



## International Journal of Horticulture and Food Science

E-ISSN: 2663-1067

P-ISSN: 2663-1075

NAAS Rating (2025): 4.74

[www.hortijournal.com](http://www.hortijournal.com)

IJHFS 2025; 7(9): 44-48

Received: 09-07-2025

Accepted: 13-08-2025

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# Sustainable agronomic practices for jackfruit (*Artocarpus heterophyllus* Lam.): Nutritional value, health benefits, and utilization of non-edible by- products

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**DOI:** <https://www.doi.org/10.33545/26631067.2025.v7.i9a.392>

## Abstract

Jackfruit (*Artocarpus heterophyllus* Lam.) has a big potential in enhancing nutritional security, rural livelihoods, and sustainable agricultural systems because the tree is a multipurpose tropical fruit. The importance of jackfruit is still that even with the volumes of this crop that are produced, it is estimated every year that one-third of the crop is being wasted due to improper post-harvest management, absence of infrastructure and post-processing infrastructure. This is a review of recent studies on sustainable agronomic methods, nutritional value, health benefits, and value-added use of jackfruit by-products in a circular economy.

The paper identifies agronomic interventions that are environmentally friendly, like integrated nutrient management, climate-sensitive irrigation, pruning, canopy management, and integrated pest and disease management to improve productivity and environmental sustainability. Jackfruit contains carbohydrates, proteins, vitamins, minerals, and bioactive compounds, including flavonoids and carotenoids, and has a wide variety of health benefits, including antioxidant, anti-diabetic, cardioprotective, anti-obesity, gut health promotion, and anti-cancer.

Also, new methods of transforming non-edible by-products, including peel, core, seeds, and latex into high-value products such as pectin, bioplastics, animal feed, nutraceuticals, and biofuels are addressed. Recommendations on practical practices to be adopted by farmers, industries, and policymakers are offered to ensure that zero-waste systems are adopted and enhance rural economies. Modern agricultural practices, processing innovations, and supportive policies can help the jackfruit cultivation to be integrated to form a sustainable horticultural model to help in food security and horticultural stability.

**Keywords:** Nutraceuticals, jackfruit, sustainable agronomy, circular economy, waste management, bioactive compounds, value addition, health benefits

## 1. Introduction

Jackfruit (*Artocarpus heterophyllus* Lam.) is one among the most significant tropical fruit trees that are planted in South and Southeast Asia, especially in India, Bangladesh, Sri Lanka, and Thailand. Jackfruit is the largest tree-borne fruit in the world, and the single fruit may weigh 50 kg, which makes it one of the most important sources of food and nutrition to the rural and urban population (FAO, 2023) <sup>[1]</sup>. The fruit is useful in several ways as it is not only food, but also animal feed and raw material in various industries such as nutraceuticals, packaging, and biofuels.

The current interest in jackfruit worldwide has been growing due to its resistance to climate and its capacity to grow on marginal and degraded land with minimum input. Jackfruits are also perennial, tolerant to drought, and hardy, thus they are very appropriate to climate-smart farming programs (ICAR-IIHR, 2022) <sup>[5, 6]</sup>. These characteristics make jackfruit a major crop when it comes to sustainable agricultural systems in the period of climatic variability and resource inadequacy. Jackfruit has potential, although it is poorly used, and it has a number of production and marketing problems. The post-harvest losses are estimated to be between 30 and 40 per cent, mostly because of the absence of cold storage, insufficient processing infrastructure and an unorganized value chain (NHB, 2022) <sup>[15]</sup>.

During the season, farmers will usually get low returns because of a glut in the market, whereas large volumes of fruits do not get harvested and are wasted. Additionally, by-products like peel, core, and seeds (almost 7080 percent of total fruit weight) are non-edible and discarded, which pollute the environment and waste useful bioresources (Lakshmi, Menon, George, and Prasad, 2023) <sup>[12]</sup>.

