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Characterization and optimization studies of cellulose-based bioplastics extracted from *Musa paradisiaca* L.

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Graphical abstract

Abstract

In recent past, attentions are towards preserving and restoring the resources of environment in terms of development of new products of environmental safety, therefore utilization of vegetable fibres, extracts from stem, leaves, fruits and roots for the production of biopolymers / improving mechanical properties/ recovery byproducts etc. are recently incorporated as reinforcing elements. Cellulose, a linear chain of molecular rings of glucose linked through covalent bond (C1 oxygen to glucose of a ring and ring adjacent C4) is an abundant polymer in nature from plants and it is advantageous in biodegradability, non toxicity, inexpensive, thermal stability etc. and has potential applications. Cellulose due to its poor solubility has a wide range of applications in packing, upholstery, coating, netting etc. and cellulose derivatives are tailored for specific industrial applications. The present investigation was concentrated to produced cellulose from banana pseudostem and characterized the nature of cellulose extracted and optimization studies for production of bioplastics from *Musa paradisiaca* L.

Keywords: Cellulose, pseudostem, FTIR, biopolymer, water absorption, solubility, optimization, bioplastic, thermal stability, vermicompost, cow dung, biodegradability.

1. Introduction

In recent past, plastic production and disposal has become a threatening widespread thought globally. It is estimated that World plastic production exceeded 367 million tones in 2020 and it was about 90% average increase since 1950 (Jambeck *et al.* 2021) and about 12.7 million metric tones of plastic enters the ocean (out of which 10% are ababdoned, lost or discarded fishing gears) and 5 trillon plastic materials enter in the World surface waters (Eriksen *et al.* 2014). It has been estimated that globally riverine system has contributed plastics ranging from 1.15 and 2.41 million tones out of which 86% from Asia, 7.81 from Africa, 4.8% South America and 1% from Europe, Australia, Central and North America, respectively (Lebreton *et al.* 2017; Ritchie and Roser 2018) wherein out of total plastics discarded 7% is recycled, 8% incinerated as residual landfilled (Müller *et al.* 2012). Plastics are monomeric repeating unit polymer (MW 1000 to 10,000 range) and they are conventional petroleum based materials formed from crude oil distillation (Ghada *et al.* 2021; Brydson 1999; Crawford 1998; Kuhn 2007; Buis 2019). The plastic materials are non biodegradable and on conversion produce CO_2 and greenhouse gases contributing environmental pollution and global warming (Saleh 2013; Armand 1994; Kjeldsen 2018). The factors influencing the non biodegradability of plastics are (i) high degree of crystallinity (ii) high hydrophobicity (iii) high molecular weight (iv) linearity of polymeric carbon such as mobility, functional groups etc (Babu *et al.* 2013; Muthukumar *et al.* 2015; Tokiwa 2009). A homogenous cellulose-chitson slurry was demonstrated by *in situ* regenaration from *Musa paradisica* Linn., *Hibiscus rosasinensis* and *Mangifera indica* which exhibited high mechanical properties (Dilip *et al.* 2023). Bioplastics have lower energy cost during manufacturing and it is noteworthy that the bioplastics produced from bio-polymers are a renewable and sustainable alternative to petrochemical based plastics and the comparative advantages are listed in the Table 1.

Kayserilioglu *et al.* 2008 produced bioplastics from orange peels (due to the high cellulose content and wide availability) with glycerol as a plasticizer and resulted in bioplastic material with excellent strength, flexibility and disintegration in soiling conditions, rough morphological surface. Liao *et al.* 2020 produced bioplastic from jackfruit seed starch reinforced with microcrystalline cellulose (MCC) cocoa pod husk using glycerol as plasticizer and investigation was carried out to determine the most

