INVESTIGATING THE COMPLEXITIES OF PLASTIC RECYCLING CHALLENGES AND REVOLUTIONARY STRIDES IN ORANGE PEEL BIOFILM RESEARCH

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Abstract -

Our study aims to check the feasibility of utilizing orange peels for the production of bioplastic, presenting a sustainable alternative to conventional plastics. The bioplastic film derived from orange peel waste exhibits promising mechanical properties, surpassing starch-gelatin blend films in micro tensile strength while offering greater elongation capabilities. Through analysis, including FTIR spectroscopy, XRD, TGA, SEM, and elemental composition assessment, the study elucidates the chemical composition, structural characteristics, and thermal behaviour of the orange peel bioplastic. Surface morphology analysis reveals a heterogeneous structure with fibres and particles, while elemental composition analysis identifies predominant elements such as oxygen, carbon, and calcium. The bioplastic demonstrates potential for aerobic microorganism degradation, enhancing its environmental compatibility. The dual environmental benefits of utilizing citrus waste for bioplastic production, mitigating landfill burdens and offering a biodegradable alternative to conventional plastics. However, challenges such as water resistance optimization remain, necessitating further research and development for broader applications. Overall, orange peel bioplastic presents a promising avenue for sustainable materials, paving the way for a more environmentally responsible future in packaging and beyond.

Keywords – Circular economy, Innovative solutions, orange peel biofilm, Plastic recycling challenges,Sustainable materials

Introduction

Bioplastics, derived from renewable resources such as biomass, sugarcane bagasse, and organic waste, represent a sustainable alternative to traditional plastics, as they can degrade fully or partially, minimizing environmental impact. While cellulose and starch-based bioplastics are commonly used in packaging, utensils, and other applications, their effectiveness is often hindered by cost and performance limitations compared to conventional plastics. To address this challenge, our research focuses on creating bioplastic from food waste, with orange peel chosen for its abundant cellulose content. This innovative approach opens up new avenues for utilizing agricultural by-products. Our developed bioplastic film, enriched with glycerol as a plasticizer, exhibits consistent and promising characteristics, including remarkable strength, flexibility, and degradation under soil conditions. The rough surface morphology further confirms its biodegradability. Through advanced characterization techniques such as Fourier transform infrared (FTIR) spectroscopy, Thermal gravimetric analysis (TGA), powder X-ray diffraction (XRD), and Scanning electron microscope (SEM) analysis, we validate the bio-based composition and surface structure of our material.

Table 1. Challenges in Plastic Recycling

Challenges	Plastic Types
Difficulty removing contaminants	Mixed waste plastic (including polyethylene)
Low yield of pyrolysis products	Waste polyethylene
High energy consumption	Waste polyethylene
Need for catalyst in pyrolysis	Waste polyethylene
Need for appropriate processing for diesel engines	Waste polyethylene
Potential emissions of pollutants during combustion	Waste polyethylene
Need for further research for fuel use	Waste polyethylene

Difficulty separating different plastics	Mixed waste plastic
Need for sorting and processing equipment	Low-density polyethylene (LDPE)
Need for a market for recycled plastics	Mixed waste plastic
Difficulty separating LDPE from other plastics	Low-density polyethylene (LDPE)
Need for appropriate processing equipment for LDPE	Low-density polyethylene (LDPE)
Need for a market for recycled LDPE	Low-density polyethylene (LDPE)
Influence of catalyst on thermal degradation	Low-density polyethylene (LDPE)
Effect of temperature, residence time, and oxygen on degradation products	Low-density polyethylene (LDPE)
Need for research to optimize degradation conditions	Polyethylene terephthalate (PET) bottles
Contamination, degradation, difficulty separating PET	Polyethylene terephthalate (PET) bottles
Need for advanced sorting and improved recycling technologies	Polyethylene (PE) waste
Presence of contaminants leading to undesired products	Polyethylene (PE) waste
Need for appropriate pre-treatment methods	Polyethylene (PE) waste
Presence of contaminants reducing mechanical properties	Polyethylene (PE) waste

