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Nutritional composition, health benefits, and industrial utilization of jackfruit (*Artocarpus heterophyllus* lam.): A circular economy approach

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Abstract

Jackfruit (*Artocarpus heterophyllus* Lam.) is an underutilized tropical fruit with exceptional nutritional, medicinal, and industrial potential. Despite being rich in carbohydrates, proteins, vitamins, minerals, and bioactive compounds, large quantities of jackfruit and its by-products are wasted annually due to inadequate post-harvest infrastructure and limited processing facilities. This review synthesizes recent research on the nutritional composition, health-promoting properties, and industrial utilization of jackfruit within a circular economy framework aimed at zero-waste production. Jackfruit pulp and seeds are abundant in phenolics, flavonoids, carotenoids, and resistant starch, offering diverse health benefits such as antioxidant, anti-diabetic, anti-obesity, cardioprotective, anti-cancer, and immune-boosting effects. Clinical and experimental studies have highlighted its role in reducing chronic disease risks and improving gut health. Equally important is the valorization of non-edible by-products peel, core, and latex into value-added products such as pectin, nutraceuticals, bioplastics, animal feed, and biofuels. These innovations not only mitigate environmental pollution but also enhance rural incomes and support sustainable food systems. The review provides practical recommendations for industries, policymakers, and researchers to strengthen jackfruit-based value chains, promote product diversification, and integrate renewable energy and eco-friendly packaging technologies. By bridging nutrition, health, and industrial applications, jackfruit holds promise as a model crop for sustainable development and circular bioeconomy initiatives worldwide.

Keywords: Jackfruit, nutritional composition, health benefits, bioactive compounds, waste valorization, circular economy, sustainable food systems, functional foods

Introduction

1. Nutritional Composition of Jackfruit

Jackfruit (*Artocarpus heterophyllus* Lam.) is a nutrient-dense fruit valued for its carbohydrates, proteins, vitamins, minerals, and diverse bioactive compounds. The composition varies depending on the maturity stage, variety, and processing methods. Both ripe pulp and seeds serve as important sources of nutrition, making jackfruit an ideal candidate for functional foods and nutraceuticals (Lakshmi, *et al.* 2023)^[1].

1.1 Macronutrients

Carbohydrates

- The ripe pulp is rich in natural sugars, primarily glucose, fructose, and sucrose, which contribute to its sweet taste and quick energy release.
- Unripe jackfruit is high in starch and dietary fiber, making it a popular ingredient in vegetarian meat substitutes.
- Resistant starch in seeds supports gut health and aids in blood sugar regulation (Kumar, *et al.* 2024)^[2].

Proteins

- Jackfruit seeds are an excellent source of plant-based proteins containing essential amino acids like lysine, leucine, and valine.

- This makes jackfruit seed flour a sustainable alternative to animal-based protein supplements in developing regions (Sharma, *et al.* 2023)^[3].

Fats

- Jackfruit pulp and seeds contain negligible amounts of fat (<1 g per 100 g), making it suitable for low-fat diets.
- The small quantity of fat present consists mostly of unsaturated fatty acids, beneficial for cardiovascular health.

1.2 Micronutrients

Jackfruit is an important source of vitamins and minerals essential for overall health.

- **Vitamin C:** Boosts immunity and acts as a natural antioxidant.
- **Vitamin A (Carotenoids):** Supports eye health and immune function.
- **Potassium:** Helps regulate blood pressure and muscle function.

- **Magnesium & Calcium:** Essential for bone health and enzymatic reactions.
- **Iron & Zinc:** Critical for haemoglobin formation and enzyme activity.

1.3 Bioactive Compounds

Jackfruit is rich in several bioactive phytochemicals, including:

- **Phenolic compounds:** Gallic acid, ferulic acid, catechins - potent antioxidants.
- **Flavonoids:** Quercetin, kaempferol - anti-inflammatory and anti-cancer properties.
- **Carotenoids:** Beta-carotene and lutein - promote eye and skin health.
- **Saponins:** Present in seeds, beneficial for cholesterol management.

