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Antimicrobial Bioplastics: A Sustainable Approach to Food Packaging Using Algae, Tamarind, and Natural Extracts

[1]Dr. Bajare J.S., [2]Kashid J.A., [3]Shinde M.R., [4] Gude S.S., [5]Patil S.D., [6]Pawar O.R., [7]Shelke R.R., [8]Dhundale V.R.
Shri Shivaji Mahavidyalaya Barshi, Solapur MH India.
Email:jitendrabajare@gmail.com , jogeshwarikashid61@gmail.com , mayurshinde5656@gmail.com .

Abstract: *This research addresses the growing need for eco-friendly alternatives to conventional plastics, focusing on the preparation and characterization of bioplastics derived from renewable resources, specifically microalgae (Nostoc) and tamarind seed powder, enhanced with natural antimicrobial extracts for food packaging applications. The primary objective was to develop biodegradable, antimicrobial packaging films that prevent contamination and microbial growth, ensuring food safety. Bioplastics were prepared using Nostoc algae with extracts from neem, citrus peel, and cinnamon, as well as tamarind seed powder with extracts from neem, turmeric, and dry ginger. Various physical tests, including evaluations of thickness, biodegradability, water solubility, antimicrobial properties, transparency, and color,were conducted to assess the bioplastics' potential. The results demonstrated that the bioplastics exhibited key characteristics such as good mechanical strength, translucency, and biodegradability. Biodegradability tests showed significant weight loss (58.52%–72.73% for Nostoc-based and 51.08%–78.26% for tamarind-based bioplastics over 15 days in soil). Water solubility ranged from 36.41% to 56.25% for Nostoc-based bioplastics and 46.21% to 55.55% for tamarind-based bioplastics. Antimicrobial testing showed varying zones of inhibition against E. coli, Proteusspp, and Bacillusspp, depending on the antimicrobial extract used. The bioplastics also demonstrated sufficient mechanical strength and different color variations based on the incorporated extracts. In conclusion, this research highlights the potential of Nostoc algae and tamarind seed powder, enhanced with natural antimicrobial extracts, as sustainable, biodegradable materials for food packaging, contributing to the reduction of plastic waste and fostering a more sustainable future.*

Key Words: *Bioplastics, Nostocalgae, Tamarind seed powder, Food packaging, Biodegradable films, Bioplastic characterization.*

1. INTRODUCTION

The growing dependence on petrochemical plastics is a major concern for both humans and the environment, prompting a shift toward greener, biodegradable alternatives. Recent studies emphasize the production of sustainable green plastics, as highlighted by **M.Goliszek** *et al*. (2018). **Taufik** *et al.* (2020) further noted an increasing interest in bioplastics and biocomposites, which could replace harmful traditional plastics in various household and industrial uses. Microalgae, belonging to the kingdom Protista, are essential players in this movement. As pointed out by **Makowska** (2017), these organisms are not only simple in structure but also carbon-neutral, aiding in the reduction of carbon dioxide levels (**Cinar** *et. al.*, 2020).Notably, the cyanobacteria genus Nostoc is known for producing biodegradable biopolymers like exopolysaccharides and polyhydroxyalkanoates (PHA). Moreover, tamarind seed powder, a by-product of the tamarind industry, is rich in starch and serves as a natural polymer for creating biodegradable plastics. The tamarind tree thrives in arid climates and offers both nutritional benefits and protein-rich seeds, beneficial for human health, as mentioned by **Pinar Kuru** *et al.* (2014).Research by **Chowdhury** *et al.* (2022, 2023) has explored using tamarind seed starch along with other natural ingredients in bioplastics development. Proper food packaging is crucial for preventing contamination and ensuring food safety. Plant extracts from sources like neem, citrus peel, and cinnamon exhibit strong antimicrobial properties. Additionally, turmeric and dry ginger powders can enhance bioplastic characteristics. Incorporating these natural extracts not only provides antimicrobial benefits (**Farah** *et al.*, 2020) but also significantly affects the degradation of biodegradable films for food packaging (**Hernandez** *et al.*, 2021).