optimum mass and volume of MCC and glycerol in producing bioplastics which resulted in a form of rod-like shaped crystals (length 5-10 µm with diameter 11.6 nm and 74% crystallinity). Baiti *et al.* 2018 extracted cellulose from teak wood (*Tectona grandis*) biowaste where, the isolation process involved nitric acid, sodium hydroxide, sodium sulphite and bleaching with calcium hypochlorite to synthesize cellulose acetate (with acetic anhydride, toluene as a solvent, and sulphuric acid as a catalyst). Saxena *et al.* 2009 fabricated and characterizised biodegradable polymer with 40% rice husk waste filler 60% polymer containing mixture of polybutylene succinate (PBS) and poly butylenes adipate-Co-terephthalate (PBAT) with good mechanical properties and achieved 92% biodegradation in six months. Ezgi and Duygu, *et al.* 2019 produced bioplastics from potato peel (food industry waste) and analyzed for water absorption capacity and biodegradability tests which showed positive result within four weeks, where PPB biodegradation was about 71% in moist soil and 100% in vermicompost during the period of study. Bioplastics from other different sources are tabulated in the Table 2.

Table 1. Comparison between Bioplastics and Petro-plastics (Ying 2014)

Properties	Bioplastics	Petroplastics
Renewable resources	Yes and partially	No
Sustainable	Yes	No
Breakdown in the environment	Biodegradable and / or compostable	Some degradable by polymer oxidation
Polymer range	Limited but growing	Extensive
GHG emissions	Usually and, low	Relatively high
Fossil fuel message	Usually and low	Relatively high
Arable land usage	Currently	None

Table 2. Bioplastic from different agro waste sources

Material	Source material	References
Starch	Corn starch	Augustin *et al.* 2014
	Potato peels	Goswami *et al.* 2015
	Banana peels	Mohapatro *et al.* 2015; Aznury *et al.* 2019; Mohapatro *et al.* 2014
	Cassava	Souza *et al.* 2012
	Giant squid	Navarro *et al.* 2019
	Newspaper pulp	Rahmatiah *et al.* 2016
Cellulose	Rice straw	Bilo *et al.*2018
	Oil palm fruit bunch	Isroi *et al.* 2017
	Citrus waste	Batori *et al.* 2017
	Corn lead biomass	Sharif *et al.* 2018
	Banana peels	Ma *et al.* 2008
	Banana pseudostem	Bilo *et al.* 2021
Protein	Sorghum and Millet	Taylor *et al.* 2019
	Rapeseed oil	Delgado *et al.* 2018
	Oil palm mesocarp fibre	Anuar *et al.* 2019
Polylactic acid	Lactic acid	Reddy *et al.* 2013
	Waste paper	Joshi *et al.* 2015
	Corn starch / egg shell	Mohamad *et al.* 2022
	Prosopis juliflora	Kasirajan *et al.* 2019
Polydroxy butyrate	Water hyacinth	Walfathiyyah *et al.* 2019
	Ralstonia solanacearum	Macagnan *et al.* 2019
	Burkholderiasacchari	Al-Battashi *et al.* 2019
Starch and cellulose	Apple pomace	Gustafsson *et al.* 2019

Bioplastics are produced from renewable natural resources and hence are biodegradable in nature. These biopolymers undergo decomposition into CO_2, H_2O and inorganic compounds or biomass under natural conditions through the enzymatic action of microorganisms (Kumar and Thakur 2017). The schematic representation of classification of bioplastic is illustrated in the Figure 1. In the present investigation, cellulose was extracted from *Musa paradisiaca* L collected from Aarupadai Veedu campus (AV campus) and the cellulose was characterized and optimized during the present study.

