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Plastiana Revolution: Tangents of Peels Converging the Dimensions of Bioplastic into Sustainable Treasure

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Abstract

To overcome the disastrous effects on the environment and human health due to plastic pollution, bioplastic is one of the most innovative and prominent alternatives for petroleum-based plastics. Bioplastics from organic waste, agriculture waste, vegetable oil, fruit, and vegetable stach are sustainable at the same time biodegradable. The present investigation gives insight into the synthesis of biodegradable plastic from Musa acuminata banana peels as it contains polymer chains called amylose and amylopectin which bond together to form bioplastic and also aim to study its characterization using FTIR, antibacterial, biodegradability, water solubility, and moisture content tests. From the observation, we found that the prepared bioplastic film with the optimum amount of plasticizer shows water solubility of about 3.27% which makes it worth commercial viability. With 100% biodegradability of prepared bioplastic within 42 days. Natural ingredients like lemon, neem, and Aloe Vera were added to further enhance its properties with the aim of creating an affordable yet natural product. The biofilm with lemon showed significant results in all the tests resisting water, microbes, and moisture. Through the antimicrobial properties of the bioplastic, a wider yield in films, bags, and wrappers can be acknowledged to reduce the use of plastics further. We believe that our research will play a pivotal role in the ongoing transition towards sustainable clean solutions and rejuvenate a compelling case for the adoption of bioplastic films, promoting a greener and more responsible approach to jeopardize plastic.

Keywords: *Antibacterial; Biodegradable; Bioplastic; Musa Acuminata Banana Peels; Sustainability.*

1. Introduction

The extensive use of synthetic plastics over the life span intensifies the climate change issues by polluting lands, waterways and oceans with increased greenhouse gasses and solid wastes. According to a United Nations Environment Programme (UNEP) estimate, up to 5 trillion single-use plastic bags are used worldwide each year, with less than 10% recycled. This can lead to diverse effects in all the forms of life on Earth. A study by EA, Earth Action showed that 220 million tonnes of plastic waste will be created in 2024 with India being included in the top 5 countries being responsible for the mismanagement of Plastic waste. To curb Plastic waste, it is essential to find a replacement for the same. Bioplastics, as the name suggests, can effectively reduce the harmful chemicals emitted by petroleum-based plastics. Bioplastics have the potential to reduce the petroleum consumption for plastic by 15 to 20 percent by 2025[1]. The material used for Bioplastics depends on its properties. Using waste materials for Bioplastics is a boon as it brings about a cycle of reversibility to better the environment. With many forms of bioplastics coming their way, our research aimed to find the optimum amount of the solvents to be used along with inculcating natural products so as to form an eco-friendly bioplastic. Plastiana stands for Plastic+Banana to bring about a revolution to curb plastic waste. Therefore, Lemon which is rich with citric acid, Aloe Vera as it is rich in mucilage and Neem (antifungal) were added as natural ingredients to improve the bioplastic films. These were also used as it is easily affordable taking into consideration the recent problems of good and low-cost materials as an additive. Musa acuminata Banana peels were used for their high starch content and also because it is easily available. Further the use of Bioplastics aligns with the Sustainability Goal – 12 making it possible for sustainable cities and communities. Different studies going on, showed varied techniques and products used. For example, Sodium Silicate solution for mechanical properties from corn and potato starch [2], mangosteen peel with cellulose nanocrystals as fillers CNCs [3], wheat Janeng starch [4], tapioca starch/polyvinyl alcohol bioplastics [5] and many recent methodologies were invented. However, the products used were expensive and the process involved addition of various chemicals silica, silver nitrate etc. This bioplastic from fruit peel showed better results with respect to biodegradability, water solubility, moisture content and water absorption. Citric acid proved to be a vital source of improvement in the properties of bioplastic. It was also found that less amount of glycerol helped with less absorptivity and water solubility and thus helped in our motive of making food packaging and bioplastic bags. Further methods to improve were also mentioned in this work.

2. Methodology

2.1. Preparation of the Banana Peels

Musa acuminata bananas were bought from the nearest market. The banana peels were boiled in a beaker containing distilled water for 30 minutes. Sodium metabisulphite was added to it so as to remove the impurities present in the peel. After 30 minutes, it was kept aside till it cools down. The banana peels were further grinded and transformed into a paste/ puree using a grinder.

