The University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

A Comprehensive Study of Sustainable and Biodegradable Bioplastic Production, Characterisation, and Decomposition

Subashish Maity[1,2] | Ayantika Santra[1] | Gouthami Kuruvalli[1] | Deepika Shekhawat[1] | Ananda Vardhan Hebbani[3] | Althaf Hussain Shaik[4] | Vaddi Damodara Reddy[1]✉

1. Department of Biotechnology, REVA University, Bengaluru-560064, Karnataka, India
2. DR Biosciences, Research and Development Unit, Bettahalasur, Bangalore-562157, India
3. Department of Biochemistry, Indian Academy Degree College, Bengaluru-560 043, India
4. Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia

Article Info

Article type:
Research Article

Article history:
Received: 23 November 2024
Revised: 29 March 2025
Accepted: 6 September 2025

Keywords:
Bioplastic
FTIR
SEM analysis
XRD
TGA

ABSTRACT

The increased quantities of thermoplastics in the ecosystem have incurred several issues related to our planet's health. This includes the threats to the lives of aquatic and terrestrial animals. Conventional plastics are non-degradable and thus remain in the soil for ages, ultimately hampering the quality of the soil. This study aims to develop an efficient biobased plastic using basil seeds, sago dana, and arrowroot powder. Bioplastic was prepared using the solvent casting method using arrowroot powder and glycerol. The prepared bioplastic showed maximum tensile strength, characterized by SEM, X-ray diffraction, FT-IR, and TGA techniques for verifying bonding, structure, and degradation. Results showed that the complete degradation of biobased plastic is observed in both soil and bacteria, which is further confirmed by the SEM analysis. In conclusion, our study reveals that the production and application of bioplastics might act as an alternative to the existing plastics and can curb the tremendous pollution caused by conventional plastics.

Cite this article: Maity, S., Santra, A., Kuruvalli, G., Shekhawat, D., Vardhan Hebbani, A., Hussain Shaik, A., & Damodara Reddy, V. (2025). A Comprehensive Study of Sustainable and Biodegradable Bioplastic Production, Characterisation, and Decomposition. *Pollution*, 11(4), 1031-1041.
https://doi.org/10.22059/poll.2025.385722.2664

DOI: https://doi.org/10.22059/poll.2025.385722.2664

INTRODUCTION

Utilizing plastic is very prominent in the day-to-day life for every individual. The ubiquitous use of plastics, due to the very reason of cheap price and has single-time use, rigorously leads to huge plastic pollution in the environment (Pooja et al.2023). Plastic pollution not only harms the soil degradation process but also contributes to water pollution. An estimated amount of nearly 8 million tons of plastic is being discarded into the ocean worldwide through the coastal region, further causing a serious threat to the aquatic creatures. When the plastics are discarded into water bodies, they get entangled over the coral reefs and around the fins of turtles and whales, which makes them unable to swim around. Often the plastics are consumed by the aquatic animals, which get clogged in their food pipes, stomach, and nostrils, leading to painful deaths. The chain of plastic pollution continues further as the aquatic animals are consumed by the big fishes, followed by humans. Consumption of plastic materials by the large aquatic mammals might block the intestines of the animals (Li et al. 2021). The stable carbon-hydrogen bond and the large complex polymeric structure remain for a longer period of time on the land as well as in the ocean environment. Thus, natural decomposing would not be effective, and burning the plastics

*Corresponding Author Email: *vdp_1975@yahoo.co.in*

for management leads to an enormous amount of smoke and hazardous gases in the atmosphere, leading to air pollution. (Verma et al. 2016).

Bioplastics, among all other initiatives, have been proved to be biodegradable and environmentally sustainable (Atiwesh et al. 2021; Shanmathy et al. 2021; Liu et al. 2020). In this era of scientific research, where sustainable development goals are fixed by the United Nations for the benefit of the people and planet, the idea of producing cost-effective, non-hazardous bioplastics aligns directly with SDGs 12, 14, and 15, where responsible consumption and production as well as life below water bodies and land are focused.

Therefore, the aims of this research are to formulate an efficient bio based plastic utilizing natural materials like basil seeds, sago dana, and arrowroot powder as a substitute for traditional plastics. Moreover, the research aims to assess the physical, mechanical, and thermal characteristics of the created biobased plastic, along with its degradation behavior in soil and bacterial environments. In addition, the study intends to compare the environmental sustainability of the biobased plastic with that of conventional plastics and investigate its potential uses across various sectors, including packaging, agriculture, and textiles.

MATERIALS AND METHODOLOGY

Materials Used

Basil seeds, sago, arrowroot powder, and vinegar were purchased from a local supermarket in Bangalore, Karnataka, India. Glycerol and distilled water were obtained from the lab of IADC-A, Bangalore, India. Other chemicals and solvents used in the studies are of high purity.

Pre-preparation technique

The basil seeds were soaked in water overnight. The next morning, the soaked basil seeds were ground well and made into a paste by adding 20ml of distilled water. The same procedure was repeated with sago to obtain a paste of sago and water. The arrowroot powder used in the preparation of the edible bioplastic was purchased. The instant form of vinegar purchased was incorporated during the bioplastic preparation.

