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Research Article

Jackfruit Seed Flour: Nutritional Composition, Functional Properties, Health Benefits, And Sustainable Applications Review

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Abstract

Purpose: Jackfruit (Artocarpus heterophyllus Lam.) is a little used tropical fruit with a reputation of being rich in nutrients and sustainable. Though the pulp of the fruit is consumed vastly, the seeds forming almost 10 15 percent of the weight of the fruit is wasted leading to food waste.

Method: The review is a synthesis of the findings of the recent studies regarding the nutritional profile, functional properties, bioactive compounds, and health benefit properties of jackfruit seeds. It also addresses how they are converted into flour and their possible uses within food systems, with the help of studies (2018-2025).

Results: Jackfruit seed flour is the good source of resistant starch, proteins, important minerals, and phytochemicals and shows meaningful functional characteristics like high water absorption ability and gelling the capacity. The good nutritional quality that it possesses when added to bakery, confectionary, and gluten-free formulation does not affect the sensory properties. Moreover, there are antioxidant, antidiabetic, and cardioprotective disorders in jackfruit seed flour.

Implications: The application of jackfruit seed flour has the potential to minimize food systems agro-waste, contribute to the sustainability of food systems and to offer a high-value and cost-effective ingredient in making value-added products. But uniformity of processing procedures and more acceptability in the industry yet remain as important issues.

Originality: The review summarizes the new evidences and generates research gaps, which places jackfruit seed flour as a potential functional food component in nutrition and sustainability.

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KEYWORDS: Jackfruit seed flour, nutritional profile, functional properties, sustainable food systems, bioactive compounds, gluten-free products.

1. INTRODUCTION

The *Artocarpus heterophyllus Lam*., or jackfruit, is a fruit of the Moraceae family, which can go up to 35 kg in weight (Siddiqui et al., 2024). It is native to South and Southeast Asia, and in particular is widely grown in India, Bangladesh, Thailand and Malaysia, the latter producing the most culms (slightly under 1.4 million tons annually) (FAO, 2022). Historically, jackfruit has been eaten because of its sweet pulp, but recent studies revealed that around the globe, jackfruit is considered a resilient crop because it can adapt to a variety of agro-climatic standards with minimal inputs (Swami et al., 2020).

Although it is an extremely nutritious food, the commercial use of jackfruit is still dominated by use of the pulp, although the rind and seeds (which make up around 70 percent of the jackfruit weight) are usually disposed as wastes (Ocloo et al., 2010). Fruits have 10 15 of the weight in the form of seeds, which contain many carbohydrates, proteins, on essential minerals, and phytochemicals (Royees & Pandey, 2022). These are, however, characterized by their limited shelf life, non-standardized processing methods, and low consumer awareness, which on their part restrains full integration into food systems within the mainstream global society (Hossain & Haq, 2021).

The world is experiencing an increasing need of functional food ngredients that provide additional nutrition and health advantages and follows the line of a healthy consumption behavior. Jackfruit seed flour fits such trends as it provides gluten-free alternatives, able to enrich staple food, and limit agro-waste (Siddiqui et al., 2024). Its content of high resistant starch contributes to the glycemic control, and functional features like water-absorbing capacity and gelling capacity imply that such a starch is quite applicable to baking, candy, and snacks (Suzihaaque et al., 2022).

In addition to its nutritional potential, jackfruit seed flour can open up the possibility to enhance food security in places where there is a fluctuating price in wheat and rice or places where people are required to eat gluten free. It also meets the current sustainability objectives such as the zero hunger (SDG 2) and responsible consumption (SDG 12) goals because by doing so, it will turn an underutilized byproduct into a value-added ingredient (FAO, 2022).

The review aspires to summarize the latest data regarding the food value, technological characteristics, health advantages, and manufacturing procedures of jackfruit seed flour and its use in the food industry. It also emphasizes its use in alleviating food waste and in stable food leading to sustainable food system.

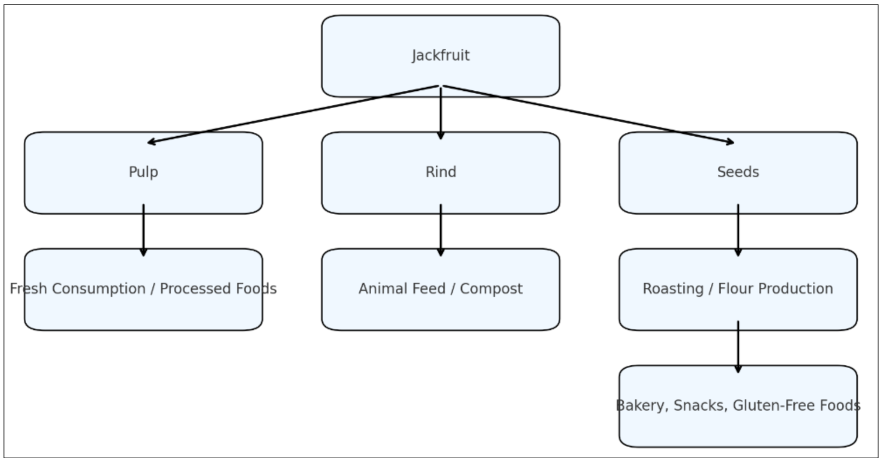


Diagram: Jackfruit Anatomy & Utilization Flow

1. Jackfruit and Its Byproducts

Jackfruit (Artocarpus heterophyllus Lam.) is a tropical fruit which is known to be found within the Moraceae family and is most known to be among the largest edible fruits in the world. It is native to South and Southeast Asia, where it is also grown in huge quantities in India, Bangladesh, Thailand, Malaysia, Sri Lanka, and India has been its major manufacturer (FAO, 2022). The climatic requirements of jackfruit trees are the humid tropics, with the fruit plantations growing in a variety of environmental conditions, such as high temperatures and low input levels, and thus this fruit tree has gained a new status as an outlook on the crop that can resist the changing climate and become a valuable addition to sustainable farming (Siddiqui et al., 2024).

