



# PECTIFILM: A NATURAL BIOPOLYMER FILM DERIVED FROM CITRUS WASTE FOR SUSTAINABLE USE

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**Abstract:** Environmental pollution caused by non-degradable plastic waste has created a growing demand for eco-friendly alternatives. This study focuses on the development of a biodegradable bioplastic film using pectin, a natural polysaccharide extracted from plant sources. The film was prepared using the solvent casting method. Its mechanical strength, flexibility, water resistance, and visual appearance were evaluated to determine its suitability for practical use. The results showed that the pectin-based film possesses moderate strength, good transparency, and biodegradability, highlighting its potential as a sustainable material for pharmaceutical and packaging applications.

**Keywords :** bioplastic ,biodegradability, orange peel, film, phytochemicals

## I. Introduction:

### 1.1 Environmental Concerns and Bioplastic as Alternatives

Synthetic plastics, derived from non-renewable resources, have become ubiquitous in modern life, but their widespread use has led to significant environmental challenges. The non-biodegradable nature of these plastics means they persist in the environment for hundreds or even thousands of years, contributing to pollution in landfills, oceans, and other ecosystems. The constant demand for synthetic plastics has led to the accumulation of plastic waste due to its non-biodegradable attributes [1].

The environmental distresses and growing demands for food safety have led biopolymers to find noble applications in food packaging films because they are biodegradable, biocompatible, and nontoxic [2], [3]. This has spurred interest in developing sustainable alternatives, particularly bioplastics derived from renewable resources. Among these, pectin has emerged as a promising material for various applications, including food packaging [4].

### 1.2. Pectin as a Bioplastic Material

Pectin is a naturally occurring polysaccharide found in the cell walls of plants, particularly in fruits and vegetables such as citrus peels, apple pomace, and sugar beet pulp [5], [6], [3]. It is a complex heteropolysaccharide composed mainly of galacturonic acid, a sugar acid derivative of galactose. Pectin's ability to form gels and films makes it an attractive option for bioplastic production [7].

Pectin is a natural material that appears in a great proportion of fruits and vegetables such as berries, apples, and oranges [5]. Pectin is a mandatory polymer, and its use in industry has diverse applications that continue to grow [5]. Pectin is a necessary component in plant cell structure, and it consists of -(1, 4)-linked D- galacturonic acid residues in which a part of the galacturonic acid is esterified or an acetylated methyl or both [5]. Pectin can be extracted from plants and isolated as a bioplastic material with different applications, including food packaging [4]. Pectin, as a natural carbohydrate polymer,

belongs to the anionic heteropolysaccharide family and is extracted from various residues of plant processing, such as apple and citrus pomaces [6]. The pectin molecules are highly branched with a backbone of -(14) linked D galacturonic acid [6].

### 1.3. Advantages of Pectin-Based Bioplastics

Pectin-based bioplastics offer several advantages over conventional synthetic plastics:

- **Biodegradability:** Pectin is readily biodegradable, meaning it can be broken down by microorganisms in the environment, reducing the accumulation of plastic waste [8].
- **Renewability:** Pectin is derived from renewable plant sources, making it a sustainable alternative to petroleum-based plastics [9].
- **Non-toxicity:** Pectin is generally recognized as safe (GRAS) for food contact applications, ensuring that it does not pose a health risk to consumers [6].
- **Film-forming ability:** Pectin possesses good film-forming properties, allowing it to be easily processed into films and coatings [6].
- **Oxygen barrier properties:** Pectin films exhibit good oxygen barrier properties, which can help to extend the shelf life of packaged foods [2].

