Development of biodegradable packaging film using Pineapple and Lime peel

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Abstract—**The present study was conducted to develop the biodegradable packaging film from the residual pineapple and lime peels. The pineapple and lime peels were dried and grounded into a fine powder using a mechanical mixer. Extraction of biopolymers was done by soxhlet extraction for developing biodegradable film. Extracted biopolymers were heated at 70-80^{0}C using hot plate and stirred by magnetic stirrer. Gelatin (1-5%) as a plasticizer used in this research. The thin films were prepared by the biopolymers with the addition of gelatin. Developed bio-films were analyzed for their water vapour permeability, FTIR & SEM analysis, biodegradability and antibacterial properties. The results revealed that with the increasing concentration of pineapple and lime peel extracts, and water vapour permeability slightly increased. The FTIR & SEM analysis showed a good interaction. In biodegradability tests, the bio-films showed better results that can be degraded after several days. The films showed a positive antibacterial effect that can be degraded by the growth of E. coli. From these results, it concluded that the bio-film developed from the fruit peels have a potential to formulate edible food packaging. In future research, the applications and the effectiveness of the biodegradable packaging film will be studied.**

Index Terms—**Pineapple peel, lime peel, plasticizer, film, antibacterial activity.**

I. INTRODUCTION

1.1. Biodegradable packaging film:

Food security is a global issue and is the serious problem of this era. Food processing and packaging seems to be the best way to cope up with this issue. A packaging material is design to protect and preserve food during handling and storage. With the increase in industrialization and modern processing techniques the need of efficient and hygienic packaging is on rise. Packaging is a unit operation which is as important as pre-processing stage i.e. during maturity and ripening of fruits and vegetables as well as at post processing stage i.e. during storage and transportation. The development of a novel packaging system that maintains the quality of food with the intention of shelf-life extension along with the assurance of its quality and safety is a big challenge for scientists and the food processing industries. Such packaging technology is called active food packaging films and can be developed from polymeric materials incorporated with active ingredients such as oxygen scavenger, antioxidant, antimicrobial, ethylene scavenger, and moisture absorber. Active ingredients interact with the constituents of packaged food to preserve the nutritional quality and freshness of packaged food during the distribution and storage period (Kumar, P. et al., 2021). Numerous raw and processed foods are available in markets which are highly perishable, needs an efficient system of packaging. A packaging material not only protect the food from physical, mechanical and environmental hazards but also protect its organoleptic properties which can be affected due to climatic change. To protect any food item from outside atmosphere and to increase its shelf life, perfect packaging material is required. Appropriate selection of material and design is required for packaging a specific food item. Barrier properties are the essential components which are considered during design of packaging materials (Ahvenainen, 2003). Currently, almost all the packaging materials are plastics. Plastics can be readily shaped in any design and are convenient to use, making them a popular food packaging material. The production of plastics is at its peak stage in your country with an annual per capita consumption of plastic in India at 2 kg/person/year (Kalia et al., 2000).

II. MATERIALS AND METHOD

2.1. Materials:

Fresh pineapple and lime peels were purchased from the local juice vendor in Thiruvarur Dt, India. Gelatin, as a plasticizer, was purchased from Sisco Research Laboratories Pvt. Ltd, India.

2.2. Sample collection and processing:

The fresh pineapple and lime peels were collected and washed thoroughly with water to remove the dirt. Then, the peels were cut into small pieces and dried in hot air oven at 50-60^{o} C for 8-12 hours. After dried, the peels were ground into a fine power using a grinder or mixer.