Sample preparation

The edible bioplastic preparation is carried out by the solvent casting technique. All the bio-based raw materials (basil seeds, sago, arrowroot) were individually taken in a suspension pan to which 30mL distilled water, vinegar and 10 mL glycerol was added. It was assured that no clumps were formed and the mixture was finely stirred until semi-solid textured slurry was obtained. The mixture was heated for 5 mins at 100˚C, followed by a constant stirring with the help of a spoon. The mixture was then uniformly transferred on an aluminium foil spread on a tray and sprayed evenly. This step was carried out to obtain appropriate thickness and shape. The tray was then placed in the hot air oven at 45˚C for 2h followed by cooling it down to room temperature overnight. Once cooled, the bioplastic was carefully removed from the aluminium foil and analysed for physical and chemical characteristics.

Characterization of the Prepared Bioplastic

Solubility: Solubility of the bioplastic was assessed to analyze the ability of water to leach the contents of bioplastic. The synthesized bioplastic (2cm x 2cm) was cut and soaked into warm water in a test tube placed in hot water bath to estimate the solubility of the bioplastic. The water-soluble content percentage was calculated by the equation below:

$$Percentage\,of\,Water\,Soluble\,Content = \frac{w_i - w_f}{w_i} \times 100$$

Whereas w_i is initial weight and w_f is final weight after water extraction.

Thickness: The thickness of the bioplastic film was measured using micrometer screw gauge. The bioplastic was cut in 2 cm x 2 cm size and used for recording the thickness. The thickness was measured 15 times at various points of the selected film of bioplastic and the average value was calculated using the following equation:

$$Thickness = \frac{Total\ of\ the\ measured\ thickness\ value}{15}$$

Biodegradability Test of the Bioplastic

The degradability of the bioplastic was determined via two ways explained as follows:

Bacterial Degradation: The bio-based plastic was checked for degradation study in batch culture. Bioplastic pieces were cut into small pieces of 2cm X 2cm and inoculated in medium containing *E. coli*. The medium containing bioplastics and bacterium was further inoculated at 37˚C for 20 days. The weight of the bioplastic was measured after interval of every 4 days. Similar experiment was also conducted using thermoplastic to compare between the degradability capacity between the two types of plastics. The percentage of biodegradability was calculated using the equation provided below:

$$Percentage\ of\ Biodegradation = \frac{W_0 - W_f}{W_0} \times 100$$

Where, W_0 indicates the weight of the plastic at 0^{th} time before the inoculation with the bacterium and W_f represents the weight of the plastics after the experiment. The biodegradation study was conducted in triplicates.

Soil Degradation: The ability of the bio-based plastic and thermoplastic to be degraded in soil was checked in a garden plot of 15cm x 15cm. Plastics of known weight was added and covered under the soil at a depth of 3-5 cm. The soil was damped using distilled water for maintaining the moist state. The plastic samples were removed from the soil after regular intervals and weighed for determining the degradation rate of the plastics.

Mechanical Strength

A tensile test was conducted to study the tensile properties of the bioplastic. A force transducer (model number: SAC Code 99834 Testing/Analysis-MTS UTM usage) with mild modification was used for carrying out the test. The film samples were cut into 15mm × 0.69mm in a rectangular shape with a grip separation of 50 mm and fixed onto the loading unit. The test was conducted with the speed of 18 18mm/min. The experiments were conducted in triplicate, and the resulting values were measured and documented (Krishnamurthy and Amritkumar 2019; Yaradoddi et al. 2022).

SEM

Biofilm samples were fixed using glutaraldehyde (3% wt.) in cacodylate buffer pH 7.2 and kept for 10 mins. Then the sample was exposed to ethanol gradients starting from 50% to 100%. For chemical dehydration, a series of 100% ethanol including hexamethyldisilazane (HMDS, Ted Pella, USA) from a 50% to 100% gradient and 2×100% HMDS for 5 mins at each conc. are simultaneously used. After drying for 24 hrs., the bare portions of biofilm were observed under an SEM/EDS system (FEI Quanta 400FEG ESEM/EDAX Genesis X4M, FEI Company, USA) at 15 kV. A total of seven images are taken from 8 different sides of the biofilm and analyzed before and after soil degradation and saved for bacterial degradation. To observe the morphology of bioplastic from a random site, the microscope software (xT Microscope Control, FEI Company, USA) is used (Gomes et al. 2017).

X-ray diffraction

The crystal structures of the edible films were investigated in CIIRC lab Bengaluru IV X-ray diffraction instrument. The scan speed was 10°/min using Cu Kα radiation with a test range from 5–40° (2θ). The X-ray generator had a tube current of 40 mA and an operating voltage of 40 kV (Matta et al. 2019).

Fourier Transform Infrared (FT-IR) Analysis

Fourier Transform Infrared (FT-IR) spectra were recorded using an infrared spectrum. Samples were synchronized into a thin pellet and analyzed by the wavelength of 1 cm. The infrared spectroscopy detects the vibration made by the compounds in the bio-based sample and helps in quick and definite identification of the compounds. The results are then recorded by using an IR beam (Matta et al. 2019).