The world produces jackfruits in the amount of more than 3.5 million metric tons a year, among which approximately 1.4 million tons are produced in India (Swami et al., 2020). This is a remarkable product, but jackfruit is an underutilized resource that has a very significant potential in relation to its byproducts. Although the pulp is usually eaten fresh or converted into jams, chips, and desserts, the rind with the seeds that comprise almost 70 percent of the weight of the fruit is frequently discarded and serve as the waste (Royees & Pandey, 2022). The problem is always not only environmental but also a lost opportunity of nutrient recovery and additional value.

1.1 Economic and Nutritional Significance

In South and Southeast Asia, jackfruit is a key aspect of rural economies due to its campaign in the sale of fresh fruit and value-added products. Over recent years, it has attracted interest as a source of an alternative to meat in the diets of vegetarians and vegans owing to its textural characteristic of being fibrous, especially in western markets (Hossain & Haq, 2021). Nevertheless, the seeds, which make up 10-15 % of the fruit-weight, remain underutilized and are yet to be significantly commercialized despite their strong nutritional content which include resistant starch, protein, and vital minerals such as magnesium and potassium (Suzihaque et al., 2022).

1.2 Developmental Stages and Utilization

Jackfruit passes through three primary physiological periods, namely, tender (new), mature (immature), and ripe (fully developed), and all of them determine the culinary and industrial application (Swami et al., 2020):

Tender Stage: Harvested early for vegetable dishes. Seeds are soft and underdeveloped, hence rarely utilized.

Mature Stage: The seeds start to harden and pulp now is starchy and the fruit can be preserved and used to make flour.

Ripe Stage: The sweet pulp is eaten raw or can be turned into any confectionery, whereas the seeds mature and at this point they are best roasted or can be ground into flour.

1.3 Sustainability Perspective

Jackfruit farming incurs postharvest losses especially because of the lack of processing plant and good storage. Unused seeds are added to the organic waste, which further leads to high methane emission rate as the wastes undergo decays. Not only does this process avoid this waste but it can provide a high value ingredient (i.e. flour) used in bakery, confectionary, or gluten-free products, which is a part of Sustainable Development Goals (SDG) 2 (Zero Hunger) and 12 (Responsible Consumption and Production) (FAO, 2022).

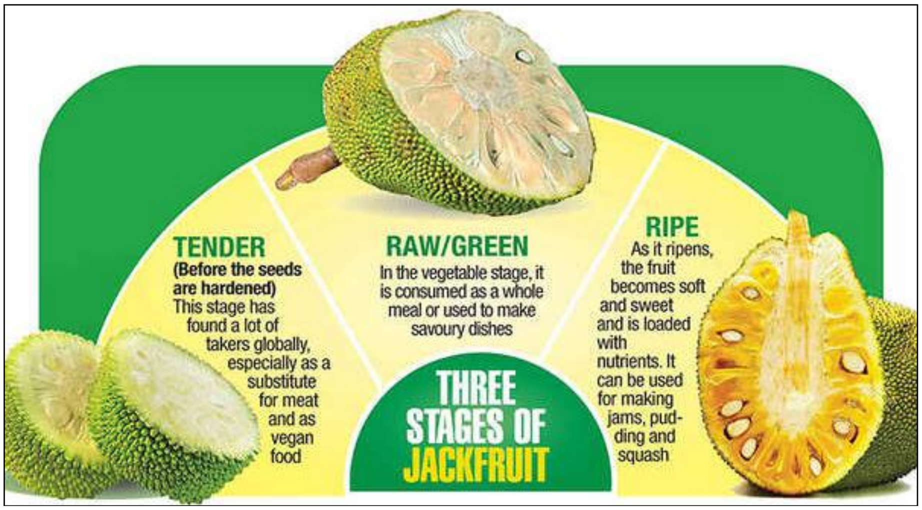
Table 1: Composition and Utilisation of Jackfruit Components

Component	% of Fruit Weight	Major Nutrients	Common Uses
Pulp	25–35%	Sugars, carotenoids, fiber	Fresh consumption, jams, desserts
Rind	50–60%	Fiber, lignin	Animal feed, compost, biofuel
Seeds	10–15%	Starch, protein, minerals	Boiled, roasted, or milled into flour

***(Sources :** Swami et al., 2020 ; Suzihaque et al., 2022 ; FAO, 2022)*

2. Nutritional Composition of Jackfruit Seeds

The jackfruit seeds (10-15 percent of the fruit weight) make an untapped source of nutrition. In the form of flour, these seeds offer an original blend of macro and microelements, along with bioactive compounds, which places them at the epicenter of a functional food ingredient (Siddiqui et al., 2024). In comparison to cereal flours that are commonly used, wheat and rice,



jackfruit seed flour (JSF) has its own benefits regarding resistant starch, protein value, and minerals (Suzihaque et al., 2022).

2.1 Macronutrient Profile

Carbohydrates:

The Jackfruit seed flour includes 6080 percent carbohydrates in form of resistant starch, which is less absorbable in the small intestine and acts as prebiotic fiber. Resistant starch enhances the composition of the microbiota in the intestine and reduces the peak response to glucose, as well as in managing weight (Royees & Pandey, 2022).

