Utilization of Jackfruit Waste as a Cellulose Source for Various Applications

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Abstract

Jackfruit is a significant source of fruit that's mostly used for food, but in the process, a lot of waste is having the edible part. Processing not only makes jackfruit easier to use but also turns it into value-added products that can be sold commercially and even exported. After taking out the bulbs, a huge amount of peel and seeds is left behind, and this waste actually has great potential. it can actually be a good source of pectin, starch, and protein-rich compounds that add value when used in food and animal feed. By making proper use of this waste, we can reduce environmental problems while also creating economic benefits. This review focuses on the current status of jackfruit production, how its waste is being managed, and the new techniques being explored to turn this waste into valuable products.

Introduction

Jackfruit (*Artocarpus heterophyllus*) is a fruit commonly known, especially in India and other tropical regions. People enjoy it in many ways—tender and raw in curries, or ripe and sweet as a fruit—but what we don't usually think about is the huge amount of waste it leaves behind. Almost 60–70% of the fruit, including the peel, fibrous core, and the perianth around the bulbs, often gets thrown away.

Instead, it can be converted into valuable resources that reduce environmental impact and even open doors for new products and income. One promising option is cellulose, which makes up the structural part of plants. Using jackfruit waste as a source of cellulose could be a smart way to turn an underused by-product into something valuable, supporting a greener and more sustainable economy. (Rahman *et al*., 2014).

Chemical Composition of Jackfruit Waste

Jackfruit waste mainly includes the peel, core, and the fibrous parts that cover the fruit bulbs. Even though these parts are usually thrown away, they actually contain useful compounds like cellulose, hemicellulose, lignin, pectin, and phenolics. Out of these, cellulose is the most important because it is widely available in plants and has many applications.

Jackfruit waste has around 20–28% cellulose, which makes it a good option for extracting cellulose in a sustainable way. To understand the cellulose better, researchers use methods like FTIR, XRD, TGA, and SEM. These tests are used to evaluate the structure, purity, stability, and surface properties, to ensure it is useful for industrial use and research use. . (Table 1)

Table 1 - Chemical Composition of Jackfruit Waste

Chemical Element / Mineral	Concentration (mg/L or ppm)
Silica (Si)	0.24
Aluminium (Al)	2.16
Cadmium (Cd)	0.001
Calcium (Ca)	30.445
Chromium (Cr)	0.027
Cobalt (Co)	0.008
Copper (Cu)	0.735
Iron (Fe)	4.184
Lead (Pb)	0.28
Manganese (Mn)	1.873
Nickel (Ni)	0.118
Silver (Ag)	1.071
Zinc (Zn)	0.9982

The jackfruit peel waste is a natural source of cellulose, lignin and hemicellulose. It is easier to make applications like biopolymer and bio-composite. the cellulose present in jackfruit peel waste ranges between 30–40%, and the hemicellulose ranges between 15–25%. And the Lignin is present about 10–15%, structural integrity and rigidity.

Apart from structural carbohydrates, jackfruit peel and core also contain pectin, starch, and crude fiber, which enhance its functional properties. Seeds are primarily composed of starch (50–60%), along with proteins (13–18%) and small amounts of lipids. The waste also carries phenolic compounds, flavonoids, and antioxidants, which offer potential for nutraceutical and functional food applications. In addition, trace minerals like calcium, potassium, and magnesium are present in appreciable amounts, along with negligible fat content.

The high carbohydrate and fiber content, combined with secondary metabolites, makes jackfruit waste a versatile raw material for bioplastics, bioethanol, animal feed, and value-added products, supporting its role in a sustainable circular economy.(Trilokesh and Uppuluri (2019)).