Table 1. explains various challenges in plastic recycling. Challenges of recycling polyethylene and polypropylene packaging materials from a circular economy perspective. Traditional mechanical and chemical recycling methods are not sufficient to meet the increasing demand for sustainable plastic solutions. Propose a novel approach called "polymer upcycling," which involves transforming waste plastics into high-value products with improved properties. The main challenge associated with this approach is the lack of infrastructure and technological know-how to implement it on a large scale [1]. Challenges of recycling polyethylene terephthalate (PET) bottles. While mechanical recycling is effective in producing low-grade products such as textiles and fibres, it is not suitable for producing high-quality products due to contamination and degradation during the recycling process. A chemical recycling method called "methanolysis," which can produce high-quality monomers for the production of virgin-quality PET. The main challenge associated with this approach is the high cost of the methanolysis process [1]. Challenges of plastic waste management, including the recycling of polyethylene. The lack of a standardized approach to plastic waste management, coupled with the low economic value of recycled plastics, creates a disincentive for investment in plastic recycling infrastructure. The development of a "circular plastic economy" that incorporates waste reduction, reuse, and recycling, as well as policy interventions, is needed to address the challenges of plastic waste management [2]. Mixed plastic waste, including polyethylene. The low economic value of mixed plastic waste, combined with the high cost of sorting and recycling, makes it difficult to implement large-scale recycling programs. A recycling method that involves separating the mixed plastic waste into its individual components using a combination of physical and chemical processes. The main challenge associated with this approach is the high cost of the separation process [3].

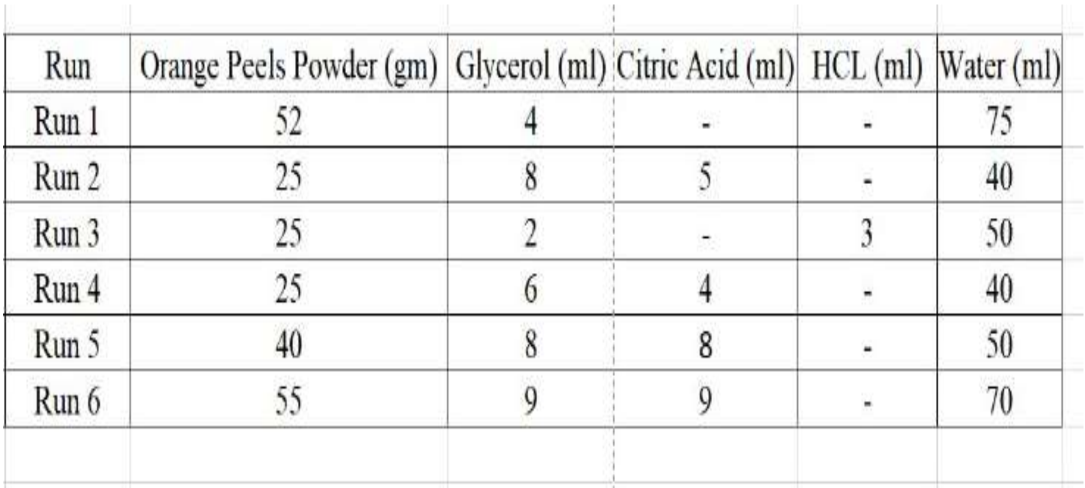
Challenges of recycling polyethylene and other plastics in the chemical process industries. the recycling of plastics in these industries is hampered by the low value of recycled plastics, as well as technical challenges related to the processing of recycled plastics. A method that involves using waste plastics as a fuel source in the production of electricity and steam. The main challenge associated with this approach is the need to overcome technical and regulatory barriers to the use of waste plastics as a fuel source [4]. Challenges associated with this method is the low yield of pyrolysis oil obtained, which limits its economic viability. Additionally, the composition of the pyrolysis oil is complex, which makes its upgrading and utilization challenging [1]. Challenges associated with this method is the development of a highly selective and efficient catalyst that can selectively break down polyethylene into useful chemicals, without producing large amounts of waste [5]. The thermal degradation of polyethylene in the presence of various additives. One of the challenges associated with this method is the potential release of toxic by-products during the degradation process, which can have negative environmental impacts [6]. The pyrolysis of polyethylene using different catalysts. The limited selectivity of the catalysts used, which can result in the formation of undesired by-products [7]. Difficulty in separating different types of plastics, the need for more efficient recycling technologies, and the lack of a well-established market for recycled plastics [1].

