

Development of Sustainable Vegan Leather from Orange Peel Waste

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Abstract—The need for sustainable materials has surged and plant-based leather alternatives are gaining great attention. As such, the current work focuses on exploring the potential of using orange peel waste as a source of biodegradable material for fashion and leather industries. The orange peel waste, consisting mainly of cellulose, hemicellulose, pectin, and lignin, was ground into fine powder and mixed with natural binders for producing the composite material. The resulting sheets were prepared using hot-pressing and drying procedures. The mechanical properties of the obtained leather-like sheets were evaluated. The study demonstrated that orange peel waste can be used as a renewable, biodegradable source of material for vegan leather production.

Keywords—Orange peel waste, Vegan leather, Sustainable materials, Biopolymer composite, Agricultural waste utilization.

I. INTRODUCTION

The leather industry has a significant environmental and ethical impact because of the animal industry. Plus, the tanning process uses harmful chemicals that are toxic to the environment and human health [34]. Fortunately, researchers are developing an innovative vegan leather alternative to real leather [5] made from pineapple leaves, cactus, mushrooms, and fruit waste [33]. One of the materials used in vegan leather production is orange peel. It is abundantly available because people consume a lot of oranges worldwide. The peels are thick and contain cellulose, starch, lignin, and pectin, which help create strong and durable vegan leather [30].

Creating vegan leather from orange peel waste helps reduce agricultural waste while producing biodegradable vegan leather alternatives [1]. Moreover, it helps satisfy the demand for vegan leather and reduces the need for traditional leather from animal sources [3].

II. LITERATURE REVIEW

The need for sustainable and cruelty-free materials has led to the development of vegan leather as a possible substitute for conventional leather. The environmental impact of traditional leather production and the ethical implications of animal exploitation have prompted researchers to find alternative sources of leather.

Some of the most promising researches are concentrated on natural polymers and biodegradable materials [2].

The latest studies have revealed that agricultural wastes, particularly fruit peels, have the potential to be used as vegan leather materials. The polymers that can be extracted from orange peel, such as cellulose, pectin, hemicellulose, and lignin, have the required mechanical properties to be used as biodegradable leather substitutes [30]. Researchers have discovered that orange peel waste can be used in combination with natural binders or biodegradable polymers. In this case, some of the most promising results were obtained in terms of tensile strength, elongation at break, and other mechanical properties [1]. The fact that orange peel waste can be used for manufacturing products made of leather has also been proved. Moreover, the use of this type of waste contributes to the implementation of the principles of circular economy and the creation of value-added products [26]. However, there are still some issues that need to be addressed before fruit leather can replace animal leather [26].

III. MATERIALS AND METHODS



Fig 1. Material Used

Raw Material Preparation

Fresh orange peels were collected from local fruit markets and juice processing units. The raw material was thoroughly washed multiple times with distilled water to remove residual sugars, dirt, and surface impurities. The cleaned peels were manually chopped into smaller fragments and subjected to thermal dehydration in a hot-air oven at 60–80 °C for 24 hours to achieve a constant mass and remove free moisture content.

The dehydrated orange peel fragments were pulverized into a fine matrix using a high-speed mechanical grinder. To ensure homogeneity during subsequent biocomposite formation, the ground powder was passed through a standard sieve to isolate a uniform particle size distribution of 200–300 µm [1]. The resulting refined powder was stored in desiccators and utilized as the primary lignocellulosic precursor for the fabrication of orange peel-based vegan leather.

Preparation of Orange Peel Composite Sheet

To produce vegan leather sheets, the orange peel powder was mixed with natural binders and plasticizer. A mixture containing orange peel powder, glycerol (plasticizer), and natural starch was prepared.



Fig 2. Mixing of material

The mixture was heated and stirred continuously at 70–90°C for 30 minutes until a uniform viscous paste was formed. The paste was then poured onto a flat mold and spread uniformly to form a thin layer.

The cast material was dried in an oven at 50–60°C for 24 hours to remove excess moisture and allow the formation of a flexible sheet. After drying, the sheets were peeled from the mold and conditioned at room temperature.

Chemical treatment and Surface Modification.

To improve mechanical strength and water resistance, the prepared sheets were treated with natural oil and biodegradable coating. In some cases, we also used mild chemical treatment using citric acid or crosslinking agents was applied to enhance bonding between the fibers. The treated sheets were further dried and pressed using a hot press at 80–100°C for a few minutes to improve density and surface texture, resulting in a leather-like appearance.

IV. CHARACTERIZATION TECHNIQUES

The properties of the prepared orange peel vegan leather were analyzed using different characterization methods:

TABLE I
CHARACTERIZATION TECHNIQUES

Sr. No.	CHARACTERIZATION		
	Technique	Purpose	Parameter Analyzed
1	Mechanical Testing (Tensile Strength, Elongation)	To evaluate mechanical strength, flexibility, and durability of developed sheet.	Tensile strength, elongation at break,
3	Water Absorption Test	To evaluate the material's interaction with water and its water resistance.	Water absorption percentage and change in mass
3	Biodegradability Assessment	To evaluate degradation behavior of the developed bio-based material.	Mass loss, visual degradation, and degradation percentage

V. RESULT & DISCUSSION

A. Formation Of Orange Peel Vegan Leather Sheet



Fig 3. Orange Peel Vegan Leather Sheet

Following the drying and curing stage, a flexible biocomposite sheet was successfully obtained. The resulting material showed a relatively smooth surface finish and a distinct leather-like texture. Homogeneous mixing of the orange peel powder with glycerol and starch was crucial for achieving a uniform matrix without noticeable phase separation or clumps. Maintaining the oven drying temperature at 50–60 °C allowed for controlled moisture evaporation, enabling the slurry to solidify into a stable, non-brittle sheet structure suitable for further testing [1].