2. MATERIALS AND METHODS:

A) METHODOLOGY FOR NOSTOC BASED BIOPLASTIC

1. Isolation of Nostoc Algae

Algal samples were gathered from a variety of sites, including Pathri, Ramling, and the surrounding areas of Barshi, located in Solapur district, Maharashtra, India. Collection was carried out using two 2-liter plastic jars. A small sample of the algae was taken, and a drop of saline solution was placed on a slide to be observed under a light microscope at a magnification of 45X. This examination revealed a chain-like structure featuring round heterocysts.

2. Cultivation of Algae and preparation of media –

Microalgae were cultivated in a 1000 ml BG11 medium broth inoculated with the collected algae. The broth was then placed on the laboratory rooftop to utilize sunlight for growth, allowing it to thrive for 10 to 12 days. To boost the biomass of Nostoc, BG11 medium is advised for optimal cultivation.

3. Identification by Morphological and Cultural Characteristics

The algae were assessed for their morphological and cultural traits to confirm the identification of Nostoc.

4. Drying and Grinding of Natural Antimicrobial Samples

Considerable quantities of neem leaves, citrus peels, and cinnamon were collected. Each sample underwent a thorough washing and was dried with a cloth. Subsequently, the samples were placed in a hot air oven at 150°C for 1 to 2 hours to eliminate all moisture. Once dried, they were ground separately in a mixer grinder to produce fine powders of natural antimicrobial samples, including neem leaves, citrus peels, and cinnamon.

5. Preparation of Extracts from samples

For the creation of plant extracts, 25% (w/v) solutions were made by mixing 2 grams of powdered plant material with 25 ml of distilled water. The extracts prepared included:

- Neem (*Azadirachta indica*): 2 g of Neem powder in 25 ml water
- Citrus peel (*Citrus sinensis*) : 2 g of Citrus peel powder in 25 ml water
- Cinnamon (*Cinnamomumverum*): 2 g of Cinnamon powder in 25 ml water

In addition, 2.5 grams of Nostoc biomass were immersed in 25 ml of distilled water. The biomass was then macerated to break down the cells and incubated for 30 minutes. Following this incubation, the mixture was filtered through Whatman filter paper.

6. Preparation of Bioplastic Formulation -

The bioplastic formulation was created by measuring 50 ml of distilled water and adding the following ingredients: 2 g of agar, 2 g of gelatin, 25 ml of a 25% algae extract, 3 ml of glycerin, and 25 ml of a 25% neem extract. All ingredients were carefully mixed in a volumetric flask and heated until achieving a homogeneous consistency. Once prepared, the mixture was poured into a plastic tray and left to air dry for three days.
This same method was applied to alternative natural antimicrobial samples, such as citrus peel and cinnamon extract, as detailed in Table 1.

Table no.1: **Nostoc based Bioplastic formulation**

Type / Samples	Nostoc + Neem based (S_1)	Nostoc + Citrus based (S_2)	Nostoc + Cinnamon based (S_3)
Nostoc Solution	25 ml	25 ml	25 ml
Agar	2 gm	2 gm	2 gm
Gelatine	2 gm	2 gm	2 gm
Glycerine	3 ml	3 ml	3 ml
Distilled water	50 ml	50 ml	50 ml
Antimicrobial extract	25 ml	25 ml	25 ml

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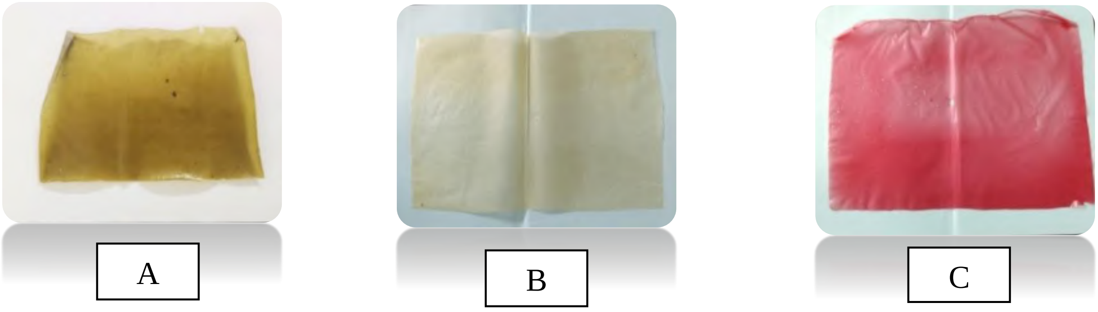


Figure 1:Nostoc based BioplasticA (Neem), B (Citrus peel)and C (Cinnamon)

B) METHODOLOGY FOR TAMARIND SEED POWDER BASED BIOPLASTIC

1. Collection of Tamarind seeds powder

Tamarind seed powder samples were gathered from Bothra Food Industry, located in the industrial area of Barshi, District Solapur, Maharashtra, India.