Thermogravimetric Analysis (TGA)

TGA is a technique used to predict the thermal capability and volatility of the biobased bioplastic components. The thermal decomposition of samples was investigated by using Biofilm Detector: DTG-60. The weighed sample was heated, initiating from 37°C to 800.9°C. The sampling time was measured to be 1 min, maintaining the flow rate of 50 ml/min. The decomposition of bio-based plastic was recorded (Cai et al. 2019).

Statistical analysis

The data is from three independent experiments as explained in the methodology section. The data is shown as mean ± SD. A $p<0.05$ is considered as a statistically significant.

RESULTS AND DISCUSSION

Sample preparation

Basil seed 2.5gm, sago 1gm and arrowroot 1gm were taken as found to be appropriate in preparing the desired bioplastic as shown in Fig. 1 (a) Glycerol 10ml, vinegar 10ml and 30 ml distilled water was used to make the film compact in nature. Other compositions were shown fragile in nature in the dried condition and thus were not considered for further studies.

Solubility and Thickness

Toughness and withstanding load-bearing pressure are the primary properties recorded in bioplastic. Determination of thickness is one of the measures to predict the toughness of a material. The thickness of the bioplastic was measured by a screw gauge. After 15 trials of measurement, the average thickness of film was detected to be 0.68±0.03 mm and would be suitable for preparing plastic bags. The thickness of bioplastic depends on the additives that are added for the preparation. In previous studies, bioplastics produced using silica extracts of bamboo leaves were reported with thickness in the range of 0.26-0.32 mm (Oluwasina et al. 2021). Earlier studies related to preparation of bioplastic from starch sources reported the thickness of the plastic to be around 53-63 microns (Marichelvam et al. 2019). However, in this particular study, the thickness might be higher due to the utilization of starch from the sago. Determination of water solubility of bioplastics is very important to understand the field of application of the particular plastic. The bio-based materials, which are known for water or moisture susceptibility, are often not chosen as a packaging material. Thus, it is better to assess the water solubility of the prepared bioplastics. It also observed that the weight loss was almost 30% (weight before immersing in water 0.76gm and weight after treatment 0.52-0.53 gm) as represented in Fig. 1 (b). Another set of degradability tests was assessed at 120°C to 125°C for 25 min, where it was found that the film was fully dissolved in water. These experimental analyses hint that in excess heat the crosslinking between the crystals might break by hydrolyzation of the bonds. Glycerol in the composition of bioplastics helps in the permeability of water vapor (Moro et al. 2017).

Degradability Test

Biodegradability of plastics is a major concern in recent days. The bioplastic in this study is prepared using environmentally safe and biodegradable components and thus assessment of the biodegradation capacity of the bioplastic was carried out.