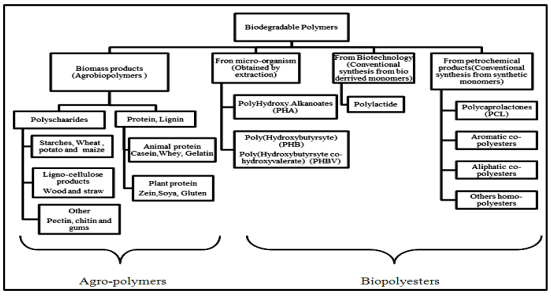


Figure 1. Schematic representation of classification of Bioplastic (Vilpoux *et al.* 2004)

2. Materials and methods

2.1. Raw material collection

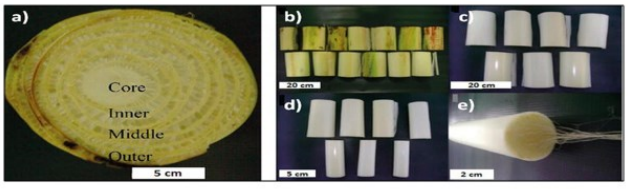
Diseased free plant (*Musa paradisiaca* L*)* was identified based on morphology characters and collected from AV Campus, Paiyanoor, Chennai. The common name of *Musa paradisiaca* L is banana and the pseudostem part of the selected plant is used as the raw material in the present investigation. Banana pseudostem is a waste biomass after fruit harvesting produced in large volume (since each plant bears fruit only once). The inedible parts, including pseudo-stems and leaves, representing about 88% of the weight of the whole plant (Reddy *et al.* 2013) and are discarded as wastes. China alone generates about 29.0 million tons per year of banana stalk residues. The banana pseudo-stem has high cellulose fiber content (Guimaraes *et al.* 2019) underutilized cellulose resource for the production of bioplastics (Figures 2-4)

Taxonomic classification of *Musa paradisiaca L*

Kingdom	Plantae
Order	Zingiberales
Family	Musaceae
Genus	*Musa*
Species	*paradisiaca*

Figure 2. Musa paradisiaca L of AV campus

Figure 3. Musa paradisiaca L pseudostem



a) 5cm pieces b)20cm outer layer pieces c) 20cm inner layer pieces d) 5cm pieces e) 2cm pieces

Figure 4. Musa paradisiaca pseudostem pieces classification

2.2. Sample preparation

The pseudostem of *Musa paradisiaca* L were cut into small pieces and were washed thoroughly multiple times with tap water and distilled water to remove all the dust, dirt and impurities, followed by shed drying the pieces for 5 days. After 5 days the dried pseudostem pieces were collected and stored in sterilized airtight container to prevent contamination and contact from moisture (Vilpoux *et al.* 2004).

2.3. Alkalization

Ten grams of dried pseudostem sample was measured and soaked in 15% NaOH for 48 hours in order to release the external components from the sample. The resulting pseudostem was soaked in 1% NaOH at 60 °C for 2 hours in a water bath. This removes the lignin and lipid components from the sample. The sample is then filtered to remove the NaOH solution and the obtained sample is said to be delignified. The delignified sample was then washed with distilled water multiple times to remove the alkali and neutralize the alkaline sample, until pH 7 was attained (Ergun 2016).

2.4. Bleaching

The delignified and neutralized pseudostem sample was bleached by soaking them in 4:1 hydrogen peroxide:acetic acid solution followed by treatment at 60 °C for 1 hour in a water bath. Through bleaching, all the pigments are removed and the sample is decolourized. The bleached sample was neutralized by multiple washing with distilled water until pH 7 was attained (Tan *et al.* 2016).

2.5. Acid hydrolysis

The bleached and neutralized sample was treated with 5M HCl at 60 °C for 30 minutes in a water bath. The obtained sample is said to be acid hydrolysed. This sample is then neutralized to pH 7 by washing with distilled water several times (Chen *et al.* 2009).

2.6. Dehydration

The cellulose fibres obtained are kept in a dessicator for dehydration process upto 5 days to 1 week to remove the moisture content from the cellulose fibers and powder form of cellulose were obtained (Delgado *et al.* 2018).

2.7. Characterization Studies of Cellulose:

Various qualitative and solubility tests were performed as per Chen *et al.* 2009 and Keyserilinglu *et al.* 2003, respectively during the period of study. FTIR study was performed to confirm quantitatively for the functional groups in the extracted cellulose.