### 1.4. Natural Sources of Pectin

Pectin is found in the cell walls of all plants, but the most common commercial sources are:

- **Citrus peels:** Orange, lemon, and grapefruit peels are rich in pectin and are a major source for commercial production [12], [13], [10], [14], [15], [9]. Orange peel has a relatively high pectin content of 42.5%, which can be synthesized into bioplastic [12].
- **Apple pomace:** Apple pomace, a byproduct of apple juice and cider production, is another significant source of pectin [16], [6].
- **Sugar beet pulp:** Sugar beet pulp, a byproduct of sugar production, is also used for pectin extraction [6].
- **Other fruits and vegetables:** Pectin can also be extracted from other fruits and vegetables, such as passion fruit, papaya, and durian rind [17], [7], [18], [19]

## II. Literature Review:

On the Formulation of Pectin Bioplastic Film Pectin, a natural polysaccharide, has garnered attention as a sustainable biopolymer for bioplastic film formulation due to its biodegradability and film-forming properties. However, its brittle nature necessitates modifications through the incorporation of plasticizers, crosslinking agents, and biopolymer blends. Studies indicate that plasticizers such as glycerol and sorbitol enhance flexibility, while crosslinking agents like calcium chloride and citric acid improve structural stability and water resistance. Blending pectin with starch, chitosan, or gelatine further enhances mechanical properties and functional attributes. Additionally, the inclusion of essential oils, nanoparticles, and antioxidants has been explored to impart antimicrobial and barrier properties, making pectin-based films suitable for applications in food packaging, pharmaceuticals, and agriculture. Despite their potential, challenges such as moisture sensitivity and scalability remain, necessitating further research into advanced crosslinking techniques and nanocomposite formulations to enhance their industrial viability.

## III. Aim and Objective:

**3.1 Aim:** To develop a biodegradable pectin-based bioplastic film with optimized mechanical, thermal, and barrier properties for sustainable applications.

### 3.2 Objective :

**Optimizing Composition:** Enhancing the mechanical, thermal, and barrier properties of pectin-based bioplastics by incorporating plasticizers, cross-linkers, or reinforcing agents.

**Biodegradability & Sustainability:** Ensuring the material decomposes naturally, reducing plastic pollution and supporting circular economy principles.

**Functional Performance:** Improving flexibility, strength, and water resistance to meet industry requirements for packaging, agricultural films, or biomedical applications.

**Eco-Friendly Production:** Developing a cost-effective and scalable production process with minimal environmental impact.

**Application-Specific Adaptation:** Tailoring the formulation to specific industries such as food packaging, medical applications, or disposable items.

#### IV. Formulation table:

Sr.no	Ingredients	Quantity	Uses
1.	Pectin	1 gm	Binder
2.	Tragacanth	0.5 gm	Stabilizer
3.	Glycerol	5 ml	Plasticizer
4.	Dist. water	50 ml	Solvent
5.	Gelatin	1gm	Polymer

**Table no 01 :formulation table**

#### V. Procedure:

##### 5.1 Materials

- In this project work , orange peels were selected as valuable raw material in the preparation of bioplastic pectin film. They were collected from local juice store from Chinchwad. The required chemicals such as Glycerol , tragacanth and distilled water were at the Pharmacognosy Laboratory , RMDIPER , Chinchwad.

##### 5.2 Prepartion of orange powder

- The process of making orange powder pectin typically involves extracting pectin from the peels of oranges. Pectin is a natural carbohydrate found in the cell walls of fruits and is widely used as a gelling agent in jams, jellies, and other food products. Here's a general procedure for making orange powder pectin.

##### 5.3 Prepare the Orange Peels

- Peel the oranges, making sure to remove the outer peel but not the bitter white pith. Cut the peels into small pieces to increase the surface area for extraction.

##### 5.4 Extraction Pectin

- Place the chopped peels in a large pot and cover them with water (approximately 2-3 cups of water for every 1 cup of peel). Optionally, you can add a tablespoon of lemon juice to aid in the extraction.
- Bring the water to a boil, then reduce the heat and simmer for about 1-2 hours. The water should thicken slightly as pectin is released from the peels. Stir occasionally to prevent burning, and add water as needed to keep the peels submerged.