2.2. Production of Polymer

The paste formed was placed in a petri dish and dried for 30 minutes at 120° Celsius in the hot air oven. This was down to remove the excess of moisture in the mixture. 25 grams of this paste was taken in 4 small beakers. 6 ml of Glycerol was added as a plasticizer. 3 ml of 0.5N Hydrochloric acid was added as a binder followed by 6 ml of 0.5N NaOH to adjust the pH of the material [4]. These are placed in the stirrer for the uniformity of the mixture.

2.3. Preparation with Different Additives

Further different additives are added to the stirrer separately and are stirred for 10 minutes for forming a uniform paste. As starch contains amylose and amylopectin molecules, vinegar (acetic acid) was added to help the branched amylopectin molecules to break into straight chained amylose molecules. Lemon (Citric Acid) is used as an organic crosslinking agent and a plasticizer for starch films. It forms hydrogen bonds with starch to enhance its thermal and water stability. In the third beaker, Aloe Vera paste is added and further in the other beaker, no solution is added and it is termed as blank. The Table 1 below shows the additives which were added so as to form a reliable bioplastic film:

Table 1 Classification of the Films Formed

BEAKER	SOLUTION	AMOUNT
1	Acetic acid	6 ml
2	Aloe Vera	6 ml
3	Lemon	6 ml
4	Blank	-

2.4. Production of the Bioplastic Film

The paste is spread over the petri dish. It is placed in a hot air oven for 3 hours at 120° Celsius. It is allowed to cool and the formed film is removed [15]. The blank sample has no additives and is prepared to compare with the other samples.

2.5. Varying the Amount of Glycerol

Glycerol is hygroscopic. This is due to the presence of 3 hydroxyl (OH) groups in its molecular structure. Glycerol molecules can form hydrogen bonds with water molecules in Figure 1-2.

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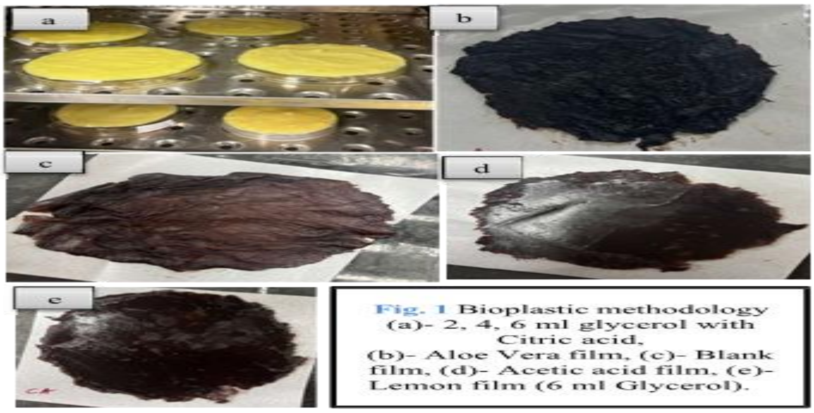