2. Collection of Natural Antimicrobial Samples

A significant quantity of neem leaves was collected. Each leaf was thoroughly washed and then dried with a cloth. Subsequently, the leaves were placed in a hot air oven at a temperature of 150°C for 1 to 2 hours to ensure complete moisture evaporation. After drying, the leaves were transferred to a mixer grinder, along with turmeric powder and ginger powder obtained from a local grocery store.

3. PREPARATION OF EXTRACTS FROM SAMPLES:

Plant extracts were prepared by creating 10% (w/v) solutions for each plant material. This was done by mixing 1 gram of the powdered substance with 10 ml of distilled water. The specific extracts prepared were as follows:

- Neem (*Azadirachta indica*): 1 g of neem powder in 10 ml of water
- Turmeric (*Curcuma longa*): 1 g of turmeric powder in 10 ml of water
- Ginger (*Zingiber officinale*): 1 g of ginger powder in 10 ml of water

4. PREPARATION OF BIOPLASTIC FORMATION:

The bioplastic formulation process began by measuring 70 ml of distilled water. Following that, the ingredients were combined: 15 g of tamarind seed powder, 6 ml of glycerine, 3 ml of acetic acid, and 10 ml of the natural antimicrobial sample (neem at 10%). All components were mixed in a volumetric flask and heated until a uniform consistency was achieved. Once ready, the mixture was poured into silicone molds or plastic trays and left to air dry for three days. The same methodology was also applied for other natural antimicrobial samples, such as turmeric and dry ginger extract, as outlined in Table 2.

Table no.2: **Tamarind seed based basedBioplastic formulation**

Type / **Samples**	**Tamarind + Neem based (T_1)**	**Tamarind + Turmeric based (T_2)**	**Tamarind + Dry ginger based (T_3)**
Tamarind Powder	15 gm	15 gm	15 gm
Glycerine	8 ml	8 ml	8 ml
Acetic acid	4 ml	4 ml	4 ml
Distilled water	70 ml	70 ml	70 ml
Antimicrobial extract	10 ml	10 ml	10 ml

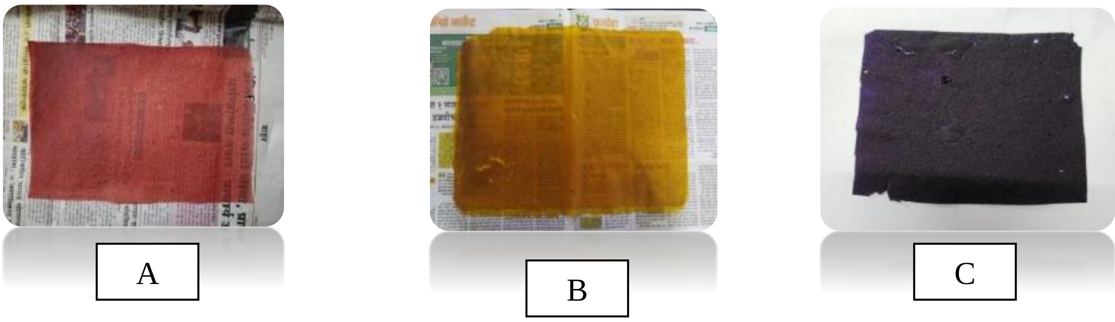


Figure 2: **Tamarind seed based Bioplastic A (Neem), B (Turmeric), and C (Dry ginger)**

5. RESULTS -

Properties of Bioplastic: In present research work produced bioplastic has showed very prominent properties such as mechanical strength, transparency, color, solubility, tensile strength, degradability, which is also cost effective as well as Eco-friendly in nature.

Color: Color is the one of the key characteristics of Bioplastic can affect their appearance, functionality and overall acceptance. Natural antimicrobial samples neem leaves, citrus peel, turmeric, dry ginger and cinnamon extract were used for enhancing color, appearance and antimicrobial activity of Bioplastic. The produced Bioplastic showed **Yellowish green color (S_1), Pale yellow color (S_2), Pink color (S_3), Brown (T_1), Bright yellow (T_2) and Blue (T_3)**.

