International Journal of Applied Home Science
(An International Double Blind Peer Reviewed / Refereed Research Journal of Home Science)
Volume 12 (3 & 4), March & April (2025) : 163-174
Received : 22.02.2025; Revised : 08.03.2025; Accepted : 22.03.2025

REVIEW PAPER
ISSN : 2394-1413 (Print)
DOI: 10.36537/IJAHS/12.3&4/163-174

Valorization of Jackfruit Seed Flour: Potential Application in Gluten- Free and High Protein Foods- A Review

SWATI MUSKAN*[1], NEETU SINGH[2], MADHVI DANIEL[3] AND PUJA KUMARI[4]
M.Sc. Students[1], Professor & Head[2], Resource Person[3] and Research Scholar[4]
Department of Food and Nutrition, School of Home Science,
Babasaheb Bhimrao Ambedkar University, Lucknow (U.P.) India

*Corresponding Author

ABSTRACT

Jackfruit (*Artocarpus heterophyllus*) seed flour (JSF) presents a promising alternative ingredient for developing gluten-free and protein-enriched food products. Rich in carbohydrates, protein, dietary fiber, and essential micronutrients, JSF offers a sustainable solution to valorize agro-industrial by-products. Several studies demonstrate its suitability in gluten-free formulations such as pasta, bread, and bakery items. Its protein content, ranging from 13–17%, and functional properties like water and oil absorption capacity, bulk density, and gelation, contribute to improved texture, structure, and nutritional profile in food applications. Gluten-free pasta prepared from JSF blended with rice flour and hydrocolloids showed flavorable sensory attributes and acceptable cooking quality, emphasizing its consumer acceptability. Moreover, the flour's high antioxidant capacity and presence of polyphenols support its role in health-promoting diets. Challenges such as mild bitterness and dense texture can be mitigated through fermentation, enzymatic treatment, or blending with other gluten-free flours. JSF also exhibits potential as a protein supplement in functional foods due to its essential amino acid profile. Its incorporation aligns with global trends towards plant-based, allergen-free diets and the circular economy, emphasizing waste reduction and nutritional innovation.

Keywords: Jackfruit seed flour, Gluten-free foods, High-protein alternatives, Functional food, Sustainability, Nutritional benefits, Processing techniques, Commercialization

INTRODUCTION

In the global effort to address food security, malnutrition, and sustainability, the valorization of underutilized agricultural by-products and unconventional food sources has emerged as a significant research frontier. Jackfruit (*Artocarpus heterophyllus*), a tropical fruit widely cultivated in South and Southeast Asia, Africa, and parts of South America, is one such resource that holds promise beyond its sweet edible bulbs. Among the parts of the jackfruit that are usually discarded, the seeds often overlooked and underutilizedare gaining attention due to their impressive nutritional profile and functional properties. The transformation of jackfruit seed into flour and its integration into gluten-free and high-protein foods aligns well with current global trends flavoring health-conscious diets and sustainable food systems.

Jackfruit seeds, comprising approximately 8–15% of the fruit's total weight, are rich in starch, protein, fiber, and essential minerals such as potassium, magnesium, calcium, and iron (Swami *et al.*, 2012). Traditionally consumed in various cooked forms in regions where jackfruit is endemic, the seeds are now being re-evaluated through the lens of modern food science and technology. The valorization process transforming waste or low-value products into higher-value commodities presents a sustainable pathway for harnessing the nutritional and functional attributes of jackfruit seeds. Specifically, the conversion of jackfruit seeds into flour opens up new avenues in the development of gluten-free and protein-

How to cite this Article: Muskan, Swati, Singh, Neetu, Daniel, Madhvi and Kumari, Puja (2025). Valorization of Jackfruit Seed Flour: Potential Application in Gluten- Free and High Protein Foods- A Review. *Internat. J. Appl. Home Sci.,* **12** (3 & 4) : 163-174.

enriched food products, catering to individuals with celiac disease, gluten intolerance, and those seeking plant-based protein alternatives.

The prevalence of celiac disease and the rising awareness of gluten sensitivity have contributed to the growing demand for gluten-free food products worldwide. However, many gluten-free products currently available on the market are nutritionally inferior to their gluten-containing counterparts, particularly in terms of protein, fiber, and essential micronutrients (Foschia *et al.*, 2016). This gap necessitates the exploration of alternative flours that not only meet gluten-free requirements but also offer improved nutritional value. In this context, jackfruit seed flour emerges as a viable candidate. Its relatively high protein content (approximately 13–18%) and presence of resistant starch known for its prebiotic effects and role in glycemic controlmake it a compelling ingredient for functional food applications (Chavan *et al.*, 2015).