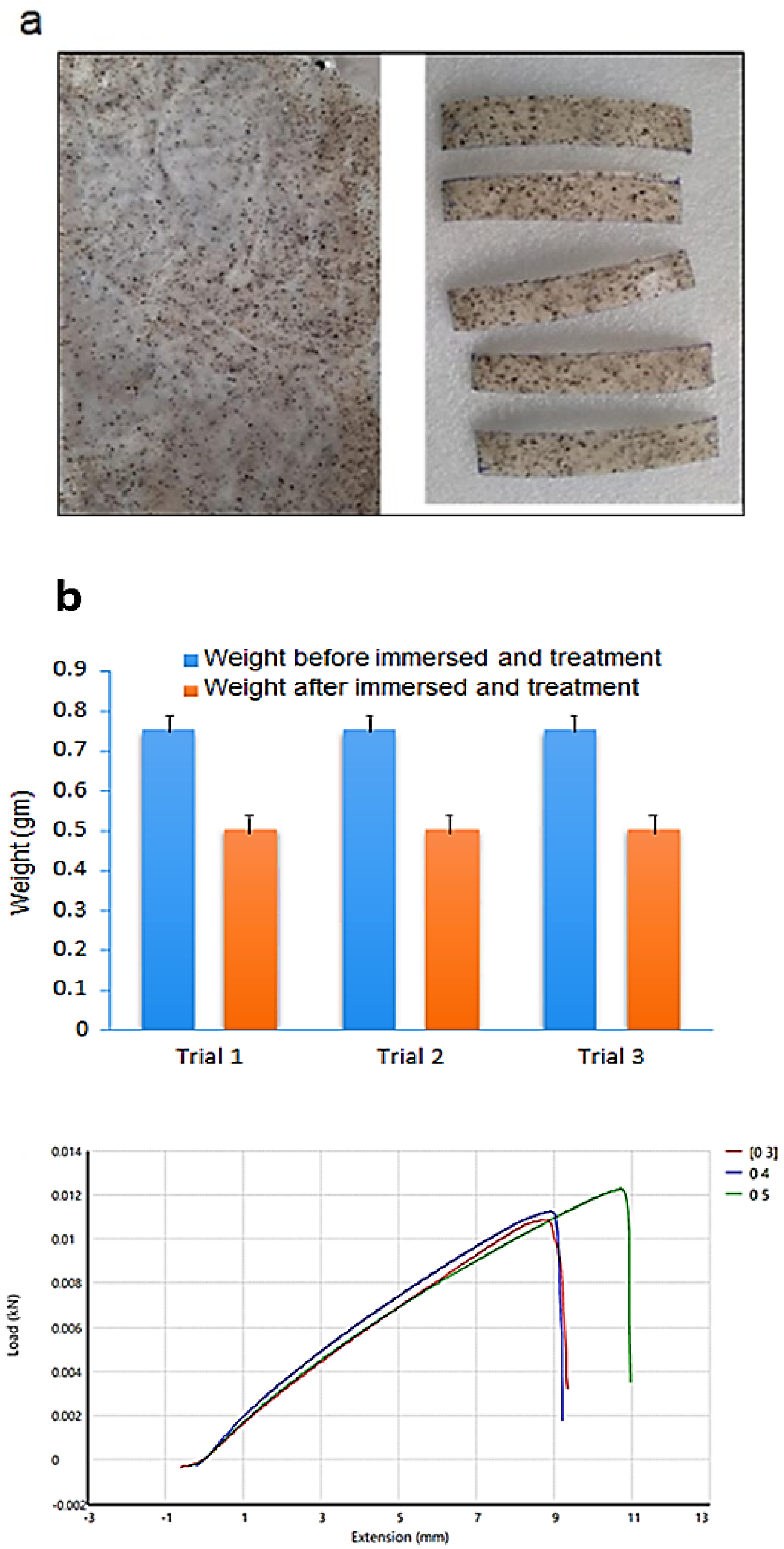

Fig. 1 a. Bio-based plastic prepared using Basil seeds, sago and arrow root, **b.** The weight loss with the 65˚C treatment, **c.** Load and extension capacity of the bioplastic. Values are mean ± SD of three independent experiments

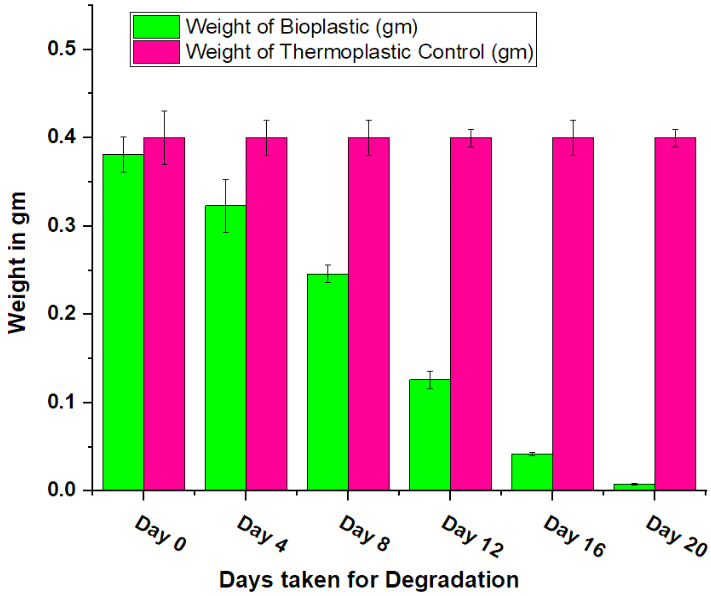

Fig. 2. Comparative study of bacterial degradation of bioplastic and thermoplastic samples. Values are mean ± SD of three independent experiments

Bacterial degradation

Actinobacteria, in earlier studies, has been found to have bioplastic degradation capacity (Butbunchu and Pathom-Aree 2019). In this study, *E. coli* was targeted for analysis of mineralization of the bioplastics. In the growth medium, bioplastic was provided as a carbon source for the growth of bacteria. *E. coli* cells were allowed to grow in the presence of bioplastic as well as the readily available thermoplastics for comparative analysis. On the very first day before treatment, the weight of a 2×2 cm film was 0.76g. After 4 days of treatment in 37°C, the weight loss was almost 8% in the case of prepared bio film. Post 16 days of interaction, the maximum degradation was almost 40%. In the case of the thermoplastic, the degradation rate was 6% after the 16th day of treatment. The *E. coli* cells readily used the components of bioplastics as carbon sources and metabolized them into simpler substances; thus, the bioplastic was broken down. Breakdown of bioplastic into non-toxic end products is a major challenge faced by the researchers since most of the biobased plastics release toxic end products or microplastics (Saygin and Baysal, 2020). However, in this study, the bioplastics were degraded into non-toxic, simple substances.

Day Soil degradation

The bioplastic sample was buried under the garden soil with a thermoplastic as a control. The biodegradation rate of the bioplastic was closely monitored after every interval of 4 days. At the very first four days, the degradation rate was 2%. After eight days, the degradation rate was approximately 5%. At the 12th day, the degradation rate was 15%, which extended up to 20% at the end of 16 days of treatment. In the case of thermoplastic, no significant changes occur. The bioplastic prepared during the study showed a better degradability rate when compared with the already existing bioplastics in the market (Adhikari et al. 2016). The observation hints that the degradation is dependent on the bacterial load in the soil and the environmental factors. The bacterial load might increase the degradation rate. The environmental factors like temperature, moisture, and pH might play a role in decreasing or increasing the degradation rate. The bioplastics, which are readily degraded in soil, are also considered to be appropriate in agricultural practices (Malinconico, 2017).