Thickness measurement: The thickness of the bioplastic film was observed using Micrometer. The thickness was obtained by holding the film in between the anvil and stylus. For each sample, the thickness was measured and the value is obtained in above table no.3[rd].

Table no.3: **Thickness of Bioplastic samples**

Sample No.	**Thickness of Bioplastic**
S_1	0.0015 Cm.
S_2	0.0017 Cm.
S_3	0.0021 Cm.
T_1	0.0025 Cm.
T_2	0.0027 Cm.
T_3	0.0023 Cm.

Cost effective Bioplastic: In recent years Bioplastic have emerged as a promising alternative to traditional plastics. Bioplastic prepared from Nostoc a type of cyanobacteria and tamarind seed powder is the byproduct of food industry. Neem, citrus peel, cinnamon, dry ginger, turmeric have been explored as sustainable and ecofriendly solution to produce bioplastic and reduce plastic waste problem.

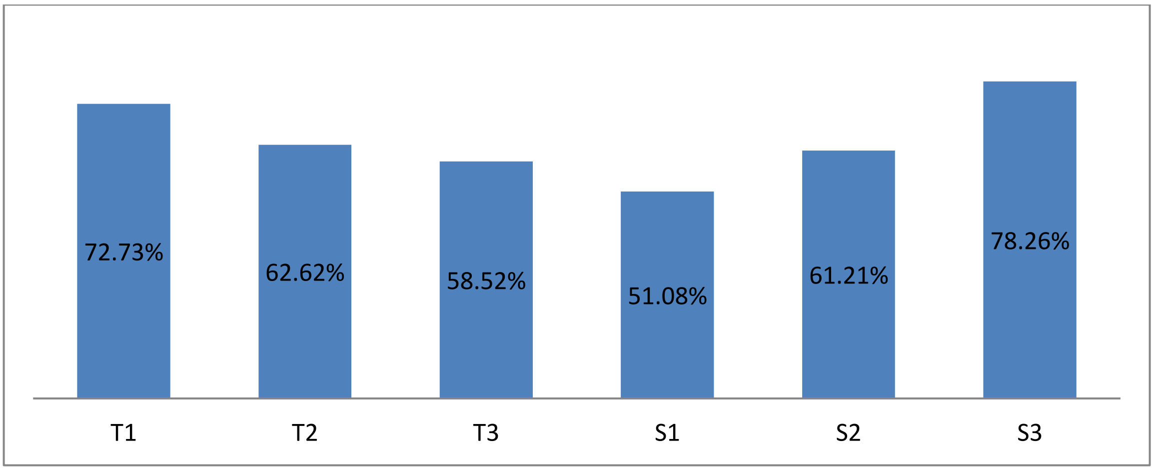
Biodegradability test: This test was performed to determine the biodegradable nature of the film. Each sample was cut into a square piece of size 2 cm^2 × 2 cm^2. The initial weight of the specimen was measured. The soil that is found near the roots of the plants was taken as they are rich in bacteria and have some moisture content. About 500 g. of such soil is taken from the root portion and stored in a container. The samples were buried at a depth of 3 cm for 15 days in the container under room conditions. After 15 days the samples are taken from the container and the final weight was measured. The weight loss due to biodegradability is calculated by adopting the following equation. Calculated value compared in graph no.1.

$$W_L (\%) = \frac{W_i - W_F}{W_i} \times 100$$

Where,
W_L - a weight loss of bioplastics
Wi - the initial weight of the bioplastics in gm.
W_F - final weight of the bioplastics in gm.