Moreover, the push towards plant-based and sustainable protein sources has intensified due to environmental, ethical, and health considerations. In contrast, plant-based proteins are generally more sustainable and can be integrated into a variety of food matrices with minimal ecological footprint. Jackfruit seed flour, being plant-derived and abundantly available in jackfruit-producing regions, offers a cost-effective and environmentally friendly protein source suitable for fortifying bakery products, snacks, and meal replacements.

The process of converting jackfruit seeds into flour involves several steps, including cleaning, boiling or roasting, drying, and milling. Each step influences the physicochemical and functional properties of the resulting flour. For instance, thermal treatment can enhance the digestibility of proteins and starches while reducing anti-nutritional factors such as tannins and phytates (Ocloo *et al.,* 2010). The functional attributes of jackfruit seed flour such as water absorption capacity, oil holding capacity, emulsification, and foaming properties are critical in determining its suitability for specific food applications. These properties can be further modified through enzymatic, chemical, or fermentation-based treatments to improve texture, palatability, and nutritional quality of gluten-free formulations.

Despite its potential, the commercial utilization of jackfruit seed flour faces several challenges. These include lack of standardization in processing methods, limited consumer awareness, and underdeveloped supply chains for seed collection and processing. Additionally, comprehensive safety evaluations and regulatory approvals are necessary before large-scale food applications can be realized. Nevertheless, ongoing research and pilot-scale studies have demonstrated the feasibility of incorporating jackfruit seed flour into various food products, including bread, cookies, pasta, and extruded snacks, without compromising sensory acceptability (Rajeswari *et al.*, 2019).

From a socio-economic perspective, the valorization of jackfruit seeds can contribute to rural development, waste reduction, and income generation in jackfruit-producing communities. By creating value-added products from what is typically discarded, smallholder farmers and local entrepreneurs can tap into new markets and reduce post-harvest losses. Furthermore, jackfruit seed flour can be integrated into national and regional food programs aimed at combating protein-energy malnutrition, particularly in low-income settings where access to animal-based proteins is limited.

Nutritional and Functional Properties of Jackfruit Seed Flour:

The nutritional and functional properties of jackfruit seed flour (JSF) are critical in establishing its value in gluten-free and high-protein food formulations. Derived from the seeds of *Artocarpus heterophyllus*, JSF offers a unique combination of macronutrients and bioactive compounds that are relevant for both health-conscious consumers and food technologists seeking alternatives to traditional cereal flours (Swami *et al.*, 2012).

Nutritional Composition:

Jackfruit seeds are composed of a significant proportion of carbohydrates, proteins, dietary fiber, and essential micronutrients have been shown in Table 1. According to (Phanthurat *et al.*,2023;Suzihaque *et al*., 2022), the proximate analysis of jackfruit seed flour shows carbohydrate content ranging from 60–75%, crude protein content between 13–17%, and dietary fiber up to 6.5%. This composition makes it a suitable base or supplementary flour in protein-enriched and gluten-free formulations.

Furthermore, jackfruit seeds contain essential amino acids such as leucine, valine, and isoleucine, which are often limiting in cereal-based diets (Talukder, 2021). This contributes to JSF's role in improving the protein quality of gluten-free foods, which are traditionally lower in

essential amino acids.

In terms of micronutrients, JSF is rich in potassium, magnesium, phosphorus, and iron. These minerals support physiological functions such as nerve transmission, muscle contraction, and oxygen transport, and are often lacking in refined gluten-free flours (Swami *et al.,* 2012; Zuwariah *et al.,* 2018).

Functional Properties:

The functional characteristics of jackfruit seed flour are equally significant for its application in food systems. These include water absorption capacity (WAC), oil absorption capacity (OAC), swelling power, bulk density, emulsion capacity, and gelation abilityall of which influence the texture, shelf-life, and palatability of final product reported in Table 1.

