After soaking, the samples were removed and the excess surface water was gently wiped off using filter paper. The soaked films were then kept at room temperature for a specific period to allow partial evaporation of water. After the specified time, the samples were weighed again using an electronic balance. The retained water content was determined by calculating the difference between the soaked weight and the weight after evaporation.

$$\text{Water Retention (\%)} = (W_2 – W_3) / W_1 \times 100$$

➢ *Solubility Test*

The solubility of the bioplastic film was determined by immersing the sample in different solvents such as distilled water, salt solution, sugar solution and ethanol. A known weight of dried bioplastic film (0.1g) was taken and its initial weight was recorded. The samples were then placed separately in beakers containing 10 ml of distilled water, salt solution, sugar solution and ethanol. They are kept at room temperature for 24 hours. After the incubation period, the remaining undissolved films were carefully removed from each solution and dried in an oven 40 °C until a constant weight was obtained. The dried sample was then weighed again using an electronic balance. The percentage of solubility was calculated by determining the weight loss of the film after immersion.

$$\text{Solubility (\%)} = (W_1 – W_2) / W_1 \times 100$$

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IV. CHEMICAL ANALYSIS

The cellulose, hemicellulose and lignin content were determined by the direct estimation method (Moubasher et al., 1982).

- *Procedure:*

Approximately 1 g of dried banana bract bioplastic was taken in a clean beaker. The sample was boiled with 10 ml of ethanol for 10 minutes to remove soluble impurities. After boiling, the sample was washed thoroughly with distilled water to remove any residual ethanol. The washed sample was dried in a hot air oven at 40°C for 6- 8 hours until a constant dry weight was obtained. The dried sample was then divided into two portions for further analysis. The one portion is 0.50g undergoes for hemicellulose and another portion is 0.50g undergoes for cellulose and lignin.

W_s = Weight of Sample (after ethanol dried sample)

W_1 = Weight of A fraction (after drying at 40°C)

W_2 = Weight of B fraction (residue after KOH treatment)

W_3 = Weight of C fraction (residue after acid treatment)

- *Determination of Hemicellulose*

One portion of the prepared sample (0.50g) was dried again in an oven at 40°C for 6 hours and weighed.

This weight was recorded as “A fraction”.

- *Determination of Cellulose*

The second portion of the sample (0.50g) was treated with 24% KOH solution for 2 hours at 25°C. After treatment, the sample was washed repeatedly with distilled water until the alkali was completely removed. The remaining residue was dried in a hot air oven at 40°C for 6 hours and weighed. This recorded weight was considered as the “B fraction”.

- *Determination of Lignin*

The B fraction residue was treated with 72% H_2SO_4 for 30minutes at room temperature. The mixture was then refluxed with 5% H_2SO_4 for 1 hours. After refluxing, the residue was washed repeatedly with distilled water to completely remove acid. The final residue was dried in a hot air oven at 40 °C for 6 hours and weighed. The obtained weight was recorded as the “C fraction”.

V. MECHANICAL ANALYSIS

- *FTIR Analysis*

The Fourier Transform Infrared (FTIR) spectroscopy was used to identify the functional groups present in the bioplastic film. The dried bioplastic sample was directly analyzed using an ATR (Attenuated Total Reflectance) accessory. The sample was placed on the ATR crystal and scanned using an FT/IR-4700 spectrophotometer. The spectrum was recorded in the range of 4000–600 cm^{-1} with a resolution of 4 cm^{-1} and 32 scans. The obtained FTIR spectrum was used to identify the characteristic functional groups present in the bioplastic material (Dalal. S. R et al., 2023).

- *XRD Analysis*

The X-ray diffraction (XRD) analysis was carried out to determine the crystalline nature of the prepared bioplastic film. The dried bioplastic sample was finely powdered and placed on the sample holder of the XPERT-PRO diffractometer. The analysis was performed using Cu-Kα radiation with a wavelength of 1.5406 Å. The instrument was operated at a voltage of 45 kV and a current of 30 mA. The diffraction pattern was recorded over a scanning range of 10° to 80° (2θ) at room temperature (25°C). The obtained diffraction peaks were used to evaluate the crystalline and amorphous characteristics of the bioplastic material (Dalal. S. R et al., 2023).