Circular economy is a new idea that can solve these problems through transforming waste materials into useful products in agriculture. Jackfruit by-products can have a future application in the extraction of pectin, biochar, bioplastics, nutraceuticals, animal feed, and biofuel generation, which would result in zero-waste processing and other revenue streams to farmers (Kumar, Reddy, and Palaniswamy, 2024) <sup>[11]</sup>.

This vision can, however, be achieved through the combination of sustainable agronomic practices with post-harvest management and processing innovations, and policy support. The existing farming methods are commonly traditional and do not involve scientific measures like integrated nutrient management (INM), climate-smart irrigation, pruning, and integrated pest and disease management (IPDM) that can enhance yield and quality of fruit (Palaniswamy, Kumar, and Reddy, 2022) <sup>[16]</sup>.

#### This review paper aims to:

- Sustainable agronomic practices.
- Nutritional composition and health benefits.
- Innovative by-product utilization strategies.
- Practical recommendations for farmers and industries.

## 2. Agronomic Measures

A sustainable jackfruit farming will be based on the management of the orchard, environmentally friendly practices, and effective use of resources.

### 2.1 Climate and Soil Requirements

- **Climate:** Ideal temperatures range between 16-35°C with annual rainfall of 150-250 cm.
- **Soil:** Grows best in well-drained sandy loam to clay loam soils with pH 6.0-7.5.
- **Avoid:** Waterlogged areas to prevent root rot (Palaniswamy, Kumar, & Reddy, 2022) <sup>[16]</sup>.

### 2.2 Propagation and Planting

- **Seed propagation:** Traditional, but results in variability.
- **Vegetative propagation:** Grafting is preferred for early bearing and uniformity.
- **Spacing:** Standard planting at 8 × 8 m; high-density planting at 6 × 6 m.

### 2.3 Nutrient Management

- **FYM:** 20-25 kg per plant annually.
- **INM (Integrated Nutrient Management):**
  - Organic manures + biofertilizers + chemical fertilizers (Begum *et al.*, 2024) <sup>[17]</sup>.
  - Balanced fertilization prevents nutrient leaching.
- **Deficiencies:**
  - Nitrogen → leaf yellowing.
  - Zinc → poor flowering and fruit set (Sharma, Singh, & Kumar, 2023) <sup>[25]</sup>.

## 2.4 Irrigation Practices

The jackfruit entails regular watering of the trees in dry seasons to achieve good growth and high fruit production. Drip irrigation is the most effective technique and it is the one that delivers water into the root zone and results in low levels of wastage. The mulching around the tree bases helps in preserving moisture as well as preventing weeds. It should be irrigated during the critical periods like flowering, fruit set, and fruit development to avoid untimely fruit drop. To enable climate-resilient farming, the rainwater harvesting systems and farm ponds can be combined to maintain the availability of water during drought periods. (ICAR-IIHR, 2022; FAO, 2023) <sup>[5, 1]</sup>.

- **Drip irrigation:** Recommended for water efficiency.
- Critical stages:
  - Flowering
  - Fruit set
  - Fruit development
- Rainwater harvesting is encouraged for sustainability.

## 2.5 Pruning and Canopy Management

Correct pruning increases the amount of light penetration and air flow, which are important in minimizing the occurrence of pests and diseases. In the younger stages, it is important to train young trees to create a robust structure to carry a lot of fruit. Once harvesting is done, overcrowded, diseased, or weak branches must be eliminated in order to keep trees healthy. Keeping trees at 45 meters tall enhances harvesting and eliminates branch damage in case of a storm. Regular thinning of the canopy will guarantee enhanced photosynthetic performance and even fruiting in the subsequent seasons (Reddy *et al.*, 2021; Palaniswamy *et al.*, 2022) <sup>[16, 11]</sup>.

- Regular pruning improves light penetration.
- Young trees are trained to develop strong frameworks to prevent breakage.