A process for the recycling of polyethylene waste by converting it into fuel. The need for a method that is energy-efficient and economically viable, as well as the issue of contamination of the polyethylene waste with other materials [8]. Presence of impurities such as dyes, additives, and other contaminants that can affect the quality of the recycled PET material. A method for removing these impurities using a proprietary process [1].

2.Materials and Methods

We gathered orange peels from the market in Pune, India, ensuring they were all from the same place. These peels were then stored in a refrigerator at around 15°C until they were needed. The orange peels were crushed to extract their components. Then, they were dried in an oven set to a temperature of 120°C for 10 minutes to remove any excess moisture. After drying, 25 grams of the crushed orange peel were used for further processing. To the crushed orange peel, 3 milliliters of 0.1 normality (N) hydrochloric acid (HCl) were added and mixed. Then, 180 milliliters of glycerol were added to this mixture along with distilled water.

Everything was thoroughly mixed to create a uniform paste. The resulting paste was poured into molds to give it a specific shape. Additionally, a portion of the paste was spread onto a glass slab and left at room temperature for approximately 48 hours. After the incubation period, which was 48 hours, the film could be easily removed from the molds or the glass slab. All steps were repeated three times to ensure the reliability and consistency of the experiment. The thickness of the resulting film was measured to be 0.2 millimeters. We poured this mixture into molds to give it the shape we wanted. We also spread some of it onto a flat surface. Then, we let it sit at room temperature for about two days. After two days, the film was ready. It was easy to peel it off from the molds or the flat surface. We did this whole process three times to make sure our results were consistent. The film we made was about 0.2 millimeters thick.



Run	Orange Peels Powder (gm)	Glycerol (ml)	Citric Acid (ml)	HCL (ml)	Water (ml)
Run 1	52	4	-	-	75
Run 2	25	8	5	-	40
Run 3	25	2	-	3	50
Run 4	25	6	4	-	40
Run 5	40	8	8	-	50
Run 6	55	9	9	-	70

Fig 1. Total 6 runs performed by varying amount of Water, Glycerol, HCL, Citric acid, peels powder.

Figure 2. Overall process for orange peels biofilm formation.