Figure 1 Bioplastic Methodology

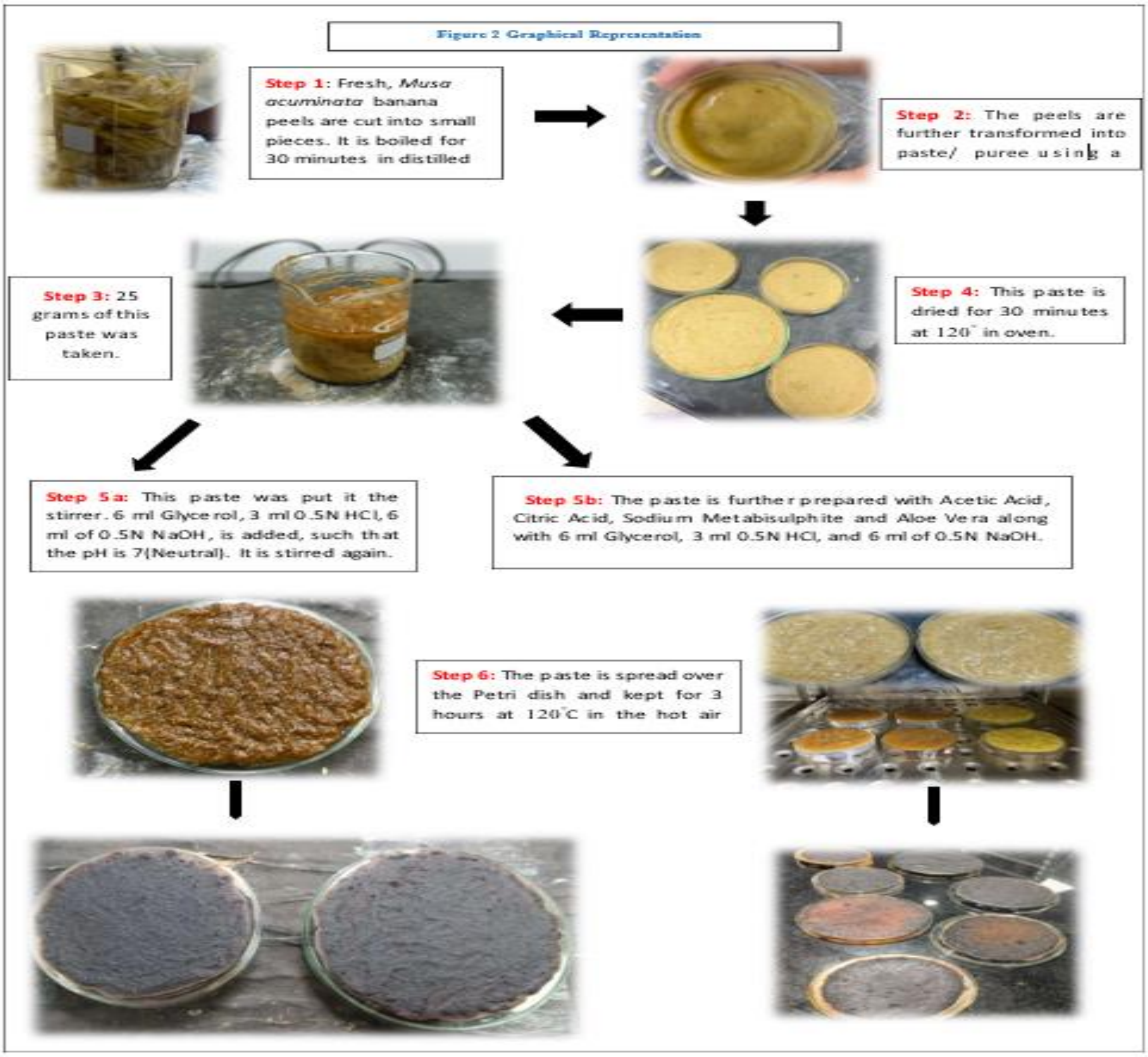

Figure 2 Graphical Representation

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Therefore, the amount of glycerol was varied accordingly so that the bioplastic will show better results for water absorption, moisture content and solubility. Since lemon showed better results with antibacterial properties, the amount of glycerol was varied with the lemon sample in Figure 3.

2.6. Application Studies

2.6.1. Biodegradability

A biodegradability test was used to analyze the synthesized material, which is necessary to determine how environmentally friendly the material is [6]. Fertilized manure (vermicomposting soil) was used in the degradation test. The synthetic sample was buried in the soil after recording the weight and dimensions. The depth of the sample below the soil was kept to be 5 cm. According to reports, the material started to deteriorate on the first day itself. Water was occasionally applied to the soil to speed up the biodegradation process. Further, the percentage of weight reduction and the rate of biodegradation of each sample were calculated using the following equations [7,8]:

$$\% \text{ Reduction Rate} = \frac{w1-w2}{w1} \times 100$$

$$\text{Rate of Biodegradation} = \frac{w1-w2}{\text{Maximum time of degradation}}$$

2.6.2. FTIR Characterization

The blank sample of the film was analyzed using FTIR spectrophotometer. The peak obtained at 3325 cm^{-1}.

2.6.3. Antibacterial Properties

There are microorganisms everywhere. The addition of sodium metabisulphite to this biodegradable product helps to prevent microbial growth on the product, which is useful for storing items. The antibacterial property can be assessed in a number of ways. The disc diffusion (Kirby Bauer) test was used in this study to measure the antimicrobial activity of the biodegradable product [9]. Mueller Hinton agar plates, whose surface has been evenly swabbed with a suspension of microorganisms, were used to hold biodegradable products. Petri dishes were then left for 20 to 24 hours to incubate. The inhibitory zone surrounding the biodegradable samples on the agar plate needs to be identified after the incubation period.