- **Water Absorption Capacity (WAC):** JSF demonstrates high water-binding ability, ranging from 1.5 to 2.5 g water/g flour (Zuwariah *et al.*, 2018; Arun *et al*., 2021). This property is beneficial in gluten-free baking, where water retention is essential to compensate for the absence of gluten networks.
- **Oil Absorption Capacity (OAC):** The OAC of JSF varies from 1.0 to 2.0 g oil/g flour, enabling better flavor retention and mouth feel in fried or baked goods. This is particularly important in gluten-free products that often suffer from poor texture (Islam *et al.*, 2020).
- **Swelling and Gelation:**The flour demonstrates strong swelling capacity and gel formation at low concentrations, indicating potential for use as a thickening or stabilizing agent (Jagtap and Waghmare, 2018).
- **Foaming and Emulsifying Capacity:** While JSF does not exhibit strong foaming, its emulsion stability allows it to maintain product consistency in emulsified foods such as sauces and batters (Zuwariah *et al.*, 2018).

Antioxidant and Phytochemical Profile:

JSF is reported to possess antioxidant properties attributed to polyphenols and flavonoids found in the seed coat and endosperm. Phytochemical screening reveals the presence of alkaloids, saponins, and tannins, which may contribute to health benefits such as glycemic control and reduced oxidative stress (Talukder, 2021). However, these compounds may also impart bitterness, necessitating processing methods like roasting, fermentation, or enzymatic treatment to enhance flavor and reduce anti-nutritional factors.

Comparative Advantage in Gluten-Free Formulations

Conventional gluten-free flours such as rice, corn, or potato are often low in protein and fiber. The higher protein and dietary fiber content in JSF makes it a valuable alternative, especially in the formulation of gluten-free pasta, bread, and snacks. For instance, Phanthurat *et al.* (2023) demonstrated that gluten-free pasta made with JSF and rice flour had acceptable texture and sensory quality while offering better nutritional value than commercial rice pasta.

Table 1 : Nutritional and Functional Properties of Jackfruit Seed Flour (JSF)

Category	Property	Details	Reference
Nutritional Composition	Carbohydrate Content	60–75%	Phanthurat *et al.* (2023); Suzihaque *et al.* (2022)
	Protein Content	13–17% (crude protein)	Phanthurat *et al.* (2023)
	Dietary Fiber	Up to 6.5%	Prasad and Banerjee (2019)
	Essential Amino Acids	Rich in leucine, valine, and isoleucine – improves amino acid profile in cereal-based diets	Talukder (2020)
	Micronutrients	High in potassium, magnesium, phosphorus, and iron – supports key physiological functions	Swami *et al.* (2012)
Functional Properties	Water Absorption Capacity (WAC)	1.5–2.5 g water/g flour – improves moisture retention in gluten-free baking	Zuwariah *et al*. (2018); Arun *et al.* (2021)
	Oil Absorption Capacity (OAC)	1.0–2.0 g oil/g flour – enhances flavor retention and texture in baked/fried goods	Islam *et al*. (2021)
	Swelling Power and Gelation	Demonstrates good swelling and gels at low concentrations – suitable as thickener or texturizer	Jagtap and Waghmare (2018).
	Emulsifying Capacity and Stability	Maintains emulsion stability, useful in sauces and batters; weak foaming properties	Zuwariah *et al.* (2018)

The functional synergy of JSF with hydrocolloids such as xanthan gum or guar gum can further improve elasticity and cohesiveness in gluten-free dough systems, compensating for the absence of gluten (Zuwariah *et al.*, 2018). Additionally, the resistant starch in JSF may offer glycemic benefits and act as a prebiotic fiber, enhancing gut health.

Processing Techniques for Enhancing Flour Quality:

Processing methods play a pivotal role in determining the physicochemical, nutritional, and functional quality of jackfruit seed flour (JSF), ultimately influencing its applicability in gluten-free and high-protein food systems. Given the innate potential of jackfruit seeds as a nutrient-rich resource, post-harvest and pre-processing treatments are essential to remove anti-nutritional factors, improve safety, and optimize functional properties such as water absorption, emulsification, and digestibility

Cleaning and Dehulling:

The initial step involves thorough cleaning to remove adhering pulp, dirt, and foreign materials. The seed coat (testa) is typically removed either manually or by mechanical abrasion. Dehulling is essential as the outer layer contains polyphenols and tannins which, although antioxidant in nature, may impart bitterness and reduce digestibility (Phanthurat *et al.*, 2023).

Drying Methods:

Drying is a critical step for both microbial safety and shelf-life stability. The seeds can be dried using sun drying, hot-air oven drying, or freeze-drying, each having distinct effects on flour characteristics. According to (Zuwariah *et al.*, 2018), oven drying at 60°C for 24 hours in Fig. 1 significantly reduces moisture content and retains higher nutritional quality compared to sun drying, which is more prone to microbial contamination and nutrient loss.