Extraction and Isolation Methods

The extraction of Cellulose from jackfruit waste goes through a simple steps. The peel and core are first washed, dried, and ground into a fine powder. Then, chemical processes such as alkaline hydrolysis and bleaching are used to take out the unwanted components and separate the cellulose. Once this is done, the material is dried and sieved to get purified cellulose. The yield can change depending on the jackfruit variety and method, but it usually comes to about 20–28% of the peel's dry weight, which shows it's a good natural source of cellulose. (sundarraj and Ranganathan (2018))

Jackfruit waste (peel)

↓

Washing

↓

Drying

↓

Grinding – fine powder

↓

Alkaline hydrolysis

↓

Bleaching

↓

Drying & sieving

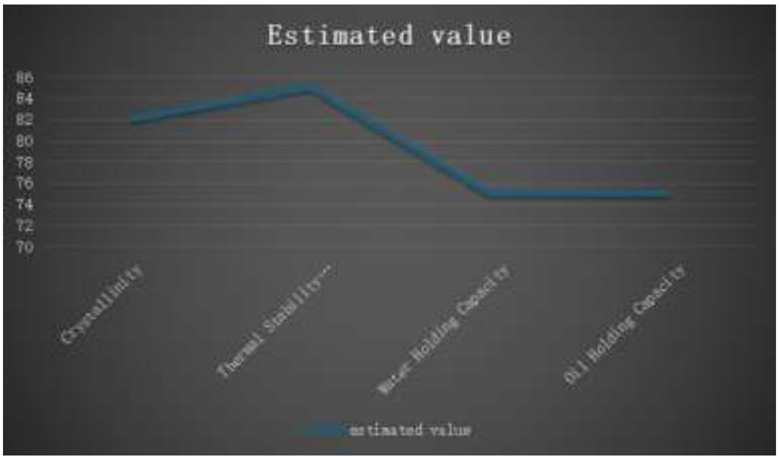
↓

Purified cellulose (20 – 28% yield)

Physicochemical and Functional Properties

Cellulose derived from jackfruit waste has been found to possess some impressive properties. the key features of the jackfruit waste is its high crystallinity, exceeding 80%, which shows a well-organized molecular structure.(fig1)

Fig 1 – Physicochemical and Functional Properties



In addition, jackfruit-derived cellulose has shown excellent water and oil holding capacities, making it especially useful in food formulations and biodegradable packaging. These properties help improve the texture, hold moisture, and increase the shelf life of food products, and they can also be used in making eco-friendly packaging (Sundarraj & Ranganathan, 2018).

In terms of functional properties, jackfruit waste demonstrates excellent water-holding capacity and oil absorption ability, attributed to its porous fiber structure. These features make it suitable as a fat replacer or texturizer in food products. The starch and pectin content in peel waste gives the gel formation, thickening ability, and swelling power, the crude fiber in the jackfruit peel waste increases the stabilize capacity and emulsifications. (Trilokesh and Uppuluri (2019))

Applications in Biodegradable Films and Packaging

Cellulose extracted from jackfruit peel waste is mixed with polyvinyl alcohol (PVA) and changed into packaging films, eco-friendly alternative of plastic. These films stand out not just because they break down naturally, but also because they are strong and flexible enough to handle daily use and transportation without damage. Their low tendency to absorb water makes them reliable even in humid environments. What makes them even more interesting is the addition of neem extract, which gives the films natural antimicrobial properties. This helps in increasing the shelf life of the food without using the synthetic preservatives. This not only reduces plastic pollution but also promotes eco-friendly and sustainable packaging as shown in (fig2) (Panda *et al*., 2022).

Fig 2 – Applications in Biodegradable Films and Packaging

The Biodegradable films extracted from the jackfruit peel waste provides a favourable barrier properties. where these are critical for food packaging applications. The use of this applications can significantly reduce the dependence of petroleum-based plastics, drastically reduce the environmental pollution and supports in sustainable packaging solutions. these films can be modified and used in various applications like fruit wraps, dry snack packaging, and inner liners for cartons.