Mechanical strength

Mechanical strength happens to be one of the important properties of bioplastic. In this characterization,

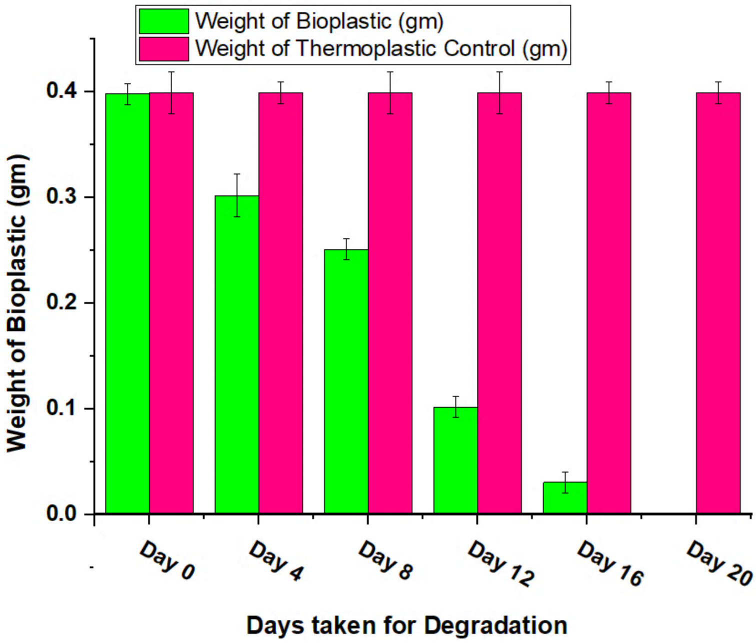

Fig. 3. Comparative study of soil degradation of bioplastic and thermoplastic samples. Values are mean ± SD of three independent experiments

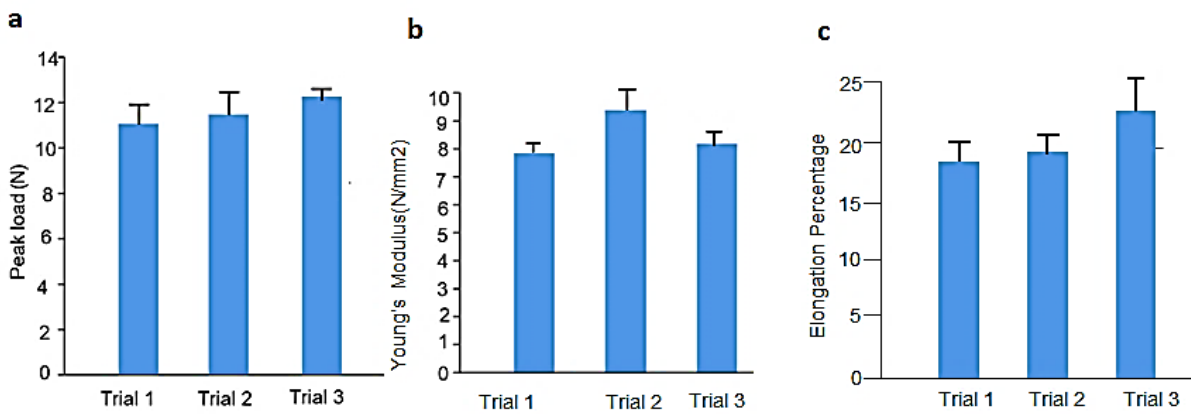

Fig. 4 Mechanical strength of the biobased plastics, (a): Peak load to the break point, (b): Young's Modulus and (c): Elongation Percentage

the strength of the material can be evaluated. Fig. 1 (c) shows the load and extension capacity. Fig. 4(a) represents the peak load to the break point. Fig. 4(b) indicates the Young's modulus of the bioplastic film. It is a fundamental property for every material that cannot be changed, but it depends on temperature and pressure. It is the stiffness of materials. Fig. 4(c) depicts the percentage of elongation. All the mechanical strength analyses had been done in triplicate. The bio-film has good flexibility and deformability. According to the strength analysis, we can conclude that the bio-film has the potential to take the load with its major applications.

SEM

Bioplastics can be degraded in the environment by 4 mechanisms, i.e., hydrolytic degradation, photo degradation, thermo-oxidative degradation, and biodegradation. Plastics posed serious threats to our environment, and their removal from the environment is imperative. The plastics that are degraded