##### 5.5 Strain the Mixture

- After simmering, strain the mixture using a cheesecloth or fine mesh strainer into another container, separating the liquid from the solid peel pieces. The strained liquid is the pectin solution.



**Figure no 01. Extraction of pectin**

## 5.6 Procedure for bioplastic film

- **Prepare the solution:** In a beaker or a heat-resistant container, combine 50 ml of water with 1 gm of pectin. Stir the mixture until the pectin is completely dissolved.
- **Add the Tragacanth:** Add 1 gm of 0.5 gm of Tragacanth to the pectin solution. Stir continuously to ensure the ingredients dissolve properly.
- **Heat the mixture:** Place the beaker over low to medium heat and continue stirring to avoid burning or clumping. Heat the mixture for about 5-10 minutes or until it thickens. The mixture should be smooth and have a viscous consistency. Be cautious not to overheat.
- **Add glycerol:** Once the mixture has thickened, add 5 ml of glycerol to the solution. Stir well to evenly distribute the glycerol. Glycerol acts as a plasticizer, making the film more flexible.
- **Add gelatin:** Gelatin was added after glycerol to form the primary polymer matrix, enhancing the film's structural integrity and flexibility.
- **Cool and pour:** Remove the mixture from heat and let it cool for a few minutes. Once it's cool enough to handle, pour the mixture onto a flat surface, such as a silicone mat or a tray. You can also pour it into a mould if you want specific shapes or sizes.
- **Spread and smooth:** Use a spatula or a spoon to spread the mixture evenly across the surface to form a thin, uniform layer.
- **Dry the film:** Allow the film to dry for several hours (typically 12-24 hours) at room temperature. You can speed up the process by placing it in a warm, dry area, but avoid high heat, which can affect the texture of the film.
- **Peel off the film:** Once the film is completely dry and firm, carefully peel it off the surface or Mold. The drying time can vary based on environmental factors such as humidity and temperature. You can experiment with different ratios to optimize the strength, flexibility, and durability of the bioplastic film. This bioplastic film can be used for various applications like packaging or crafting, depending on its properties.



Figure no 02. process of bioplastic film

## VI. Characterization/ Evaluation of bioplastic film:

### 6.1. Organoleptic properties:

Organoleptic features describe a substance's sensory qualities, specifically those that can be detected by the senses of humans. The evaluation of organoleptic qualities is crucial when analysing bioplastics for a report in order to analyse their sensory components and potential influence on consumer acceptability. Some of the factors assessed are odour, colour, durability.

### 6.2. Biodegradation Test:

The biodegradation of the developed plastic was carried out according to the soil burial method. Two 250 ml beakers were used for the test; the orange peel derived film chopped at  $2 \times 2$  CMS dimensions, and each glass beakers are filled with mud of about 150 g. Preweighed films of weight 0.5 g chopped and were noted as an initial weight before soiling conditions and placed in the beakers at a depth of 5 cm from the mud surface. One of the film samples was sprinkled with water to study moisture content's

effect on the sample's degradation, while the other was without moisture. These two samples kept observed over for 24 hrs. The rate of degradation was observed after 24 hrs.

### 6.3. Solubility test:

To check the solubility of film, take various types of solvents such as tap water, acetone, chloroform, ethanol, methanol and petroleum ether. Then take the 1×1cm of film and dip into 10 ml of each solution and observe the solubility of film after 24 hrs.

### 6.4. Film thickness:

Film thickness was measured with a digital capillary. The thickness was measured in 10 randomly selected points on each film; an average value was calculated.

### 6.5. Moisture content determination:

The pre made film was firstly weighed and then kept into the hot air oven for 1 hour. Then the film was once more weighed. After that the result of following calculation for the percentage of moisture content are shown below.