2.6.4. Moisture Content

The sample was placed out for 48 hours. Moisture content was calculated by using the initial weight (W_1) and the final weight (W_2) of the bioplastic film (1 cm ×1 cm) after drying it for 3 hours in the oven at 100 °C [8].

$$\% \text{ Moisture content} = \frac{w1-w2}{w1} \times 100$$

2.6.5. Solubility In Different Solvents

The packaging materials should not be soluble in solvents as it will affect the food inside. To test this, the prepared bioplastic film (1cm x 1cm) was placed in a beaker filled with different solvents for 24 hours. Through this, the solubility of bioplastic in different solvents were analyzed.

2.6.6. Water Solubility

A known weight (W_1) of the bioplastic film was subjected to 24 hours of water immersion with continuous agitation. After the experimental time, it was removed from the water and dried for 3 hours at 150°C [12]. The percentage of water solubility was calculated.

$$\% \text{ Water solubility} = \frac{w1-w2}{w1} \times 100$$

2.6.7. Water Absorption

A known weight (W_1) of the bioplastic film was subjected to 24 hours of water immersion with continuous agitation (Fig.3). After the experimental time, it was removed from the water, cleaned of adhered water, and its weight was determined (W_2) [11]. The percentage of water absorbed was calculated.

$$\% \text{ Water absorbed} = \frac{w1-w2}{w1} \times 100$$

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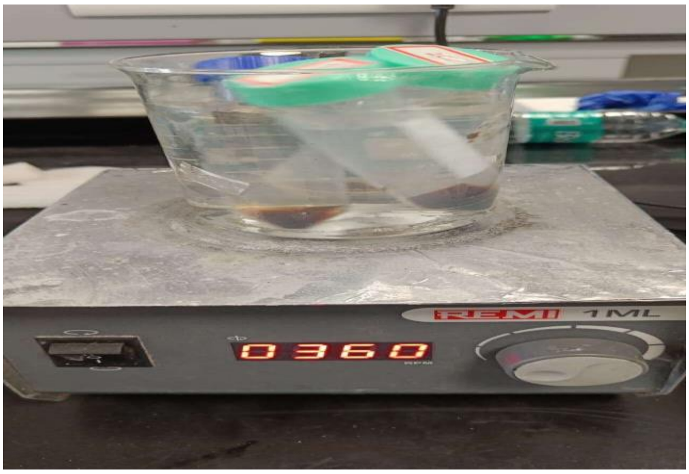

Figure 3 **Continuous Agitation**

3. Results and Discussions

3.1. Biodegradability Test

The initial weight of the sample was noted and the weight after every alternate day was noted. Table 2 shows the biodegradability test results for the synthetic bioplastic film. The sample's color turned black as the number of days it spent in the soil increased, according to the study's findings. In the days that followed, it also lost weight and became less glossy. The data also indicates that the sample underwent degradation in the soil in 37 days. 93.85% of bioplastic degraded with decay rate of 0.0043 gm/days within 37 days.

Figure 4 **Vermicomposting Soil, Day 1**

It took 42 days for the entire sample to completely degrade. This shows that the prepared bioplastic is biodegradable and therefore will not emit any harmful substances like the petroleum-based plastics. Often, animals like cows, eat plastic and succumb to the consequences. However, this will not be the case with the prepared bioplastic. This showed improved observation than reported in literature [14,15] in Figure 4-6.