2.3. Extraction of biopolymers:

The biopolymers pectin and cellulose from the peels were extracted by using soxhlet extraction (water at 80^{o} C for 6 hours). In soxhlet extraction, 15g of dried, grinded, and finely powdered samples (pine apple and lime peels) were placed inside porous bag (thimble) made up of a clean cloth or strong filter paper and tightly closed the extraction solvent is poured into the bottom flask, followed by the thimble into the extraction chamber. The 200 ml of distilled water (solvent) is then heated from the bottom flask, evaporates, and passes through the condenser where it condenses and flow down to the extraction chamber and extracts the drug by coming in contact. Consequently, when the level of solvent in the extraction chamber reaches the top of the siphon, the solvent and the extracted plant material flow back to the flask. The entire process continues repeatedly until the drug is completely extracted. After extraction, filter the solution using Whatman filter paper to remove insoluble particles. Heat the extracted pectin at 70-80^{o} C using a hot plate and stir using a magnetic stirrer. Adjust the pH 4 - 5). These extracted biopolymers were stored at 4^{0}C for later use.

2.4. Addition of plasticizer & film formation:

After the extraction of pectin and cellulose, the plasticizers namely gelatin (1-5%) was added into the film forming solution and mix at 60^{o} C for 30 minutes in a hot plate. Then, the solution was filtered using vacuum filtration to remove any solid particles. Later, the filtered solution was gently poured into the petridishes and spread evenly using a spatula to achieve a uniform thickness.

2.5. Drying and film curing:

The thin film was dried in an oven at 40 -50 ^{o}C for 12-24 hours. Alternatively, air-dry at room temperature for 48-72 hours. The next day, a thin bio film was created. The dried film was stored in a humidity chamber to analyse moisture absorption.

2.6. Characterization & testing:

2.6.1. FT-IR Analysis:

Fourier transform infrared (FT-IR) spectra of the prepared films were carried out in the wave number of 4000–400 cm^{-1} using an attenuated total reflectance-Fourier transform infrared (ATR FT-IR) spectrophotometer (Perkin Elmer spectrophotometer (Chicago, USA)). The films were placed directly on the sample holder and scanned at the resolution of 4 cm^{-1}. All the films were oven-dried prior to testing (Uppasen, S. et al., 2023).

2.6.2. SEM analysis:

The morphology and distribution of the cellulose and pectin fibers were investigated using Scanning Electron Microscopy (SEM). The analysis was performed using an LEO 1450 VP operated at 15 kV. A Polaron Range Model SC 7620 Ion Sputter Coater was used for the gold sputtering of the samples (Uppasen, S. et al., 2023).

2.6.3. Water Vapor permeability Test:

Modified ASTM E96/E96M has been used to measure the water vapor permeability of prepared films. The desiccant method, commonly known as a cup method, was followed to analyze the barrier properties using three replicates of each composition. Before testing, conditioning of all film samples was done at 55% RH for 24 h. 10 g silica gel was taken in an open test mouth dish (Cup) consisting of aluminum, and films were sealed to them carefully before testing. The relative humidity in a desiccator was maintained at 75% RH (using the saturated solution of sodium chloride, NaCl), and the desiccator was then placed in an oven kept at 25^{0} C. The weight gain by the cups was observed regularly at an interval of 24 h until three successive similar values were obtained. WVTR is calculated by dividing the slope of the weight gain vs. time graph to the open area of the cup (25 cm^{2}). Afterward, the WVP value was calculated employing the below Eq.

$$WVP\ (g\ mm/\ m^2\ h\ kPa) = WVTR*T / \Delta p$$

where, Δp is the difference in water vapour pressure below and above the film surface (kPa), and X is the average thickness of the films (mm).

2.6.4. Biodegradability Test:

Composting test was conducted according to Nouraddini et al. (2018). Film samples (1 cm × 2 cm) were cut, weighed and placed on an iron wired gauze and buried at 2 cm depth in an aluminium tray containing natural soil at room temperature. Everyday water was sprayed to the soil. Every 7 days for 28 days, the film samples were taken out and the degradation of the films was evaluated in terms of percentage of weight loss using equation (Sekhar et al., 2016):

$$WL\ (\%) = (W0 - W1)\ W0 \times 100$$

were, WL % is the percentage weight loss of the film, W0 is the initial weight of the film and W1 is the weight of the film after degradation.

2.6.5. Antibacterial activity:

Culture Preparation:

Escherichia coli (bacterial strain) was cultured in Nutrient broth. The cultured organism will be taken to the plating methods.