2.8. Optimization studies of Cellulose based Bioplastic production from Musa paradisiaca L

Optimization is the method of finding the best suitable values of the concentration of the components present in a mixture or solution. Optimization is carried out by considering a basic ratio of cellulose : plasticizer, taken from review of literature. The closely related successive values were checked in three possible ways: i) keeping both cellulose and plasticizer ratio constant for a range of % concentration in percentage (10:10, 11:11, 12:12, 13:13,

14:14, 15:15, 16:16, 17;17, 18:18, 19:19 and 20:20) ii) keeping plasticizer concentration constant while varying the cellulose concentration varying for a range of values % (10:15, 11:15, 12:15, 13:15, 14:15 and 15:15) and iii) keeping the cellulose concentration constant and varying the plasticizer concentration for a range of % concentrations (15:10, 15:11, 15:12, 15:13, 15:14 and 15:15) (Jean *et al.* 2009).

2.9. Casting of cellulose based bioplastic

As determined from the optimization, 15%:15% of cellulose:plasticizer is the optimum concentration for the casting solution. The following steps are performed to prepare the casting solution for the synthesis of bioplastic film:

- 100ml of water is taken in a beaker.
- The beaker is kept on a hot oven plate and the temperature is kept at 100°C (Isroi *et al.* 2017).
- When the water starts boiling, 15% cellulose powder is poured into the hot water and stirred well in order to make sure that there is no formation of cellulose powder chunks, followed by 1% agarose.
- As the cellulose dissolves completely, take the beaker off the hot plate and transfer it on a magnetic stirrer with hot plate.
- The magnetic pellet is introduced into the beaker and rotation is set to the maximum point.
- 15% plasticizer is poured slowly into the cellulose solution.
- The magnetic stirring is continued with temperature maintained at 100 °C and this process is continued for gelatinization till the solution becomes slightly translucent and attains a gel like matrix appearance. This state is known as the gelatinized state (Hayatun *et al.* 2020).
- Once the solution attains such characteristics, it is allowed to cool for 10 minutes at room temperature.
- The solution is poured onto a casting plate or petri plate and kept for about 3 days for drying.
- After complete drying, the formed bioplastic film is peeled of carefully and kept for 1 day at room temperature for further drying.

2.10. Thickness

The thickness of the film was measured using an Air Wedge Shearing Interferometer. It is the simplest type of interferometer designed to visualize the disturbance of the wave front after propagation through a test object. This interferometer is based on utilizing a thin wedged air-gap between two optical glass surfaces and can be used with virtually any light source even with non-coherent white light.

3. Characterization studies of cellulose based bioplastic

The prepared biodegradable plastic film was studied for various qualitative and quantitative characterization studies: (i) Moisture content (ii) Water absorption (iii) Solubility in water (iv) Solubility in alcohol (v) Biodegradability test (vi) FTIR (vii) Thickness

3.1 *Moisture content*

Cellulose based plastic sample was weighed to calculate the initial weight (W1). The sample was dried in an oven at 85°C for 24 hours. The sample was weighed once again to measure the final weight (W2) after drying. The moisture content was then determined using the following formula (Sharif *et al.* 2018)

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

3.2 *Water absorption*

Water absorption rate of the Cellulose based bioplastic was estimated from the little modified ASTM D570-98 method. Biodegrradable plastic sample was first dried at room temperature for 24 hours to allow measuring its dry weight (W1), followed by placing them in beaker of 50 ml distilled water at room temperature for 24 hours. After 24 hours the sample was obtained by filtering the water, and then its weight was measured to find its final weight (W2). The absorption of water was found using the given formula (Shahzadi *et al.* 2014).

$$\text{Water absorption (\%)} = \{(W2 - W1)/W1\} \times 100$$

3.3 *Solubility in water*

The Cellulose based bioplastic sample was first dried in oven at 85 °C for 24 hours to measure its dry weight (W1), followed by placing in a beaker of 50 ml distilled water at room temperature for 24 hours. After 24 hours the sample residue was obtained by filtering the water and again dried at room temperature for 24 hours and then weighed to calculate the final weight (W2). The solubility was found using the following formula (Sharif *et al.* 2018)