These compounds are largely responsible for jackfruit's therapeutic potential, as detailed in Section 3 on health benefits (Sharma, *et al.* 2024)^[4].

1.4 Nutritional Table

Table 1: Nutritional composition of jackfruit (per 100 g edible portion)

Nutrient	Ripe Pulp	Seeds	Health Significance
Energy (kcal)	95 kcal	137 kcal	Energy supply for daily activities
Carbohydrates (g)	23.0	36.0	Main source of energy
Protein (g)	1.7	6.6	Muscle repair, enzyme function
Fat (g)	0.3	0.5	Essential fatty acids
Dietary Fiber (g)	2.6	1.5	Digestive health, satiety
Vitamin C (mg)	13.7	7.0	Immunity, antioxidant activity
Vitamin A (µg)	110	35	Vision, immune health
Potassium (mg)	448	300	Blood pressure regulation
Calcium (mg)	34	50	Bone health
Magnesium (mg)	29	54	Nerve and muscle function
Iron (mg)	0.6	1.2	Hemoglobin synthesis
Zinc (mg)	0.4	0.7	Enzymatic reactions
Phenolic Content (mg GAE)	45.0	60.0	Antioxidant activity

Sources: Lakshmi *et al.* (2023); Kumar *et al.* (2024); Sharma *et al.* (2023)^[1, 2, 3]

1.5 Summary of Nutritional Significance

Jackfruit is not only a nutritional powerhouse but also a sustainable alternative for addressing malnutrition.

- The pulp is ideal for fresh consumption, juices, and processed products.
- The seeds can be processed into flour, protein powders, or used in bakery products.
- Peel and other by-products contain high phenolic content, making them valuable for nutraceutical and pharmaceutical industries.

2. Health Benefits of Jackfruit: Jackfruit (*Artocarpus heterophyllus* Lam.) has gained recognition as a functional food due to its wide array of bioactive compounds, including phenolics, flavonoids, carotenoids, saponins, and dietary fiber. These compounds have been linked to prevention and management of chronic diseases, such as diabetes, cardiovascular disorders, obesity, cancer, and inflammatory conditions (Lakshmi, *et al.* 2023)^[1].

The key health benefits of jackfruit, supported by laboratory studies, clinical trials, and epidemiological data.

2.1 Antioxidant and Anti-Inflammatory Properties

Mechanism of Action

Phenolic acids (gallic acid, ferulic acid) and flavonoids (quercetin, kaempferol) neutralize free radicals, preventing oxidative stress-related cell damage.

These compounds reduce chronic inflammation by inhibiting pro-inflammatory cytokines like TNF- α and IL-6 (Sharma, *et.al* 2024)^[4].

Scientific Evidence

- Lakshmi *et al.* (2023)^[1] reported that jackfruit peel extracts exhibit 40% higher antioxidant activity compared to other tropical fruits such as mango and papaya.
- Animal studies showed a 35% reduction in oxidative stress markers, such as malondialdehyde (MDA), following jackfruit seed supplementation (Singh, Thomas, Iyer, & Kumar, 2023)^[13].

Implication: Regular consumption of jackfruit may help reduce the risk of age-related and chronic degenerative diseases. (Selva M, 2024)^[16]

2.2 Anti-Diabetic Properties

Mechanism of Action

- Saponins and flavonoids in jackfruit seeds improve insulin sensitivity and regulate glucose metabolism.
- Inhibition of α -amylase and α -glucosidase enzymes slows carbohydrate digestion, reducing postprandial blood sugar spikes (Kumar, *et al.*, 2023) ^[13].

