

Development And Characterisation of Biodegradable Packaging Film Using Apple Pomace Pectin and Potato Peel Starch

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Abstract—Traditional packaging made from petroleum (about 90% of the 144 Mt annual demand) produces significant waste and CO₂ emissions, which drives the search for biodegradable alternatives. In this study, compostable films were created using agro-industry Sample byproducts: pectin derived from apple pomace and starch extracted from potato peels. Pectin was obtained through a "green" extraction process using citric acid and sodium citrate, and films were produced by solvent casting mixtures of pectin and potato starch in various proportions (1:0, 1:1, 1:2, 1:3, 3:1). The characterization involved tensile testing, assessments of water vapor and oxygen permeability, water absorption, density, thickness, oil resistance, and optical clarity. The optimized formulation (pectin: starch ratio of 1:2) demonstrated a tensile strength of approximately 7.2 MPa, low gas permeability, about 63% water absorption, a light density of 269 kg/m³, a thickness of roughly 0.2 cm, minimal oil transmission with only 0.24% grease spotting, and high levels of transparency. Significantly, an increase in starch content led to greater film thickness and a decrease in water solubility and vapor permeability, resulting in improved barrier and mechanical characteristics. These enhancements, along with rapid biodegradation, indicate that the films are well-suited for use in food packaging. By utilizing food-processing byproducts, this research further supports circular bioeconomy goals and decreases dependence on plastic derived from petrochemicals.

Index Terms—Biodegradable film, apple pomace pectin, potato peel starch, solvent casting, food packaging, circular bioeconomy

I. INTRODUCTION

The increased global emphasis on sustainable packaging, driven by environmental concerns and stiffer regulatory requirements, has accelerated research into biodegradable alternatives to petroleum-

based plastics. Although synthetic polymers have good mechanical strength and barrier qualities, they are non-biodegradable, which creates significant environmental challenges. In this regard, agricultural byproducts such as apple pomace and potato peels have emerged as attractive raw materials for the production of bio-based packaging films. Apple pomace-derived pectin and potato peel starch are both eco-friendly, low-cost, and widely available biopolymers with excellent film-forming properties. When combined, they provide synergistic benefits by increasing tensile strength, flexibility, and barrier qualities, making them suited for sustainable packaging solutions. This study aims to extensively assess the potential of apple pomace pectin and potato peel starch for biodegradable film production. It emphasizes their extraction processes, film formulation techniques, physical and functional properties, and overall contribution to waste valorization. and the circular economy.

APPLE

Apple is a widely farmed fruit crop in India, particularly in Jammu and Kashmir, Himachal Pradesh, and Uttarakhand, where it contributes significantly to local economies. A significant number of apples are processed into juice, pulp, and concentrates, leaving apple pomace as the primary residue. It is estimated that India creates more than 10,000 tons of apple pomace trash annually.

Because apple pomace is highly biodegradable, inappropriate disposal near processing facilities can cause environmental damage and economic losses for the fruit processing industry.

POTATO PEEL

Potato peel, a byproduct of the potato processing industry, is frequently discarded as garbage, adding to environmental issues. However, it is a rich source of starch that may be used as a low-cost raw material in a variety of food and manufacturing applications. Potato peel starch is biodegradable, renewable, and has significant film-forming and thickening capabilities, making it an ideal choice for the production of biodegradable packaging films, adhesives, and functional foods. Extracting starch from potato peels not only increases the value of agricultural waste, but it also promotes sustainable resource use and lowers pollution. As a result, starch recovery from potato peels is an environmentally friendly and sustainable solution that adheres to circular economy concepts in the food industry.

**II. MATERIAL AND METHODOLOGY
MATERIALS**

The major raw materials employed in the development of biodegradable packaging films were apple pomace and potato peels, which were collected as byproducts

from local juice processing facilities and fruit markets. The study used analytical-grade chemicals and reagents, such as hydrochloric acid (HCl) for pectin extraction, 95% ethanol for pectin precipitation, sodium hydroxide (NaOH) for starch isolation, and distilled water as the solvent medium. Plasticizers such as glycerol and sorbitol were used to increase the films' flexibility, tensile strength, and workability. All reagents were used without additional purification.

PREPARATION OF RAW MATERIALS

To remove any remaining dirt and contaminants, apple pomace and potato peels were carefully rinsed with distilled water. The cleaned materials were then dried in a hot air oven at 50-60°C for 24-48 hours to attain a constant weight. The dried materials were finely ground with a mechanical grinder and sieved through a 60-mesh sieve to ensure uniform particle size. The resulting powders were stored in sealed containers at room temperature for future use.