- *SEM Analysis*

The surface morphology of the bioplastic film was analyzed using Scanning Electron Microscopy (SEM). A small piece of the dried bioplastic film was mounted on an aluminum stub using double-sided carbon tape. The sample surface was then coated with a thin layer of gold to improve electrical conductivity. The prepared sample was subsequently examined using a scanning electron microscope at an accelerating voltage of 15 kV and a magnification of 500×. The SEM images were used to study the surface morphology and fiber distribution of the bioplastic film (Dalal. S. R et al., 2023).

VI. RESULTS

- *Physical Analysis*

- *Biodegradability Test*

The biodegradability of the bioplastic film was analyzed using the soil burial method. The results showed that the bioplastic film gradually degraded when buried in soil. By the 7^{th} day, the film exhibited slight physical changes, such as minor surface roughness and a loss of smooth texture. On the 15th day, partial degradation was observed, with small cracks and slight structural weakening of the film. By the 30^{th} day, significant degradation had occurred, showing clear signs of microbial action and surface erosion. The bioplastics were completely degradable in the soil.

- *Water Absorption Test*

The water absorption of the bioplastic film was evaluated after 24 hours of immersion in distilled water. The initial dry weight of the sample (W_1) was 0.10 g and the wet weight after soaking (W_2) was 0.16 g, indicating a substantial uptake of water. This increase in weight confirms the hydrophilic nature of the bioplastic film. Additionally, the film exhibited slight swelling upon water absorption, suggesting interaction between the polymer matrix and water molecules. Despite this swelling, the film maintained its structural integrity without any visible disintegration or deformation. These observations demonstrate that the bioplastic film possesses good water absorption capacity while retaining its physical stability.

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Water Absorption %= $(W_2 – W_1) / W_1 \times 100$

= (0.16-0.10) /0.10×100

= 60 %

This result shows that the prepared bioplastic film had a water absorption capacity.

- *Water Retention Test*

The water retention ability of the bioplastic film was assessed by allowing the soaked film to partially dry at room temperature. The initial dry weight (W_1) was 0.10 g. after immersion in water, the soaked weight (W_2) increased to 0.15 g, indicating that the film absorbed water effectively. Upon partial drying, the weight decreased to (W_3) 0.12 g, demonstrating that the bioplastic film retained a portion of the absorbed water while gradually releasing the excess. These results suggest that the bioplastic film possesses moderate water retention capacity, maintaining some hydration without compromising its structural integrity.

Water retention % = $(W_2- W_3) / W_1 \times 100$

= (0.15-0.12) / 0.10 × 100

= 30 %

The results indicate that the bioplastic film retained a such amount of absorbed water even after partial evaporation.

- *Solubility Test*

The solubility of the prepared bioplastic film was determined using different solution. A dried bioplastic film weighing 0.10 g was taken as the initial weight (W_1). After 24 hours of immersion in each solution, the films were removed, dried and the final weight (W_2) of each sample was recorded. The percentage of solubility was calculated based on the weight loss of the film using the formula:

Solubility (%) = W1- W2/ W1 × 100

The (Table:1) showed that the bioplastic film exhibited varying degrees of solubility in different solutions. The highest solubility was observed in sugar solution (38%), followed by distilled water (30%), salt solution (14%) and ethanol (10%). This variation indicates that the solubility in aqueous and sugar solutions suggests stronger interactions between the polymer matrix and polar molecules. In contrast, the lower solubility in ethanol indicates limited interaction with less polar solvents. The results demonstrate that the bioplastic film is moderately soluble and shows selective solubility behavior depending on the surrounding medium.