With growing consumer demand for eco-friendly packaging and stricter regulations on single-use plastics, jackfruit waste-based films present a cost-effective and sustainable alternative, aligning with the principles of the circular economy. (Panda *et al*. (2022))

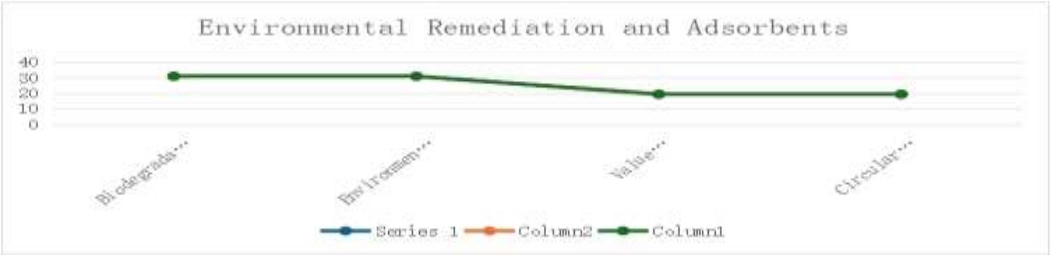
Environmental Remediation and Adsorbents

Because of their high surface area and porosity, cellulose and nanocellulose from jackfruit waste can be used as adsorbents to remove dyes and heavy metals from polluted water. It is helpful in the water purification, mainly in treating industrial waste waters. When chemically modified, they perform even better at capturing different pollutants. The best part is that these adsorbents are biodegradable, safe, and made from waste, which makes them eco-friendly and low-cost.

It reflects a more sustainable and practical approach towards solving pollution issues, especially in the context of waste management and circular economy initiatives.

Such adsorbents have demonstrated strong potential for removing heavy metals (e.g., lead, cadmium, chromium), dyes, pesticides, and organic pollutants from contaminated water. This mechanism involves ion exchange, hydrogen bonding and electrostatic interaction, which are developed after the surface activation (fig3)

Fig 3 – Environmental Remediation and Adsorbents



The usage of jackfruit waste not only helps in reducing environmental pollution caused by agricultural residues, this also gives a low-cost alternatives and sustainable alternative for conventional synthetic adsorbents. This remediation aligns with the waste valorization strategies, this also contributes to the development of eco-friendly techniques for wastewater treatment, and air purification. (Al-Ghouti and Al-Absi (2020)).

Biomedical and Tissue Engineering Applications

Through enzymatic, acid hydrolysis, the peel can be broken down to obtain fermentable sugars where it serves as raw materials for producing, organic acids, and other useful products. Its biocompatibility and biodegradability make it a promising material for these kinds of sensitive uses.(table 2)

Table 2 - Biomedical and Tissue Engineering Applications

Aspect	**Details**
Source Material	Nanocellulose derived from jackfruit waste
Biomedical Applications	Wound dressings- Tissue engineering scaffolds- Drug delivery systems
Key Properties	Biocompatibility- Biodegradability- Supports cell growth and healing
Advantages	Derived from natural, renewable resources- Reduces dependence on synthetic materials- Safe degradation inside the body
Sustainability Impact	Contributes to eco-friendly and sustainable healthcare solutions
Relevance in Medical Innovations	Suitable for sensitive biomedical uses due to non-toxicity and ability to integrate with biological systems

It is derived from a natural and renewable source, it not only reduces dependence on synthetic materials but also aligns with the goals of sustainable healthcare solutions. The ability of jackfruit-based nanocellulose to support cell growth and healing, while safely degrading in the body, makes it particularly suitable for medical innovations. (Seddiqi *et al*., (2021))

1. Wound Healing and Dressing

The nanocellulose is extracted from the jackfruit waste can be formed into hydrogel-based wound dressings with oxygen permeability and high water retention.The natural antioxidant compounds present in jackfruit peel can also contribute to reducing oxidative stress at the wound site. (Bezerra *et al*. (2015))

2. Drug Delivery Systems

Due to its non-toxic and biodegradable nature, jackfruit-derived cellulose can be modified to produce nanoparticles and films for controlled drug release. (Janmohammadi *et al*. (2023))