FORMULATION

Table 1.1 Ingredient Composition for Product Formulation

Component	Sample1	Sample2	Sample3	Sample4	Sample5
Potato peel Starch(g)	5	2.5	2.5	1.5	4.5
Apple Pomace Pectin (g)	-	2.5	5	4.5	1.5
Biopolymer(g)	5	5	7.5	6	6
Distilled water(ml)	100	100	150	100	100
Glycerol(ml)	2	2.5	3	3	3
Casting per volume	30	30	30	30	30

EXTRACTION OF PECTIN FROM APPLE POMACE (ACID HYDROLYSIS METHOD)

Pectin extraction was done using the acid extraction method. Approximately 50 g of dried apple pomace powder was combined with 500 mL of 0.05 N hydrochloric acid (HCl) and cooked at 80°C for 1 hour, stirring constantly. The heated extract was filtered using muslin cloth, followed by Whatman No. 1 filter paper. The filtrate was chilled, then pectin was precipitated using an equal volume of 95% ethanol. The precipitate was filtered, washed with ethanol, and

dried at 40°C in a hot air oven. The dried pectin was pulverized and stored in desiccators for later use.

DRYING & GRINDING

To eliminate extra moisture, the collected apple pomace was dried in a hot air oven at 50°C until it reached a consistent weight. The dried pomace (Fig. 1.1) was ground into a fine powder with a grinder to increase surface area and improve pectin extraction efficiency.



Fig. 1.1 Dried Apple Pomace

ACID EXTRACTION

The powdered pomace was combined with distilled water at a 1:10 (w/v) ratio, and the pH was adjusted to 1.5-2.0 with dilute hydrochloric acid (HCl). The mixture (Fig. 1.2) was then heated to 90°C for 1.5 hours with continuous stirring to aid in the release of pectin from the cell wall material (Fig. 1.3).



Fig. 1.3 The mixture



Fig. 1.2 Heating

FILTRATION AND PRECIPITATION

Following extraction, the heated mixture was filtered through muslin cloth or Whatman No. 1 filter paper to

remove the solid residue. The filtrate was treated with 2-3 liters of cold 95% ethanol to precipitate the pectin. The mixture was then held at 4 degrees Celsius for 12 hours to ensure total precipitation.

SEPARATION & DRYING

The precipitated pectin was filtered, washed with ethanol, and dried at 40°C in a hot air oven to produce a fine powder (Fig. 1.4). The dried pectin powder was stored in a desiccator before being used to make biodegradable films.



Fig. 1.4 Pectin powder

PECTIN EXTRACTION PROCESS

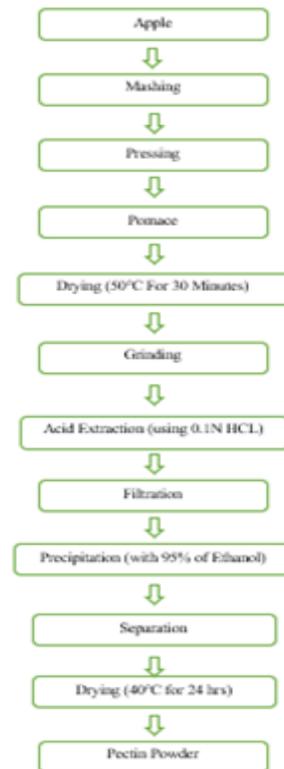


Fig. 1.5 Pectin Extraction Process

EXTRACTION OF POTATO PEEL STARCH (WET MILLING METHOD)

WASHING AND GRINDING

The gathered potato peels (Fig. 1.6) were properly washed with clean water to remove any dirt, soil, or contaminants. The cleaned peels were combined with distilled water in a laboratory blender to generate a homogeneous slurry suitable for starch extraction.



Fig. 1.6 Potato Peel

FILTRATION AND SEDIMENTATION

The produced slurry was filtered using a muslin cloth to remove fibrous remnants from the liquid extract. To encourage sedimentation, the resultant filtrate was left undisturbed overnight at room temperature (Fig. 1.7). Following complete sedimentation, the supernatant was carefully decanted, leaving the starch sediment at the bottom of the container.



1.7 Filtrate

DRYING

The separated starch sediment was collected and dried at 40-50°C in a hot air oven until it reached a consistent weight (Fig. 1.8). The dried starch was then ground into a fine powder with a mortar and pestle and stored in sealed containers for later use in biodegradable film manufacturing.



