Orange Peel (Citrus sinensis) Waste as a Sustainable Source for Biodegradable Textile Fibres: A Review

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Abstract

Orange peel is a major agro-industrial by-product generated in large quantities by the juice and food processing industries. Rich in cellulose, pectin, hemicellulose, and bioactive compounds, this biomass has attracted growing research interest as a sustainable raw material for biodegradable fibers and functional materials. This review critically examines existing literature on the composition of orange peel, fiber extraction techniques, material properties, and reported applications in textiles, nonwovens, wipes, packaging, and bio composites. The challenges, environmental benefits, and future research directions for orange peel valorization within a circular economy framework are also discussed.

Keywords

Orange peel fiber, Citrus sinensis, Biodegradable Textile, Hygiene textile, Reusable bio component ,Circular economy.

Introduction

The widespread use of synthetic fibers such as polyester and polypropylene in textiles and hygiene products has raised serious environmental concerns due to their non- biodegradability and contribution to micro plastic pollution. At the same time, the citrus processing industry generates enormous quantities of orange peel waste, which is often underutilized or disposed of in landfills. Recent research highlights the potential of orange peel (Citrus sinensis) as a renewable and sustainable resource for fiber and biopolymer production. This review consolidates recent research on the utilization of orange peel waste for biodegradable fiber development and related applications.

Botanical Characteristics of Orange Peel

The fruit peel, also known as the pericarp, is anatomically divided into two major layers: the flavedo and the albedo. The flavedo is an outer colored layer rich in pigments such as carotenoids and chlorophyll, along with oil glands containing essential oils. The albedo is the inner white spongy layer composed mainly of pectin, cellulose, and hemicellulose.

These structural components contribute to the fibrous nature of orange peel, making it suitable for fiber extraction and functional applications.

Botanical Parameter	**Description**
Botanical name	Citrus sinensis
Family	Rutaceae
Plant type	Evergreen fruit tree
Fruit type	Hesperidium
Peel layers	Flavedo (outer colored layer), Albedo (inner white spongy layer)
Flavedo composition	Carotenoids, chlorophylls, flavonoids, oil glands
Albedo composition	Cellulose, hemicellulose, pectin
Functional relevance	Fiber extraction, essential oil recovery, biodegradable applications

Table 1. Botanical characteristics and structural composition of orange peel (Citrus sinensis)

Orange Peel Waste

Orange peel constitutes approximately 45–50% of the total fruit weight and is generated in large quantities by citrus juice and food processing industries. Chemically, orange peel contains cellulose, hemicellulose, pectin, lignin, flavonoids, polyphenols, and essential oils such as limonene. The high cellulose and pectin content enables fiber formation, while the presence of essential oils provides antimicrobial and antioxidant properties.

Figure 1. Orange peel waste generated from citrus fruit processing.

Chemical Composition of Orange Peel Relevant to Textile Applications

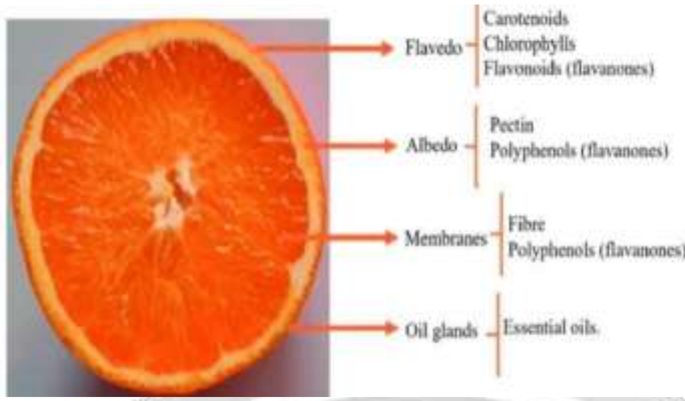

Figure 2. Schematic representation of orange peel layers and their major components.

- **Flavonoids (hesperidin, naringin):** Provide antioxidant and antimicrobial properties, supporting antibacterial and hygienic textile finishes.
- **Phenolic compounds:** Enhance UV absorption and contribute to antibacterial activity, making them suitable for protective and functional textiles.
- **Carotenoids:** Act as natural pigments, producing yellow to orange shades for eco-friendly textile coloration.
- **Essential oils (limonene):** Impart natural fragrance along with antimicrobial and insect-repellent effects, useful in apparel and home textiles.
- **Pectin:** Functions as a natural film-forming and binding agent in textile printing, coating, and finishing processes.
- **Organic acids (citric acid):** Assist in pH regulation and chelation during dyeing and finishing, enabling cleaner processing routes.
- **Dietary fibres:** Provide structural reinforcement when used in biodegradable nonwovens and textile composite materials.