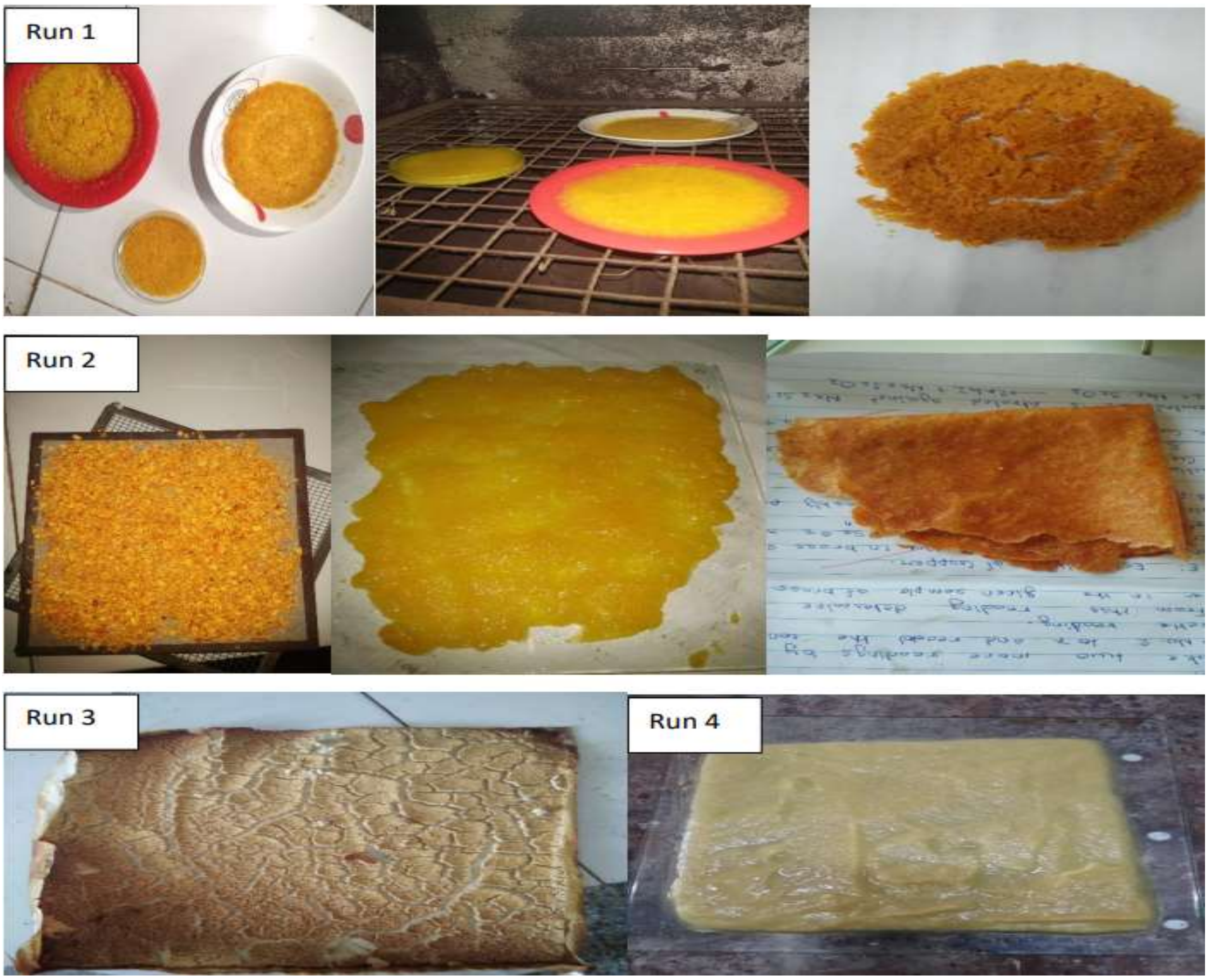


Fig 3. Experiments performed for biofilm production.

Orange Peels Oil extraction using soxhlet process.
The orange peels oil was extracted using 25 g orange zest with 200ml Ethanol as a solvent at 70 Degree C and for 1 hour. The extracted oil was further applied at biofilm which increases the antioxidant properties of biofilm [20].
Table 2 explains Amount of Feed and Solvent for Soxhlet Process at 70C for 1 hour.

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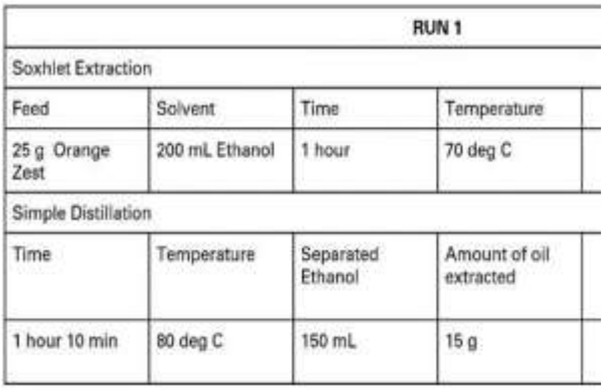


RUN 1			
Soxhlet Extraction			
Feed	Solvent	Time	Temperature
25 g Orange Zest	200 mL Ethanol	1 hour	70 deg C
Simple Distillation			
Time	Temperature	Separated Ethanol	Amount of oil extracted
1 hour 10 min	80 deg C	150 mL	15 g