Fig. 1.8 Powdered potato peel Starch

STARCH EXTRACTION PROCESS

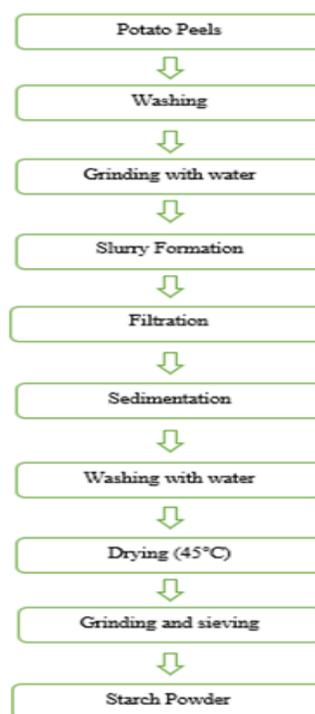


Fig. 1.9 Starch Extraction Process

FILM PREPARATION

FILM-FORMING SOLUTION

Biodegradable film-forming solutions were created by combining apple pomace pectin and potato peel starch in various ratios (for example, 1:1 and 1:2). To achieve a homogenous mixture, the components were dissolved in distilled water and heated to 70-80°C while stirring continuously. Glycerol was used as a plasticizer at a 20-30% (w/w) concentration of total

solids to improve the films' flexibility, tensile strength, and workability. The pH of the solution was adjusted to 4.5-5.5 as needed to ensure film stability and uniform dispersion.

CASTING

The produced film-forming solution was poured onto clean petri dishes or acrylic plates and dried in a hot air oven at 50°C for 48 hours, or until the films peeled readily off the casting surfaces. The drying procedure removed all leftover moisture and produced smooth, translucent films suitable for further investigation.

CONDITIONING

Prior to characterization, the dry films were conditioned for 48 hours at 50 percent relative humidity and 25°C. This conditioning phase served to stabilize the moisture content and ensured homogeneity in the films' mechanical, physical, and barrier properties.

EVALUATION OF PHYSICAL, CHEMICAL, AND FUNCTIONAL PROPERTIES

Five Samples were conducted to prepare the biodegradable film, with the fifth Sample producing the most desirable results. All analytical tests and evaluations were carried out on the video received from the fifth experiment. The physicochemical and functional parameters of the biodegradable packaging film made from apple pomace pectin and potato peel starch were determined using standard analytical methods.

TENSILE STRENGTH

The tensile strength (TS) was measured as the maximum force required to break the film under tension. It was calculated using the formula:

$$\text{Tensile Strength (MPa)} = \frac{F}{A}$$

where

F= Force at break (N)

A= Cross-sectional area of the film (m²)

WATER VAPOUR TRANSMISSION RATE (WVTR)

The WVTR determines the rate at which water vapour passes through a film and is expressed as:

$$\text{WVTR (g/m}^2\cdot\text{pday)} = \frac{W}{A \times t}$$

where

W= Weight gain of desiccant due to water vapour (g)

A= Area of exposed film (m²)

t = Time (days)

OXYGEN TRANSMISSION RATE (OTR)

The oxygen transmission rate indicates the amount of oxygen that can permeate through the film over a given area and time, calculated as:

$$\text{OTR (cm}^3\text{/m}^2\cdot\text{pday)} = \frac{Q}{A \times t}$$

where

Q= Volume of oxygen transmitted (cm³)

A= Film area (m²)

t= Time (days)

DENSITY

Film density was determined using mass and volume measurements according to:

$$\text{Density (kg/m}^3\text{)} = \frac{m}{V}$$

where

m= Mass of film (kg)

V= Volume (m³)

WATER ABSORPTION

Water absorption capacity was determined by immersing the film in distilled water for 24 hours and calculating:

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

where

W₁= Initial dry weight of the film (g)

W₂= Final weight after immersion (g)

OIL RESISTANCE

Oil resistance was evaluated by exposing the film to edible oil and measuring weight gain:

$$\text{Oil Resistance (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

ELONGATION AT BREAK (E%)

The elongation at break measures the film's stretchability before rupture:

$$\text{Elongation at Break (\%)} = \frac{L_2 - L_1}{L_1} \times 100$$

Where

L₁= Original length (mm)

L₂= Length at break (mm)

THICKNESS

Film thickness was measured at random points using a micrometer screw gauge and averaged:

$$\text{Thickness (mm)} = \frac{\sum T_i}{n}$$

where T_i = individual thickness readings, n = number of measurements.