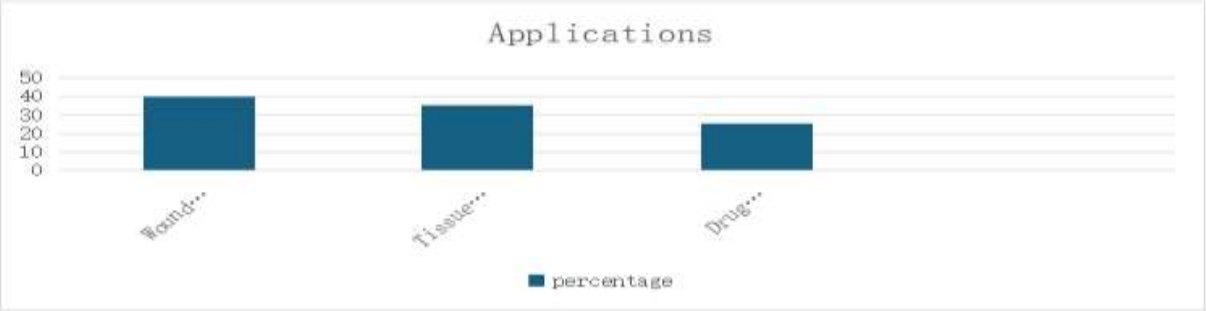
3. Tissue Engineering Scaffolds

Nanocellulose from jackfruit waste can be integrated into 3D scaffolds to support cell adhesion and proliferation. These scaffolds imitate the extracellular matrix (ECM) and can be merged with natural polymers like gelatin, or mixed to enhance the mechanical properties and biocompatibility. Such composites have potential in bone regeneration, cartilage repair, and skin tissue engineering. (Seddiqi *et al.* (2021))

Biofuel and Bioproduct Conversion

Through enzymatic and acid hydrolysis, jackfruit peel can be broken down to release fermentable sugars, which can subsequently be converted into bioethanol. This provides a efficient pathway for transforming fruit wastes into a renewable energy source, so this can help to reduce the uses of fossil fuels. Using the jackfruit waste for bioethanol gives a strong example of implementing waste management practices for sustainable energy development (fig4).

Fig 4 – Biofuel and Bioproduct Conversion



Bio-ethanol: the seeds from the jackfruit waste can be fermented and converted into biofuel, which it can be used in petrol alternatives

Bio – gas: through the anaerobic digestion the jackfruit waste can produce biogas, which it can be used for various purposes like heating , electricity generation and also can be used for vehicle fuel. (Munshi *et al.* (2020))