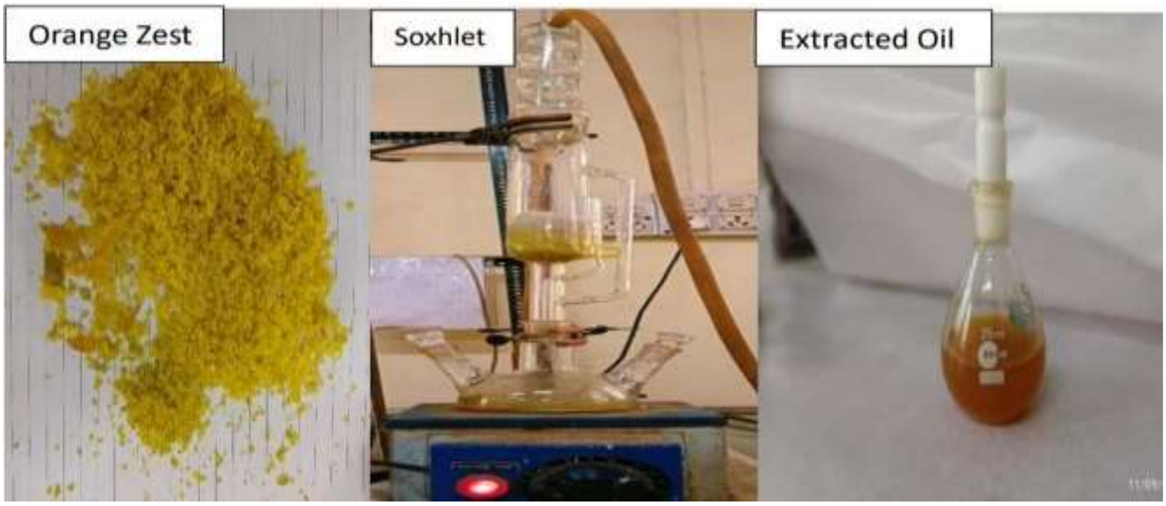


Fig 4. Orange zest Oil Extracted Using Soxhlet which is further applied on Biofilm.

3.Characteristics

3.1. Water, Oil Permeability, Biodegradation Test

We assessed the biodegradability of the plastic developed from orange peel waste using the soil burial method [9]. In Fig 5, Two 250 ml beakers were prepared, each containing approximately 150 g of mud. Film samples derived from orange peel were cut into dimensions of 2x2 cm and placed at a depth of 5 cm from the mud surface in each beaker. One sample was sprinkled with water to simulate moisture conditions for degradation, while the other remained without additional moisture. Both samples were observed over the course of one month, and their degradation rates were evaluated by analysing the data obtained from the observation period. Additionally, we evaluated the oil and water permeability of the developed sample based on previous reports [9].

Fig 5. Biodegradability Test.

3.2. FTIR (Fourier Transform Infrared) Analysis

The chemical interactions between components in the bio-based material sample using Fourier Transform Infrared (FTIR) spectroscopy. The sample, dissolved in chloroform, was spread as a smear onto a sodium chloride (NaCl) block. Subsequently, FTIR analysis was conducted in the range of 450 to 4000 cm^-1 using a Spectrum 2 FT-IR/SP 10 instrument by PerkinElmer, Singapore Pte. Ltd. This analysis was performed in Attenuated Total Reflection (ATR) mode with a spectrum resolution set at 1 cm^-1 and a scan rate of 100 scans per second. FTIR helped us understand the chemical composition and structure of the bio-based material [10].

3.3. XRD (X-Ray Diffraction)

Used a Philips Analytical X-ray Diffractometer to obtain the powder X-ray pattern of the plastic made from orange peel waste. A sample approximately 107 mm thick was placed on the sample holder for analysis. The sample was scanned in reflection mode, meaning X-rays were directed onto the sample at various angles (2θ) ranging from 5 to 60 degrees. The scanning speed was set to 8 degrees per minute. This allowed to identify the crystal phases present in the dried film, providing insights into the material's structure and composition [11].