Figure 5 **Day 15**

Figure 6 **Day 37**

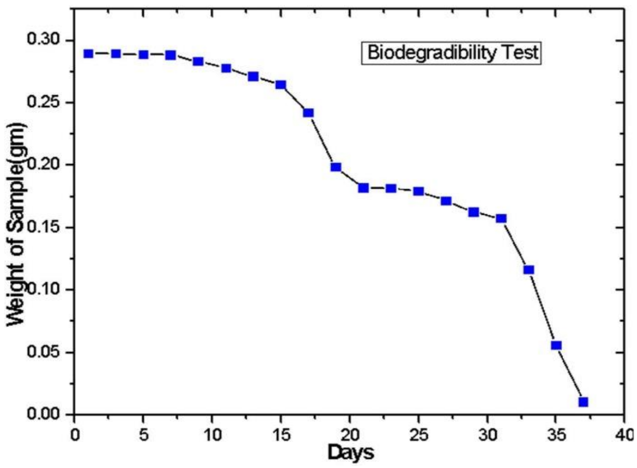

Figure 7 **Graphical Analysis of Degradation**

Table 2 **Rate of Degradation**

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Days	Weight of Sample (gm)
1	0.28949
3	0.28940
5	0.28901
7	0.28844
9	0.28328
11	0.27785
13	0.27121
15	0.26497
17	0.24221
19	0.19855
21	0.18215
23	0.18153
25	0.17913
27	0.17156
29	0.16245
31	0.15732
33	0.11637
35	0.05610
37	0.01044

3.2. FTIR Characterization

The peak obtained at 3325 cm-1 represents the OH group's strong absorption due to O-H stretching characteristics. Similarly, the occurrence of C-H stretching vibrations of CH, CH2, and CH3 groups resulted in a sharp peak at 2933 cm-1. Moreover, the observed peak at around 1700 cm-1 is attributed to C=O stretching vibrations of carboxylic groups (-COOH, -COOCH3) which can be due to the presence of carboxylic acids or their esters [10]. The peak at 1627 cm-1 showed a C=O bond. The 1412 cm-1 assigned to CH2 bending vibrations in bioplastics. Likewise, the strong absorption peak at 1018 cm-1 corresponds the C-O-C bond stretching in the anhydrous glucose ring that developed because of starch. [12] in Figure 7.

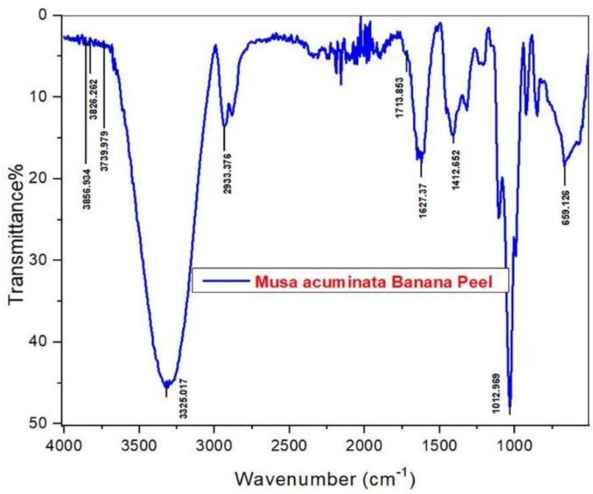

Figure 8 **Banana Treated with $Na2S2O5$**

3.3. Antibacterial properties

The antibacterial activity of banana peel extract against Bacillus cereus, Escherichia coli, Staphylococcus aureus, and Pseudomonas was tested using the well diffusion assay. The colonies were moved to the Muller Hinton Agar using a loop or swab. After that, the sterile cotton swab was dipped into the inoculum and used to swab the agar plate's surface. The wells on each plate were created using hollow tubes with a diameter of 1 to 5 mm. The bioplastic films were then placed into the appropriate wells. The plates were kept in an incubator at 37°C for 24 hours. Three wells were created: one held the bioplastic film sample for various solvents (acetic acid, citric acid, aloe Vera, without any solvent), the second held the antibiotic positive control, and the third held the DMSO negative control [9]. Following a 24-hour incubation period, the product demonstrates antimicrobial activity against the following as seen in Table 3 & in Figure 8.

Table 3 **Antibacterial property**

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Solvents	Organism	Zone of Inhibition
Acetic Acid	Bacillus cereus	No zone of Inhibition
	Escherichia coli	
	Staphylococcus aureus	
	Pseudomonas	
Citric Acid	Bacillus cereus	4 mm
	Escherichia coli	2 mm
	Staphylococcus aureus	1 mm
	Pseudomonas	1 mm
Aloe Vera	Bacillus cereus	No zone of Inhibition
	Escherichia coli	
	Staphylococcus aureus	
	Pseudomonas	
Without any Solvent	Bacillus cereus	No zone of Inhibition
	Escherichia coli	
	Staphylococcus aureus	
	Pseudomonas	

As seen in the above table, when citric acid was added to the incubated bacteria, it formed a 4 mm zone of inhibition for Bacillus cereus, a 2 mm zone for Escherichia coli, and a 1 mm zone for Staphylococcus aureus and Pseudomonas, respectively (Fig.9). These results demonstrated the beneficial effects of citric acid. Aloe Vera may not have shown the antibacterial property due to high moisture content as 6 ml of glycerol is added along with Aloe Vera also acting as a plasticizer in Figure 10.

