Green Synthesis and Characterization of Bio-plastics from Agro-waste

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Abstract: This study explores the synthesis of biodegradable plastics using banana peel starch, a renewable agro-waste, combined with glycerol& sorbitolas plasticizers. Bioplastics were tested to understand their strength, flexibility, and biodegradability. The results indicates that the choice of plasticizers significantly influence the properties of the resulting bioplastics, highlighting their potential as sustainable alternatives to conventional plastics.

Key words: Banana peel, bio-plastic, plasticizer, glycerol, sorbitol

1.INTRODUCTION:

Our whole world is wrapped in Plastic Plastics are widely used in everyday life. Plastics are organic polymers which contains other inorganic compounds. From precious petrochemicals, conventional plastics are derived. Raw materials to make plastic can be Fossil fuels.[1] Due to the plasticity property, the plastics can be molded into a specific shape which is needful. The adaptability and wide range of properties of plastics like flexibility, light weight of material, inexpensive quality has led to the widespread of the plastic use in all fields.[2] Plastic offers many benefits such as flexibility, multiple shapes such as sheets, panels, film. Its adaptability makes it useful in many applications.[3]

Plastics are vital materials in modern life, offering unique properties that make them invaluable in many fields. Due to its properties such as versatility, Lightweight, durability, Cost-Effect, Energy Efficiency etc. Plastics are used in packaging, Medical and Healthcare, Construction, Automotive industries.
With these advantages plastics have much more disadvantages. Few are listed below:

1. Environmental Pollution
2. Threat to Marine and Wildlife
3. Human Health Risks
4. Economic Costs
5. Low Recycling Rates and Waste Management Challenges

The use of plastics cannot be stopped completely as plastics are so crucial to our lives but due to their environmental pollution alternative solution to this problem is being looked into and the alternate solution called 'Biodegradable Plastic'. Due to the activities of living organisms like fungi, bacteria or other microorganisms, plastic can be broken down biologically into organic substances such as carbon-dioxide and water[4], such plastic is called as biodegradable plastic.
In the present research work we synthesized bioplastics from banana peel with glycerol and sorbitol as plasticizer and their different characterization were studied.

2.MATERIALS AND METHODS:

Banana peels were usedto make bioplastic because they are very rich in starch and consist of two different types of polymer chains called amylose and amylopectin. These chains are made up of adjoined glucose molecules that are bonded together to form bioplastic. Banana fruits were purchased from local market at Latur, Maharashtra, India.

2.1 Synthesis of bioplastic from banana peel:

a) Preparation of banana starch from banana peel:

Banana peels obtained from 5-6 bananas were dipped in sodium metabisulphite (0.2M) solution for 45 minutes to increases the biodegradation period of plastic. These banana peels then boiled it in water for about 30 minutes. Water was removed from the beaker and the peels were left to dry. When peels were completely dried, grinded using grinder until uniform powder was obtained[5].

2.2 Production of bio-plastic:

A) By using glycerol as plasticizer:

In a beaker 5gm of banana powder was placed. 30ml of (0.5 N) HCl was added to this mixture and stirred using glass rod. 2ml Plasticizer (Glycerol) was added and stirred. Then according to pH desired, 0.5 N NaOH was added to maintain neutral pH. The mixture was spread on a Ceramic tile and this was put in the oven at 120°C and was baked. The tile was cooled and the film was scraped off the surface.[6]

B) By using sorbitol as plasticizer:

In a beaker 5gm of banana powder was placed. 30ml of (0.5 N) HCl was added to this mixture and stirred using glass rod. 2ml Plasticizer (sorbitol 1M) was added and stirred. Then according to pH desired, 0.5 N NaOH was added to maintain neutral pH. The mixture was spread on a Ceramic tile and this was put in the oven 120°C and was baked. The tile was cooled and the film was scraped off the surface.[7]

		
Fig- 2.1 Preparation of banana starch from banana peels	**Fig- 2.2 A Production of bio-plastic using glycerol as plasticizer**	**Fig- 2.2 B Production of bio-plastic using sorbitol as plasticizer**

Mechanism:

- The hydrochloric acid is used in the hydrolysis of amylopectin (present in starch), in order to help the process of film formation due to the H-bonding amongst the chains of glucose in starch, since amylopectin blocks the film evolution.
- To neutralize the pH of the medium, sodium hydroxide is used
- Plasticizers glycerol& sorbitol are added to make bioplaqstic more flexible.
- Sodium metabisulfite ($Na_2S_2O_5$) is used To prevents the microbial growth in the peels by acting as an antioxidant.