3.4. TGA (Thermogravimetric Analysis)

Thermogravimetric analysis (TGA) of the plastic made from orange peel waste was performed using an SDT Q600 Instrument. The analysis was conducted under an artificial air atmosphere to simulate real-world conditions. Approximately 6.56 mg of the sample (including the sample holder) was loaded into a platinum crucible. The sample was then subjected to heating from ambient temperature to 600°C at a constant rate of 10°C per minute. This process helped to understand how the material responds to heat, revealing its thermal stability and decomposition behaviour [12].

3.5. SEM with EDS Analysis

Scanning Electron Microscope (SEM) from JEOL-JSM-IT500 in Tokyo, Japan, to examine the surface and cross-sectional areas of the plastic made from orange peel waste. Before analysis, the sample was thoroughly dried and then coated it with a conductive layer of aluminium sheet approximately 40 nm thick. This coating helps in making the sample conductive for SEM analysis. Analysed the sample at an acceleration voltage of 20 kV and a magnification of 4500. Additionally, used Energy Dispersive X-ray Spectroscopy (EDS) to determine the elemental composition of the plastic. This analysis helped to understand the structure and composition of the plastic [12].

3.6. Mechanical Analysis

A tensile test according to ASTM D882-2 standards to evaluate the mechanical properties of the plastic made from orange peel waste. The test was performed using a Micro Tensile Universal Testing Machine, with a cross-head speed of 0.5 mm/min. Samples with dimensions of 40 x 50 x 0.2 mm were analysed. During the test, measured the force required to break the plastic, as well as the extent of sample stretch and elongation up to the breaking point. These parameters helped in determining the mechanical strength and flexibility of the plastic [12]

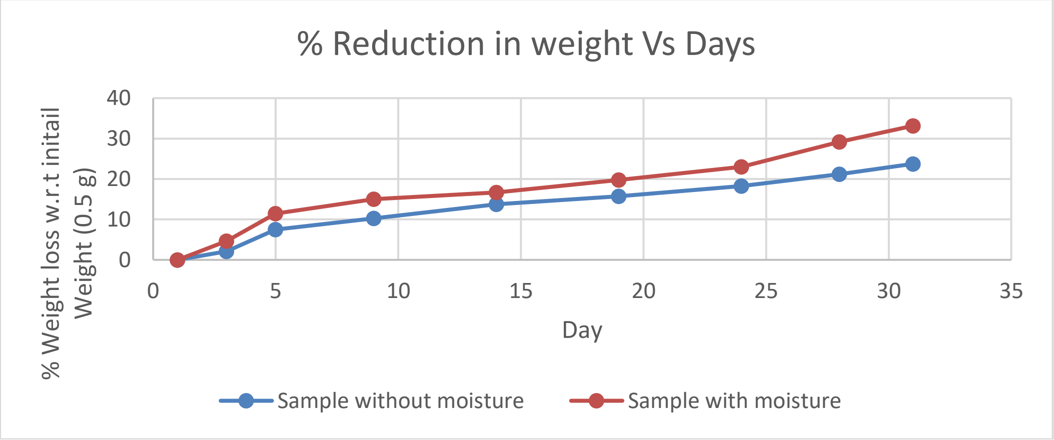
4.Results

4.1. Water, Oil Permeability, Biodegradation Test

The biodegradation test conducted over 31 days showed that the degradation of the sample in soil gradually increased after the initial period where soil microbial life acclimatized to the material [9]. Components like starch, pectin, and cellulose present in orange peel served as carbon sources for the growth of microorganisms in the soil. These microorganisms produced enzymes that kick-started the breakdown of the film, leading to a noticeable decrease in weight by the 19th day.

Results indicated that degradation happened faster when there was additional moisture present compared to natural conditions. Approximately 33.18% degradation was observed with extra moisture, while 23.76% degradation was observed without extra moisture. This suggests that the bioplastic derived from orange peel can degrade within roughly three months without extra moisture and possibly over four months or longer with moisture. Fig 6. explains percent reduction in sample with moisture and without moisture [12].