Scientific Evidence

- A 2023 clinical trial demonstrated that diabetic patients consuming jackfruit seed flour daily for 12 weeks experienced a 16% decrease in fasting blood glucose and improved HbA1c levels.
- Animal model studies confirmed a 22% reduction in insulin resistance with jackfruit seed supplementation (Sharma, *et.al* 2024) ^[4].

Dietary Application

Jackfruit seed flour can be incorporated into bread, chapatis, and baked goods as a functional food ingredient.

2.3 Cardioprotective Effects

Role of Key Nutrients

- **Potassium:** Regulates blood pressure and prevents hypertension.
- **Dietary Fiber:** Binds bile acids, lowering LDL cholesterol.
- **Phenolic compounds:** Prevent oxidative damage to vascular tissues (Reddy, *et al.* 2021) ^[8].

Scientific Evidence

- A population-based study (FAO, 2023) ^[5] found that communities with higher jackfruit intake had an 11% lower incidence of hypertension.
- Reddy, *et al.*, (2021) ^[8] verified that jackfruit consumption for 30 days significantly decreased total cholesterol and triglycerides in hyperlipidemic individuals.

2.4 Gut Health and Prebiotic Effects

Mechanism of Action

- Jackfruit seeds contain resistant starch that acts as a prebiotic, stimulating beneficial gut bacteria like *Bifidobacterium* and *Lactobacillus*.
- Improves digestion and may alleviate inflammatory bowel disorders (Lakshmi, *et al.*, 2024) ^[7].

Scientific Evidence

- A human trial reported a 27% increase in gut microbiota diversity among participants consuming jackfruit seed flour daily.
- Polysaccharides from jackfruit seeds were shown to reduce irritable bowel syndrome (IBS) symptoms in 60% of patients (Palaniswamy, *et al.* 2022) ^[8].

2.5 Anti-Obesity Properties

Mechanism of Action

- High fiber content creates satiety and reduces caloric intake.
- Polyphenols inhibit adipogenesis (formation of new fat cells), reducing fat storage (Kumar, *et al.*, 2024) ^[2].

Scientific Evidence

In a 12-week weight management study, participants who consumed 200 g of boiled jackfruit seeds daily showed a 5% greater reduction in body weight compared to the control group.

2.6 Anti-Cancer Potential

Mechanism of Action

- Flavonoids and saponins suppress cancer cell proliferation.
- Carotenoids neutralize free radicals, preventing DNA mutations (Sharma *et al.*, 2024) ^[4].

Scientific Evidence

- Jackfruit peel extracts inhibited colon cancer cell growth by 32% *in vitro*.
- Animal studies showed apoptosis (programmed cell death) in breast cancer cells treated with jackfruit seed extracts.

2.7 Immune System Support

Role of Key Nutrients

- Vitamin C and carotenoids enhance white blood cell production and immune defense.
- Zinc and copper act as cofactors for enzymes that regulate immune function.

Scientific Evidence

- FAO (2023) ^[5] reported that jackfruit-based diets improves immune resilience, especially in malnourished populations.
- Children consuming jackfruit regularly had 25% fewer respiratory infections compared to those with low intake.

Table 2: Health benefits of jackfruit and associated bioactive compounds

Health Benefit	Key Compounds/Nutrients	Mechanism of Action	Key Reference
Antioxidant & Anti-inflammatory	Phenolics, flavonoids	Neutralizes free radicals, reduces inflammation	Lakshmi <i>et al.</i> , 2023 ^[1]
Anti-diabetic	Saponins, flavonoids, resistant starch	Enhances insulin sensitivity, regulates glucose	Kumar <i>et al.</i> , 2023 ^[23]
Cardioprotective	Potassium, fiber, phenolic compounds	Reduces BP, lowers LDL cholesterol	Reddy <i>et al.</i> , 2021 ^[8]
Gut Health & Prebiotic	Resistant starch, polysaccharides	Improves gut microbiota, digestion	Palaniswamy <i>et al.</i> , 2022 ^[8]
Anti-obesity	Fiber, polyphenols	Satiety, prevents fat accumulation	Kumar <i>et al.</i> , 2024 ^[2]
Anti-cancer	Flavonoids, carotenoids, saponins	Suppresses tumor growth, DNA protection	Sharma <i>et al.</i> , 2024 ^[4]
Immune Support	Vitamin C, zinc, copper	Enhances immune response, antibody production	FAO, 2023 ^[5]