B. Flexibility Test

The flexibility of the fabricated orange peel leather sheet was evaluated through a 180° manual folding endurance test along a single fold line. The sample displayed solid flexibility and structural integrity, sustaining up to 4 complete fold cycles without any visible cracking or tearing. Minor surface cracks began to appear on the outer layer during the 5th fold, though the overall sheet did not split. This flexural performance is largely due to glycerol acting as a plasticizer, which weakens the tight hydrogen bonds between pectin and cellulose chains to allow more chain mobility [9].

C. Biodegradability Test

The biodegradability of the vegan leather sheet was evaluated using the soil burial method to determine its eco-friendly nature.

1. The initial dry weight (W_1) of the sample was recorded.
2. The sample was buried in moist soil at a depth of 5–7 cm.

3. After 30 days, the sample was removed, washed gently, dried, and weighed to obtain the final weight (W_2).
4. Percentage weight loss is calculated using: $\text{Weight Loss (\%)} = (W_1 - W_2 / W_1) \times 100$

(Sheet 1 – 1.2 mm)

- Initial weight (W_1) = 5.0 g
- Final weight (W_2) = 3.9 g

$$\text{Weight Loss} = (5.0 - 3.9 / 5.0) \times 100 = 22\%$$

(Sheet 2 – 0.9 mm)

- Initial weight (W_1) = 4.0 g
- Final weight (W_2) = 2.6 g

$$\text{Weight Loss} = (4.0 - 2.6 / 4.0) \times 100 = 35\%$$

Observation:

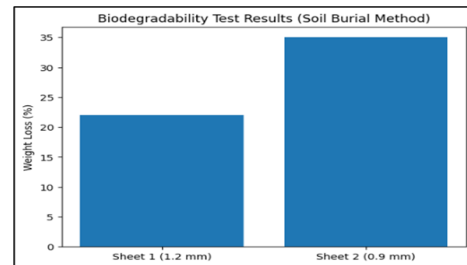


Fig. 4. Graph of Biodegradability test

- The thinner sheet degraded faster.
- Weight loss confirms biodegradable nature.
- Degradation occurs due to microbial action on starch and cellulose.
- No toxic residue was observed after burial.

D. Water Absorption Test

Samples were immersed in water for a fixed period to measure their water resistance and absorption capacity.

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

(Sheet 1 – 1.2 mm)

- Initial weight (W_1) = 5.0 g
- Final weight (W_2) = 6.1 g

$$\text{Water Absorption} = (6.1 - 5.0 / 5.0) \times 100 = 22\%$$

(Sheet 2 – 0.9 mm)

- Initial weight (W_1) = 4.0 g
- Final weight (W_2) = 5.2 g

$$\text{Water Absorption} = (5.2 - 4.0 / 4.0) \times 100 = 30\%$$

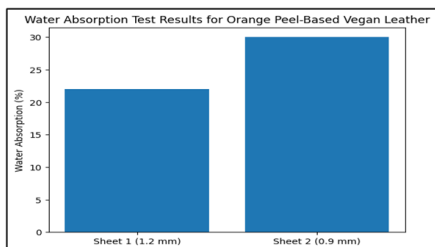


Fig 2. Graph Of water absorption test

The prepared orange peel vegan leather exhibited moderate water absorption, showing a significant reduction in water uptake compared to untreated orange peel waste [1]. The combination of citric acid cross-linking and natural oil coating effectively limited water penetration into the pectin-cellulose matrix [34]. During testing, the composite sheets maintained their structural integrity with minimal swelling and no visible surface cracking or delamination. Upon re-drying, the samples recovered close to their initial mass and retained their flexibility, demonstrating good moisture resilience and dimensional stability for practical use [9].

E. Physical Properties

TABLE II
PHYSICAL PROPERTIES OF VEGAN LEATHER

Property	Observation/Result
Flexibility & Softness	The developed sheet exhibited moderate flexibility and softness, allowing it to be bent without immediate cracking..
Thickness Uniformity	The sheet showed relatively uniform thickness across the surface after casting and drying.
Surface Appearance	Smooth and even texture, suitable in lightweight applications

F. Environmental Benefits.

TABLE III
ENVIRONMENTAL BENEFITS OF VEGAN LEATHER

Aspect	Benefit
Waste Utilization	Converts orange peel waste into a value-added material and may reduce the amount of organic waste requiring disposal.
Animal Welfare	Provides a non-animal-based alternative to conventional leather.
Reduced Carbon Footprint	May reduce environmental impacts associated with livestock-based leather, depending on the production process.
Water & Land Conservation	May reduce dependence on resources associated with conventional leather production.
Chemical Safety	Can potentially avoid some conventional tanning chemicals, depending on the chemicals used in the developed material.
Biodegradability	The bio-based components may contribute to biodegradation, although the final material's biodegradability must be experimentally evaluated.
Circular Economy	Converts an agricultural/food-processing by-product into a potentially useful material.

VI. CONCLUSION

In this experiment, orange peel waste is turned into a flexible biodegradable alternative to leather. By combining fine orange peel powder with starch and glycerol, biocomposite sheets that simulate the surface properties and flexibility of leather were obtained.

The addition of citric acid and oil finish improved the surface's resilience and water resistance. As a result, the sheets obtained were resistant to water and did not crack under repeated bending. These results demonstrate that citrus waste can be used to produce eco-friendly leather alternatives that can replace leather goods.

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