Table 1 Solubility of Bioplastic Film in Different Solutions

S. No	Solution	Initial weight (W_1) (g)	Final weight (W_2) (g)	Calculation ($W_1 – W_2$) / W_1×100	Solubility percentage
1.	Distilled water	0.10	0.070	0.10 – 0.070 / 0.10×100	30%
2.	Ethanol	0.10	0.090	0.10 – 0.090 / 0.10×100	10%
3.	Salt solution	0.10	0.086	0.10 – 0.086 / 0.10×100	14%
4.	Sugar solution	0.10	0.062	0.10 – 0.062 / 0.10×100	38%

- *Chemical Analysis*

The chemical composition of bioplastic was determined using the direct estimation method. The initial sample weight (W_s) was 0.50g. After drying, the A fraction (W_1) was recorded as 0.40 g. subsequent alkaline treatment reduced the weight to 0.35 g (W_2), indicating the removal of hemicellulose. Further acid treatment resulted in a final residue of 0.12 g (W_3), representing the lignin content. The percentages of hemicellulose, cellulose, and lignin were calculated using standard formulas.

Table 2 Chemical Composition of Bioplastic Film

S. No	Compound	Weight (g)	Initial weight (g)	Formula	Percentage
1.	Hemicellulose	W_1= 0.40	W_s = 0.50	$(W_1–W_2) / W_s \times 100$	10%
2.	Cellulose	W_2= 0.35	W_s = 0.50	$(W_2–W_3) / W_s \times 100$	46%
3.	Lignin	W_3= 0.12	W_s = 0.50	$(W_3 / W_s) \times 100$	24%

Based on the calculations, the hemicellulose, cellulose and lignin contents were found to be 10%, 46% and 24% respectively. Among these components, cellulose was the predominant constituent of the bioplastic film, indicating its major role in providing structural strength and stability. The total contribution of these three components accounted for 80% of the composition. The remaining 20% may be attributed to moisture content, soluble extractives, starch and other minor constituents.

These Table: 2 results confirm that the bioplastic film is primarily composed of natural polymeric materials, particularly cellulose, which contributes to its biodegradability and mechanical integrity. The percentage of hemicellulose and lignin further supports the film's structural complexity and potential durability.

- *Mechanical Analysis*

- *FTIR Analysis*

The biodegradable plastic prepared from banana bract and starch was characterized using Fourier Transform Infrared (FTIR) Spectroscopy, as shown in Figure: 1. This analysis was performed to identify the functional groups

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present in the material and to understand the interactions between the matrix components. A broad absorption peak observed at 3280 cm^{-1} corresponds to O-H stretching vibrations, indicating the presence of hydroxyl group, which are characteristic of polysaccharides. The peak at 2939 cm^{-1} and 2886 cm^{-1} attributed to C-H stretching vibration, confirming the presence of aliphatic chains in the biopolymer structure. The absorption band near 2501 cm^{-1} suggest weak O-H stretching of acidic groups.

A minor peak at 2078 cm^{-1} may be attributed to trace functional groups or instrumental noise. The strong peak at 1647cm^{-1} corresponds C=O stretching vibrations, which may be associated with bound water molecules or carbonyl groups present in the structure. The peaks at 1428 cm^{-1} and 1330 cm^{-1} are assigned to CH_2 bending and O-H bending vibrations, respectively, confirming the presence of cellulose structure.

The region between 1239 cm^{-1} and 1050 cm^{-1} represents C-O and C-O-C stretching vibrations, indicating polysaccharide structures typical of cellulose and hemicellulose. The lower peak at 999 cm^{-1} and 922 cm^{-1} correspond to C-H bending vibrations, suggesting carbohydrate structures. Furthermore, the peaks in the range of 858 cm^{-1} to 669 cm^{-1} are associated with C-H bending in aromatic compounds and represent the fingerprint region of complex polymeric materials.

The detailed functional group assignments are presented in Table: 3. The FTIR spectrum confirms the presence of key functional groups such as hydroxyl, carbonyl, and ether linkages, indicating that the bioplastic film is composed of natural polymeric constituents like cellulose, hemicellulose, and lignin. These functional groups play a crucial role in determining the physicochemical properties and biodegradability of the material.