OPTICAL PROPERTIES

Transparency and appearance were visually and spectrophotometrically evaluated at 600 nm wavelength using the formula:

$$\text{Transparency} = \frac{A_{600}}{x}$$

where: A_{600} = Absorbance at 600 nm

x = Film thickness (mm)

COMMON TEST PARAMETERS

The samples were prepared according to standard dimensions and conditioned at a temperature of 23 ± 2 °C and relative humidity of $50 \pm 5\%$ for 24 hours prior to testing to ensure uniformity. A total of five Samples were conducted to evaluate the tensile strength, oxygen transmission rate, water absorption, and thickness of the material.

For the tensile strength test, samples were tested using a Universal Testing Machine (UTM) as per ASTM D882. The width and thickness of each specimen were measured using a micro meter before mounting it on the machine. The test was carried out at a constant crosshead speed of 50 mm/min until the sample broke, and the maximum load and elongation were recorded. Tensile strength was calculated by dividing the maximum load by the cross-sectional area of the specimen.

The oxygen transmission rate (OTR) was determined following ASTM D3985 using an oxygen permeation analyzer. The conditioned samples were mounted in the test cell, with oxygen passed on one side and nitrogen on the other. The oxygen transmission rate was recorded once steady-state conditions were achieved, and the results were expressed as a percentage relative to the baseline film.

Water absorption was measured in accordance with ASTM D570. The specimens were first dried in an oven at 50 °C for 24 hours and weighed (W_1). They were then immersed in distilled water at 23 ± 2 °C for 24 hours, removed, surface-dried, and weighed again

(W_2). The percentage of water absorption was calculated using the formula $(W_2 - W_1)/W_1 \times 100$.

Therefore, Sample 5 was considered to be the best composition, yielding a biodegradable packaging film with the highest mechanical integrity, flexibility, and visual homogeneity ideal for eco-friendly food packaging. The study effectively revealed the potential of agro-industry Sample byproducts such as apple pomace and potato peels in the formulation of sustainable packaging materials, so contributing to waste valorization, environmental conservation, and the establishment of a circular economy.

III. RESULTS AND DISCUSSION

BIODEGRADABLE PACKAGING FILM USING APPLE POMACE PECTIN AND POTATO PEEL STARCH

SAMPLE 1

The film formed during the starch-only Sample (Sample 1, 1:0 ratio) (Fig. 1.10) was difficult to remove from the Petri plate due to its sticky texture and high adherence to the surface. The produced film had an uneven surface and poor texture quality. It was brittle, weak, and prone to tearing, preventing the production of a continuous and uniform sheet. The mechanical evaluation found a low tensile strength of around 1.2 MPa, indicating inadequate structural integrity. Furthermore, the film exhibited considerable water absorption (72%), low oil resistance (0.05%), and limited transparency, rendering it unsuitable for further characterization. Overall, the starch-only film has poor flexibility, mechanical qualities, and handling characteristics, making it unsuitable for packaging applications.



Fig. 1.10 Sample 1 Film

SAMPLE 2

The film created with the starch-pectin (1:1) formulation (Sample 2, Fig. 1.11) was effectively cast and easily peeled from the Petri plate, demonstrating better film-forming capabilities over starch alone. Minor surface flaws, such as wrinkles and uneven smoothness, were found, but the film had a more consistent, self-supporting structure. The inclusion of pectin increased flexibility and decreased stickiness, resulting in improved handleability. The film's tensile strength increased to 3.5 MPa, but water absorption declined to 58%, indicating better intermolecular connections and lower hydrophilicity. The film also had moderate transparency and mild flexibility, but lacked the necessary mechanical strength and barrier qualities for practical packing applications.



Fig. 1.11 Sample 2 Film

SAMPLE 3

The film formed with the starch-pectin (1:2) formulation (Sample 3, Fig. 1.12) had a robust, flexible, and self-supporting structure, which was a substantial improvement over earlier Samples. The final sheet was extremely homogeneous, smooth, and texture, with a non-sticky surface and easy peel ability from the casting plate. The higher pectin content helped to improve film integrity and cohesion, resulting in a visually clean and appealing film. The tensile strength increased to 6.0 MPa, demonstrating greater mechanical performance, while the water vapor resistance increased, proving stronger moisture barrier qualities. Despite these developments, the film maintained considerable oil resistance (0.18%) and an oxygen transfer rate of roughly 68%, indicating that barrier efficiency is limited to some extent. Overall, the starch-pectin (1:2) combination was the most stable and functional.