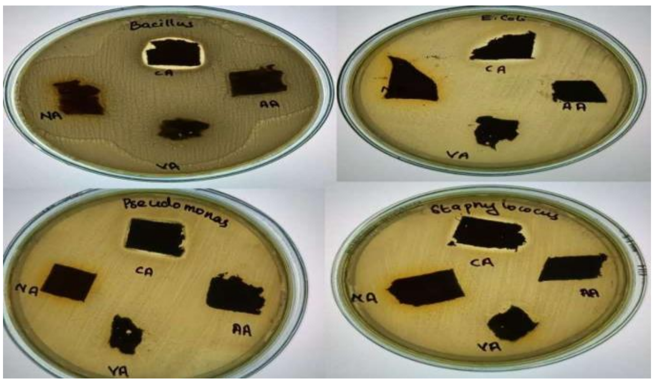

Figure 9 Zone of Inhibition Formed with Citric Acid

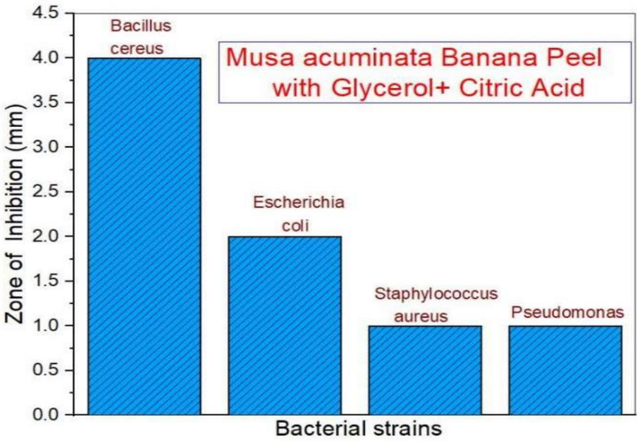

Figure 10 Graphical Representation of the Inhibition

3.4. Moisture Content

Moisture content is essential in the view of food packaging so as to avoid food spoilage, as moisture will accelerate the growth of fungi, bacteria and other microbes can colonize the film. Our results revealed that bioplastic films produced with the addition of additives have lesser moisture content than the one formed with only sodium metabisulphite. The moisture content results (Fig. 11) depicted that the bioplastic with Aloe Vera have lesser moisture content (16.95%) than the film formed with Lemon (23.23%). This could be attributed to the hydrophilic nature of Aloe Vera which can bind and absorb the moisture and considerably reducing the moisture content in the bioplastic film in Table 4 and Figure 11.

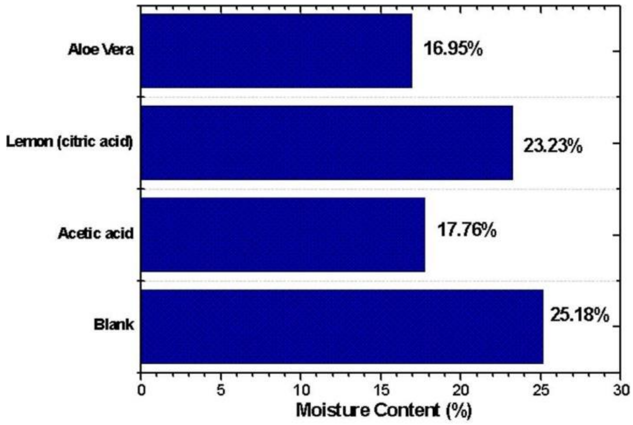

Figure 11 **Moisture Content Graphical Analysis**

Table 4 **Moisture Content Test for Bioplastic Films**

Solvents	Initial Weight (gm)	Final Weight (gm)	Water Uptake (%)
Acetic acid	0.10773	0.08859	17.76
Citric acid	0.12757	0.09793	23.23
Blank	0.23446	0.1754	25.18
Sodium metabisulphite	0.17427	0.139	20.23
Aloe Vera	0.18017	0.14963	16.95

Further modifications were made as mentioned in the methodology (2.5) with the variations in the glycerol levels. The results showed that sample with 2ml glycerol shows a better result for moisture content. Therefore, this is considered to be the optimum glycerol amount for better results. Higher moisture content than this have been stated with moisture content as 14.26-11.24 % with silica extracts [2],15.3-24.8[13] in Table 5 & Figure 12.