#### Formula:

$$\text{M.C.(\%)} = (w_1 - w_2) \div w_1 \times 100$$

Whereas,

w<sub>1</sub> :- crucible weight with sample

w<sub>2</sub> :- crucible weight with sample after 45 min

### 6.6. Water absorption test :-

The pre made bioplastic film was weighed (0.50g) after being dried and soaked in water at room temperature for 30 mins. The finding of the following calculation of the percentage of water absorption are provided.

#### Formula :

$$\text{Water absorption (\%)} = (\text{wet wtg} - \text{dry wtg}) \div \text{wet wtg} \times 100$$

### 6.7. Tensile strength :

#### 7.1 Materials Needed:

- A. Two clamps (or binder clips)
- B. A ruler
- C. A plastic bag or soft string
- D. Weights (coins, water bottles, or sand-filled bags)
- E. A sturdy surface (table or beam)

#### 7.2 Procedure:

1. Cut the Film Sample: Cut a strip of your pectin film (e.g., 10 cm long and 1 cm wide).
2. Secure One End: Fix one end of the film to a rigid support using a clamp (e.g., attach to a table edge or door handle).
3. Attach Weights: Clip the other end of the film to a plastic bag or string. Gradually add weights (e.g., coins or small water bottles) until the film breaks.
4. Measure Force Applied: Weigh the total weight added (in grams or kilograms). Convert it into Newtons (1 kg ≈ 9.81 N).
5. Calculate Tensile Strength:

#### formula:

$$\{\text{Tensile Strength}\} = \frac{\text{maximum force (f)}}{\text{cross-sectional area (A)}}$$

### 6.8. Disintegration test :

1. Preparation :
  - Cut the film into uniform dimension (1x1cm).
  - Fill the disintegration vessel with distilled water.
2. Set condition :
  - Temperature of medium : 37 ± 0.5 °C
  - Up – down frequency : 20-25 cycles per min
  - Use the standard basket rack assembly .
3. Test :
  - Place one film sample in each tube of the basket.
  - Start the disintegration machine.
  - Observe and record the time taken for each film to completely disintegrate (i.e., no palpable fragments remain on the mesh).

## 4. Repeatability:

- Test 6 films for uniformity. Report the average disintegration time  $\pm$  standard deviation.

**VII Result and discussion: -****7.1 Organoleptic Properties: -**

Sr.no	Properties	Observation
1.	Colour	Orange
2.	Odour	Nil
3.	Texture	Smooth
4.	Transparency	Opaque
5.	Extensibility	Stretchable

**Table no 02: organoleptic properties****Fig no. 03. orange pectin based bioplastic film****7.2. Biodegradation test:-**

Material is biodegradable under soil conditions within 48hrs.

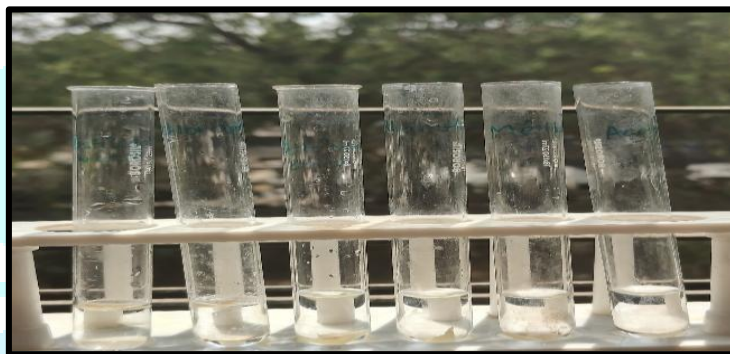
**Fig no.04. Film biodegradability test****Observation:**

1. **Visual changes :-** discoloration, cracks, surface erosion
2. **Physical degradation :-** Percentage of material lost
3. **Fragmentation :-** The sample broke into pieces

### 7.3 Solubility test: -

Sr.no	Solvent	Solubility (g/10ml)	Observation	Solubility class
1.	Water	1g/10ml	Clear solution	Freely soluble
2.	Petroleum ether	1g/10ml	Partially soluble	Sparingly soluble
3.	Ethanol	1g/10ml	Insoluble	Insoluble
4.	Methanol	1g/10ml	Insoluble	Insoluble
5.	Acetone	1g/10ml	Insoluble	Insoluble
6.	Chloroform	1g/10ml	Remained undissolved & showed swelling	Insoluble

**Table no03: solubility test**



**Fig no.05 Solubility of film in different solvents**

### 7.4. Film thickness:-

The average value of film thickness was found to be **0.4 mm**.