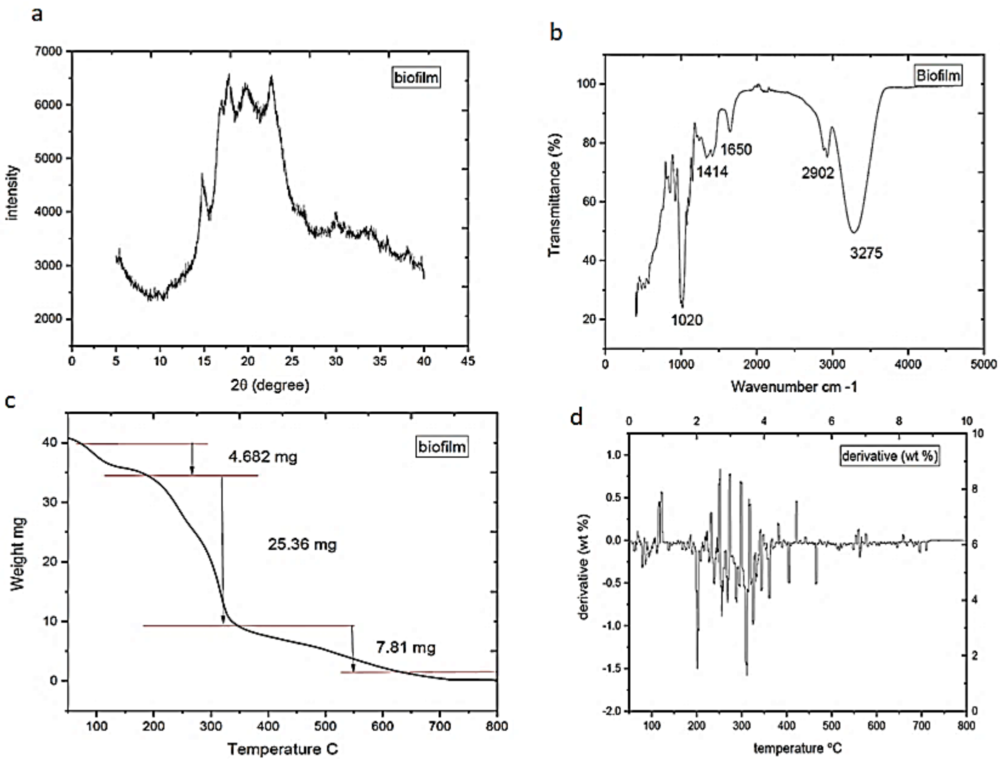

Fig. 5a. X-ray diffractogram of the bioplastic, **b.** FTIR spectrum of the bioplastic **c.** Thermogravimetric analysis graph (weight loss against temperature) **d.** Thermogravimetric analysis graph (derivative against endothermic peaks)

by microorganisms are known as biodegradable plastics, and microorganisms can degrade them into H_2O and CO_2. Bio-based bioplastics are types of plastics in which 100% of carbon is obtained from renewable resources, like forestry and agricultural resources, and are known as bio-based plastics. Basal seeds, Sabu dana, chia seeds, and glycerol are examples of these resources.

The result of SEM analysis shown in Fig. 7. A small piece of the plastic film was added to the soil and the culture media for up to 16 days. In the bacterial culture the degradation rate was more significance. At the end of the 20th day it has been found that the bioplastic was completely degraded.

X-ray diffraction

X-ray Diffractometry was conducted to identify the crystallinity of the bioplastic prepared with basil seed, sago, arrowroot, glycerol and vinegar. The diffractogram is shown in fig. 5(a). The crystalline properties of the material were analyzed by the pattern of XRD graph.

In this study, the first peak region starts at 2θ = 5° and the maximum peak was observed at 2θ = 17.89°. The intensity of peaks verifies that the biofilm was very compact in nature, which makes it crystalline. Glycerol, vinegar and water helps to increasing the intermolecular interaction between basil seed and sago (Rao et al. 2022). By analyzing the crystalline and amorphous peak, it can be claimed that the produced bioplastic in this study is 99% crystalline in nature which was calculated by the equation below:

Crystallinity = (area of crystalline peak/ area of all crystalline and amorphous peak) × 100

FTIR analysis

FTIR analysis was carried out to determine the molecular structure of the prepared bioplastic using basic seeds, sago, and arrowroot. The functional groups present in the bioplastics can be easily and efficiently assessed using FTIR. Fig. 5(b) and Table 3 show the significant peaks of the functional groups present in the bioplastics. The presence of C-H and O-H groups in bioplastics is also reported in similar

Table 1. Location and assignment of the peaks identified in FTIR spectra for bio-film

SL. No	Peak wavenumber (cm−1)	Assignment and remarks
1	850	C—H stretch strong to medium tri substituted alkenes. Presence of vinyl.
2	924	C═CH2 group present with strong bonding. And there might be presence of little bit aromatic substrate.
3	1020	C—O stretch with primary alcohol strongly bonded.
4	1414	C—H stretch with strongly bonded methylene. And Organ phosphorus compounds are also presents in very less.
5	1650	C═C group present with medium bonded alkenes
6	2902	C—H and N—H groups presents. Ammonium ions, aldehyde and alkynes.
7	3275	O—H stretch with high concentration of alcohols and phenols.