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

3.4 *Solubility in alcohol*

The biodegradable plastic sample was first dried in oven at 85 °C for 24 hours to measure its dry weight (W1), followed by placing it in 3 ml ethanol in test tubes with caps at room temperature for 24 hours, after which the sample residue was obtained by filtering the water and again dried at room temperature for 24 hours and then weighed to find the final weight (W2). The solubility in alcohol was found using the following formula (Sharif *et al.* 2018)

$$\text{Solubility in alcohol (\%)} = \{(w1 - w2)/w1\} \times 100$$

3.5 *Fourier-Transform Infrared Spectroscopy (FTIR)*

FT-IR technique was utilized to out the functional groups present in the bioplastic samples, using 4000–650 cm wave number range and 2 cm1 resolution. Beam splitter: Germanium-coated KBr for Middle IR (Standard). The spectrum data in graphic form was analyzed in results.

3.6 *Biodegradability test*

The biodegradable plastic samples were weighed to measure the initial weight (W1). The samples were buried

under 2 cm of 4 different types of soil along with different combinations contained in Styrofoam cups and kept for 5 days at room temperature. The set ups were as follows:

i) Garden soil
ii) Vermicompost
iii) Cow dung
iv) Crop field soil
v) Garden soil + Vermicompost
vi) Vermicompost + Cow dung
vii) Garden soil + Cow dung

The soils were kept moist for 9 days, after which the sample residues were collected from the soil, followed by washing with water and drying at room temperature for 24 hours and then again weighed to measure the final weight (W2). The biodegradability was measured from the following formula (Tan *et al.* 2016)

$$\text{Biodegradability (\%)} = \{(W1 - W2)/W1\} \times 100$$

4. Results and discussion

The pseudostem of *Musa paradisiaca* L were cut into small pieces, dried and powered for further investigations. Ten grams of dried pseudostem sample was measured and soaked in 15% NaOH for 48 hours in order to release the external components from the sample. The resulting pseudostem was soaked in 1% NaOH at 60 °C for 2 hours in a water bath to remove lignin and lipid components from the sample. The sample is the filtered to remove the NaOH solution and the delignified sample was then washed with distilled water several times to remove the alkali and neutralized the alkaline sample, until pH 7 was attained (Ergun 2016). The results are represented in Figures 5 and 6.

Figures 5 and 6. Powdered pseudostem sample soaked in 15% NaOH solution for 48 hours and treated at 60°C for 2 hours in a water bath *and* Delignified sample treated in H_2O_2: CH_3COOH (4:1) at 60°C for 1 hour

The delignified and neutralized pseudostem sample was bleached by soaking them in 4:1 hydrogen peroxide:acetic acid solution followed by treatment at 60 °C for 1 hour in a water bath. Through bleaching, all the pigments are removed and the sample is decolourized. The bleached sample was neutralized by multiple washing with distilled water until pH 7 was attained as per Tan *et al.* 2016.

The bleached and neutralized sample was treated with 5M HCl at 60 °C for 30 minutes in a water bath. The obtained sample is said to be acid hydrolysed. This sample is then neutralized to pH 7 by washing with distilled water several times as per standard methods of Cheb *et al.* 2009. The cellulose fibres obtained are kept in a dessicator for dehydration process upto 5 days to 1 week to remove the moisture content from the cellulose fibers and powder form of cellulose were obtained Dobele *et al.* 1999.

4.1 Qualitative analysis of cellulose

Various qualitative tests were performed to confirm the presence of cellulose Chen *et al.* 2009 (Table 3).