3.CHARACTERIZATION OF BIOPLASTICS:

1) Moisture content:

Bio-plastic samples of size 1.5 cm^2 were weighed to measure the initial weight (W_1). The samples were dried in an oven at 85°C for 24 h and then weighed again to measure the final weight (W_2). The moisture content was then determined using the following formula[8]:

$$\text{Moisture content (\%)} = \frac{W1-W2}{W1} \times 100$$

2) Absorption of water:

Firstly bio-plastic samples with size 1.5 cm^2 were dried in oven at 85°C for 24 h and then their dry weight (W_1) was measured. For 24 h, the samples were placed in a beaker with 50 ml distilled water at room temperature. After that the bio-plastics were filtered out and its final weight (W_2) was measured. By using the following formula, absorption of water was found[8]:

$$\text{Absorption of water (\%)} = \frac{W2-W1}{W1} \times 100$$

3) Swelling Test:

The swelling test is carried out to evaluate their water absorption capacity and hydrophilicity. 1g piece of samples were taken in the test tube containing various solvents such as water, chloroform and methanol and kept in the medium for about 2 hours and the results were recorded accordingly[9].

4) Solubility:

a) **Solubility in water**: To test water solubility, synthesized bio-plastic samples, each 1.5 cm², were dried in an oven at 85°C for 24 hours. The dry weight (W_1) of the bioplastic samples was measured. The weighed bio-plastic was placed in a beaker with 50 ml of distilled water and left at room temperature for 24 hours. After that the bio-plastic residue was obtained by filtering the water and dried again in an oven at 85°C for 24 h. After 24 h the weight of dried sample was taken as final weight (W_2). The solubility of the bio-plastic in water was calculated using a specific formula given below[10]:

$$\text{Solubility in water (\%)} = \frac{W1-W2}{W1} \times 100$$

b) **Solubility in alcohol**: Synthesized bio-plastic samples, each 1.5 cm², were dried in an oven at 85°C for 24 hours. The dry weight (W_1) of the samples was measured. Kept this weighted bio-plastic in test tubes with caps containing 10 ml ethanol for 24 hrs. at room temperature. After 24 hrs. the bio-plastic residue was obtained by filtering the water and again dried in an oven at 85°C for 24 hrs. After 24 hrs. the weight of dried sample was taken asfinal weight(W_2).The solubility in alcohol was calculated using a specific formula given below[10]:

$$\text{Solubility in Alcohol (\%)} = \frac{W1-W2}{W1} \times 100$$

5) Bio-degradability Test:

Bio-plastic samples of size 1.5 cm^2 were weighed to measure the initial weight (W_1). This weighted samples were placed under 2 cm of wet garden soil. They were kept in Styrofoam cups. The bioplastic samples with Styrofoam cups were kept at room temperature and the soil was kept moist for 5 days. After 5 days, the bio-plastic residue was collected from the soil and cleaned with water and then dried at 85°C in an oven for 24 hours. After 24 h the weight of dried sample was taken as final weight (W_2). Biodegradability was calculated using a specific formula given below[11]:

$$\text{Bio-degradability (\%)} = \frac{W1-W2}{W1} \times 100$$

6) Thickness measurement:

A screw gauge was used to compute the thickness of the bioplastics. The thickness of samples were measured at various points. Then average thickness was calculated[12].

7) **Chemical resistance:** To check chemical resistance, bioplastic films were socked in 0.1N NaOH and 0.1N HCl solution for 24 hours. The effects of strong acid and base on the samples were ascertained by measuring change in appearance[13].

8) **Flame test:** Bio-plastics were weighed in order to obtain initial weight and then they were subjected to high flame for 30 seconds and was observed for any poisonous gases[14].

9) Creep measurements:

To measure the creep behavior of bio-plastics, we need to assess how the material deforms over time under a constant load and temperature. Synthesized bio-plastic samples with consistent dimensions were used. The thickness of each sample at multiple points using a screw gauge was measured and the average thicknesses were calculated.