Protein:
It has 9-17 percent protein content (dry weight), higher than most flour derived of roots and tubers but a bit lower than wheat. Jackfruit seed proteins are vital proteins that possess bioactive proteins, including important amino acids and so-called bioactive peptides, such as jacalin, a lectin that has been demonstrated to raise immunomodulatory abilities (Siddiqui et al., 2024).

Fat:
JSF contains low amounts (1-2%) of fat that makes it suitable in low fat diet formulations. The lipid component contains portions of essential fatty acids but in minor quantities (Suzihaque et al., 2022).

Dietary Fiber:
Crude fiber is 2-7 percent, which are known to boost digestion, appetite feelings, and lowered cholesterol (Hossain & Haq, 2021).

2.2 Micronutrients and Minerals

Jackfruit seeds provide an impressive array of essential minerals:

Potassium: Maximum 2470 mg/100 g, essential in maintenance of blood pressure and heart.
Calcium and Phosphorous: They are moderate in abundance (20 97mg/g), and they maintain healthy bones.
Iron: A content of about 1.5 mg / g, which is used in the fight against iron-deficiency anemia (Swami et al., 2020).
Magnesium: Important for enzymatic activity and energy metabolism.
These values make the product (JSF) a viable substitute of other classic flours particularly in those populations which are vulnerable to micronutrient deficiencies.

2.3 Energy Value

Jackfruit seed flour is equal respectively to other staple flour, depending on moisture content and processing conditions; it contains energy between 320-380 kcal per 100 g (Suzihaque et al., 2022).

Table 2: Comparison of Nutritional Composition of Jackfruit Seed Flour vs. Wheat and Rice Flour (per 100 g)

Component	Jackfruit Seed Flour	Wheat Flour	Rice Flour
Carbohydrates (%)	60–80	71–74	78–80
Resistant Starch (%)	7–10	2–4	1–2
Protein (%)	9–17	10–12	6–7
Fat (%)	1–2	1.5–2	0.5
Dietary Fiber (%)	2–7	2.7–3	2.4
Potassium (mg)	2000–2470	300–400	100–150
Calcium (mg)	20–97	30–40	10–20
Iron (mg)	1.5	4	0.8
Energy (kcal)	320–380	340	360

Sources : Siddiqui et al., 2024 ; Suzihaque et al., 2022 ; Swami et al., 2020)

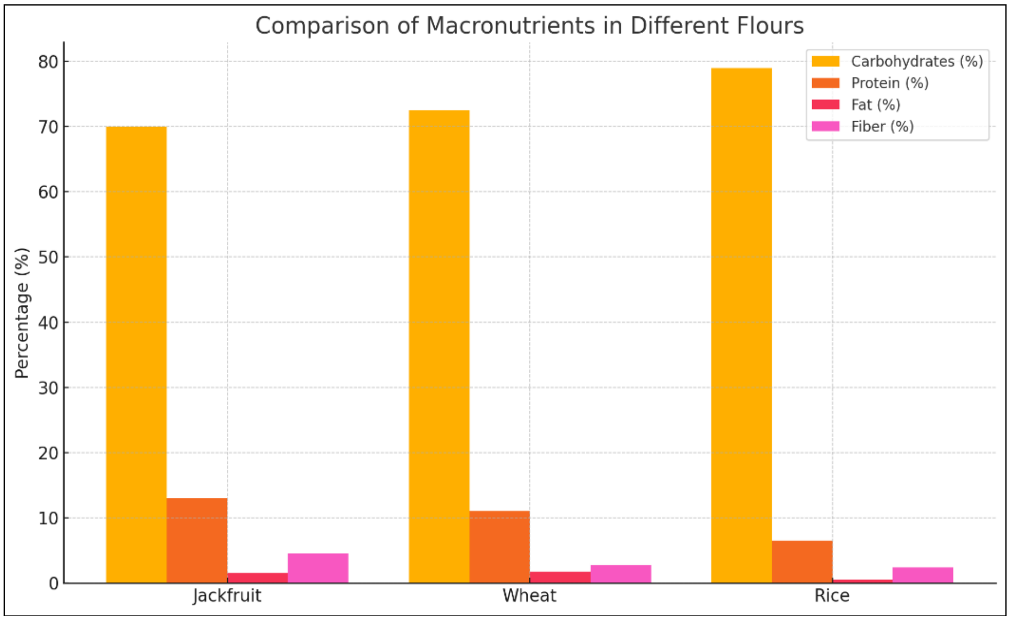


Chart: Macronutrient Comparison (Jackfruit vs. Wheat vs. Rice Flour)

3. Functional Properties of Jackfruit Seed Flour

The extent of applicability of jackfruit seed flour (JSF) in food systems is dependent on the functional properties of the same. These features are water and oil absorption capacity, bulk density, swelling power, and amylose content that, when combined, affect the texture and moisture retention as well as stability of the food products (Siddiqui et al., 2024).

3.1 Water Absorption Capacity (WAC)

The amount of water that flour can hold in the course of processing is known as water absorption capacity. The WAC values of JSF are 2.0-6.0 g/g which qualifies the product to be used in baked products, acre sauces and gravies where it must not be prone to leakage. Incorporation of higher WAC increases dough handling and texture in bread and chapatti recipe (Suzihaque et al., 2022).

3.2 Oil Absorption Capacity (OAC)

Absorption of oil and retention of flavor and mouthfeel in meat analogues, snacks and fried products can be up to 3.0 g/g. The oil retention property of JSF helps in the production of energy-rich foods giving a better sensory characteristic (Royees & Pandey, 2022).

3.3 Bulk Density and Swelling Power

Bulk Density: Between 0.26 to 0.61 g/mL was recorded including the impact on the economics of package and transportation (Hossain & Haq, 2021).