Table 3. Qualitative tests for the presence of cellulose

TEST	OBSERVATION	INFERENCE
SOLUBILITY TEST		
1g cellulose powder dissolved in 10ml water	Cellulose is insoluble in water	The obtained powder compound is cellulose
IODINE POTASSIUM IODIDE TEST		
1g cellulose powder is dissolved in 10ml iodine potassium iodide solution	No change in colour was observed	Cellulose do not produce any colour with iodine potassium iodide solution
IODINE TEST		
1g cellulose powder is dissolved in 5ml 5% sulphuric acid and allowed to stand for 2 to 3 minutes followed by addition of 5ml iodine solution	Blue colour appeared and cellulose is dissolved in sulphuric acid	Cellulose is present
ACIDIFIED IODINE POTASSIUM IODIDE TEST		
1g cellulose powder was dissolved in 5ml iodine potassium iodide and 5ml concentrated sulphuric acid	Violet colour appeared	Cellulose is present
ZINC CHLORIDE TEST		
1g cellulose powder was dissolved in 10ml iodinated zinc chloride solution in the presence of 1 drop of iodine and 1 drop of sulphuric acid	Deep blue colour appeared	Presence of cellulose was confirmed

4.2 Solubility test of cellulose

Table 4. Solubility test of cellulose (Kayserilioglu et al. 2003)

SOLVENT	PHYSICAL APPEARANCE	SOLUBILITY
Distilled water	No change	Insoluble
Water (pH 5)	Partial milky appearance	Partially soluble
Water (pH 10)	Milky appearance	Soluble
Water at 100 °C	Milky appearance	Soluble
Ethanol	Partial milky appearance	Partially soluble
Acetone	No change	Partially soluble

4.3 Quantitative analysis of cellulose

Fourier Transform Infrared Spectroscopy (FTIR) was performed and showed the following result (Figure 7).

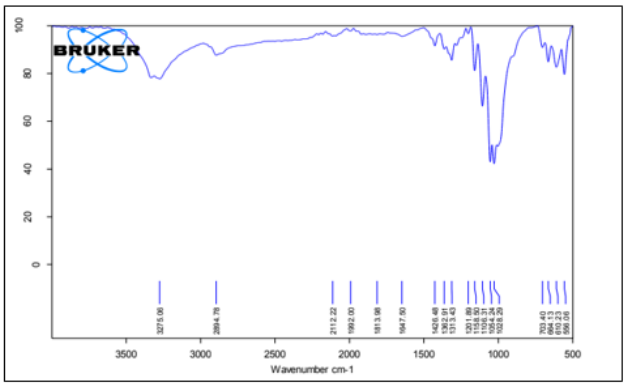


Figure 7: FTIR results of cellulose extracted from *Musa paradisiaca* L

Table 5. FTIR results of extracted cellulose from *Musa paradisiaca* L

Absorption (cm^{-1})	Appearance	Group	Class of compound
2894.78	Strong broad	N-H stretching	Amine salt
2112.22	Weak	C≡C stretching	Alkyne
1992.00	Medium	C=C=C stretching	Allene
1647.50	Medium	C=N stretching	Oxime
1426.48	Medium	O-H bending	Carboxyllic Acid
1362.91	Medium	O-H bending	Phenol
1313.43	Strong	S=O stretch	Sulfone
1201.89	Strong	C-O stretching	Vinyl Ether
1158.50	Strong	C-O stretching	Aliphatic Ether
1106.31	Strong	C-O stretching	Secondary Alcohol
1054.24	Strong broad	CO-O-CO stretching	Anhydrid
703.40	Strong	C=C bending	Alkene
664.13	Strong	C-Br stretching	Halo Compound
610.23	Strong	C-Br stretching	Halo Compound
556.06	Strong	C-I stretching	Halo Compound

5. Optimization studies of cellulose based bioplastic from *Musa paradisiaca* l

Three different optimization studies for the production of cellulose based bioplastic were conducted with varying concentrations of cellulose and plasticizers in 1:1 ratio (Table 6), with varied concentrations of cellulose and 15% constant concentration of plasticizer (Table 7) and with varied concentrations of plasticizer and 15% constant concentration of cellulose (Table 8). In all the optimization studies the concentration at 15% of both cellulose and plasticizer proved to be perfect bioplastic film after casting during the period of study and the results are tabulated in the Tables 6-8. The degree of polymerization of cellulose is higher than 10,000 units of anhydroglucose, though it may differ based on the botanical sources. The properties of cellulose like mechanical resistance and reduced water interaction are due to the arrangement of repeating units of monomers. The polysaccharide chains interacting through hydrogen and hydrophobic bonds, via monomers of glucose, resulted in a confirmation of planar sheets (Liao *et al.* 2020).