### 7.5. Moisture Content

$$\begin{aligned} \text{M.C. (\%)} &= (w_1 - w_2) \div w_1 \times 100 \\ &= (31.57 - 30.57) \div 30.57 \times 100 \\ &= 3.27 \% \end{aligned}$$

the moisture content of film was found to be **3.27%**.

### 7.6. Water absorption test :-

$$\begin{aligned} \text{Water absorption (\%)} &= (\text{wet wtg} - \text{dry wtg}) \div \text{wet wtg} \times 100 \\ &= (2 - 0.50) \div 2 \times 100 \\ &= 75 \end{aligned}$$

The water absorption percentage was found to be **75**



**Fig no.06. Water absorptivity test on film**

**7.7. Tensile strength:**

1cm wide (0.01m)

0.01mm thick

(0.0001m)

$$\text{Cross sectional area} = 0.01 \times 0.001$$

$$= 0.000001m^2$$

Break under 200g (0.2kg)

 $0.2 \times 9.81 = 1.962$ Tensile strength =  $1.96 / 0.000001$ **= 1.96 M****7.8. Disintegration test :**

The film takes 20 cycles per min for disintegration.

**Figure no 07. disintegration test****VIII. Future research should focus on:**

Developing cost-effective extraction and purification methods for pectin. Optimizing pectin film formulations for specific applications. Investigating the long-term performance and biodegradability of pectin films in different environments. Exploring new applications for pectin bioplastics in areas such as agriculture, pharmaceuticals, and cosmetics. Scaling up the production of pectin bioplastics to meet the growing demand for sustainable packaging materials. By addressing these challenges and pursuing these research directions, pectin bioplastics can be effectively synthesized. The chemical modification of pectin derived from orange peel, through carboxymethylation and thiolation, opens promising research avenues for the development of multifunctional bioplastic films. Future work can focus on optimizing the degree of substitution in both modifications to fine-tune film characteristics such as mechanical strength, flexibility, water vapor permeability, and biodegradability. The incorporation of bioactive compounds, nanoparticles, or natural antimicrobials into the modified pectin matrix could lead to the creation of active and intelligent packaging materials with extended functionality. In biomedical applications, thiolate pectin films offer significant potential for drug delivery due to their enhanced mucoadhesive properties and enzymatic resistance; however, further in-vivo studies are necessary to assess their biocompatibility, degradation behavior, and sustained release profiles. Co-modification strategies—combining carboxymethyl and thiol groups—may produce hybrid films with synergistic effects, such as improved water resistance alongside strong mucoadhesion, making them suitable for advanced wound dressings or smart fertilizer carriers. Additionally, scale-up studies and techno-economic analyses are essential to evaluate the feasibility of industrial production. Emphasis should also be placed on environmental degradation studies and lifecycle assessments to ensure the integration of such materials into circular economy frameworks and sustainable bioplastic initiatives lay a significant role in creating a more sustainable and environmentally friendly future.

**IX. Conclusion :**

A pectin-based bioplastic film was successfully developed and evaluated. The film exhibited acceptable mechanical and barrier properties, making it a viable eco-friendly alternative to conventional plastics. Its natural origin, biodegradability, and ease of preparation support its potential use in pharmaceutical packaging and related fields. Further work can focus on enhancing its flexibility and durability through natural modifications or blends with other biopolymers.

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