Disc Diffusion method:

The antibacterial activities of the bio-films were studied according to the zone of inhibition in the disc diffusion method. The respective nutrient agar medium was prepared and autoclaved at 1210C for 30-45 mins to sterilize the contaminating microorganisms. Then it was allowed to cool down at room temperature and when it reaches nearly 500C, the media was poured in the culture plates and allowed for further solidification. Then the overnight grown Escherichia coli culture was spread evenly onto the plates by using sterile cotton swab. Bio-films were cut into pieces (6mm) and exposed to UV for 20 min. The UV treated bio-films were placed onto the inoculated nutrient agar plates using sterile forceps. The standard and control were tested in the plates which were impregnated in the sterile filter papers. Ciprofloxacin (10µg) was used as the positive control and distilled water was used as the negative control. Then the plates were incubated at 370C for 12-24 hrs. After incubation, the zone of inhibition was formed around the colonies and measured (Toppo KI et al., 2013).

III. RESULTS AND DISCUSSION

3.1. Sample collection and processing:

In this study, the pine apple and the lime peels were safely collected and processed. The peels were washed with water and air dried. Later, the peels were cut and dried in a hot air oven at 50^0C for several hours until the samples completely dry. After dried, the peels were grounded into a fine powder which was shown in the fig 3.1.

A) Pineapple peel

b) Lime peel

Fig 3.1: Powdered samples of pineapple and lime peels.

3.2. Extraction of biopolymers:

An aqueous extract of pineapple and lime peels were successively extracted using a soxhlet extraction which was shown in the fig 4.2 (a). In this extraction, dried, powdered samples and 200 mL of distilled water were used to extract phytoconstituents. The heating power was set and simultaneously adjusts the heat when the solvent starts boiling, to avoid chemical compounds damage. It was done in ten extraction cycles in three hours. The extracts were filtered using Whatman No. 1 filter paper. The filter biopolymers were heated and stirred for the pure compound which was shown in the fig 4.2(b) and 4.2(c).