Table 5 **Variations with The Amount of Glycerol**

Amount of Glycerol (ml)	Initial weight (gm)	Final weight (gm)	Moisture content (%)
2	0.13715	0.12643	7.82
4	0.19287	0.15699	18.60
6	0.12757	0.09793	23.23

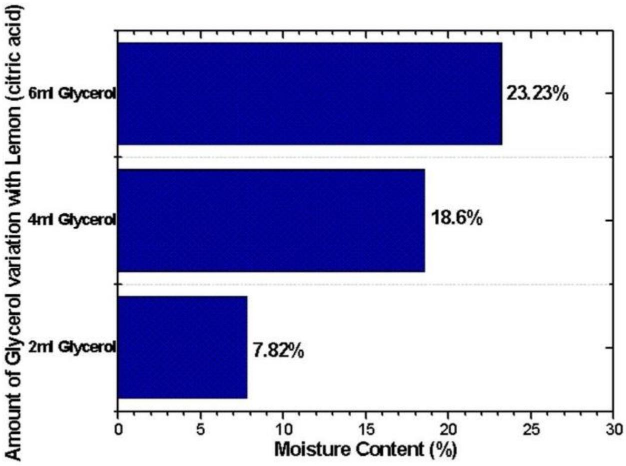

Figure 12 **Moisture Content Results with Variations in The Amount of Glycerol**

3.5. Solubility in Different Solvents

The bioplastic film with 2ml glycerol and citric acid was placed in the solvents for 24 hours in Figure 13.

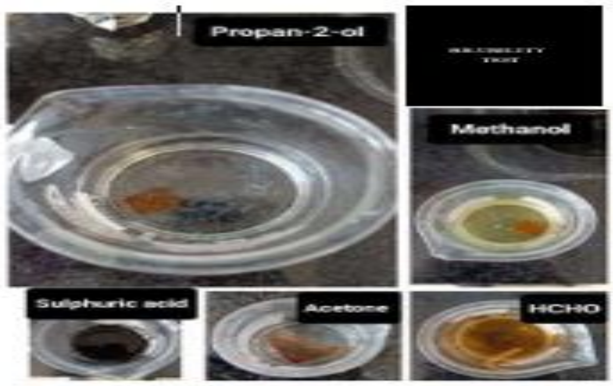

Figure 13 **Bioplastic**

None of the samples demonstrated complete solubility in the different media, which is desirable result for the production of bioplastics when compared to the conventional methods. This illustrates the bioplastic materials made from banana peels is suitable for food packaging and in making covers for objects. However, in concentrated sulphuric acid, the bioplastic showed a decrease in weight and was almost soluble in Table 6.

Table 6 Solubility Test with Different Solvents

Solvents	Sample	Insoluble	Partially soluble	Completely soluble
Propan-2-ol	Citric acid with 2 ml glycerol	Yes		
Acetone		Yes		
Formaldehyde		Yes		
Methanol		Yes		
Sulphuric acid				Yes

3.6. Water Solubility

For any packaging material, its property is defined by its solubility and absorption in Figure 14.

Figure 14 Bioplastic with Neem and Lemon

The bioplastic which is soluble in water cannot be used as a packaging material as it will easily degrade due to hydrolysis. The solubility test was done with the citric acid sample. This was mainly done as citric acid participate in cross linking reaction in the bioplastic which enhances the mechanical strength of the formed film. Neem was also used in one sample as neem has natural oils which can resist water in Table 7 & Figure 15.