Equipment calibrated to maintain constant1.0MPa stress and 25°C temperature and ensuring proper alignment to avoid inaccurate readings. Bio-plastic samples were secured in the grips of the testing machine and strain at regular intervals was recorded.

10) Fourier Transform Infrared Spectroscopy (FTIR)

Aligent Cary 630 FTIR spectrometer was used to investigate the interaction and chemical composition changes in synthesized bio-plastics. Spectra of bio-plastics synthesized from banana peels were recorded.

4. Result And Discussion

In the present study bio-plastics were prepared from banana peel using plasticizers as glycerol and sorbitol etc. Also prepared bio-plastics were characterized by moisture content, absorption of water, swelling test, solubility, bio-degradability, thickness measurement, chemical resistance, flame test, Creep measurements and Fourier Transform Infrared Spectroscopy (FTIR).
The result of moisture content and absorption of water test is depicted in Table-1

Table-1 Moisture content and Absorption of water test

Sr. No.	Sample No.	Moisture content (%)	Water Absorption (%)
1	1	35.36	41.36
2	2	11.45	32.48
3	**Control-1**	5.38	69.72

Control-1, had the lowest moisture content while samples with glycerol had the higher and sample with sorbitol had the lower. A previous study explained that glycerol has hydroxyl groups that attracts water molecules forming hydrogen bonds and contain more water in the structure[15] while sorbitol forms substantial hydrogen bonds with the starch molecules, which bring down the affinity for water molecules.

In the test of water absorption, control -1 absorbed more water. This is because the hydroxyl group in starch attracts water molecules and gelatinization breaks starch granules, allowing water to diffuse. Previous studies show water absorption increases with more starch. Thus, adding plasticizer reduces water absorption.[16]. With glycerol had the highest absorption of water, followed sorbitol. Glycerol attracts water molecules more strongly than sorbitol.

The result of swelling test is depicted in Table-2.

Table-2 Swelling Test

Sample No.	Final weight of the sample in water (g)	Difference in weight (g)	Final weight of the sample in Chloroform (g)	Difference in weight (g)	Final weight of the sample in Methanol (g)	Difference in weight (g)
1	1.64	0.64	1.04	0.04	1.03	0.03
2	1.21	0.21	1.01	0.01	1.02	0.02
Control-1	1.00	0.00	1.00	0.00	1.00	0.00

When the bioplastic was soaked in organic solvents like chloroform and methanol, its weight changed narrowly. However, when soaked in water, it gained a little weight making it a more reliable material than other materials.

Bioplastics swell in water because they are hydrophilic in nature and water is polar, hydrogen bonding solvent so strong polymer-water interaction allowed water to enter and expand polymer size. Organic solvents like chloroform (non-polar) and methanol (less-polar) cannot form strong hydrogen bond with polymer.

The result of solubility in water and in alcohol depicted in Table-3

Table-3 Solubility in water and in alcohol

Sr. No.	**Sample No.**	**Solubility in water (%)**	**Solubility in alcohol (%)**
1	1	65.75	57.18
2	2	60.76	52.38
3	**Control-1**	48.39	46.95

From the above results we found that adding plasticizers increased the water solubility of all bioplastics. Starch molecules have a crystalline structure with hydrogen bonds, making starch granules insoluble in cold water[17]. Like water absorption, bioplastics with glycerol as a plasticizer showed the highest water solubility and lowest in samples with sorbitol. This can be explained with the fact that glycerol has a smaller molecular weight and attracts water more than sorbitol, making it easier for water molecules to enters easily into polymer chains.[18] Previous studies show that the type of plasticizer affects a bioplastic's water solubility.[19]

From the result of above study, adding plasticizers increased the alcohol solubility of all synthesized bioplastics. In existence of glycerol plasticizer, bioplastic samples had the elevated solubility in alcohol, and in presence of sorbitol plasticizer had the lesser solubility in alcohol and samples with glycerol and polyvinyl chloride had solubility levels between those with glycerol l and sorbitol. At room temperature, sorbitol is slightly soluble in alcohol but starch does not dissolve.[20]

The result of bio-degradability and thickness measurement is depicted in Table-4

Table-4 Bio-degradability and thickness measurement

Sr. No.	Sample No.	Bio-degradability (%)	thickness mm
1	1	71.59	0.03
2	2	60.52	0.05
3	**Control-1**	43.69	0.02

Physiochemical properties include chemical structure, molecular weight, water affinity, and surface area etc. of the bio-plastics determine their biodegradation ability.[21] Control-1 was observed to have the lowest biodegradation. Biodegradation of bioplastic samples increased. with the plasticizers. Also, biodegradation increased due to better water absorption and water absorption increased due to the water affinity of plasticizers like glycerol and sorbitol towards water. Bio-plastic samples with glycerol showed the highest biodegradation than sample with sorbitol.