## 2.6 Integrated Pest and Disease Management (IPDM)

Sustainable pest management is based on the use of a blend of biological, cultural and mechanical control in the control of pests before the use of chemicals. Frequent monitoring of orchards can be used to identify the early infestation of pests such as fruit borers and mealybugs. Bio-agents like *Trichoderma* and *Bacillus*, neem-based biopesticides are suggested to be used in control which is environmentally friendly. Pest repellent plants that are intercropped with orchard sanitation further decrease the population of pests. Selective and low-residue chemical pesticides can be utilized in case of severe outbreaks in accordance with the principles of integrated pest management to reduce the impact on the environment (ICAR-CISH, 2021; Sharma *et al.*, 2019) <sup>[4, 21]</sup>.

- **Major pests:** Fruit borer, mealybugs.
- **Diseases:** Bacterial blight, stem rot.
- **Management:**
  - Neem-based biopesticides and pheromone traps.
  - Orchard sanitation and intercropping for pest control.

## 2.7 Harvest and Post-Harvest Handling

The fruits should be harvested at the time when they are at optimum maturity, and this means that the spines are flattened, they have a particular aroma, and they sound dull when tapped. Sharp tools used are sterile to avoid contamination with microbes. Fruits are to be washed,

graded, and packed in ventilated crates after harvesting to minimize mechanical damage. Relative humidity of 85-90 percent in cold storage at 12-14 °C would increase shelf life up to a period of 7-10 days. Marketability and minimization of the loss in the post-harvest period can be improved further by the adoption of better packaging technologies (modified atmosphere packaging), (Reddy *et al.*, 2021; ICAR-IIHR, 2022) <sup>[5, 6]</sup>.

- Harvest at optimal maturity using sanitized tools.
- Cold storage at 10-12°C extends shelf life by up to 10 days (ICAR-IIHR, 2022) <sup>[5, 6]</sup>.

### 3. Practical Recommendations

#### Farmers

- Adopt drip irrigation and INM.
- Prune regularly for better canopy management.
- Harvest at the correct maturity stage.

#### Industries

- Establish processing units for pectin and nutraceuticals.
- Invest in cold chain infrastructure.
- Promote bioplastics from jackfruit peel starch.

**Table 1:** Recommended Agronomic Practices

| Agronomic Practices   | Recommendations                                                                                      | Key Reference(s)                                                                                                |
|-----------------------|------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| Climatic Requirement  | 22-35 °C; annual rainfall 1500-2500 mm                                                               | FAO (2023) <sup>[1]</sup> ; NHB (2022) <sup>[15]</sup>                                                          |
| Soil Requirement      | Deep, well-drained loamy soil; pH 6.0-7.5                                                            | Palaniswamy, Kumar & Reddy (2022) <sup>[16]</sup>                                                               |
| Spacing               | 8 × 8 m (standard); 6 × 6 m (high-density)                                                           | ICAR-CISH (2021) <sup>[4]</sup> ; Palaniswamy, Kumar & Reddy (2022) <sup>[16]</sup>                             |
| Pit Preparation       | 1 × 1 × 1 m pits; mix topsoil + 20 kg FYM + neem cake                                                | NHB (2022) <sup>[15]</sup> ; ICAR-CISH (2021)                                                                   |
| Nutrient Management   | FYM 20-25 kg/tree/yr; N:P:K ≈ 400:200:400 g/tree/yr; apply micronutrients per soil test              | Sharma, Singh & Kumar (2023) <sup>[25]</sup> ; Palaniswamy, Kumar & Reddy (2022) <sup>[16]</sup>                |
| Irrigation            | Drip irrigation; increased frequency at flowering & fruit development; mulching to conserve moisture | ICAR-IIHR (2022); FAO (2023) <sup>[1]</sup>                                                                     |
| Pruning & Canopy Mgmt | Annual post-harvest pruning; open-center canopy; maintain tree height 4-5 m                          | Reddy, Mohan & Lakshmi (2021) <sup>[20]</sup> ; Palaniswamy, Kumar & Reddy (2022)                               |
| Pest Management       | Monitor pests; pheromone traps; biopesticides (neem oil, Bacillus/Trichoderma)                       | ICAR-CISH (2021) <sup>[4]</sup> ; Sharma, Singh & Kumar (2023) <sup>[25]</sup>                                  |
| Disease Management    | Sanitation, copper/or organic fungicides, Trichoderma soil treatment for root rot                    | ICAR-CISH (2021) <sup>[4]</sup>                                                                                 |
| Harvesting            | Harvest at flattened spines + aroma; use sanitized cutting tools                                     | FAO (2023) <sup>[1]</sup> ; NHB (2022) <sup>[15]</sup>                                                          |
| Post-harvest Handling | Clean, grade, pack in ventilated crates; cold storage at 12-14 °C (85-90% RH) to extend shelf life   | FAO (2023) <sup>[1]</sup> ; Kumar & Singh (2024) <sup>[9]</sup> ; Reddy, Mohan & Lakshmi (2021) <sup>[20]</sup> |