3. Utilization of Non-Edible By-Products

Jackfruit processing results in a significant proportion of non-edible waste materials such as peel, core, seeds' outer skin, and latex, which make up approximately 70-80% of the total fruit weight (FAO, 2023) ^[5]. Traditionally, these by-products are discarded or composted, contributing to environmental pollution and loss of potential revenue. However, recent research emphasizes the valorization of these by-products into high-value industrial products,

supporting a circular economy model and ensuring zero-waste production systems (Kumar, *et al.* 2023) ^[13]. Valorizing jackfruit waste can generate income for farmers, promote rural entrepreneurship, and reduce pressure on natural resources, aligning with Sustainable Development Goals (SDGs).

3.1 Composition of By-Products

Jackfruit by-products are rich in nutrients and bioactive compounds, making them ideal for industrial applications.

Table 3: Key Constituents Potential Industrial Applications

By-Product	Key Constituents	Potential Industrial Applications
Peel and Rind	Pectin, cellulose, phenolics, lignin	Pectin extraction, bioplastics, biochar, animal feed
Core	Starch, simple sugars, fiber	Animal feed, fermentation substrates
Seeds' outer skin	Resistant starch, protein, minerals	Nutraceuticals, flour, prebiotic supplements
Latex	Natural rubber compounds	Adhesives, industrial rubber products
Leaves	Polyphenols, tannins	Bio-pesticides, compost, livestock medicine

Sources: FAO (2023); Lakshmi *et al.*, (2023); Kumar *et al.*, (2023) ^[1, 13, 5]

3.2 Pectin Extraction

Jackfruit peel contains 2.1-2.6% pectin (dry weight basis), a natural gelling agent extensively used in the food, pharmaceutical, and cosmetic industries (Lakshmi *et al.*, 2023) ^[1].

Applications

- Jam, jelly, and confectionery production.
- Controlled drug release systems.
- Biodegradable film packaging.

Recent Findings

Lakshmi *et al.*, (2023) ^[1] demonstrated that jackfruit pectin has higher gelling strength than commercial citrus pectin, making it a promising alternative for industrial use.

3.3 Animal Feed Production

Jackfruit peel and core are valuable feed sources due to their high fiber and energy content.

Nutritional Profile of Dried Peel

- Crude protein: 5-6%
- Crude fiber: 15-20%
- Digestible carbohydrates: 40-50%

Processing Steps

1. Peels are chopped and sun-dried.
2. Fermentation enhances palatability and protein availability.
3. Mixed with other feed components to create balanced rations.

Case Study - Kerala, India

A farmer producer group developed jackfruit peel silage, which increased dairy cow milk yield by 8% and reduced feed costs by 15% (ICAR-CISH, 2021) ^[11].

3.4 Bioplastics and Eco-Friendly Packaging

Jackfruit peel contains starch and cellulose, which can be processed into biodegradable plastics, offering a sustainable alternative to petroleum-based packaging.

Advantages

- Fully decomposes within 90 days.

- Safe for food packaging.
- Reduces plastic pollution in the environment.

Innovation Example - ICAR-IIHR, India

In 2022, researchers developed jackfruit starch-based trays that kept fruits fresh for up to 10 days under refrigeration, reducing post-harvest losses (ICAR-IIHR, 2022) ^[12].

3.5 Bio-Fuel and Energy Production

Jackfruit waste, being rich in carbohydrates, can be used for bio-energy generation through various conversion processes:

- **Anaerobic digestion:** Produces biogas for cooking and electricity.
- **Fermentation:** Generates ethanol for fuel blending.
- **Pyrolysis:** Produces biochar and bio-oil.