Glycerol films are thicker due to higher moisture retention but less dense. Sorbitol films are usually thicker and denser because of their tight and crystalline structure. It makes stronger bio-plastics.The result of Chemical resistance is depicted in Table-5

Table-5 Chemical resistance measurement

Sample	Acid solubility	Base solubility
I	Yes	No
II	Yes	No
Control-I	Yes	No

Three bioplastic samples were tested to see how they resist acid and alkali. All the three samples broke down quickly in acid while it was not in alkali.

Flame Test: When the three bio-plastic samples were burned, they degraded without releasing harmful gases making them eco-friendly to environment. They burned like a regular paper.
The result of creep measurement is depicted in Table-6

Table-6 Creep Measurement

Sr. No.	Time (hours)	Strain (%)		Creep Rate (%/hrs.) = strain/time	
		Sample I	Sample II	Sample I	Sample II
1	0	0.00	0.00	--	----
2	1	0.15	0.10	0.15	0.10
3	24	0.22	0.18	0.0091	0.0075
4	48	0.35	0.25	0.0072	0.0052

Glycerol, a hydrophilic plasticizer, reduced intermolecular forces in the starch by forming hydrogen bonds with glucose chain, increasing chain mobility. This enhances flexibility but likely increases creep deformation under constant load, as the loosen structure allows polymer chains to slip more easily over time.

Sorbitol, with its stronger hydrogen bonding and lower hygroscopicity, creates a stiffer, more cohesive matrix. This reduces chain movement resulting in lower creep rates indicating better dimensional stability.

Table-7 IR Measurements

Sample No.	O-H stretching	C-H stretching	C=O stretching	C-O stretching	C-H deformation	C-C stretching
1	3380.7 cm^{-1}	2918.5 cm^{-1}	1710.8cm^{-1}	1162.9 cm^{-1}	1390.3cm^{-1}	872.1cm^{-1}
2	3291.2 cm^{-1}	2937.1cm^{-1}	1636.3cm^{-1}	1103.3cm^{-1}	1364.2cm^{-1}	861.0cm^{-1}

Broad peaks at 3380.7 cm^{-1} and 3291.2 cm^{-1} indicating hydrogen bonding, primarily from hydroxyl groups in starch (amylose and amylopectin), glycerol and sorbitol respectively. These peaks reflect the interaction between glycerol, sorbitol and the starch matrix, enhancing flexibility.[23]

Peaks at 2918.5 cm^{-1} and 2937.1cm^{-}1 are associated with C-H stretching vibrations from the aliphatic chains in starch, glycerol and sorbitol. This confirms the presence of organic components in the bio-plastics.[24]

Peak at 1710.8 cm^{-1} and 1636.3cm^{-1} indicates carbonyl groups, often from residual organic acids or ester linkages formed during processing. This can also reflect interactions between starch, glycerol and sorbitol.

Peaks in the range at 1162.9 cm^{-1} and 1103.3$cm^{-1}$are associated with C-O stretching in starch, glycerol and sorbitol indicating the polysaccharide backbone and plasticizer integration, confirming C-O stretching in the starch-glycerol and starch-sorbitol matrix.

5.CONCLUSION

This research is significant because it uses agro-waste, like banana peel to create valuable materials. FTIR analysis showed the presence of functional groups, confirming no harmful substances are in the material, making it environmentally safe. The carboxylic acid in the material suggests potential uses in pharmaceuticals. Plasticizers added to the material make it more workable, while pectin and cellulosic fibers provide strength and ensure biodegradability, making it suitable for short-term packaging.

Although promising, the material needs further improvements, especially to make it more water-resistant. Using banana peel as waste to produce bioplastic is an effective way to address fruit waste disposal and promote sustainable resource use.

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