Fig 6. Percent reduction in sample with moisture and without moisture. [12]



4.2 Film formation Characteristics

The bio-plastic made from orange peel showed rigidity, mainly due to the presence of pectin and cellulosic fibers. The addition of oil and glycerol acted as plasticizers, helping to bind the material together [25]. However, it was observed to be relatively rigid and less flexible, which makes it suitable for items like biobased spoons, straws, and cups. Nonetheless, there's room for improvement for wider commercial applications and sustainable packaging. To enhance its usefulness and impact strength, it's important to address factors such as rigidity, flexibility, and hydrophobicity. The film exhibited oil permeation of 16.2 ± 3 and water permeation of 903 ± 57, suggesting potential suitability for packaging applications [15]. Its ability to retain oil and water was better than what was reported in previous studies. Moreover, its versatility in terms of thickness and opacity suggests it can be used in various applications. Additionally, the film's translucency offers potential advantages in specific uses [26].

4.3. FTIR Analysis

Significant bands indicative of chemical groups present in polysaccharides were observed. Alcohols (3352.82 cm^-1) and carboxylic acids (2919.84 cm^-1) were detected, suggesting the presence of functional groups typically found in polysaccharides[16-24]. Ketone (1691.92 cm^-1) stretching band indicates the presence of carbonyl groups, which could be attributed to certain components in the orange peel. Alkene/aromatic/amino acids (1604.83 cm^-1) stretching band suggests the presence of aromatic compounds or amino acids. The ratio among these bands can be used to measure the degree of esterification, which is crucial for understanding material properties.

Analysis of the FTIR spectra showed the presence of alcoholic and sp3 hybridized carbon atoms, along with sp2 hybridized carbon atoms, indicating decent bond strength within the material.

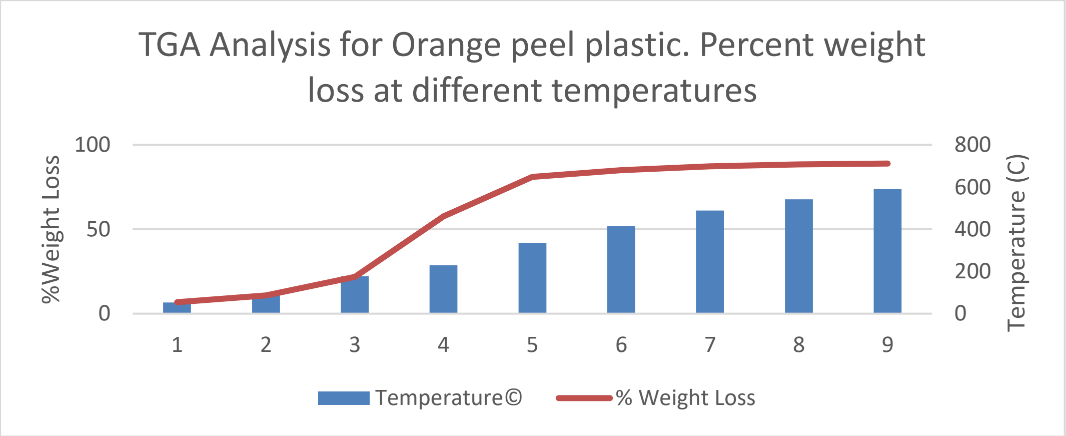
4.4 XRD Analysis

Broad peaks observed in the X-ray diffractogram indicate the amorphous nature of orange pectin. This suggests that the molecular structure lacks long-range order typically associated with crystalline materials [12].

4.5 Thermogravimetric Analysis (TGA)

Four main steps of thermal degradation were observed, each corresponding to different components of the orange peel. Water evaporation occurred in the temperature range of 150-250°C. Hemicellulose degradation and cellulose chain disintegration took place in the temperature range of 250-360°C. Lignin disintegration occurred in the temperature range of 380-585°C. Significant gas release, including CH4, CO, CO2, light hydrocarbons, and water vapor, was observed during the degradation processes. Complex phenolic compounds [12].

Fig 7. TGA Analysis [12].