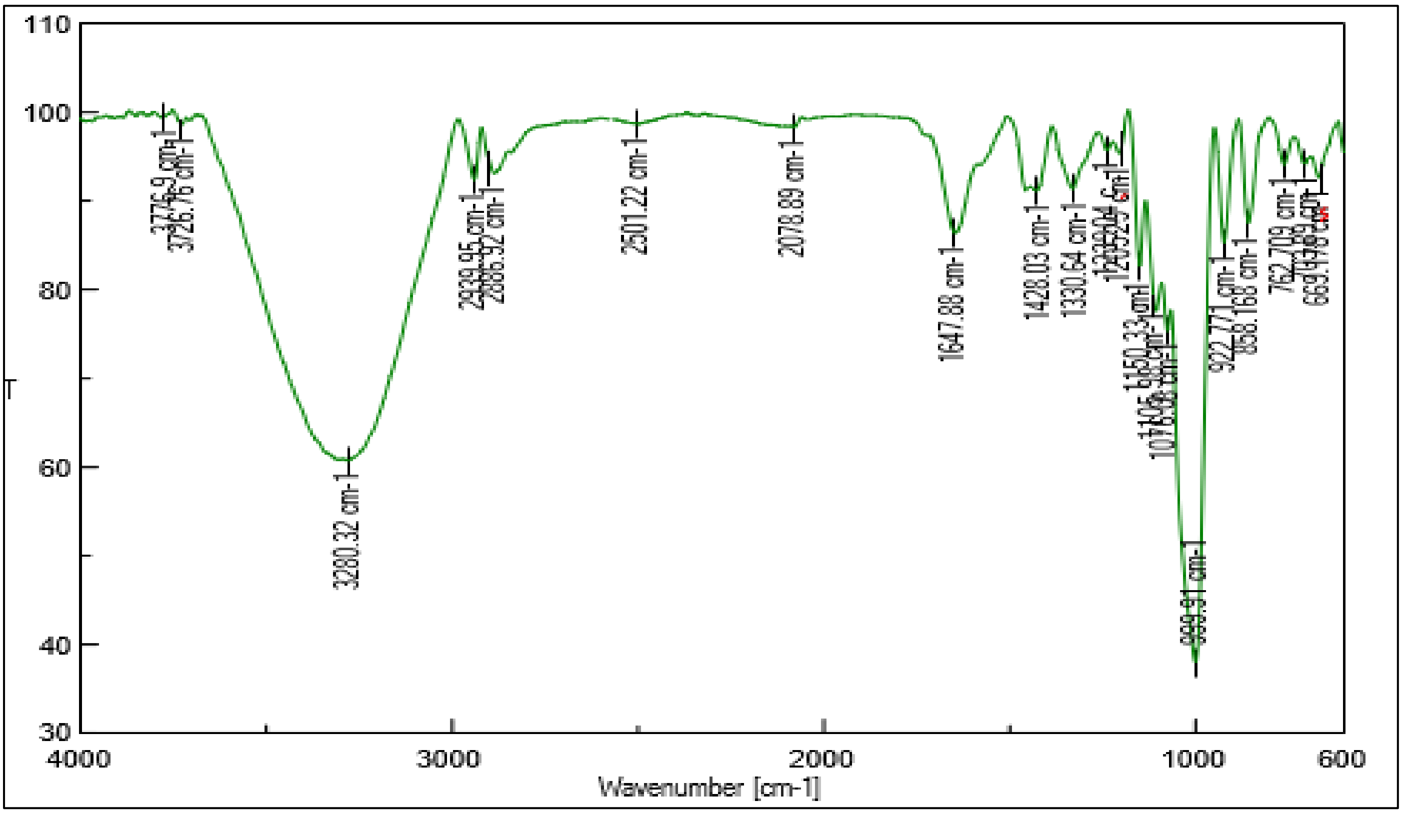

Fig 1 FTIR Spectrum of Bioplastic Film

Table 3 FTIR Functional Group Analysis of Bioplastic Film

S. No	Wave number cm^{-1}	Bond / vibration	Functional group
1.	3280 cm^{-1}	O – H Stretching	Presence of hydroxyl groups
2.	2939 cm^{-1}	C – H Stretching	Aliphatic chains in biopolymer
3.	2886 cm^{-1}	C – H Stretching	Methyl/methylene groups
4.	2501 cm^{-1}	O – H(acidic) Stretching	Weak acidic groups present
5.	2078 cm^{-1}	–	Minor functional groups
6.	1647 cm^{-1}	C = O Stretching	Carbonyl groups
7.	1428 cm^{-1}	CH_2 Bending	Cellulose structure confirmation
8.	1330 cm^{-1}	O – H Bending	Phenolic/alcoholic groups
9.	1239 cm^{-1}	C – O Stretching	Hemicellulose/lignin presence
10.	1205 cm^{-1}	C – O Stretching	Polysaccharide structure
11.	1150 cm^{-1}	C – O – C Stretching	Ether