5.1. Casting of cellulose based bioplastic

After optimization of cellulose based bioplastic at 15:15 ratio of cellulose and plasticizer as per standard protocol nd the solution waspoured into a casting plate with carefulprecautions. The plate was kept for dryng for three days and the bioplastic film was carefully peeled off for further investigations (Isroi *et al.* 2017). The casted bioplastic is represented in the Figure 8

Figure 8. Casting of bioplastic after optimization

Table 6. Optimization studies 1 with 1:1 ratio of cellulose and plasticizer

Sl no.	Concentration of cellulose	Concentration of plasticizer	Result
1	10%	10%	Unstable bioplastic film
2	11%	11%	Unstable bioplastic film
3	12%	12%	Unstable bioplastic film
4	13%	13%	Fragile bioplastic film
5	14%	14%	Fragile bioplastic film
6	15%	15%	Perfect bioplastic film
7	16%	16%	Cracks on surface of film
8	17%	17%	Cracks on surface of film
9	18%	18%	Bubbled appearance film
10	19%	19%	Unstable bioplastic film
11	20%	20%	Fragile bioplastic film

Table 7. Optimization studies II with varied concentrations of cellulose and constant concentration of plasticizer

Sl no.	Concentration of cellulose	Concentration of plasticizer	Result
1	10%	15%	Sticky bioplastic film
2	11%	15%	Unstable bioplastic film
3	12%	15%	Fragile bioplastic film
4	13%	15%	Fragile bioplastic film
5	14%	15%	Cracks on bioplastic film
6	15%	15%	Perfect bioplastic film

Table 8. Optimization studies III with varied concentrations of plasticizer and constant concentration of cellulose

Sl no.	Concentration of cellulose	Concentration of plasticizer	Result
1	15%	10%	Cracks on bioplastic film
2	15%	11%	Fragile bioplastic film
3	15%	12%	Unstable bioplastic film
4	15%	13%	Sticky bioplastic film
5	15%	14%	Sticky bioplastic film
6	15%	15%	Perfect bioplastic film

5.2. Thickness

The thickness of cellulose based bioplastic was measured using Air Wedge Shearing Interferometer as per standard procedure (Figure 9). The thickness of the film was calculated to be 0.16mm.

Figure 9. Measurement of thickness of bioplastics by Air Wedge Shearing Interferometer

5.3. Characterization Studies of cellulose based bioplastic

5.4. Moisture content studies of bioplastic

The casted cellulose based bioplastics was subjected to calculate the moisture content as per standard procedure od Sharif *et al.* 2018. According to the formula for calculating the moisture content (Sanyang *et al.* 2016) of the bioplastic film, it was found to have a moisture content of 40%, which was quite favourable as most part of the solution used, contained water and also it has been explained in previous chapters that the plasticizer used being a glycerol derivative, contains hydroxyl groups, which have an affinity for water molecules that allow them to contain water in the structure and the same results were also observed by Mohan *et al.* 2016.

5.5. Water absorption studies of bioplastic

According to the formula (Shafqat *et al.* 2021) the water absorption capacity of the final product was calculated as per the protocol. The percentage of absorption of water by the bioplastic film was calculated to be 25%, which is due to the fact that the hydroxyl group in cellulose has an affinity for water molecules and the gelatinization property also diffused water molecules (Azahari *et al.* 2011). Addition of plasticizer also increased the absorption of water to a certain extent since glycerol molecules also has an affinity for water molecules.