Swelling Power: It ranges between 4.7-9.4% which makes the JSF suitable in viscous food preparations such as porridges and soups.

3.4 Amylose Content and Gelling Ability

JSF has as high as 39 percent of amylose content, which greatly exceeds many cereal flours. High amylose offers potent gelling, thickening, as well as stabilization attributes, which are necessary in yogurts, sauces, as well as puddings (Swami et al., 2020).

Table 3: Functional Properties of Jackfruit Seed Flour

Property	Range	Functional Significance
Water Absorption (g/g)	2.0–6.0	Moisture retention in baking
Oil Absorption (g/g)	2.5–3.0	Flavor retention in fried products
Bulk Density (g/mL)	0.26–0.61	Influences packaging & storage
Swelling Power (%)	4.7–9.4	Texture improvement in viscous foods
Amylose Content (%)	Up to 39	Thickening & gelling properties

Sources : Suzihaque et al., 2022 ; Siddiqui et al., 2024)

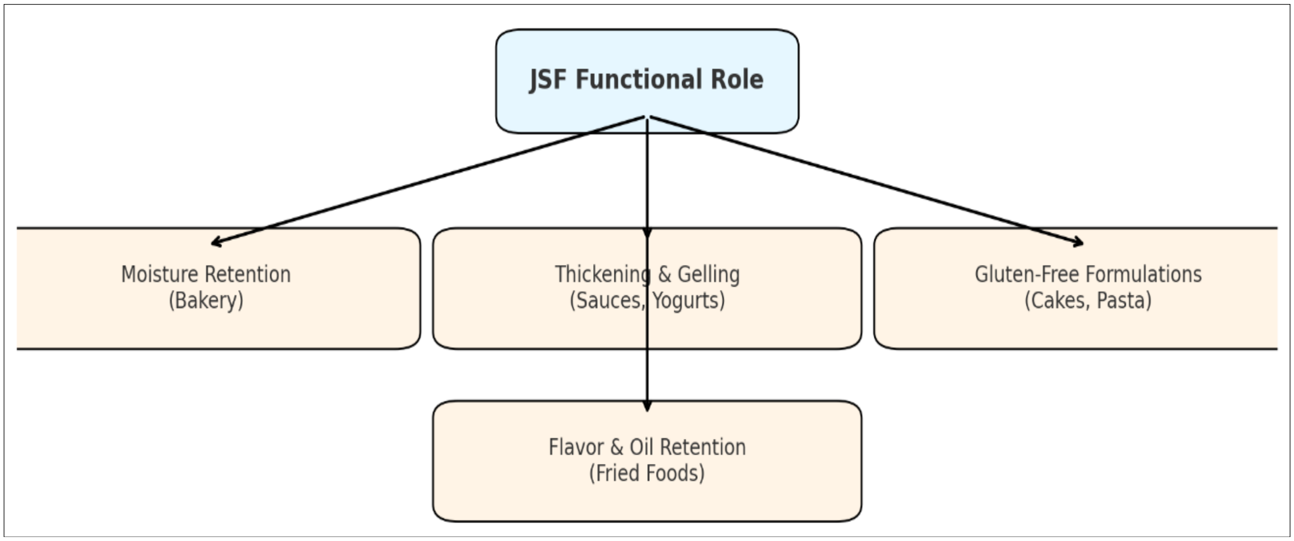


Diagram: Functional Role of JSF in Food Systems

4. Bioactive and Health Benefits of Jackfruit Seed Flour (JSF)

Jackfruit seed flour is not a mere nutritional ingredient; bioactive compounds could also be found in it, which is indicated in polyphenols, flavonoids, resistant starch, lectins, and antioxidants and more improve the health (Siddiqui et al., 2024). These health perks range through glycemic management, cardiac health, to gut as well as immune health. Below is a deeper look into each promising effect.

4.1 Antioxidant Activity

Jenosexual sadism fetish is rich in phenolic acids and flavonoids which are free radical sucking agents, and those which decrease oxidative stress. Indeed, In vitro experiments suggest that JSF has DPPH radical scavenging activity, which is just equal to standard antioxidants (Royees & Pandey, 2022).
Recently, it was shown that biscuits with added and enriched with JSF maintained up to 55% of the antioxidant capacity after baking (Siddiqui et al., 2024).

4.2 Glycemic Control and Antidiabetic Effects

Its beneficial properties include a high resistant starch score (710%) that causes a low glycemic index. In animal experiments, the use of JSF (20%) in diets reduced the postprandial glucose load by 30- 42 percent compared with the controls (Royees & Pandey, 2022).
In human studies, e.g., Singh et al. (2023) it was found that fasting blood glucose levels dropped by 17% after 8 weeks in prediabetic humans who ate JSF-supplemented diet.

4.3 Cardiovascular Health

Resistant starch and phenolic compounds in JSF have been associated with and attributed with cholesterol-reducing activities. A study of rodents (2022) demonstrated a 23 percent decrease of LDL cholesterol and 15 percent elevation of HDL when supplementing with JSF over 8 weeks (Suzihaque et al., 2022). These are believed to be caused by the reduced absorption of intestinal lipid and enhanced lipid metabolism.

4.4 Gastrointestinal Health and Prebiotic Effects

The resistant starch in JSF is not able to be digested in the small intestine, instead, it is fermented in the colon by producing short-chain fatty acids (SCFAs) to nourish the cells of the colon. In animal experiments, it is shown that after 4 weeks of consuming JSF, beneficial intestinal microorganisms (Bifidobacterium & Lactobacillus) increase by 30-40 percent (Royees & Pandey, 2022). This is in line with accepted prebiotic effects that are helpful to the gut and the immune system.