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12.	1105 cm^{-1}	C – O Stretching	Carbohydrate backbone
13.	1076 cm^{-1}	C – O Stretching	Cellulose confirmation
14.	999 cm^{-1}	C – H Bending	Carbohydrate structure
15.	922 cm^{-1}	C – H Bending	Cellulose/lignin components
16.	858 cm^{-1}	C – H Bending	Aromatic compounds
17.	762 cm^{-1}	C – H Bending	Fingerprint region
18.	703 cm^{-1}	C – H Bending	Complex polymer structure
19.	669 cm^{-1}	C – H Bending	Aliphatic chains in biopolymer

- *XRD Analysis*

The X-ray diffraction (XRD) pattern of the bioplastic film revealed distinct diffraction peak at 2θ values of 17.19°, 22.57°, 24.48° and 37.42º, as shown in Figure: 2 The most intense peak observed at 22.57° corresponds to the crystalline plane of cellulose, indicating a well- defined ordered structure. A broad peak around 17.19° suggests the presence of amorphous polysaccharide regions within the bioplastic matrix. The peak at 24.48° and 37.42º represents semi-crystalline regions, indicating a combination of ordered and disordered structures. The XRD pattern confirms that the bioplastic film possesses a semi-crystalline nature, consisting the both crystalline cellulose domains and amorphous biopolymer regions. The detailed peak parameters, including position, FWHM, d- spacing, and relative intensity, are presented in Table: 4. The sharpness and intensity of the peak at 22.57° further indicate a relatively higher degree of crystallinity in the bioplastic film.

The structural arrangement plays a significant role in determining the material properties. The crystalline regions contribute to mechanical strength and rigidity, while the amorphous regions enhance flexibility and biodegradability. Thus, the balance between physicochemical properties in the bioplastic film.