Sample T_1 T_2 T_3
Fig.3

Sample S_1 S_2 S_3
Fig.4

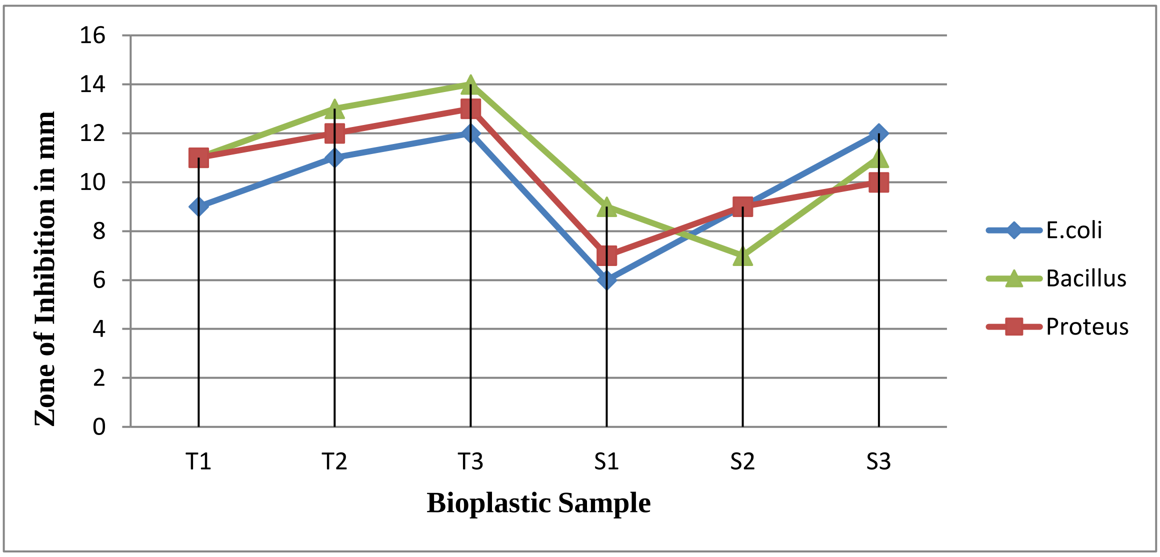


Graph 1: **Percentage of Biodegradation of Bioplastic**

Transparency: Transparency is an important property of bioplastic especially for various applications. In present research work produced Bioplastic showed **translucent transparency**. Transparency helps to increase the shelf life of product from avoiding sunlight contact

Antimicrobial Activity: Prepared Bioplasticshowed antimicrobial activity against *E.coli, Proteus, and Bacillus.* The antibacterial activity of each Bioplastic sample was determined using the **Disc diffusion method** on **Muller Hinton Agar Plates.** Zones of inhibition were measured after 24 hours of incubation at 37^0C.Indicating strong antibacterial effects.Neem and Ginger extracts showed moderate activity, while Turmeric demonstrated the least inhibitory effect. Values of zone of inhibition mentioned in graph no 2.

Graph 2: **Zone of growth Inhibition (mm) of Bioplasticagainst*Pathogens***



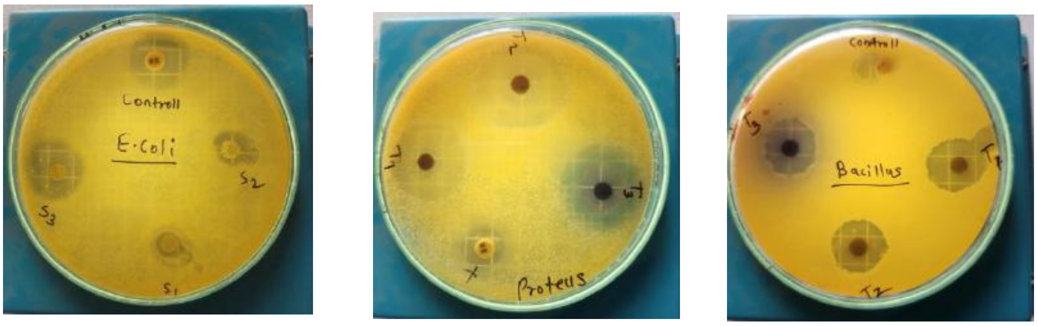


Figure 5: Zone of growth Inhibition (mm) of Bioplastic against *Pathogens*

Mechanical strength: The produced Bioplastic exhibit **much sufficient mechanical strength** for various applications. Mechanical strength is essential for bioplastic to withstand normal use during handling for instance, Bioplastic packaging materials require sufficient tensile strength to resist damage and puncture. Mechanical strength also impacts the shelf life of Bioplastic product.