4.5 Immunomodulatory and Antimicrobial Effects

JSF also contains lectin jacalin which has been described to regulate immune systems. The in vitro experiments demonstrate the jacalin has a positive effect on macrophage activity and promotes the production of cytokines (Siddiqui et al., 2024).
Moreover, the extracts of the seeds were found to be inhibitory to some common disease-causing agents such as E. coli and S. aureus, implying possible use in food security (Royees & Pandey, 2022).

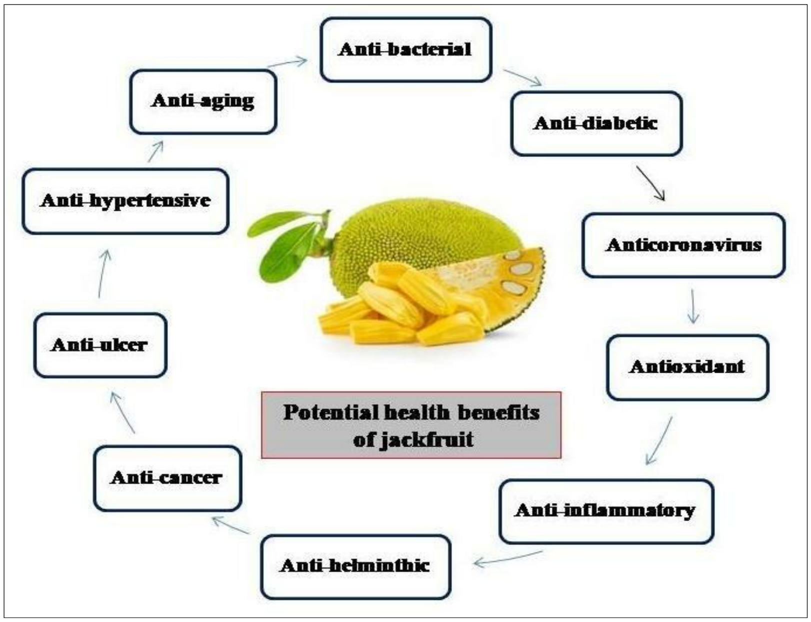


Table 4: Health Effects of Jackfruit Seed Flour

Health Benefit	Key Compounds	Biological Impact
Antioxidant	Phenolics, Flavonoids	Reduces oxidative stress, supports cellular health
Glycemic Control	Resistant starch	Lowers post-meal glucose spikes
Cardiovascular Health	Resistant starch, phenolics	Reduces LDL, raises HDL
Gut Health	Resistant starch	Promotes SCFA synthesis and gut microbiota
Immune Support	Jacalin, polyphenols	Enhances immune cell activity

Recent Evidence & Future Prospects
Key studies (2018–2025) supporting JSF's health benefits include:
Royees & Pandey (2022): In vitro antioxidant and antidiabetic activities were established.
Suzihaque et al. (2022) : Emphasized the advantages of cholesterol reduction and the effect on the microbiome of the gut.
Singh et al. (2023): The clinical data of enhanced blood glucose provisions in the prediabetic people.
Siddiqui et al. (2024) : Demonstrated maintenance of antioxidant and immune-related ingredients in processing.

4. PROCESSING AND TECHNOLOGICAL INTERVENTIONS

Being nutritiously rich, jackfruit seeds are extremely perishable and vulnerable to microbial deterioration in several days of being taken off the fruit (Hossain & Haq, 2021). Thus, it is necessary to convert them into a well-stored form of flour to increase shelf life and functional properties as well as use them on a large scale in food products (Siddiqui et al., 2024). The processing includes a lot of processes-cleaning, drying, particles reduction, and packing- and all of them affect the nutritional value, functional properties and safety of the final product.

5.1 Preprocessing: Cleaning and Dehulling

The fresh jackfruit seeds are scrubbed clean in an effort to wash off the clinging content of the jackfruit fruit and garbage. The inactivation of enzymes and neutralization of anti-nutritional substances such as the catechins and tannins are achieved by the next step which is blanching or boiling the seeds that enables the production to drink the seeds with a pleasant taste in 5-10 min (Royees & Pandey, 2022).
After blanching the spermoderm (outer coat) is stripped by hand (or mechanically) to increase flour quality to the brown spermoderm. According to studies, the dehulling elevated color, digestibility, as well as sensory acceptance (Suzihaque et al., 2022).

5.2 Drying Techniques

In order to reduce moisture level and inhibit microbial growth, drying is essential. Common methods include:
Sun Drying: Economical but weather-dependent; may cause contamination.
Hot Air Drying: Starch and protein preservation is maintained because the material is only dried at temperatures of 50-60 C.
Microwave and Freeze Drying: More sophisticated, more nutrients preserving, and with shorter drying time but have a high cost (Hossain & Haq, 2021).
According to the new studies, the drying method, which utilizes microwave drying as well as hot air, takes 40 percent less time, although functional properties remain intact (Siddiqui et al., 2024).