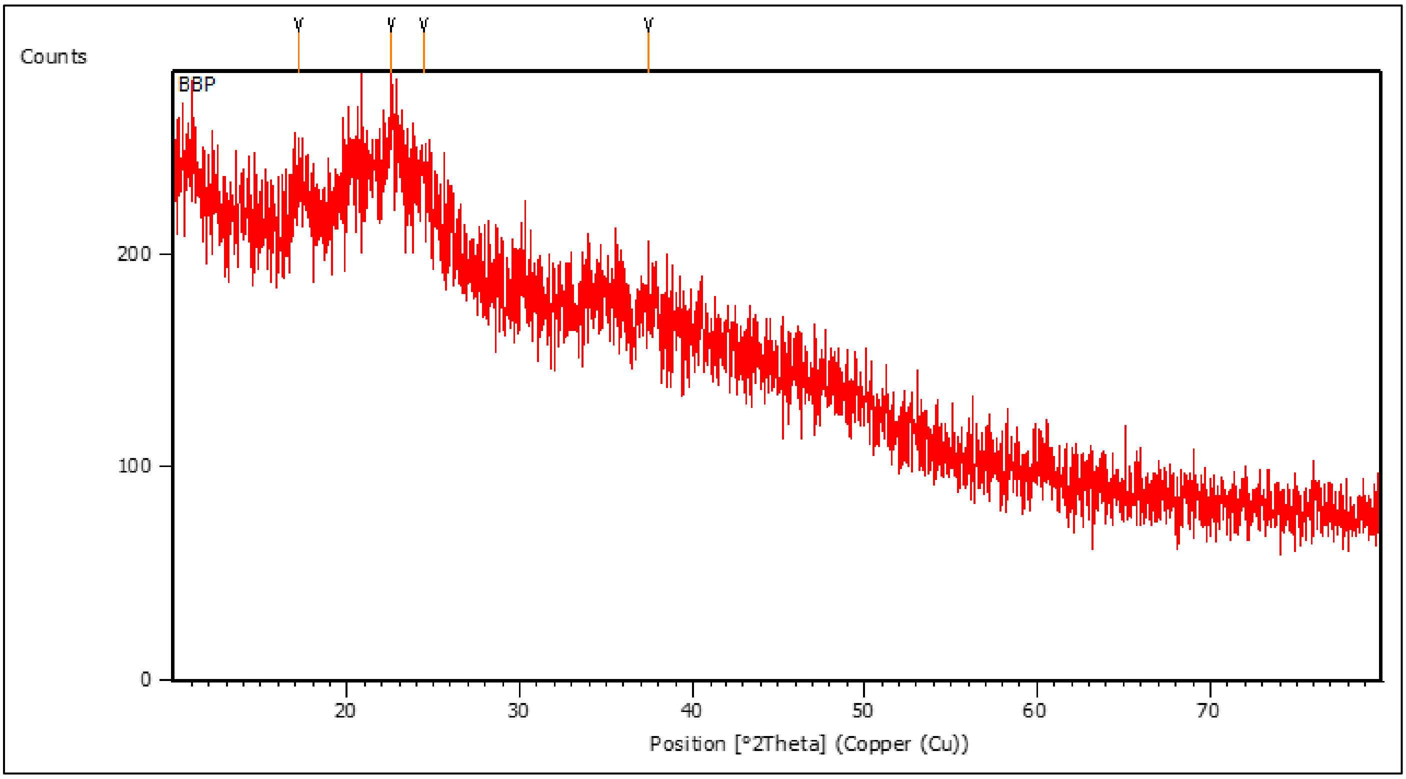

Fig 2 X-ray Diffraction Pattern of Bioplastic

Table 4 XRD Peak Parameters of Bioplastic Film

S. No	Position [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Relative Intensity [%]
1.	17.1987	25.85	0.6691	5.15594	95.30
2.	22.5789	27.12	0.2007	3.93806	100.00
3.	24.4858	18.64	0.8029	3.63552	68.72

- *SEM Analysis*

The surface morphology of the prepared bioplastic film was examined using Scanning Electron Microscopy (SEM) at different magnifications. The SEM micrographs revealed that the bioplastic film exhibited a relatively heterogenous and irregular surface structure. The presence of pores, cracks uneven region indicates the distribution of biopolymer component such as cellulose, hemicellulose and lignin within

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the matrix. At lower magnification, the surface appeared moderately rough, suggesting partial compatibility and interaction between the polymer chains. At higher magnification, the fibrillar arrangement was observed, confirming the presence of cellulose microfibers, which contribute significantly to the structural integrity and mechanical strength of the material. Additionally, the porous nature of the surface may facilitate water adsorption and enhance biodegradability. The SEM analysis indicates that the bioplastic film possesses a complex microstructure with both compact and porous regions, which plays an important role in determining its physicochemical and functional properties.

VII. DISCUSSION

The present research work demonstrated the successful preparation of bioplastic from banana bract blended with potato starch, showing that agricultural waste materials can be effectively utilized to produce eco-friendly polymeric materials. This work is the first to develop bioplastic using the banana bract (*Musa paradisiaca*), and it exhibits desirable physical, chemicals and structural properties.

In starch-based bioplastic weight loss of the film during burial in soil indicates the extent of degradation in the natural environment due to the action of microorganisms. The starch content consumed by soil microorganisms, which leads to the breakdown of polymer chains and results in biodegradation (Khoramnejadian S. et al., 2013). In a study on Jackfruit waste flour and sago- based bioplastics, three composites (PV, AV and PAV films) were evaluated using the soil burial method. On day 45, the PV film disintegrated into pieces and about half of the sample degraded, while 20% of AV film and 35% of PAV film degraded. By day 60, PV film completely degraded, while 50% of AV film and 80% of PAV film had degraded (Krishnamurthy A et al., 2019).

The present study confirms that the prepared bioplastic undergoes gradual degradation in soil, with visible changes appearing from the 7th day and complete degradation by the 30th day. This behavior indicates high susceptibility to microbial activity. The natural polymeric components, such as cellulose, hemicellulose and starch, are easily broken down by soil microorganisms. This demonstrates the ecofriendly nature of the material, which is highly important for reducing environmental pollution caused by synthetic plastics.