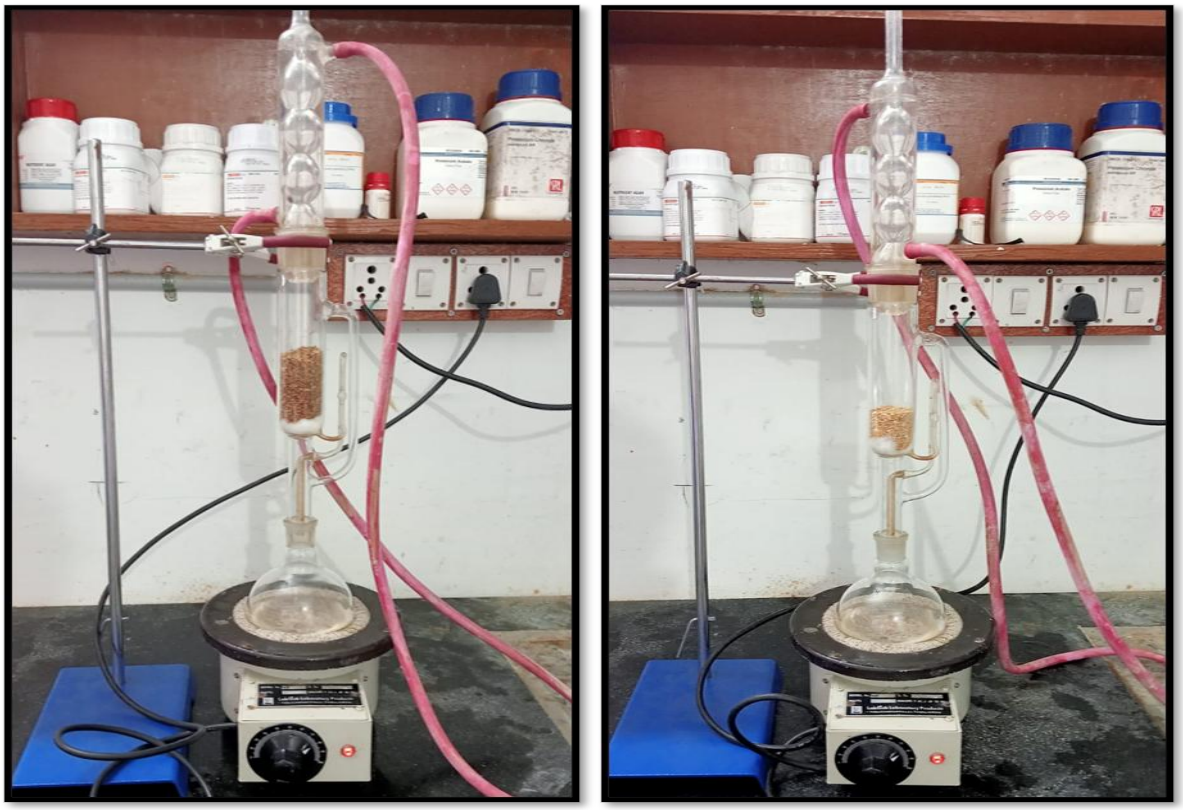
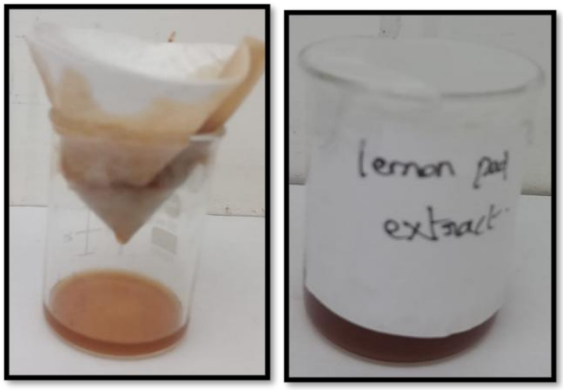
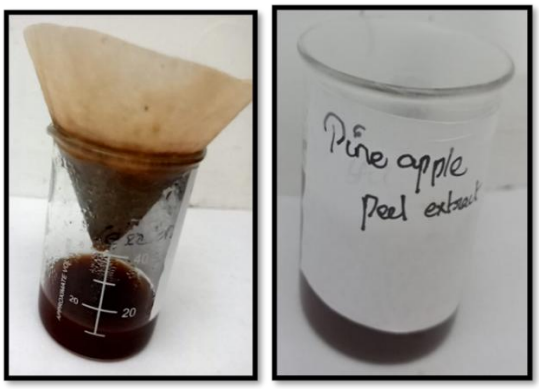


Fig 3.2(a): Aqueous extraction of pineapple and lime peels using soxhlet extractor



A) before b) after

Fig 3.2(b): Lemon peel extract



A) before b) after

Fig 3.2(c): Pineapple peel extract

3.3. Addition of plasticizer & film formation:

In this method, the extracted biopolymers were mixed with the plasticizers to form the bio film. The bio-firm samples were prepared by adding lime extract with glycerol & lime extract with gelatin; pineapple with glycerol & pineapple with gelatin; both pineapple and lime with glycerol & gelatin separately which was shown in the fig 4.3(a). These solutions were poured in slides, aluminium foil and petridishes as shown in the fig 4.3(b) to confirm whether the film is produced or not.