Fig. 1.12 Sample 3 Film

SAMPLE 4

The film produced by the starch-pectin (1:3) formulation (Sample 4, Fig. 1.13) showed multiple crack lines and surface imperfections, indicating structural non-uniformity and potential incompatibility between the polymeric components. The surface seemed uneven, rough, and pitted, with visible white residue, possibly due to phase separation, uneven drying, or inadequate starch and pectin mixing during production. These morphological inconsistencies indicated that the formulation needed to be further optimized in terms of biopolymer ratio, plasticizer concentration, and processing parameters in order to achieve a uniform and defect-free film structure.



Fig. 1.13 Sample 4 Film

In this Sample, the tensile strength was determined at 5.2 MPa with a film density of around 125 kg/m³. Although the film had satisfactory water vapor transfer and a considerably better visual appearance, the high pectin content resulted in lower elasticity and slightly brittle properties.

As a result, the 1:3 formulation was ruled unsuitable for final optimization since it did not provide an acceptable mix of mechanical integrity and flexibility.

SAMPLE 5

The film formed from the starch-pectin (3:1) formulation (Sample 5, Fig. 1.14) was significantly more uniform and structurally intact, resembling a big, smooth, and flexible sheet. Unlike the broken and uneven structure seen in the fourth Sample, this film had few internal faults and no visible cracks, indicating improved compatibility and matrix formation between the starch and pectin biopolymers. The enhanced clarity, reduced surface pitting, and consistent texture demonstrated greater control over film-casting and drying conditions, resulting in a cohesive and structurally stable structure.



Fig. 1.14 Sample 5 Film

Table 1.2 Common Parameters for All Samples

Parameters	Sample1	Sample2	Sample3	Sample4	Sample5
Tensile Strength (Mpa)	1.2	3.5	6	5.2	7.2
Oxygen transmission rate (%)	92	78	68	52.9	76.9
Water Absorption (%)	72	58	60	43	63

In the analysis, three common parameters—tensile strength, oxygen transmission rate (OTR), and water absorption rate—were analyzed for all five Samples of the developed film. Each Sample was carefully evaluated to determine the mechanical, barrier, and moisture resistance properties of the samples. Among the five Samples, Sample 4 and Sample 5 exhibited the most desirable and consistent results in terms of tensile strength, lower oxygen permeability, and minimal water absorption. Therefore, these two Samples were considered optimal, and further analyses and characterization tests were carried out specifically for Sample 4 and Sample 5 to ensure a comprehensive evaluation of the film’s overall performance.

Table 1.3 Best Compositions

Parameter(unit)	SAMPLE 4	SAMPLE 5
Formulation ratio (Strach: Pectin)	01:03	03:01
Tensile Strength (Mpa)	5.2	7.2
Water vapour Transmission	passes test	Passes test

Oxygen transmission rate (%)	52.9	76.9
Water Absorption (%)	43	63
Oil Resistance (%)	0.11	0.24
Elongation at break	passes test	Passes test
Thickness	0.1	0.2
Optical (Transparency)	Slightly Residue	transparent

Therefore, Sample 5 was considered to be the best composition, yielding a biodegradable packaging film with the highest mechanical integrity, flexibility, and visual homogeneity ideal for eco-friendly food packaging. The study effectively revealed the potential of agro-industry Sample byproducts such as apple pomace and potato peels in the formulation of sustainable packaging materials, so contributing to waste valorization, environmental conservation, and the establishment of a circular economy.

IV. CONCLUSION

The results confirmed that the biodegradable film made from apple pomace pectin and potato peel starch had good physicochemical and functional qualities. The film demonstrated outstanding tensile strength, transparency, and grease resistance, as well as satisfactory oxygen and water vapour barrier properties. Its hydrophilic and biodegradable properties make it a more environmentally friendly alternative to traditional synthetic packaging materials. Furthermore, the use of pectin and starch successfully repurposed agro-industry Sample byproducts, encouraging sustainability, waste valorization, and circular bioeconomy practices. Therefore, Sample 5 produced a biodegradable packaging film with the highest mechanical integrity, flexibility, and visual homogeneity perfect for environmentally friendly food packaging it was determined to be the best composition. The study successfully demonstrated the potential of agro-industry sample wastes, such as potato peels and apple pomace, in the creation of sustainable packaging materials, so promoting waste valorization, environmental preservation, and the development of a circular economy.

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