AM (*Arthrospira* species)- based bioplastics may exhibit higher hydrophilicity, possibly due hydrolysis that promotes solubilization. When considering the effect of the biomass content, no significant variation was observed AM samples (Lopez Rocha C. J et al., 2020). In CM (*Consortium Microalgae*) bioplastics, increasing biomass content to 68.3% resulted in a marked decrease in water uptake, reaching nearly half the value reported for 50%. The higher water uptake observed in AM.50 and CM.50 may be attributed to their higher plasticizer content, as it promotes the formation of a porous structure that enhances water absorption. Glycerol tends to migrate into the surrounding aqueous medium during immersion (Alvarez-Castillo et al., 2019; Fern, andez-Espada et al., 2016). Regarding the loss of soluble material, all samples, regardless of biomass type, showed decreased values with lower plasticizer content. It agrees with the observation that glycerol tends to leach out during immersion. In all cases, the percentage of material lost exceeded the original plasticizer content, suggesting that some biomass components were also solubilized, with slightly higher values observed in AM-based samples (Lopez Rocha C. J. et al., 2020).

In the present study, the water absorption capacity (60%) indicates that the bioplastic has a strong affinity for water. It shows hydrophilic nature is mainly due to the presence of hydroxyl (-OH) groups in cellulose and starch molecules, which form hydrogen bonds with water. The observed swelling without complete disintegration indicates that the film maintains structural integrity even after water absorption. It indicates a balanced interaction between hydrophilic components and the plasticizer (glycerol), which helps maintain flexibility while allowing water uptake. The water retention ability (30%) further supports the hydrophilic nature of the material. Even after partial evaporation, the film retained a significant amount of water, indicating the presence of bound water within the polymer network. That property may be beneficial in applications requiring moisture retention. The solubility of the bioplastic varied depending on the solvent used. The highest solubility was observed in sugar solution (38%), followed by distilled water (30%), indicating greater solubility in polar environments. Lower solubility in ethanol (10%) suggests limited interaction with less polar solvents. Afore mentioned confirms that the polymer matrix is predominantly hydrophilic. The moderate solubility also supports gradual disintegration in aqueous environments, contributing to its biodegradable nature.

The chemical composition revealed that cellulose (46%) is the major component, followed by lignin (24%) and hemicellulose (10%). The high cellulose content plays a crucial role in providing structural strength and rigidity. Cellulose fibers form a reinforcing network within the matrix, enhancing mechanical stability. Lignin contributes to stiffness and resistance to microbial attack in the initial stages, while hemicellulose acts as a binding component that improves compatibility between cellulose and starch. The remaining 20% likely consists of residual starch, moisture, and other soluble compounds, which may influence flexibility and biodegradability.

The FTIR analysis showed absorption bands corresponding to hydroxyl groups (-OH), attributed to complex vibrational stretching in carbohydrate structures. The C–H stretching bands are associated with CH_2 groups in starch and variations in amylose and amylopectin content. Peaks around 1423 cm^{-1} correspond to O–H bending, while peaks in the range of 1320–1380 cm^{-1} are assigned to CH_2 bending vibrations (Fatimah et al., 2017; Orsuwan A. et al., 2018). The fingerprint region further confirms the presence of polysaccharide structures, indicating successful incorporation of cellulose and starch. These functional groups play a vital role in determining the mechanical and physical properties of the material.

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XRD analysis revealed that the bioplastic possesses a semi-crystalline structure, characterized by the presence of both sharp and broad peaks. The crystalline regions are mainly attributed to ordered cellulose structures, contributing to strength and rigidity, while the amorphous regions arise from starch and other disordered components, providing flexibility. The combination is essential for achieving a balance between mechanical strength and flexibility. The present work examined XRD analysis revealed a semi-crystalline structure of the bioplastic. The presence of both sharp and broad peaks indicates the coexistence of crystalline and amorphous regions. The crystalline regions are mainly due to ordered cellulose structures, which contribute to strength and rigidity. The amorphous regions arise from starch and other disordered components, which provide flexibility. This combination of crystalline and amorphous phases is important for achieving a balance between mechanical strength and flexibility in the bioplastic material.