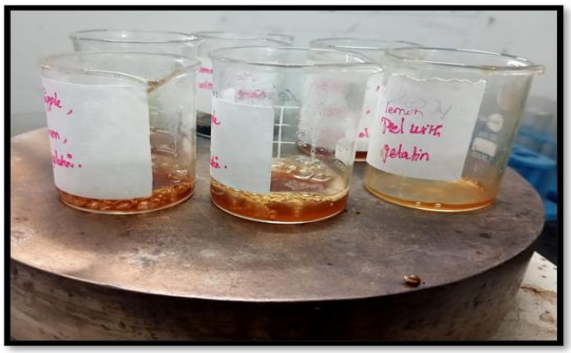


Fig 3.3(a): Plasticizers in biopolymers extract

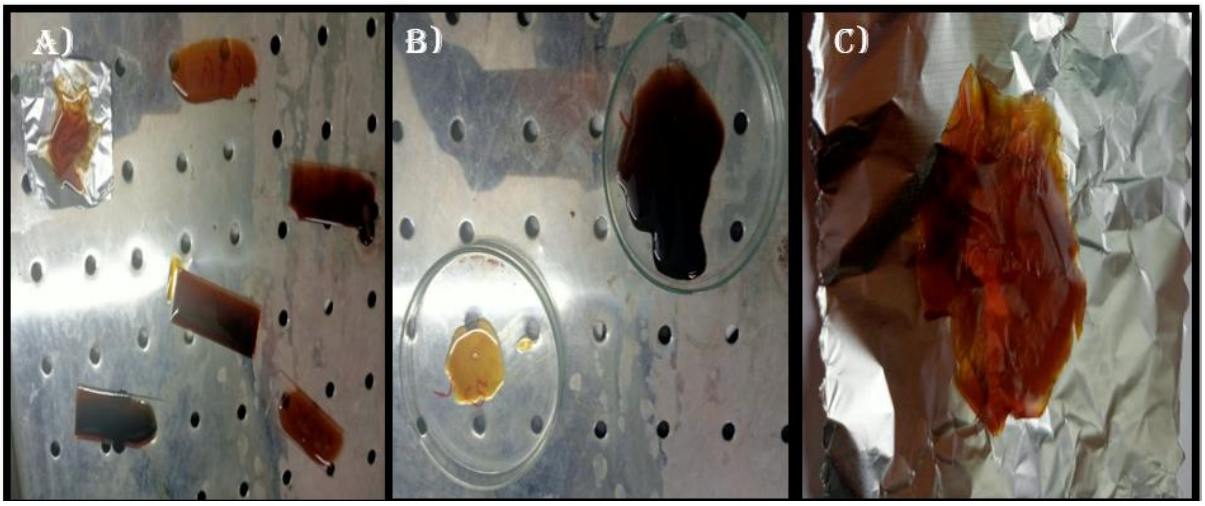
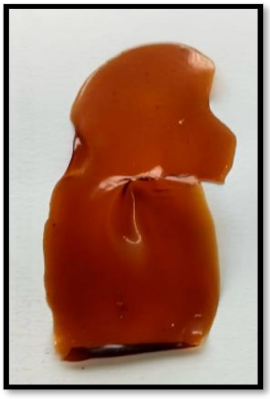


Fig 3.3(b): Formation of films

3.4. Drying and film curing:

The thin bio film was formed after dried the solutions in a hot air oven at 50^0C for 24 hrs which was shown in the fig 4.4. From these results, the extracted biopolymers with the addition of gelatin formed a thin bio-film, whereas in glycerol, a bio-film was not formed when compared to gelatin.

a) Lemon + gelatin



b) Pineapple + gelatin

c) Pineapple + lemon + gelatin

Fig 3.4: Bio-film formation

3.5. Characterization & testing:

3.5.1. Water Vapor permeability Test:

The Water Vapor Permeability (WVP) test was conducted to assess the moisture barrier properties of the biodegradable film developed from pineapple peel and lime peel. The film's WVP was determined under

controlled laboratory conditions following the standard cup method. The film exhibited a WVP of 2.85×10^{-10} g·m/m²·s·Pa, reflecting moderate permeability to water vapor. This is expected due to the natural hydrophilic constituents such as cellulose and pectin in pineapple peel, and organic acids and flavonoids in lime peel which tend to absorb moisture. Nonetheless, the film maintains suitable barrier properties for packaging applications involving dry or semi-moist products.

Table 1: Water Vapor Permeability (WVP) test

Parameter	Value
Film Thickness (mm)	0.115 ± 0.005
Test Temperature (°C)	25
Relative Humidity Gradient (%)	75% (inside cup) / 0% (outside)
Water Vapor Transmission Rate (WVTR)	4.92×10^{-3} g/m²·h
Water Vapor Permeability (WVP)	2.85×10^{-10} g·m/m²·s·Pa
Observations	Moderate permeability; suitable for dry or semi-moist food packaging

These results confirm that the pineapple–lime peel film offers a reasonable balance of biodegradability and water resistance, making it a promising candidate for sustainable packaging solutions.