Fiber Extraction Techniques from Orange Peel

Several studies have reported methods for extracting cellulose fibers from orange peel waste. Conventional approaches include alkaline treatment to remove pectin and hemicellulose, followed by washing and drying. Enzymatic treatments have also been explored to improve fiber purity while reducing chemical usage. Recent research emphasizes the use of green solvents, such as deep eutectic solvents and mild enzymatic systems, to enhance sustainability. These reported techniques demonstrate that orange peel-derived fibers possess adequate structural integrity for further processing into textile and nonwoven forms.

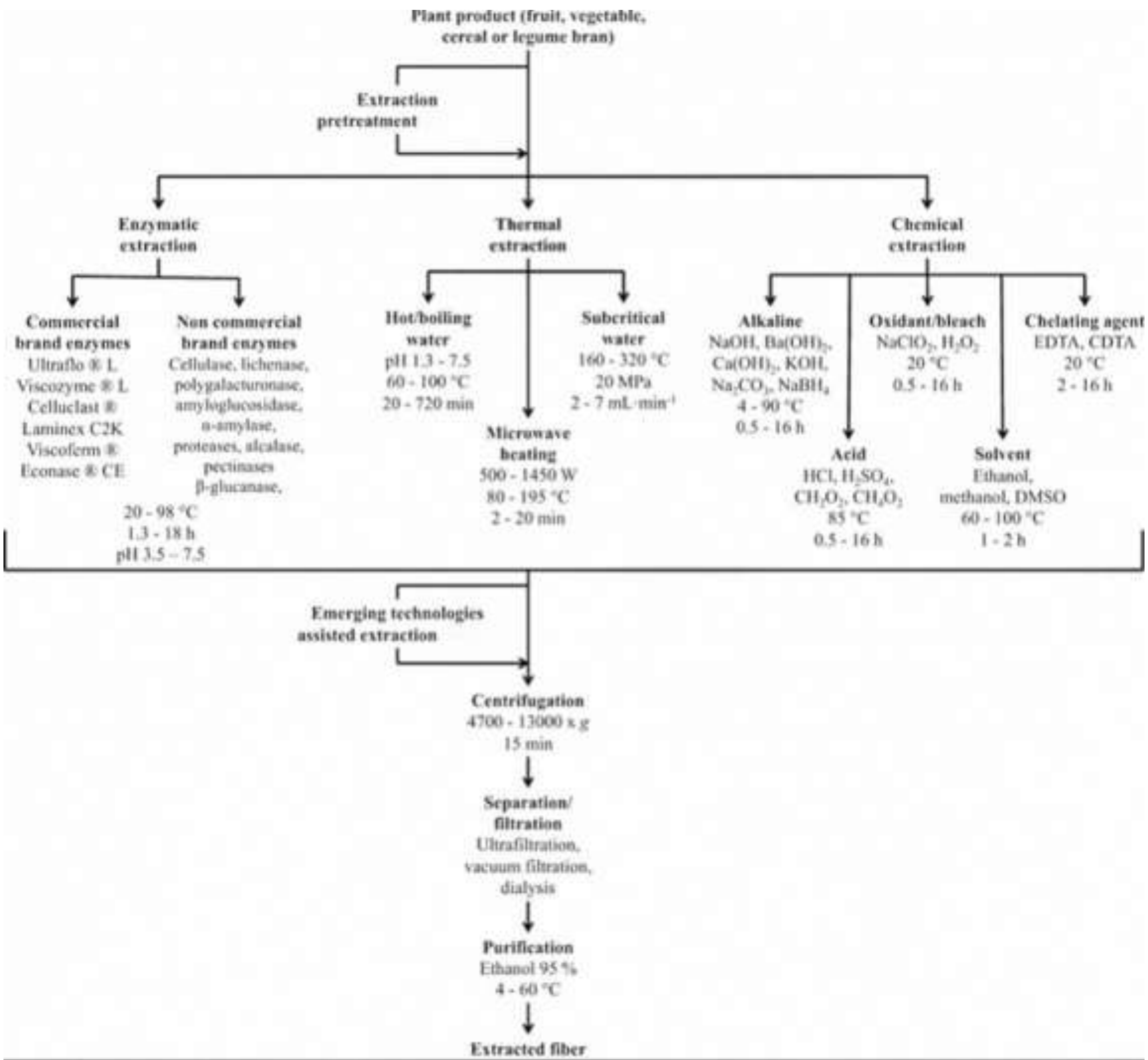

Figure 3. Process flow diagram for cellulose extraction from orange peel biomass and fiber recovery.