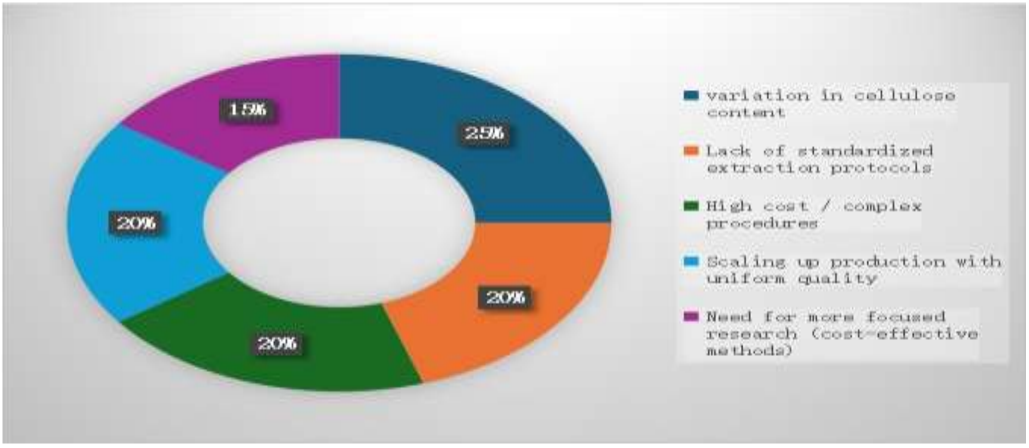
Challenges and Limitations

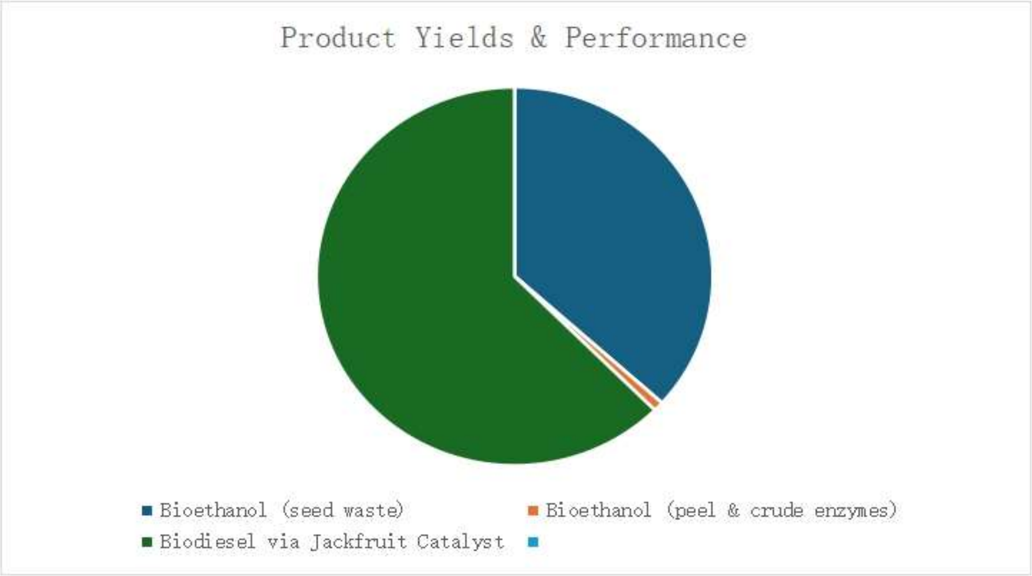
There are still a few challenges in using jackfruit waste for cellulose extraction. A major problem is that the cellulose content differs between jackfruit varieties(table 3), which makes it difficult to get consistent results ().Scaling up while keeping the quality the same is another big hurdle . (Sundarraj and Ranganathan (2018))

Table 3 - Challenges and Limitations

Challenge	**Description**	**Impact**	**Possible Solution Direction**
Variation in cellulose content	Different jackfruit varieties have varying cellulose percentages	Inconsistent final product quality	Select high-cellulose varieties; develop blending standards
Lack of standardized extraction protocols	No uniform method for cellulose extraction from jackfruit waste	Difficult to compare results and scale up processes	Establish industry-wide standard protocols
High cost & complexity of some methods	Certain extraction techniques are expensive or complicated	Not feasible for large-scale industrial application	Research simpler, low-cost extraction methods
Scaling up with consistent quality	Maintaining uniform cellulose quality during mass production is challenging	Quality variations affect market adoption	Optimize process control and quality monitoring systems
Limited industrial & academic research	Insufficient targeted studies on jackfruit waste utilization	Slower progress in developing efficient methods	Encourage collaborative research and funding support

Fig 5 – Challenges and Limitations





Conclusion and Future Scope

Jackfruit waste is not used widely in various regions, but the jackfruit is a great source of cellulose. With the right extraction methods, the jackfruit waste can be converted into valuable materials which are useful for eco-friendly packaging materials, medical applications, and also helps to clean the environment.

It is important to work on the extraction method to get a proper final output from the extraction of jackfruit waste.

Future research should focus on scaling up extraction techniques for cellulose and nanocellulose from jackfruit waste using cost-effective and green methods. Incorporating advanced modification techniques could improve the mechanical strength, barrier properties, and functionality of bioplastics and packaging films. In environmental applications, surface-engineered adsorbents from jackfruit waste could be tailored for specific pollutants, enhancing wastewater treatment efficiency. Establishing techno-economic feasibility studies and life cycle assessments will be essential for commercial adoption, making jackfruit waste a sustainable alternative in multiple industries.

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