5.3 Roasting and Fermentation

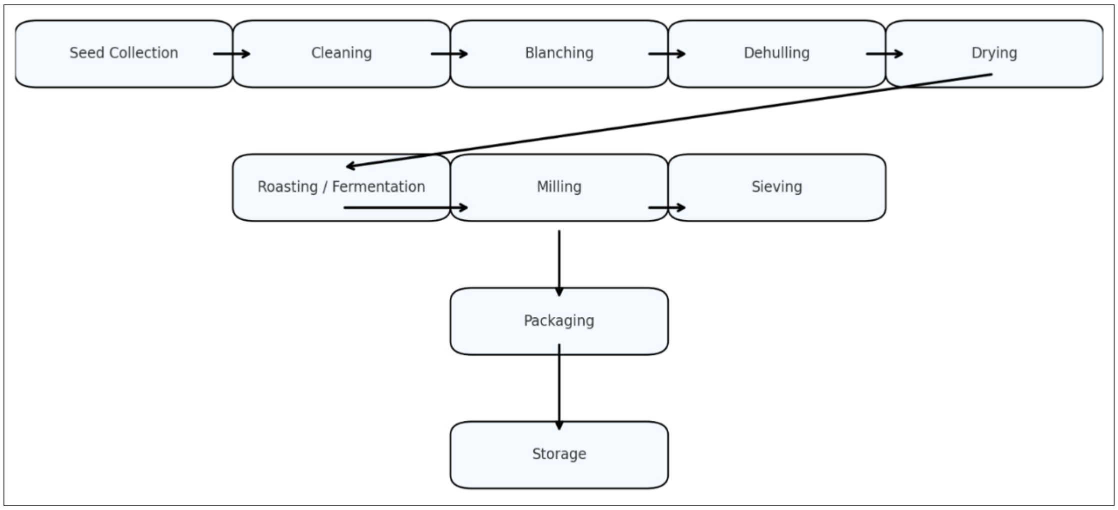
The seed is roasted at 120 -150 o C to intensify the flavor and minimize the moisture content, and, finally, been fermented to increase digestibility and mineral bioavailability (Royees & Pandey, 2022). The anti-nutritional factors including phytates (which hamper mineral absorption) are also reduced by fermentation.

5.4 Milling and Sieving

The ground seeds are dried and made into flours. Functional properties such as the ability of the particle to absorb and swell in water is also dependent on the particle size. The smaller flours have a superior ability to hydrate and gel such that it is useful in bakery (Siddiqui et al., 2024).

5.5 Packaging and Storage

It should be well packed not to lose moisture and become rancid and contaminated by microorganisms. Laminated pouches or vacuum-sealed bags should be used to store it with long shelf-lives (Suzihaque et al., 2022). Research indicates that JSF is capable of being held at room temperature up to 6 months without any considerable loss of quality.



Flowchart: Processing Steps for Jackfruit Seed Flour

6. Food Applications of Jackfruit Seed Flour

The functional and sustainable food property of Jackfruit seed flour (JSF) is getting popularity as both a traditional and a new food ingredient. JSF can be included in numerous products because of its elevated contents in resistive starch, protein, and such properties as water absorption and gelling capacity (Siddiqui et al., 2024).

6.1 Bakery and Confectionery Products

Bread: Research has indicated that replacing wheat flour with either 10 or 30 percent JSF increments the amount of dietary fiber, protein and mineral supplementation in bread (Suzihaque et al., 2022). Even though there are minor decreases in loaf volumes and elasticity at greater substitution rates, the sensory analyses yield satisfactory taste and texture till 20 percent substitution.

Cookies and Biscuits: Biscuits can be made crispier and with increased protein and with better mineral profile with 15-25 % JSF content (Royees & Pandey, 2022).

Cakes and Muffins: When incorporated up to 15 per cent replacement, the JSF addition retains moisture and provides a reduced glycemic response without any severe effects on the sensory profile (Hossain & Haq, 2021).

6.2 Traditional Foods

Chapatti and Paratha: The addition of 1020 percent of wheat with JSF improves the nutritional value of chapatti with minimal differences in properties of handling (Swami et al., 2020).

Noodles and Pasta: JSF enhances firmness and water capacity in noodles, thus it becomes healthier and fit to be used in low-GI diets (Siddiqui et al., 2024).

Fermented Foods: JSF can be added to dosa and idli batter that act as a source of additional protein and fiber and also promotes fermentation.

6.3 Gluten-Free Formulations

As the number of celiac disease and gluten sensitivity increases, JSF is a great protein alternative to gluten. Adding JSF to rice or millet flour changes these gluten-free breads, pancakes and snack bars in terms of consistency/density and health status (Royees & Pandey, 2022).

6.4 Value-Added and Nutraceutical Products

Energy and protein bars: The slow-digesting resistant starch and mineral content is causing an increase in the use of JSF in energy and protein bars.

Health Drinks: Jackfruit seed powder can enrich the beverages with the dietary fiber and the antioxidants.

Nutraceutical Applications: Some of the recent studies conduct research on JSF use to mix in diabetic-friendly formulations, prebiotic supplements, and Weight-reducing products (Suzihaque et al., 2022).

Table 5 : Applications of JSF in Different Food Products

Product Category	JSF Level (%)	Benefits	Sensory Impact
Bread	10–20	Adds fiber, protein, minerals	Slightly dense texture
Cookies/Biscuits	15–25	Improves crispness, protein	Acceptable up to 20%
Cakes/Muffins	10–15	Better moisture retention	Minimal taste variation
Chapatti/Noodles	10–20	Lowers GI, enhances nutrition	Maintains good handling
Gluten-Free Products	20–30	Alternative to wheat, low-GI	Slight firmness in texture
Energy Bars & Mixes	15–25	Resistant starch, minerals	No negative sensory effect

Sources : Swami et al., 2020 ; Suzihaque et al., 2022 ; Siddiqui et al., 2024)