4.6 Micro tensile analysis

The influence of chemical composition, structure, and film formation on the mechanical strength of bioplastic film made from orange peels. Compared the film's micro tensile strength and elasticity to starch-based and conventional polyethylene (HDPE) plastics. The orange peel-derived plastic (A1) displayed a superior micro tensile strength of 7.38 MPa, exceeding the typical starch-gelatin blend film (A2) with 1.35 MPa. However, A1 exhibited a lower modulus of elasticity (25.33 MPa) compared to A2 (53.4 MPa) and significantly lower than conventional plastic (A3) with a modulus of 800 MPa [27-29]. These results suggest that the orange peel bioplastic film offers greater elongation capabilities and forms a more uniform structure compared to starch-gelatin blends.

4.7 Elemental composition and Surface morphology

4.7.1 Surface Morphology

The surface appeared rough and uneven, indicating a heterogeneous structure. Fibers and particles of varying shapes and sizes were observed, suggesting a complex microstructure. The presence of uneven pores, smooth, and highly irregular particles further emphasized the heterogeneous nature of the surface [32-37]. Different polymers present in the material influenced the shape of the particles, contributing to the overall surface morphology. At a magnification of 200x, the surface appeared uniform, indicating an even distribution of particles in the composite film and the formation of more intact structures.

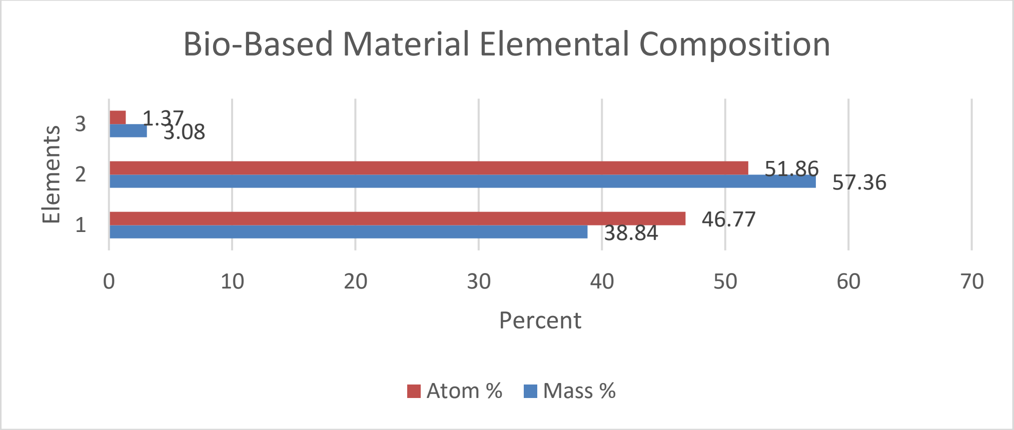
4.7.2 Elemental Composition

The elemental composition analysis revealed the following predominant elements:

1) Carbon atoms: 38.84 ± 0.28%
2) Oxygen molecules: 57.36 ± 0.81%
3) Calcium: 3.80 ± 0.14%

The high percentage of oxygen molecules suggests that the material would facilitate aerobic microorganism degradation, which could be advantageous for certain applications. Fig 8. explains Bio-Based Material composition. Carbon atoms contribute to the organic nature of the material. The presence of calcium indicates the incorporation of this mineral, which could contribute to the strength and structural integrity of the material [37-40].

Fig 8. Bio-Based Material composition [12].



Conclusion

Utilizing orange peels for bioplastic production offers a two-fold environmental benefit. Firstly, it diverts citrus waste from landfills, reducing disposal challenges. Secondly, the resulting bioplastic itself can potentially decompose through natural processes, unlike conventional plastics. The bioplastic's strength comes from its inherent components. Pectin and cellulose fibers, naturally present in orange peels, provide structural integrity. This, combined with biodegradability, makes the material ideal for short-term packaging applications. However, development are needed to address specific properties like water resistance (hydrophobicity). Optimizing these characteristics will be crucial for expanding the potential applications of this eco-friendly biomaterial. Overall, orange peel bioplastic represents a promising avenue for creating sustainable alternatives to conventional plastics. It not only tackles waste management issues but also utilizes fruit waste effectively, paving the way for a more environmentally responsible future.

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