**Table 2:** Nutritional Composition of Jackfruit (per 100 g edible portion)

| Nutrient                      | Pulp (per 100 g) | Seeds (per 100 g) | Source(s)                                                                          |
|-------------------------------|------------------|-------------------|------------------------------------------------------------------------------------|
| Energy                        | 95 kcal          | 133 kcal          | FAO (2023) <sup>[1]</sup> ; Lakshmi, Menon, George & Prasad (2023) <sup>[13]</sup> |
| Carbohydrate                  | 23.5 g           | 38 g              | FAO (2023) <sup>[1]</sup> ; Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>           |
| Protein                       | 1.7-1.8 g        | 6-7 g             | FAO (2023) <sup>[1]</sup> ; Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>           |
| Fat                           | 0.6-0.7 g        | 0.3-0.5 g         | FAO (2023)                                                                         |
| Dietary fiber                 | 1.5-2.6 g        | 1.2-2.0 g         | FAO (2023) <sup>[1]</sup> ; Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>           |
| Vitamin C                     | 13-15 mg         | ~11 mg            | FAO (2023) <sup>[1]</sup> ; Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>           |
| Vitamin A (β-carotene equiv.) | 2-3 µg           | 1-2 µg            | Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>                                       |
| Potassium                     | 300-450 mg       | 240-300 mg        | FAO (2023) <sup>[1]</sup> ; Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>           |
| Magnesium                     | 25-35 mg         | ~40 mg            | FAO (2023) <sup>[1]</sup>                                                          |
| Calcium                       | ~24 mg           | ~34 mg            | FAO (2023) <sup>[1]</sup>                                                          |
| Iron                          | 0.2-0.3 mg       | ~1.5 mg           | FAO (2023) <sup>[1]</sup> ; Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>           |
| Zinc                          | ~0.15-0.4 mg     | ~0.25-0.4 mg      | Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>                                       |
| Phosphorus                    | ~20 mg           | ~30 mg            | FAO (2023) <sup>[1]</sup> ; Lakshmi <i>et al.</i> (2023) <sup>[13]</sup>           |

Jackfruit provides essential nutrients supporting human health

**Notes:** Nutrient values vary by variety, maturity stage, and analysis method. Sources above provide the ranges used

**Table 3:** Utilization of Non-Edible By-Products (Peel, Core, Seeds, Latex)

| By-product          | Value-added product / use                                                                                    | Primary reference(s)                                                                                                         |
|---------------------|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Peel / Rind         | Pectin extraction for food/pharma; biodegradable films/bioplastics; adsorbent for wastewater; biochar        | Lakshmi, Menon, George & Prasad (2023) <sup>[12]</sup> ; Kumar, Reddy & Palaniswamy (2024) <sup>[11]</sup>                   |
| Core / inner pulp   | Fermented animal feed; substrate for anaerobic digestion (biogas); feedstock for ethanol                     | Reddy, Mohan & Lakshmi (2021) <sup>[18]</sup> ; FAO (2023) <sup>[1]</sup> ; Kumar, Reddy & Palaniswamy (2023) <sup>[8]</sup> |
| Seeds               | Roasted/boiled food; flour for bakery/food products; resistant starch for prebiotics; nutraceutical extracts | Lakshmi <i>et al.</i> (2023) <sup>[13]</sup> ; Palaniswamy, Kumar & Reddy (2022) <sup>[16]</sup>                             |
| Latex               | Industrial adhesives and rubber-linked products (research/early stage)                                       | Reddy, Mohan & Lakshmi (2021) <sup>[18]</sup>                                                                                |
| Mixed waste streams | Bio-ethanol, pyrolysis oil, biochar, compost for soil improvement                                            | FAO (2023); Kumar, Reddy & Palaniswamy (2023) <sup>[8]</sup> ; Reddy, Mohan & Lakshmi (2021) <sup>[18]</sup>                 |