Freeze-drying, although energy-intensive, is considered superior in retaining bioactive compounds and improving the physicochemical characteristics of JSF. However, its use is currently limited to laboratory-scale processing due to high operational costs (Talukder, 2021).

Roasting and Thermal Treatment:

Thermal treatment such as roasting has shown to reduce anti-nutritional factors (e.g., oxalates, phytates) and enhance flavor and aroma. Roasting at moderate temperatures (120–150°C) for 20–30 minutes improves water absorption capacity and enhances the palatability of the resulting flour (Islam *et al.*, 2020). However, excessive roasting can lead to protein denaturation and Maillard reactions that may alter color and reduce sensory acceptability.

Blanching and boiling are also employed to deactivate enzymatic browning and soften the seeds before milling. Phanthurat *et al.* (2023) reported that boiling jackfruit seeds prior to drying improved texture and milling efficiency while reducing bitterness.

Fermentation:

Fermentation is an effective bioprocessing strategy to enhance nutritional value and reduce undesirable compounds. Natural or controlled fermentation using *Lactobacillus* species has been found to increase protein bioavailability, reduce phytic acid, and improve flavor profile (Zuwariah *et al.*, 2018). This technique can also introduce probiotic potential, which is advantageous in functional food development.

Fermented JSF exhibits improved water-holding and emulsifying capacities, in Fig.1 making it suitable for use in baked products and high-moisture formulations such as gluten-free batters and doughs (Talukder, 2021).

Enzymatic and Chemical Treatments:

Enzymatic hydrolysis using amylase, protease, or cellulase can be applied to modify starch and protein fractions in JSF. These treatments help improve solubility, reduce viscosity, and increase the rate of digestion, which is beneficial for diabetic-friendly and high-protein food formulations (Phanthurat *et al.*, 2023). Moreover, enzymatic treatments can help reduce off-flavors associated with native seed flours. Chemical treatments, in Fig. 1 such as pH adjustment or the addition of sodium bicarbonate, are sometimes used to improve flour whiteness and reduce tannin content. However, such treatments must be carefully regulated due to food safety concerns and regulatory restrictions.

Milling and Particle Size Optimization

The choice of milling method significantly affects the functional behavior of the flour. Fine milling increases the surface area, enhancing hydration properties and gelation but may reduce the dietary fiber content due to breakage of fiber structures. Coarser flours, on the other

hand, may retain more fiber but negatively affect mouthfeel in baked products (Islam *et al.*, 2020).

Proper sieving post-milling ensures uniform particle size, which is essential for achieving consistent textural and baking properties in gluten-free applications.

Blending with Other Flours and Additives:

JSF is often blended with other gluten-free flours such as rice, millet, or sorghum to balance its strong flavor, improve sensory qualities, and achieve desired textural attributes. Hydrocolloids such as xanthan gum or guar gum may also be added to mimic the viscoelasticity of gluten. According to (Phanthurat *et al*., 2023), a blend of 30–50% JSF with rice flour produced gluten-free pasta with acceptable cooking quality and sensory scores.

Packaging and Storage:

Post-processing, the flour should be stored in moisture-proof, air-tight containers to prevent spoilage and rancidity. Due to its moderate fat content, JSF is prone to lipid oxidation. Vacuum or nitrogen-flushed packaging can significantly extend shelf life (Zuwariah *et al.*, 2018).

Fig. 1 : Processing technique for JSF

Applications in Gluten-Free and High-Protein Food Products:

Jackfruit seed flour (JSF) offers immense potential as a functional and nutritional ingredient in the development of gluten-free and high-protein food products. Given the increasing demand for plant-based, allergen-free, and nutritionally fortified foods, JSF has emerged as a promising alternative to conventional cereal and legume flours. Its unique combination of protein, resistant starch, and dietary fiber, along with favorable functional properties such as water and oil absorption capacities, makes it an ideal candidate for a wide range of applications.

Gluten-Free Pasta and Noodles:

One of the most studied applications of JSF is in the development of gluten-free pasta. Phanthurat *et al.* (2023) investigated the incorporation of jackfruit seed flour in rice-based gluten-free pasta. The results demonstrated that substituting 30–50% of rice flour with JSF significantly improved the protein content and dietary fiber levels while maintaining acceptable cooking and sensory qualities. The pasta exhibited good firmness, minimal cooking loss, and favorable consumer acceptance, highlighting JSF's functional compatibility with traditional gluten-free starches.