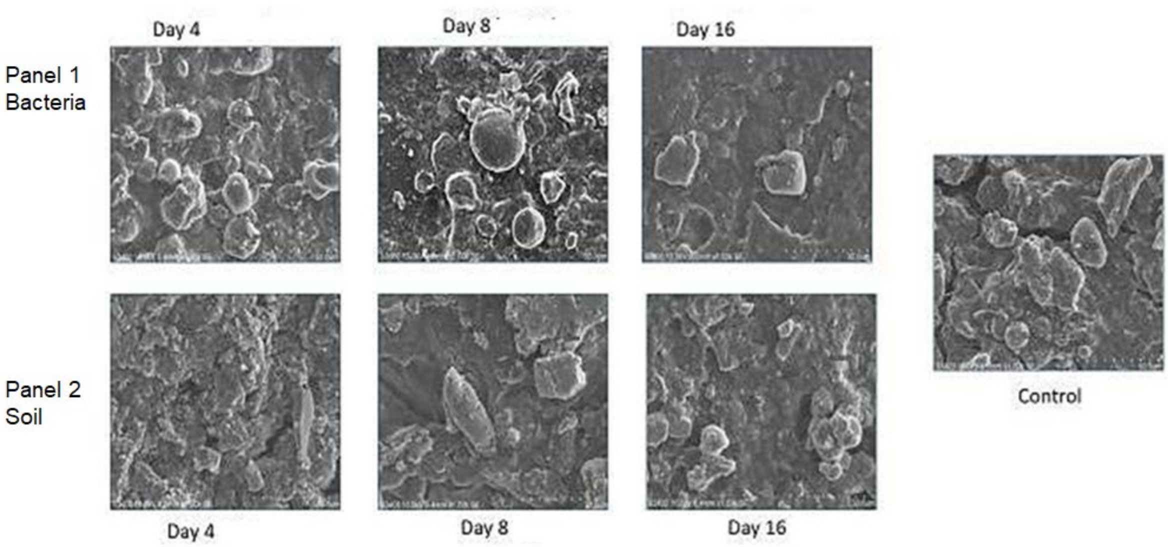

Fig. 6. Degradation of bioplastic by SEM analysis

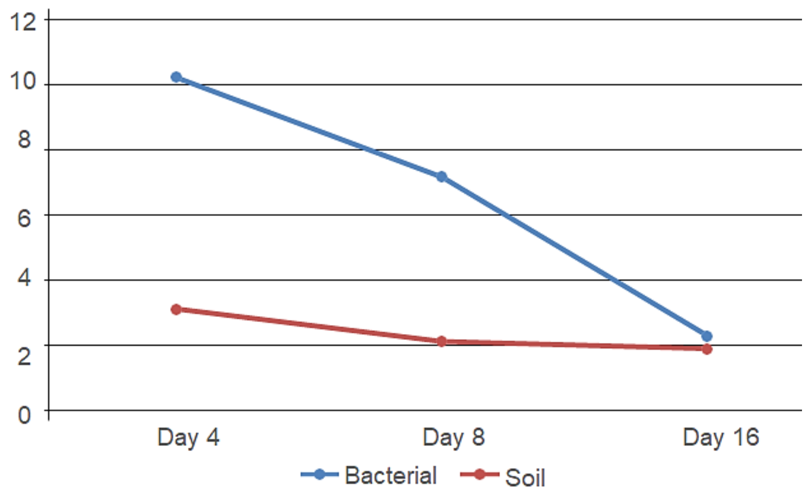

Fig. 7. Graphical representation of Bioplastic degradation in soil and bacteria

studies earlier (Shafqat et al. 2021). The O-H group clearly indicates the presence of plasticizer, that is, glycerol in this study. Presence of similar functional groups in bioplastics was reported earlier by Saygin and Baysal in 2020 (Saygin and Baysal 2020).

Thermogravimetric Analysis

TGA analysis was done to evaluate the strength of the bio-film and degradation against temperature changes. A 41.2 mg sample was taken while initiating the experiment at a temperature of 30°C. Preliminary weight loss was noticed at 191.75°C. 11.5% of weight loss was observed at the particular time. At 345°C, approximately 73% of weight loss was observed, followed by 84% at 640°C. The weight loss with the inserted temperature graph is shown in figure 5(c). The biomass loss might occur due to the depolymerization of the crystals. Moreover, dehydration also occurred during the first phase of weight loss. According to the degradation rate, the polymer is stable in nature. Fig. 5(d) represents the derivative TGA graph. The main purpose of providing the derivative graph is to understand the phase transformation, crystallization, and phenomenon change in the particles by analyzing each endothermic peak (Yaradoddi et al. 2022).

CONCLUSION

This study was conducted with an aim to synthesize eco-friendly and cost-effective bioplastic from basil seed and tapioca (sago) as resources. This study formulated one bioplastic film using the same starch source with vinegar, glycerol, and water but with different cross-linkers. The film displayed different properties with respect to hardness and tensile tensility. The formulated films' physical, chemical, mechanical, and biological parameters were characterized. Bio-film showed the best tensile strength of 12 N and least elongation at break of 21%. FTIR analysis of films showed spectral similarity with synthetic plastics. In thermogravimetric analysis (TGA), all the films displayed gradual desorption occurring between 200°C and 300°C, where the volatile compounds started to evaporate and around 550°C. The lower molecular weight compounds like plasticizer, cross-linker, and other additives started to release; pyrolysis of carbonated compounds occurred above 500°C. This film displayed the best thermal stability with half decomposition at 350°C. Biodegradability of films was demonstrated through the soil burial method and culturing of pure cultures of microorganisms in minimal media by providing the film as a carbon source. The bio-films formulated displayed different mechanical properties and hence have potential application in different areas according to the needs.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

ETHICAL APPROVAL

Not Applicable.