Cellulose Extraction from Orange Peel and Conversion into Yarn

The extracted cellulose is then dissolved in suitable solvent systems, such as N-methylmorpholine-N- oxide (NMMO) or selected ionic liquids, and regenerated into fibers using wet-spinning techniques. The regenerated filaments are subsequently washed, stretched, and dried to form yarns. Studies report that yarns produced from orange peel–derived cellulose exhibit properties comparable to conventional regenerated fibers like viscose or lyocell, including adequate tensile strength, good moisture absorbency, and biodegradability. These characteristics indicate strong potential for orange peel–based cellulose yarns in sustainable textile and apparel applications.

Properties of Orange Peel-Derived Fibres

Recent studies indicate that cellulose fibres extracted from orange peel exhibit good moisture absorbency, biodegradability, and moderate tensile properties. When compared with conventional regenerated fibers, orange peel fibers show comparable hygroscopic behavior due to their polysaccharide-rich structure. Blending with other natural or regenerated fibers such as cotton or viscose has been reported to improve mechanical strength and process ability, making them suitable for nonwoven and textile applications.

Use of Orange Peel in Nonwoven Textiles Other Than Cellulose Extraction

Apart from cellulose extraction, orange peel waste has been directly utilized in nonwoven textiles in the form of **powdered biomass, fibrous particles, and bio-composite blends**. In this approach, orange peel is not chemically converted into regenerated fibres; instead, it is mechanically and physically processed to function as a sustainable filler or reinforcing component within nonwoven structures.

Form of Orange Peel Used

Orange peel is first washed, dried, and finely ground to obtain powder or short fibrous particles. This processed material retains bioactive components such as phenolic compounds, essential oils, and dietary fibres. The powdered or fibrous orange peel is then incorporated into nonwoven webs either as a surface layer or as a bulk additive. In some studies, orange peel powder is also encapsulated or coated to improve dispersion and durability within the nonwoven matrix.

Blending of Orange Peel in Nonwovens

Orange peel material is commonly blended with natural or synthetic fibres during nonwoven formation. Typical blending fibres include cotton, viscose, polyester, polypropylene, and polylactic acid (PLA). The blending is carried out at controlled weight ratios to maintain web integrity while introducing functional properties. Mechanical entanglement (needle punching), thermal bonding, or bio-based binders are used to consolidate the nonwoven structure.

Functional Role in Nonwoven Products

When blended into nonwovens, orange peel contributes antimicrobial, deodorizing, and antioxidant properties due to its inherent bioactive compounds. The dietary fibre content enhances bulk and porosity, making such nonwovens suitable for filtration, insulation, and absorbent applications. Additionally, the natural fragrance and insect-repellent nature of orange peel improve performance in hygiene and home textile products.

Advantages and Limitations

The direct use of orange peel in nonwovens offers advantages such as low processing cost, waste valorisation, and reduced chemical usage. However, challenges remain in terms of uniform dispersion, moisture sensitivity, and long-term durability, which are being addressed through surface treatments and hybrid blending strategies.

Applications

Orange peel–based nonwoven blends have been explored for biodegradable mats, hygiene products, packaging materials, insulation layers, and acoustic panels. These materials demonstrate improved sustainability, reduced reliance on petroleum-based components, and potential for end-of-life biodegradation.

Products Made from Orange Peel

Orange peel has been converted into a wide range of value-added products including functional textiles, natural dyes, antimicrobial fabrics, nonwovens, composites, sustainable packaging materials, regenerated fibres, and bio-based fashion and lifestyle products, supporting circular economy practices.

A. Textile and Apparel–Related Products

In textile and apparel applications, orange peel is primarily utilized in the form of aqueous or solvent extracts, essential oils, powdered biomass, pectin, and organic acids. These forms are applied during dyeing, finishing, coating, printing, and nonwoven fabrication to impart functional and aesthetic properties.