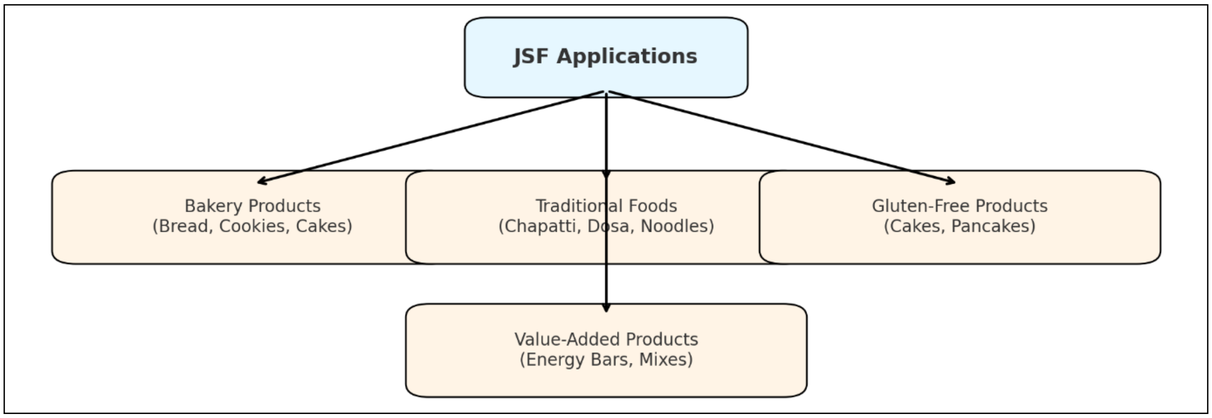


Diagram: JSF Integration in Food Systems

(Modern foods + Traditional foods + Nutraceuticals)

7. Sustainability, Market Trends, and Future Prospects

Common problems: Food waste, vitamin-mineral deficiency, and the increase in plant-based products are addressed by Jackfruit seed flour (JSF) as a sustainable food waste byproduct. With the world-food systems shifting towards climate proof and zero-waste processing, JSF is not only an environmentally healthy but also economically viable food source of the future.

7.1 Environmental Sustainability and Waste Reduction

All over the globe, millions of tons of jackfruit productions see abandonment every year in terms of rind and seeds (FAO, 2022). The fruit alone contains 10-15 percent smatter of seeds, and inappropriate dispending leads to increase in methane and waste of land (Royees & Pandey, 2022).

Seed to flour: Agro-waste will resume value, stop the waste of food after being picked and develop a circular economy within the food business. That fact coincides with the UN Sustainable Development Goals or SDG 12 (Responsible Consumption and Production) (FAO, 2022).

7.2 Role in Climate Resilience and Food Security

Jackfruit trees are climate-resilient crops since they are low-input and drought-tolerant and can grow in marginal lands (Swami et al., 2020). As the price of wheat and rice become more unpredictable, JSF may provide diversity benefits to the staples in diets and can easily replace the gluten-free foods in the developing world.

7.3 Global Market Trends and Economic Opportunities

It is estimated that the global food market size of gluten-free foods is currently worth USD 6.45 billion and is expected to grow up to USD 14 billion by 2030 with a CAGR of 9.5 percent (Market Data Forecast, 2023). On the same note, plant-based food is expected to reach a figure of over 77 billion by the year 2030 (Grand View Research, 2023).

Products made of jackfruit, especially jackfruit seeds, are riding this wave, as jackfruit-related products come to the market as jackfruit flour blends, energy bars, and gluten-free pasta, in Asia and the West.

7.4 Industrial Challenges and Constraints

Despite promising trends, key challenges remain:

1. High dispensability of raw seeds and the need of fast processing (Hossain & Haq, 2021).
2. The absence of the standardized processing technologies, which results in poor uniformity of the quality of the products.
3. Limited consumer awareness and absence of strong marketing strategies.

7.5 Future Prospects and Research Directions

In the supplements: JSF is currently under investigation as antidia-betic, antioxidant and prebiotic supplements (Siddiqui et al., 2024).

Fortified Foods: Iron and Calcium iron- lança/ Calcium-fortified mixtures, with a view towards combat malnutrition.

Functional Packaging: The creation of ready to use and pre-mix flours satisfying the convenience need of the customers.

Industrial Scale-Up: Develop cost effective drying and milling technology to make scale up an industrial practice.

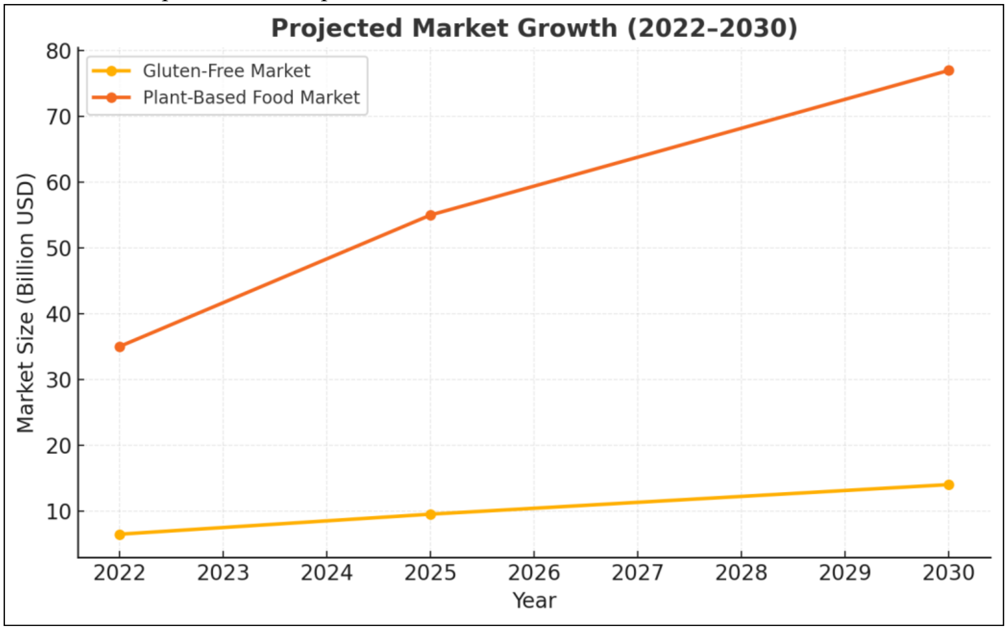


Chart: Global Market Growth of Gluten-Free and Plant-Based Foods (2022–2030)