Circular economy model ensures zero waste, boosting farmer income and environmental sustainability (FAO, 2023) <sup>[1]</sup>.

**Table 4:** Health Benefits

| Health Benefit                           | Key bioactive compounds/nutrients                                                           | Mechanism / Effect                                                                                                                    | Level of evidence                                                         |
|------------------------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Antioxidant & Anti-inflammatory          | Phenolic acids (gallic acid, ferulic acid), flavonoids (quercetin, kaempferol), carotenoids | Scavenges free radicals, reduces lipid peroxidation and inflammatory markers (↓MDA, ↓pro-inflammatory cytokines)                      | <i>In vitro</i> & animal studies; supportive lab analyses                 |
| Anti-diabetic (glycemic control)         | Saponins, flavonoids, resistant starch (seed flour)                                         | Improve insulin sensitivity; inhibit $\alpha$ -amylase/ $\alpha$ -glucosidase; reduce post-prandial glucose excursions                | Clinical pilot + animal studies                                           |
| Cardioprotective                         | Potassium, dietary fiber, phenolics                                                         | Potassium → blood pressure regulation; fiber → lowers LDL cholesterol; phenolics → protect vascular endothelium from oxidative damage | Population observations and interventional feeding studies (small trials) |
| Gut health / Prebiotic effects           | Resistant starch, polysaccharides (seed & pulp)                                             | Serve as prebiotic substrate → enrich <i>Bifidobacteria/Lactobacillus</i> , increase microbiota diversity, improve SCFA production    | Human dietary trials & microbiome studies (pilot)                         |
| Anti-obesity / Satiety                   | Dietary fiber, polyphenols                                                                  | Increase satiety, reduce energy intake; polyphenols may inhibit adipogenesis                                                          | Randomized controlled trial (small), animal models                        |
| Anti-cancer potential                    | Carotenoids, flavonoids, saponins                                                           | Induce apoptosis in cancer cells, inhibit proliferation, antioxidant protection of DNA                                                | <i>In vitro</i> and animal tumor model studies                            |
| Immune support                           | Vitamin C, carotenoids, zinc                                                                | Enhance phagocytic activity, antibody responses; antioxidant protection reduces infection susceptibility                              | Observational data and nutritional assessments                            |
| Antimicrobial (food safety applications) | Phenolics, tannins                                                                          | Inhibit growth of common foodborne pathogens (e.g., <i>E. coli</i> , <i>Salmonella</i> ) useful as natural preservative               | <i>In vitro</i> challenge tests and food model studies                    |

Jackfruit's bioactive compounds offer numerous health advantages

## Conclusion

Jackfruit (*Artocarpus heterophyllus* Lam.) is a highly versatile tropical fruit with immense potential to enhance food security, improve farmer livelihoods, and promote environmental sustainability. Adoption of scientific agronomic practices, including integrated nutrient management, efficient irrigation, and pest and disease control, can significantly improve yield and quality while conserving resources. Beyond its nutritional and health benefits, effective utilization of non-edible by-products through circular economy strategies, such as pectin extraction, biochar production, and bioplastics, can reduce waste and generate additional income. Strengthening post-harvest infrastructure, value-added processing, and market linkages will be crucial to unlock the full potential of jackfruit, positioning it as a model crop for sustainable horticulture and rural development.

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