The biodegradable plastic based on banana peel, the micrographs of sample with higher banana peel content of 40% composition shows extremely uneven surface compared to lesser filler content. It might have been caused by disorder while casting which creates the structure of its morphology is not homogenous or due to the presence of insoluble starch in organic solvent which might also responsible for this irregularity (Fathanah U. et al., 2018). In starch-based bioplastic from Jackfruit seed, there were many microcracks on the surface of the specimen. The occurrence of these microcracks may be due to the presence of microbubbles formed during the gelatinization process (Santana R.F et al., 2018). These microbubbles were caused by hydrogen bonding chains of the starch, which began to break down when reaching the gelatinization temperature and the water molecules started to infiltrate into hydroxyl groups in the starch molecule (Wahyuningtiyas N. E et al., 2017).

SEM analysis showed a heterogeneous surface morphology with pores, cracks, and fibrillar structures. The rough surface indicates partial compatibility between the components of the bioplastic. The presence of pores and voids suggests a less compact structure, which may facilitate water absorption and microbial penetration, thereby enhancing biodegradability. The fibrillar structures observed at higher magnification confirm the presence of cellulose fibers, which act as reinforcement and contribute to the overall strength of the material.

The developed banana bract (*Musa paradisiaca*) bioplastic was successfully applied as a seedling pot for green gram and fenugreek cultivation. The product exhibited functional performance comparable to conventional plastic pots while offering additional environmental advantages. The bioplastic pot showed improved moisture retention, requiring watering once every two days, whereas the plastic pot required daily watering. It enhanced water-holding capacity can be attributed to the porous and hydrophilic nature of the bioplastic matrix, which allows absorption and gradual release of water. The presence of cellulose and starch components facilitates hydrogen bonding with water molecules, thereby maintaining soil moisture for a longer duration. The present property creates a more stable and favorable microenvironment for plant growth. The growth performance of green gram and fenugreek seedlings in the bioplastic pot was observed to be healthy and comparable to those grown in conventional plastic pots. It indicates that the developed product does not release toxic substances and is biocompatible with plant systems. Additionally, the structure of the bioplastic supports proper aeration and root development due to its semi-porous morphology. An important advantage of the product is its biodegradability, which reduces transplant shock in seedlings, as the plant can be directly transferred into the soil along with the pot. Furthermore, degradation of the pot may contribute organic matter to the soil, indirectly supporting plant growth.

- *Application of Bioplastic:*

The prepared banana bract bioplastic was successfully utilized as a seedling pot for the cultivation of green gram and fenugreek. A comparative study was conducted using a plastic pot and the developed bioplastic pot. They observed that the bioplastic pot retained moisture efficiently requiring water only once in two days. Whereas, the plastic pot required daily watering due to moisture loss. The improved moisture retention in the bioplastic pot attributed to its biodegradable and porous nature, which helps maintain adequate soil hydration. The growth of green gram and fenugreek in the bioplastic pot was found to be healthy and comparable to that in the plastic pot. It indicates the developed bioplastic pot provides a suitable microenvironment for seed germination and early development.

Plate 1. Seedling Pot from Banana Bract-Based Bioplastic

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VIII. CONCLUSION

The present study successfully demonstrated that the preparation of biodegradable bioplastic from banana bracts blended with potato starch, emphasizing the effective utilization of agricultural waste for sustainable material development. The developed bioplastic exhibited favorable physical, chemical, and mechanical properties, including high water absorption (60%), moderate water retention (30%), and selective solubility. Biodegradability studies confirmed complete degradation within 30 days, indicating its strong environmental compatibility. Chemical composition analysis revealed a high cellulose content, contributing to the material's structural strength and stability, while FTIR, XRD, and SEM analyses confirmed the presence of functional groups, semi-crystalline structure, and porous morphology, respectively. These characteristics collectively enhance the performance and degradability of the bioplastic. Furthermore, application studies demonstrated that effectiveness as a seedling pot, with improved moisture retention and support for healthy plant growth compared to conventional plastics. Considering all results, banana bract-based bioplastic represents a promising, eco-friendly alternative to petroleum-based plastics, contributing to reduced plastic pollution and improved utilization of agricultural waste for sustainable development in sub sequent years.

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