3.5.2. FT-IR Analysis:

FTIR spectrum

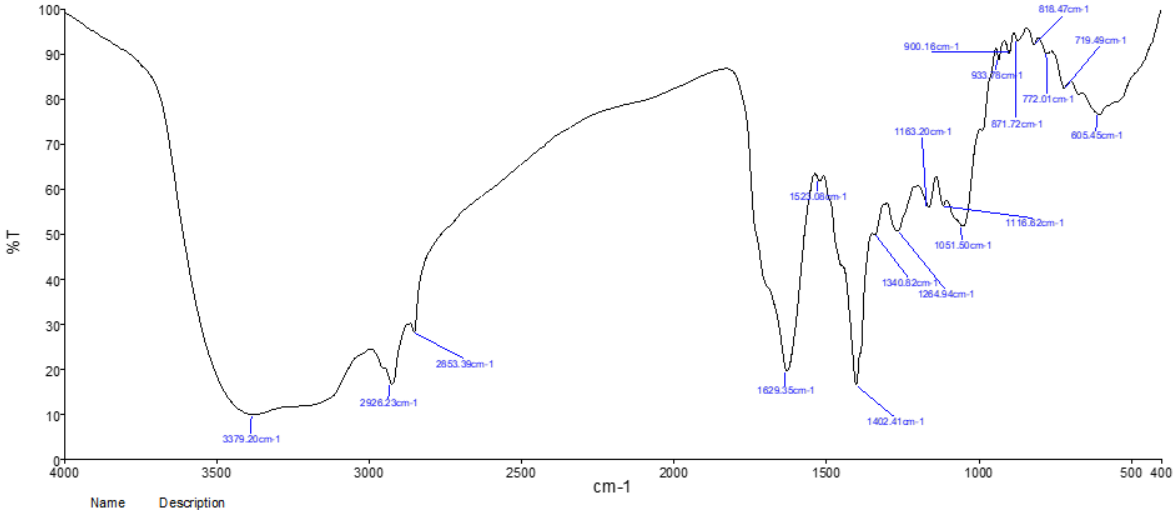


Fig 3.5: FTIR spectrum

Table 2: FTIR Peak details

S.NO	PEAK INTENSITY
1	3379.20
2	2926.23
3	2853.39
4	1629.35
5	1523.08
6	1402.41
7	1340.82
8	1264.94
9	1163.20
10	1051.50
11	1116.62
12	900.16
13	933.78
14	871.72
15	772.01
16	818.47
17	719.49
18	605.45

FTIR (Fourier Transform Infrared) spectroscopy was used to identify the functional groups present in the sample and to better understand its chemical composition. The spectrum showed a range of well-defined peaks, each representing specific molecular vibrations that point to the types of bonds and functional groups in the material. The most prominent peak appeared at 3379.20 cm^{-1}, which is typically associated with O–H or N–H stretching vibrations. This suggests the presence of hydroxyl or amine groups, commonly found in alcohols, phenols, or

proteins. Strong peaks at 2926.23 cm^{-1} and 2853.39 cm^{-1} were also observed, indicating C–H stretching vibrations from aliphatic hydrocarbons, pointing to the presence of long-chain organic compounds. A distinct peak at 1629.35 cm^{-1} may correspond to C=C stretching in aromatic rings or C=O stretching in amide linkages, suggesting some degree of conjugation or proteinaceous content. Another significant peak at 1523.08 cm^{-1} is likely due to N–O asymmetric stretching, which is often seen in nitro groups or other nitrogen-containing compounds.