Bread and Bakery Product:

The gluten-free bakery sector often struggles with issues related to poor dough structure, dryness, and low protein content. Incorporation of JSF into bread, muffins, or cookies can enhance the nutritional profile while also contributing to water retention and improved texture. According to Talukder (2021), partial substitution of wheat or rice flour with JSF in bread formulations increased protein content by 20–30% and improved the crumb softness due to its high water-binding capacity. However, balancing the bitterness and dense structure introduced by JSF requires careful optimization, often through blending with other flours and the use of hydrocolloids like xanthan gum or guar gum.

Protein Bars and Snacks:

Due to its high protein and starch content, JSF can be utilized in energy and protein bars targeted at athletes, children, or individuals on specialized diets. The resistant starch in JSF also provides a slow-release carbohydrate source, which is beneficial for sustained energy. Zuwariah *et al.* (2018) noted that roasted jackfruit seed flour incorporated into snack bars improved not only protein content but also antioxidant activity, contributing to functional food attributes. Additionally, the mild nutty flavor of roasted JSF enhances the organoleptic profile of snack products.

Gluten-Free Cookies and Crackers:

Cookies and crackers made with JSF offer an excellent vehicle for delivering plant-based proteins and fibers to gluten-intolerant populations. JSF improves the bulk density and binding capacity in cookie dough, and its color and flavor profile align well with cocoa or vanilla-based products. Studies by Islam *et al.* (2020) showed that up to 40% substitution of JSF in cookies yielded products with increased protein and fiber content, and acceptable texture and taste.

Meat Extenders and Analogues:

Jackfruit seed flour can also function as a plant-based protein extender in meat products or meat analogues. Its textural attributes, particularly after thermal or enzymatic treatment, allow it to mimic fibrous meat structures. Moreover, its protein content and neutral flavor make it suitable for blending with soy, pea, or lentil proteins in developing vegetarian or vegan burgers, sausages, and meatballs (Talukder, 2021). As consumer demand grows for sustainable and ethical protein sources, JSF could serve as a cost-effective, underutilized resource in the plant-based meat industry.

Dairy Alternatives and Protein Shakes:

In powdered form, JSF can be used as a nutritional supplement in protein shakes, smoothies, or dairy alternative products. While not a complete protein on its own, it complements other plant proteins well and offers thickening properties that are useful in drinkable formulations. Its resistant starch also offers prebiotic potential, adding a functional benefit beyond nutrition (Zuwariah *et al.*, 2018).

Infant and Geriatric Nutrition:

Given its digestibility, hypoallergenic nature, and nutritional richness, JSF is also suitable for formulations in infant and elderly nutrition. Talukder (2021) notes that enzymatically processed jackfruit seed flour can be included in weaning foods or soft-textured foods for elderly individuals, contributing essential amino acids and energy without burdening the digestive system. The mild flavor and smooth texture post-processing are additional advantages in this segment.

Health Benefits and Functional Advantages of Jackfruit Seed Flour:

Jackfruit seed flour (JSF) offers an array of health-promoting properties and functional advantages that make it a highly promising ingredient for incorporation into gluten-free and high-protein food systems. Derived from the seeds of *Artocarpus heterophyllus*, a widely grown tropical fruit, jackfruit seeds have historically been underutilized and discarded as waste. However, recent studies have increasingly highlighted the nutraceutical potential of these seeds due to their dense nutritional profile, presence of bioactive compounds, and unique functional attributes.

Nutritional Density and Protein Enrichment:

One of the most critical health benefits of JSF lies in its high protein content, which typically ranges from 12% to 18%, depending on processing methods (Phanthurat *et al.*, 2023; Zuwariah *et al.*, 2018).The presence of essential amino acids—especially leucine, valine, and isoleucine—supports muscle repair, growth, and overall protein metabolism. The relatively low glycemic index and rich complex carbohydrate content also make JSF beneficial for sustained energy release, suitable for diabetic-friendly foods (Talukder, 2021).

Dietary Fiber and Digestive Health:

JSF is rich in both soluble and insoluble dietary fiber. This promotes gastrointestinal health by supporting bowel regularity, preventing constipation, and feeding beneficial gut microbiota. Zuwariah *et al.,* (2018) observed that the high resistant starch content of jackfruit seed flour functions as a prebiotic, contributing to improved gut flora balance and enhanced immunity. The consumption of such prebiotics is linked to reduced risk of colorectal cancer and inflammatory bowel diseases.