ACKNOWLEDGEMENTS

The authors thank Dr. Althaf Hussain Shaik under the Researchers Supporting Program No. RSP2025R371 - King Saud University, Riyadh, Saudi Arabia.

REFERENCES

Adhikari, D., Mukai, M., Kubota, K., Kai, T., Kaneko, N., Araki, K.S., Kubo, M. (2016) Degradation of bioplastics in soil and their degradation effects on environmental microorganisms. *J Agri Chem Environ,* 5(01), 23.

Atiwesh, G., Mikhael, A., Parrish, C.C., Banoub, J., Le, T.A. (2021) Environmental impact of bioplastic use: A review. *Heliyon*, 7 (9), 07918.
Pooja, N., Chakraborty, I., Rahman, M. H., & Mazumder, N. (2023). An insight on sources and biodegradation of bioplastics: a review. *3 Biotech*, *13*(7), 220.
Butbunchu, N., Pathom-Aree, W. (2019) Actinobacteria as promising candidate for polylactic acid type bioplastic degradation. *Front Microbiol,* 10, 2834.
Cai, L., Shi, H., Cao, A., Jia, J. (2019) Characterization of gelatin/chitosan ploymer films integrated with docosahexaenoic acids fabricated by different methods. *Sci Rep*, 9 (1), 1-1.
Krishnamurthy, A., Amritkumar, P. (2019) Synthesis and characterization of eco-friendly bioplastic from low-cost plant resources. *SN Applied Sci*, 1 (11), 1-3.
Li, P,. Wang, X., Su, M., Zou, X., Duan, L., Zhang, H. (2021) Characteristics of plastic pollution in the environment: a review. *Bull Environ ContamToxicol*, 107, (4), 577-84.
Liu, J., Yang, Y., An, L., Liu, Q., Ding, J. (2020) The Value of China's Legislation on Plastic Pollution Prevention in 2020. *Bull Environ Contam Toxicol,* 108 (4), 601-8.
Malinconico, M. (2017) Soil degradable bioplastics for a sustainable modern agriculture. *Springer*; 2017 Feb 14.
Marichelvam, M.K., Jawaid, M., Asim, M. (2019) Corn and rice starch-based bio-plastics as alternative packaging materials. *Fibers*, 7 (4), 32.
Matta Fakhouri, F., Nogueira, G.F., de Oliveira, R.A., & Velasco, J.I. (2019) Bioactive edible films based on arrowroot starch incorporated with cranberry powder: Microstructure, thermal properties, ascorbic acid content and sensory analysis. *Polymers*, 11 (10), 1650.
Moro, T., Ascheri, J.L., Ortiz, J.A., Carvalho, .CW., & Meléndez-Arévalo, A. (2017) Bioplastics of native starches reinforced with passion fruit peel. *Food Bioproc Technol*, 10 (10), 1798-808.
Oluwasina, O.O., Akinyele, B.P., Olusegun, S.J., Oluwasina, O.O., & Mohallem, N.D. (2021) Evaluation of the effects of additives on the properties of starch-based bioplastic film. *SN Applied Sci*, 3 (4), 1-2.
Rao, L.S., Naidu, .CD., & Tiwari, S. (2022) Investigation on synthesis, structure and degradability of starch based bioplastics. Materials Today: Proceedings 49, 257-61.
Saygin, H., & Baysal, A. (2020) Biofilm formation of clinically important bacteria on bio-based and conventional micro/submicron-sized plastics. *Bull Environ Contam Toxicol*, 105 (1), 18-25.
Saygin, H., & Baysal, A. (2020) Similarities and discrepancies between bio-based and conventional submicron-sized plastics: in relation to clinically important bacteria. *Bull Environ Contam Toxicol*, 105 (1), 26-35.
Shafqat, A., Al-Zaqri, N., Tahir, A., & Alsalme, A. (2021) Synthesis and characterization of starch based bioplatics using varying plant-based ingredients, plasticizers and natural fillers. *Saudi J Biol Sci*, 28 (3), 1739-49.
Shanmathy, M., Mohanta, M., & Thirugnanam, A. (2021) Development of biodegradable bioplastic films from Taro starch reinforced with bentonite. *Carbohydr. Polym Tech*, 2:, 00173.
Verma, R., Vinoda, K. S., Papireddy, M., & Gowda, A. N. (2016) Toxic pollutants from plastic waste-a review. *Procedia Environ Sci*, 35, 701-8.
Yaradoddi, J. S., Banapurmath, N. R., Ganachari, S.V., Soudagar, M.E., Sajjan, A. M., Kamat, S., Mujtaba, M. A., Shettar, A. S., Anqi, A. E., Safaei, M. R., & Elfasakhany, A. (2022) Bio-based material from fruit waste of orange peel for industrial applications. *J Mat Res Technol*, 17 (3), 186-97.
Gomes, L.C., & Mergulhão, FJ (2017). SEM Analysis of Surface Impact on Biofilm Antibiotic Treatment. Scanning. 11, 2960194.