In the mid-infrared region, peaks at 1402.41 cm^{-1} and 1340.82 cm^{-1} could be attributed to C–H bending or deformation vibrations, typically linked with methyl and methylene groups. Other smaller but meaningful peaks were recorded at 1264.94 cm^{-1}, 1163.20 cm^{-1}, and 1116.62 cm^{-1}, which are usually related to C–N or C–O stretching, suggesting the presence of amines, esters, or ethers. The fingerprint region, which lies below 1000 cm^{-1}, showed multiple peaks including at 933.78 cm^{-1}, 900.16 cm^{-1}, 871.72 cm^{-1}, 818.47 cm^{-1}, 772.01 cm^{-1}, 719.49 cm^{-1}, and 605.45 cm^{-1}.

3.5.3. SEM analysis:

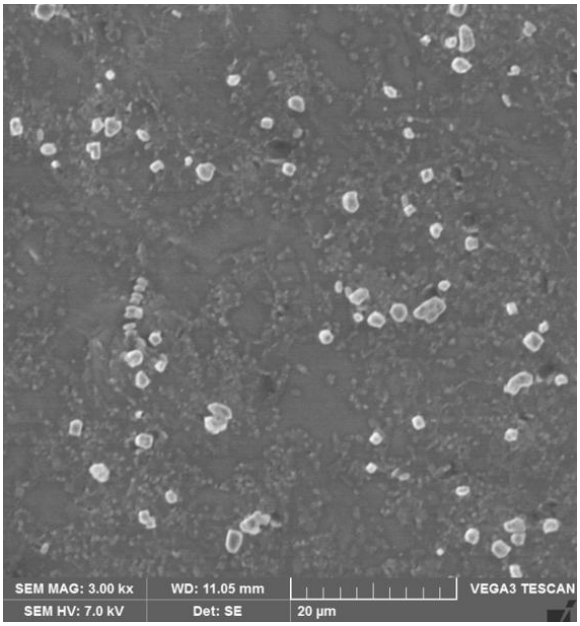


Fig 3.5: SEM image

The surface morphology of the biodegradable packaging film developed from pineapple peel and lime peel was examined using Scanning Electron Microscopy (SEM). The micrograph at 3.00 kx magnification provides clear evidence of the film's structural characteristics, directly influenced by the natural fiber and phytochemical content of the fruit peels. The film surface exhibits a heterogeneous texture, marked by the presence of dispersed granular and crystalline structures. These features are likely attributed to residual cellulose, hemicellulose, and pectin components from the pineapple peel, as well as citric compounds and flavonoids present in the lime peel. The particles appear irregularly shaped and vary in size, suggesting partial aggregation during the drying or film-casting process.

Despite the visible roughness, the overall matrix shows good film formation, with a compact base layer and absence of major cracks or voids. This suggests that the natural biopolymers extracted from the peels provided sufficient cohesion and structural integrity, even without synthetic additives.

3.5.4. Biodegradability Test:

Table 3: Biodegradability test

Burial Duration (Days)	Weight Loss (%)	Visual Observation
7	18.6%	Slight discoloration, edges begin softening
14	37.9%	Noticeable surface degradation, small tears
21	64.7%	Film becomes brittle, significant breakdown
28	85.3%	Film heavily fragmented, mostly decomposed

The film exhibited a progressive increase in weight loss over 28 days, with an 85.3% degradation observed at the end of the test period. This confirms the film's high biodegradability under natural soil conditions. The early onset of physical changes (e.g., softening and tearing) further supports its susceptibility to microbial activity and moisture absorption primarily due to the cellulose, hemicellulose, and pectin content in pineapple peel and the organic acids and flavonoids in lime peel. Such rapid degradation indicates that the film is environmentally friendly and suitable for short-term food packaging, especially for applications where compostability and waste reduction are desired.