Gluten-Free and Hypoallergenic Properties:

Unlike wheat, rye, and barley, jackfruit seed flour is naturally gluten-free, making it suitable for individuals with celiac disease or non-celiac gluten sensitivity. Its hypoallergenic nature makes it a safer alternative to other protein sources such as soy and nuts, which are common allergens (Phanthurat *et al*., 2023). This positions JSF as a desirable ingredient in allergen-free and specialty health foods for both children and adults.

Low Fat and Cholesterol-Free Profile:

JSF contains a relatively low-fat content—typically less than 1.5%—and is free from cholesterol, making it a heart-friendly ingredient. Its lipid profile is dominated by unsaturated fats and minimal saturated fats, which supports cardiovascular health and may aid in maintaining healthy blood lipid levels (Talukder, 2021). These attributes make it a valuable ingredient in formulating health-conscious foods aimed at weight management and metabolic health.

Antioxidant and Antimicrobial Potential:

Jackfruit seed flour contains phenolic compounds and flavonoids with antioxidant properties that scavenge free radicals and reduce oxidative stress. Phytochemical

screening of processed jackfruit seeds by (Islam *et al.,* 2020) confirmed the presence of tannins, saponins, and alkaloids that contribute to antioxidant activity. These compounds play a role in preventing chronic diseases such as cardiovascular disorders, cancer, and neurodegenerative conditions. Additionally, the antimicrobial activity exhibited by jackfruit seed extracts against certain bacterial strains supports its potential as a functional food ingredient with natural preservative qualities. This could reduce dependence on synthetic additives in food production.

Glycemic Control and Diabetes Management:

Due to its resistant starch and low digestibility index, JSF causes a slower rise in postprandial blood glucose levels, which can aid in glycemic management. This is particularly beneficial for diabetic individuals. According to (Zuwariah *et al*., 2018), incorporating JSF in composite flours for baked goods or pasta reduces the overall glycemic response compared to conventional wheat products.

Moreover, resistant starches have been shown to enhance insulin sensitivity and reduce fat accumulation by modulating lipid metabolism. Thus, JSF not only aids in blood sugar control but may also have secondary benefits for obesity and metabolic syndrome management.

Satiety and Weight Management:

High-protein and high-fiber foods are known to promote satiety and reduce overall caloric intake. The dual action of protein and resistant starch in JSF contributes to prolonged digestion and fullness, which can help reduce snacking and overeating (Talukder, 2021). Products formulated with JSF can be targeted toward weight-loss diets or meal replacement categories.

Functional Technological Benefits:

Beyond health, the functional properties of JSF enhance its application in food processing. It exhibits flavorable water absorption capacity, emulsification, and foaming properties that are crucial in the formulation of gluten-free baked products, pasta, and meat analogues. Phanthurat *et al.* (2023) demonstrated that JSF enhanced the textural integrity and cooking quality of gluten-free pasta without compromising sensory appeal.

Additionally, its neutral to mildly nutty flavours and light colour profile make it adaptable to a wide range of food systems—from sweet baked goods to savory snacks.

Market Potential and Commercialization Strategies:

The growing global interest in functional foods, gluten-free alternatives, and sustainable plant-based proteins has created a promising market opportunity for jackfruit seed flour (JSF). Once considered an agricultural byproduct, jackfruit seeds are now being increasingly recognized for their nutritional density and functional versatility, making their valorization an attractive venture in the food innovation landscape.

Global Trends Driving Market Demand:

The increasing prevalence of gluten intolerance, celiac disease, and consumer demand for high-protein and allergen-free diets are key market drivers. According to Talukder (2021), the global gluten-free food market is expected to surpass USD 15 billion by 2026, with a significant share driven by demand for alternative flours and functional baked goods. Jackfruit seed flour, with its high protein, fiber, and resistant starch content, aligns well with these evolving consumer preferences.

Additionally, in Fig. 2 shows the rise in plant-based diets and clean-label products has prompted food manufacturers to explore underutilized yet sustainable ingredients. Jackfruit, abundant in tropical regions like South and Southeast Asia, offers a scalable and low-cost source of raw material, enabling economical large-scale production of JSF.