5.6. Water solubility studies of bioplastic

The casted cellulose based bioplastic was subjected for solubility in water by heating at 85°C followed by soaking in distilled water and subsequent drying after 24 hours using the formula of Sharif *et al.* 2018, the percentage of solubility in water was found to be 2% during the period of study. This can be explicated by the characteristic of cellulose molecules consisting of hydrogen bonds, being insoluble in water. The plasticizer also contributes to such properties which have also been shown by previous studies of Chiumarelli and Hubinger 2014.

5.7. Organic solvent solubility studies of bioplastic

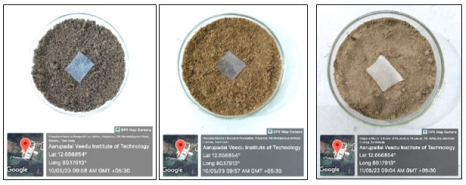
The casted cellulose based bioplastic was subjected for solubility in organic solvents by heating at 85°C followed by soaking in organic solvents such as ethanol, methanol, ethyl acetate, petroleum ether, chloroform and subsequent drying after 24 hours using the formula of Sharif *et al.* 2018 during the period of study. According to the formula the solubility cellulose based bioplastic in different organic solvents were found to be 8% in ethanol, 8% in ethyl acetate, 6% in methanol, 10% in petroleum ether and 8% in chloroform, respectively. Following the trend of moisture content, water absorption and water solubility of final bioplastic film, was also seen to be within 10% in case of solubility in organic solvents which is due to the insolubility of cellulose in organic solvents as reported by (Chen *et al.* 2015).

Table 9. Biodegrability studies of bioplastic produced from cellulose extracted from *Musa paradisicae L*

S.No.	Soil composition	% of Biodegradability (seventh day)
1	Garden soil	49.57
2	Vermi compost	59.11
3	Cow dung	54.16
4	Crop field	50.48
5	Garden soil + vermin compost	54.57
6	Vermi compost + cow dung	54.06
7	Garden soil + cow dung	50.43

5.8. Biodegrability studies

Biodegradability test was carried out with the final product (cellulose based bioplastic) for seven days with various types of soils and fertilizers (individually and in combinations – 50:50 ratios) such as garden soil, vermin compost, cow dung, crop field soil as incividual and in combinations of garden soil + vermin compost, vermi compost + cow dung and garden soil + cow dung in the period of study according to Tan *et al.* 2016 and the percentage of biodegradability results are listed in the Table 9. The highest biodegradability was registered in the vermicompost and in combinations with different soils during the period of study. It was observed that almost 50% of degradability occurred with 7 days (Figures 10 a-d and 11 a-d) in all the tested soils and in combinations which proves that the cellulose based bioplastic will be eco friendly to use. Cellulose bioplastics including cellulose acetate and nitrocellulose are thermoplastics, compostable, biodegradable plastics (Song 2019; Yaradoddi *et al.* 2019). Biologically based polymers easily decomposes naturally whereas biodegradable polymers needs a physical support like anaerobic digester or composting unit (to break down the organic material into simpler forms) and further these substances need strict controlled environmental factors for degradation (Andrady *et al.* 2009; Muniyasamy *et al.* 2021)



a) Vermi compost b) garden soil c) cow dung d) crop field soil

Figure 10. a-d Zeroth day of cellulose based bioplastic in different soils and fertilizers

a) Vermi compost b) Garden soil c) cow dung d) crop field soil

Figure 11. a-d Seventh day degradation results of cellulose based bioplastic in different soils and fertilizers

6. Conclusion

The introduction of bioplastics in the society gradually reduces the dependence on fossil resources while at the same time improving the carbon footprint of the product. This solves the problem of fast depletion of fossil fuels as well as environmental pollution. Currently, the packaging industry is the largest user and consumer of bioplastics. Increased use of bioplastics impacts the resource efficiency by increasing it as well as contributing to a more circular economy. With respect to the farmers, bioplastics on being decomposed aids in stabilizing the temperature of the roots, preserve soil nutrients and moisture in addition to improving the stable development of the plantation.

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