- Naturally dyed fabrics (cotton, silk, wool, jute)
- Antimicrobial textiles (cotton fabrics, medical and hygiene textiles)
- Odor-control garments (socks, innerwear, activewear)
- UV-protective fabrics
- Fragrance-finished textiles
- Printed textiles using pectin-based thickeners
- Wrinkle-resistant cotton fabrics (citric-acid-based finishing)
- Biodegradable nonwoven mats
- Textile composites (insulation and upholstery padding)
- Acoustic textile panels
- Automotive interior textile components
- Sustainable garment covers
- Textile-based packaging materials

B. Fibres and Materials Derived from Orange Peel

In this category, orange peel is processed into purified cellulose, biopolymers, and composite matrices through chemical and physico-chemical treatments. These materials are converted into fibers, films, and sheets suitable for textile and allied applications.

- Regenerated cellulose fibres (orange fiber at laboratory and pilot/industrial scale)
- Bio-based films and surface coatings
- Biopolymer composites
- Eco-leather and leather-like sheets
- Paper and bio-coated paper products

C. Fashion, Accessories, and Lifestyle Products

For fashion and lifestyle applications, orange peel derivatives are used as dyed fabrics, bio-finished textiles, composite sheets, and deodorizing finishes. These products emphasize sustainability, aesthetics, and user comfort.

- Scarves and stoles
- Eco-fashion garments
- Footwear linings

- Insoles with deodorizing properties
- Handbags and accessories (experimental bio-material-based products)

D. Home and Interior Textile Products

In home and interior textiles, orange peel is mainly applied in the form of antimicrobial extracts, essential oils, and functional finishes to enhance hygiene, fragrance, and durability.

- Curtains and upholstery fabrics
- Carpets and rugs with functional finishes
- Bed linens with antimicrobial properties
- Fragrance-infused home textiles

E. Packaging and Auxiliary Textile Products

Orange peel waste is increasingly explored in bio-based packaging materials and auxiliary products, using pectin, fibres, and composite structures to replace synthetic plastics and coatings.

- Compostable packaging materials
- Garment tags and labels
- Shopping and carry bags
- Protective wrapping textiles
- Fragrance-infused packaging materials

Sustainability and Circular Economy Impact

Utilization of orange peel waste supports waste valorization, reduces landfill disposal, & minimizes dependence on petroleum-based fibers. This approach aligns circular economy principles by transforming food processing waste into value-added biodegradable products.

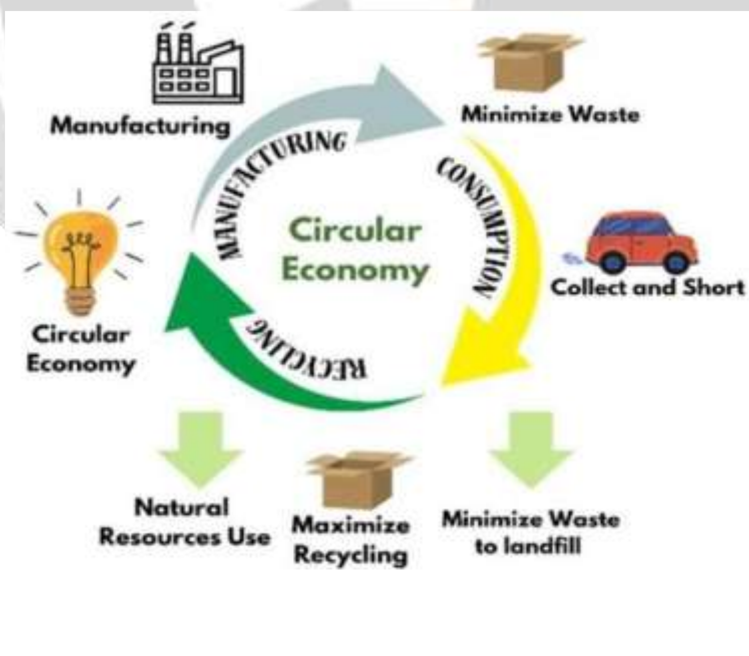

Figure 4. Schematic representation of circular economy concepts.

Future research should focus on optimizing extraction methods, blending orange peel fiber with other biodegradable fibers, life cycle assessment, and large-scale commercialization of orange peel fiber-based wipes.

Conclusion

This review demonstrates that orange peel waste is a renewable and underutilized resource with strong potential for biodegradable fiber and material applications. Existing literature confirms its feasibility in textiles, nonwovens, wipes, packaging, and composite materials. While technical and economic challenges persist, continued research and innovation can enable large-scale valorization of citrus waste, contributing to sustainable material development and circular economy goals.

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