3.5.5. Antibacterial activity:

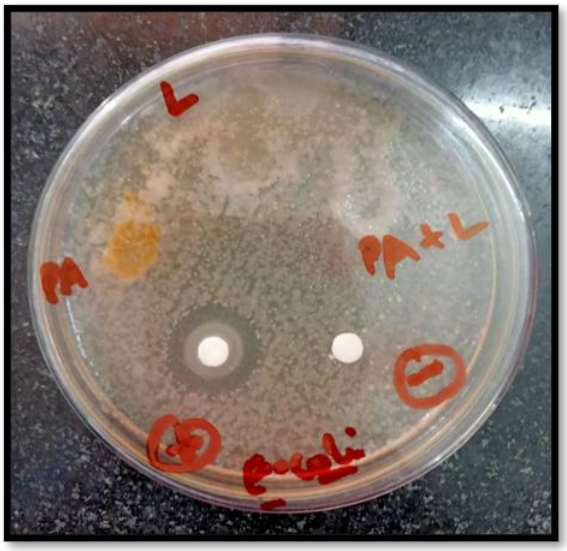


Fig: Antibacterial activity of different bio-films against E. coli

Note:
Disc size – 6mm
Standard used – Ciprofloxacin
The paper disc method with a 6 mm disc size was used to test the antibacterial activity of different bio-films against E. coli which was shown in Table. The result revealed that the sample showed no antibacterial activity against E. coli instead the bio-films degraded by the organism which was shown in the fig. Ciprofloxacin had a zone of inhibition (20 mm) against E. coli. Whereas, the negative control did not show any inhibition around the colonies. From these results, E. coli can degrade the bio-films easily.

Microorganism	Samples			Zone of Inhibition (in mm)	
	Pineapple	Lime	Pineapple + lime	Positive control	Negative control
E. coli	Nil	Nil	Nil	20	Nil

Table: Antibacterial activity of different bio-films against the organism E. coli.

IV. SUMMARY AND CONCLUSION

This study aimed to develop a biodegradable packaging film from pineapple and lime peels, exploring their potential in sustainable packaging applications. The process involved several key steps:

1) Sample Collection and Processing: Fresh pineapple and lime peels were collected, thoroughly washed, and air-dried. After drying in a hot air oven at 50-60°C, the peels were ground into a fine powder.
2) Extraction of Biopolymers: The biopolymers, pectin and cellulose, were extracted from the dried peels using soxhlet extraction with distilled water at 80°C for six hours. These biopolymers were then filtered and stored for use in the film preparation.
3) Film Formation: The extracted biopolymers from both pineapple and lime peels were mixed with plasticizers (gelatin or glycerol) to form the film solutions. The solutions were poured into petri dishes and dried in an oven at 50°C for 12-24 hours, resulting in thin, biodegradable films.
4) Characterization: The films were characterized through several tests:

a) Water Vapor Permeability (WVP): The films exhibited moderate water vapor permeability, making them suitable for packaging dry or semi-moist products.
b) FT-IR Analysis: FTIR spectra revealed the presence of functional groups, such as O–H, C–H, and C=O, confirming the complex chemical structure of the biopolymers derived from the peels.
c) SEM Analysis: Scanning Electron Microscopy (SEM) analysis showed a heterogeneous surface with granular and crystalline structures, indicating that the films had a robust and cohesive structure.
d) Biodegradability: The biodegradability test confirmed that the film degraded significantly over 28 days, with an 85.3% weight loss, highlighting the film's compostability and suitability for environmentally friendly applications
e) Antibacterial activity: The result revealed that the sample showed no antibacterial activity against E. coli instead the bio-films degraded by the organism Ciprofloxacin had a zone of inhibition (20 mm) against E. coli. Whereas, the negative control did not show any inhibition around the colonies. From these results, E. coli can degrade the bio-films easily.

The biodegradable film developed from pineapple and lime peels demonstrated excellent potential for sustainable packaging. The film showed moderate water vapor permeability, strong structural integrity, and high biodegradability, with an 85.3% weight loss over 28 days. These attributes, coupled with the eco-

friendly nature of the materials, position pineapple and lime peel-based films as a promising alternative to conventional synthetic packaging, particularly for applications requiring compost ability and waste reduction. This study underscores the potential of using fruit peel waste, specifically pineapple and lime peels, in the development of biodegradable packaging films, contributing to more sustainable and environmentally friendly packaging solutions.

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