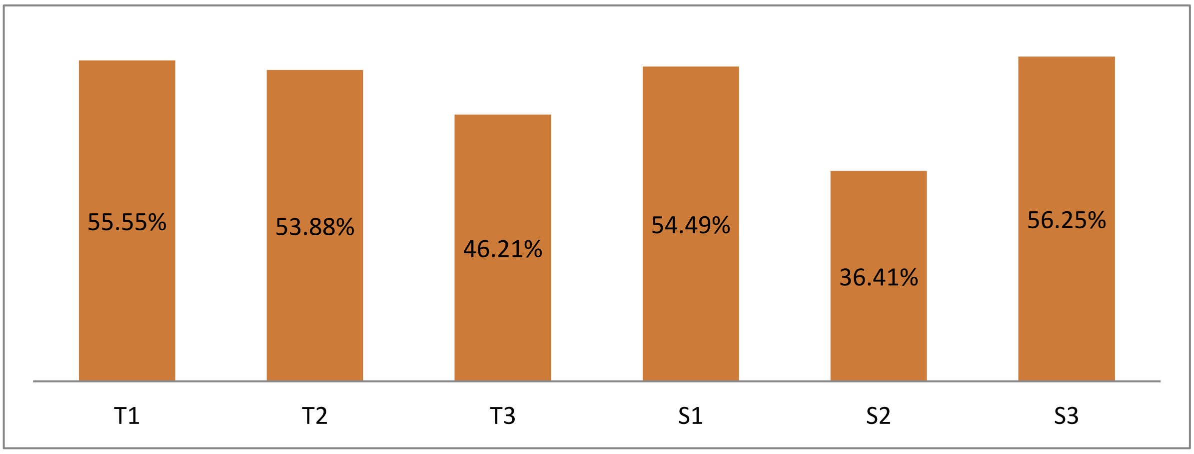
Water solubility test: This test was taken to know how fast the bioplastic film dissolves in water. The film was cut into a square section of size 2 cm × 2 cm. The weight of the dry film sample was measured and noted accurately. 100 ml of distilled water was filled in a 250 ml beaker to immerse the film sample in distilled water. The beaker was kept on a magnetic stirrer and stirred at 180 rpm for 3 h. After 3 h the remaining portion of the film was taken outside. The remained film of bioplastic mass was dried at 110 ^{0}C in a hot air oven until a fixed dried mass is obtained. The dried mass was weighed and the readings were noted. The percentage of the total soluble matter was computed using the following formula. Summarized in following graph no 3.

$$W_L (\%) = \frac{W_i - W_F}{W_i} \times 100$$

Where,

W_L - a weight loss of bioplastics
Wi - the initial weight of the bioplastics in gm
W_F - final weight of the bioplastics in gm

Graph 3: **Percentage of water solubility of Bioplastic**



6. DISCUSSION:

The present study successfully developed **eco-friendly bioplastics from *Nostoc* algae and tamarind seed powder, incorporating natural antimicrobial extracts**. These bioplastics demonstrated **significant biodegradability**, aligning with findings from **Domenek** *et al.* (2004) and **Chowdhury** *et al.* (2022) regarding the rapid degradation of biopolymers in soil. The variation in biodegradability across samples was due to the both the base materials and the added antimicrobial agents added during preparation influenced the degradation rate, as noted by **Hernandez** *et al.* (2021).Furthermore, the incorporation of neem, citrus peel, cinnamon, turmeric, and dry ginger extracts imparted

notable antimicrobial activity against common foodborne pathogens, supporting their potential for active food packaging applications, consistent with the work of **Farah** *et al.* (2020) and **Yavor** *et al.* (2024). While the bioplastics exhibited **sufficient mechanical strength** for intended use, further quantitative analysis will be needed for a comprehensive evaluation. The **translucent to colored appearance** has been influenced by the natural extracts, which could be advantageous for specific applications. The use of sustainable resources like *Nostoc* and tamarind seed powder suggests **potential cost-effectiveness**, contributing to a circulate economy. Overall, this research highlights the promising potential of these bioplastics as sustainable alternatives to conventional plastics for food packaging, addressing both plastic pollution and food safety. However, further research is needed to optimize their mechanical and barrier properties and conduct detailed economic and life cycle assessments.

7. CONCLUSIONS

In conclusion, this research highlights the promising potential of *Nostoc*-based and tamarind seed-based bioplastics, enhanced with natural antimicrobial extracts, as eco-friendly alternatives for food packaging. The demonstrated biodegradability and antimicrobial properties underscore their contribution towards a more sustainable future by reducing plastic waste and enhancing food safety. Further research and development will be crucial to overcome current limitations and fully realize the potential of these innovative biomaterials.

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