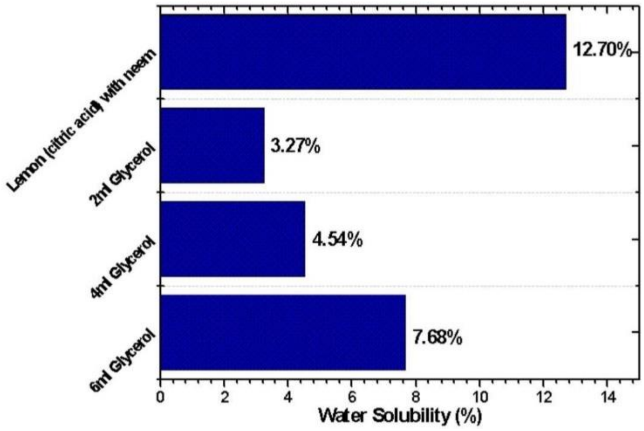

Figure 15 Water Solubility Test

Table 7 Water Solubility

Glycerol Variation in Citric acid (ml)	Initial weight (gm)	Final weight (gm)	Water Solubility (%)
Citric acid with 6 ml Glycerol	0.2171	0.02499	7.6874
Citric acid with 4 ml Glycerol	0.12007	0.02164	4.5485
Citric acid with 2 ml Glycerol	0.1308	0.03061	3.2731
Citric acid with neem	0.18311	0.01336	12.7058

From the results, we conclude that the film formed with 2ml glycerol shows good result for water solubility (3.27%) compared to the film with 4ml and 6ml glycerol. This is also because glycerol easily reacts with water molecules. With 3.27% solubility, the prepared Banana peel can be used as food packaging material.

3.7. Water Absorption

Less water absorption of tap water leads to less degradation of its tensile strength. The bioplastic

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with Aloe Vera showed better results. The same was performed with varied glycerol levels and the sample with 2ml glycerol showed better result of 7.05%. Higher absorption than those reported in this study have been reported by other authors: 12.42-82.19% [14] and 58.10% [2]. It is therefore analyzed that the bioplastic with citric acid and 2ml glycerol is vital and shows the best results in Figure 16.

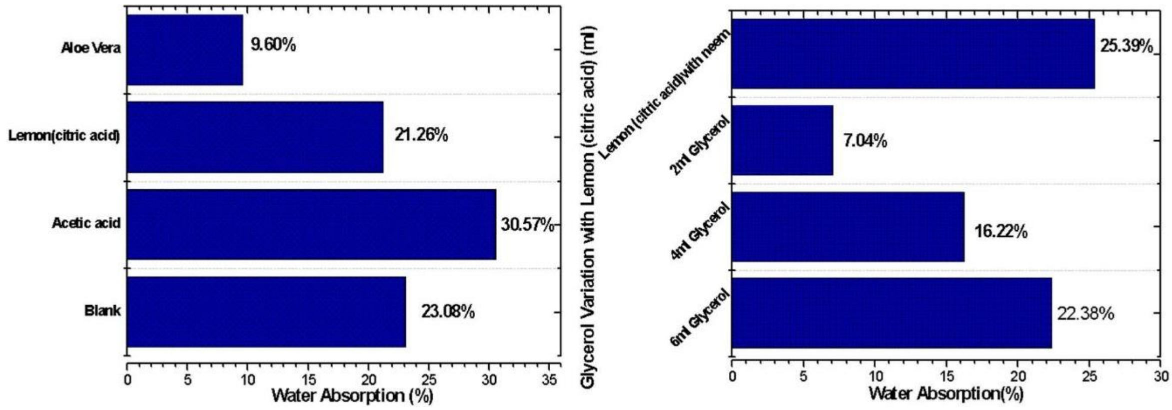

Figure 16 Water Absorptivity Test

Conclusion

In this work, bioplastics using glycerol, in addition with Citric acid, Acetic acid, Sodium metabisulphite, blank and Aloe Vera were successfully synthesized from banana peels. The Musa acuminata banana peel bioplastic film with 2ml glycerol in addition with citric acid showed optimum results for water solubility (3.27%), water uptake, moisture content and antibacterial activity. The glycerol concentration of 2 ml also proved to be vital for the food packaging materials. With neem, lemon and Aloe Vera, the study truly proved to be environmentally friendly and natural. The bioplastic showed efficient biodegradability of 100%. Hence the prepared bioplastic with addition of citric acid is efficient for packaging application to address the growing concerns related to plastic pollution and environmental sustainability.

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