Global Case Study - Thailand

A pilot bio-ethanol plant processed jackfruit peel and core, producing 1,200 liters of ethanol per ton of waste, demonstrating commercial feasibility (FAO, 2023) ^[5].

3.6 Nutraceuticals and Functional Ingredients

Jackfruit peel and seeds are rich in polyphenols, flavonoids, and carotenoids, which have medicinal properties.

Potential Products

- Dietary supplements for immune health.
- Natural antioxidants for food preservation.
- Anti-diabetic capsules and powders.

Recent Findings

Sharma, *et al.* (2024) ^[4] reported that jackfruit peel extract inhibited the growth of foodborne pathogens such as *Salmonella* and *E. coli* by 85%, indicating its potential as a natural preservative.

3.7 Wastewater Treatment and Biochar

- Jackfruit rind-based biochar improves soil fertility by enhancing water retention and nutrient availability.
- Biochar can also be used as an adsorbent to remove heavy metals like lead and cadmium from wastewater.

Sri Lanka Initiative

Smallholder farmers reduced chemical fertilizer usage by 30% after integrating jackfruit peel biochar into organic farming practices (FAO, 2023) [5].

3.8 Circular Economy Perspective: Valorizing jackfruit by-products follows the circular economy model, where waste is repurposed into resources, ensuring environmental and economic sustainability (Fao.2023) [5]

Table 4: Circular Economy Step Application in Jackfruit Processing

Circular Economy Step	Application in Jackfruit Processing
Waste Reduction	Conversion of peel to animal feed or compost
Resource Recovery	Pectin and nutraceutical extraction
Energy Production	Biogas and ethanol generation
Eco-Friendly Packaging	Bioplastics from peel starch
Value Addition	Nutraceutical and functional food products

Outcome

Reduces greenhouse gas emissions.

Generates alternative income streams for farmers.

Supports sustainable food production systems.

Table 5: By-products and Their Industrial Applications

By-Product	Value-Added Product	Industry Benefited
Peel	Pectin, bioplastics, biochar	Food, pharmaceuticals, packaging
Core	Animal feed, ethanol substrate	Livestock, energy production
Seeds	Nutraceuticals, flour	Food supplements, bakery industry
Latex	Adhesives, natural rubber	Industrial products
Leaves	Bio-pesticides, compost	Agriculture, organic farming
Country	Innovation	Outcome
India	Jackfruit starch trays for packaging	Reduced post-harvest losses by 25%
Thailand	Bio-ethanol from peel and core	Renewable energy production
Sri Lanka	Peel-based biochar in organic farms	Reduced fertilizer costs by 30%
Philippines	Frozen jackfruit exports	Increased international trade revenue

4. Practical Recommendations

- Industries:** Diversify products, valorize waste into pectin, bioplastics, and biogas, ensure GMP standards, and expand into health food markets.
- Policymakers:** Support infrastructure, provide subsidies for mini-processing units, promote jackfruit in nutrition missions, and integrate into climate-resilient crops.
- Researchers:** Focus on nutraceutical development, post-harvest technologies, sustainability assessments, and international collaborations.
- Integrated Value Chain:** Collaboration among farmers, industries, policymakers, and researchers ensures sustainable jackfruit utilization.

5. Conclusion

Jackfruit is a nutrient-rich tropical fruit with vast potential to address malnutrition, lifestyle diseases, and environmental sustainability. Its pulp and seeds offer multiple health benefits, while by-products can be transformed into value-added products such as pectin, bioplastics, animal feed, and biofuels. By adopting circular economy strategies, industries, policymakers, and researchers can ensure zero-waste processing, enhanced farmer incomes, and sustainable development. Thus Jackfruit stands as a model crop for global circular bioeconomy initiatives.

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