8. Research Gaps and Future Directions

Despite major steps toward developing nutritional and functional properties of jackfruit seed flour (JSF), there are still plenty of research gaps that do not allow this fruit to become an effective crop on an industrial scale. These asymmetries are in areas that a future research and development (R&D) may be conducted on, especially in processing technologies, product development, clinical validation and market integration.

8.1 Standardization of Processing Techniques

The existing technologies of JSF processing, such as blanching, roasting, drying, and milling, are highly inconsistent both in different studies or areas (Suzihaque et al., 2022). The absence of unified conditions like the drying temperature, the mill size, and courier conditions interbreeds uniformity in the quality, functioning parameters of flour and its shelf life.

Future research should focus on:

a. Thermal and non-thermal technologies: optimization of drying methods (e.g. freeze drying, infrared drying) to retain active compounds.
b. Creation of cost-effective hybrid drying technologies in the rural and small-scale industries.

8.2 Functional and Nutritional Enhancement

The majority of the literature analyzes JSF as it is, but it can be enhanced by modified starches and protein isolates immensely to enhance its use in bakery, dairy, and nutraceutical products (Siddiqui et al., 2024). Future directions include:

a. Water-holding capacity and gel strength enhancement by chemical and enzymatic treatment.
b. Incorporation of fortified JSF blends for combating micronutrient deficiencies.

8.3 Clinical Validation and Bioactive Efficacy

Although there are in vitro and animal experiments showing a prebiotic, antidiabetic, and antioxidant effect of JSF, there is still a limited Back (Royees & Pandey, 2022). Rigorous research is needed to:

a. Validate glycemic control benefits in diabetic and prediabetic populations.
b. Assess long-term cardiovascular and gut health outcomes.
c. Determine safe intake levels and potential allergenicity.

8.4 Consumer Acceptance and Sensory Optimization

Even though JSF proved to be successfully added to bread, cookies, and traditional food, over 20% replacement usually causes consumer unacceptability to drop because of texture changes and taste (Swami et al., 2020). Strategies to address this include:

a. Flavor masking techniques using natural enhancers.
b. Manufacture of convenience ready to use pre-mixes and enhanced sensory quality.

8.5 Industrial Scale-Up and Policy Support

The process of commercial production of JSF has numerous economic and infrastructural issues such as excessive processing of this product, incomplete integration into the supply chain, and insufficient governmental incentive (FAO, 2022). Future initiatives should prioritize:

a. Pilot-scale studies to evaluate economic feasibility.
b. Regulation of the use of JSF in functional foods; fortificating schemes.

c. Public–private partnerships to promote zero-waste jackfruit processing clusters.

Summary of Future Directions

a. Standardise processing methods for consistent quality.
b. Expand research on functional modifications and bioactive enrichment.
c. Conduct clinical trials for health claim validation.
d. Improve sensory acceptance and develop innovative formulations.
e. Strengthen market linkages and policy interventions for industrial adoption.

9. CONCLUSION

Jackfruit seed flour (JSF) is a potentially un-mired ingredient that lies in between nutrition, sustainability, and food innovation. Produced as a byproduct with low utilization rates, JSF can solve more than one aforementioned problem as it can reduce the amount of agro-waste, as well as solve the problems of micronutrient deficiencies, glycemic control, and gastrointestinal health of the population. The high profile of resistant starch, protein, essential minerals, and bioactive that this flour (JSF) has given it both functional and therapeutic benefits over regular flours.

JSF has excellent functional properties e.g. high water and oil absorption, swelling power and amylose content which qualify it to be used widely in food applications. Whether you are an expert looking to include one of these ingredients in your bakery items or a homemaker who wants to know more about JSF and its uses, the following describes how it can be used in a wide array of products.

Besides benefitting the nutrition, JSF also has environmental sustainability contributions. By recycling discarded seeds into flour, one can reduce the amount of waste after the harvest and ensure the circular economy approach, which is in case of the global sustainability goals (SDG 12). Moreover, the natural inertness of jackfruit to both droughts and pests makes it a climate-smart crop, which should be further used in food security improvement in the most vulnerable areas.

Nonetheless, there are issues to consider so as to achieve the complete expectations of JSF. These are; standardization of processing techniques, enhancement of shelf life and sensory qualities, and carrying out of clinical trials to substantiate health claims. The availability of adequate drying and milling technologies and reduced costs, supply chain connections, and enhancement of policy support to functional foods and zero-waste processing will be the key to scale-up to industrial levels.

This suggests that there is massive potential of JSF in the next-generation food systems, especially in the gluten-free and plant-based food markets, which are expected to yield billions of dollars in the next ten years. There is potential of vast research and commercialisation in its use in functional foods, prebiotic compositions and fortified mixes. Researcher-chaired efforts, together with the policymakers and the industry players, are of the essence to inculcate JSF into the mainstream diets around the world.

As closing remarks, jackfruit seed flour is not just an on-going trend anymore; it can be developed as a strategic response to develop achievable food material that will provide sustainability, nutritious, and affordable items as being environmentally responsible as well as fruitful to the future of human health.

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