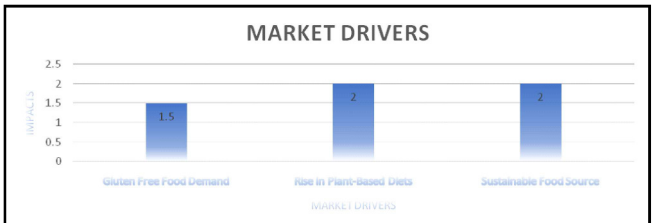

Fig. 2 : A relative or hypothetical scale of impact or importance for each market drivers

Opportunities in Health-Focused Product Segments:

Based on current research and pilot applications (Phanthurat *et al.*, 2023; Zuwariah *et al.*, 2018), JSF has shown promise in various gluten-free products including pasta, baked goods, snack bars, and protein supplements. These segments offer immediate entry points for commercialization. Furthermore, the flour's compatibility with vegan and vegetarian diets opens markets in sports nutrition, elderly care, and diabetic-friendly foods.

Jackfruit seed flour is also gaining attention in the clean-label movement, where consumers demand

minimally processed foods without artificial additives. Its natural antioxidant and antimicrobial properties make it suitable for developing functional foods with extended shelf life (Islam *et al.,* 2020).

Commercialization Challenges and Solutions:

Despite the promising outlook, several barriers hinder widespread commercialization. One of the major challenges is the perishability and seasonal availability of jackfruit seeds, which requires proper post-harvest handling and drying technologies. As noted by (Talukder, 2021), without appropriate processing infrastructure, the seeds are prone to microbial spoilage, limiting their usability.

To mitigate these issues, integrated supply chains should be developed, involving smallholder farmers, cooperatives, and food processors. Investment in affordable, decentralized drying and milling equipment can help ensure year-round availability of high-quality JSF. Government support and public-private partnerships may also play a vital role in strengthening this value chain. Furthermore, consumer perception is a key commercialization factor. Since jackfruit seed is relatively unknown in mainstream global markets, marketing strategies should focus on education and awareness campaigns emphasizing its health benefits, sustainability, and culinary versatility.

Value Addition and Export Potential:

Adding value through fortified or blended flour products can significantly enhance marketability. For instance, combining JSF with other gluten-free flours like rice, sorghum, or millet can create balanced nutritional profiles tailored to specific dietary needs. Such formulations can be positioned in both domestic and international markets, particularly in regions where demand for high-protein and gluten-free products is rising.

Countries like India, Bangladesh, Thailand, and Sri Lanka—where jackfruit is abundant—can explore export opportunities by developing standardized, packaged JSF products for specialty health food markets in Europe, North America, and Australia. These products can be exported as flour, baking mixes, or ready-to-cook pasta and snack items.

Strategic Marketing and Branding:

For successful commercialization, JSF-based products must be aligned with modern branding strategies. Positioning JSF as a "sustainable superfood" can resonate with eco-conscious consumers. Labels such as "gluten-free," "plant-based," "high in fiber," and "source of antioxidants" are important to highlight on packaging. Certifications like organic, non-GMO, and fair trade could further enhance consumer trust and market appeal (Zuwariah *et al.,* 2018).

Collaborating with chefs, nutritionists, and influencers to showcase recipes and product applications can help penetrate urban and health-oriented markets. In addition, e-commerce platforms offer an efficient channel for reaching niche consumers who seek health foods not typically available in conventional retail stores.

Sustainability and Environmental Impact:

The valorization of jackfruit seed flour (JSF) is not only a response to the growing demand for functional, gluten-free, and high-protein foods but also an innovative approach to sustainable food production. Jackfruit (*Artocarpus heterophyllus*) is widely grown across tropical regions, particularly in South and Southeast Asia. However, its seeds often considered agricultural waste—are typically discarded or underutilized. Transforming these seeds into value-added flour contributes significantly to environmental sustainability, waste reduction, and resource efficiency in agri-food systems.

Waste Reduction and Circular Economy:

Jackfruit seeds constitute approximately 10–15% of the total fruit weight. Despite their nutritional richness, they are largely discarded post-harvest. The conversion of these byproducts into edible, functional ingredients align with the principles of a circular economy by re-integrating agricultural waste back into the production cycle (Phanthurat *et al.*, 2023; Zuwariah *et al.,* 2018). This practice not only reduces the volume of biodegradable waste but also creates new economic value from materials that would otherwise contribute to landfill overload or emissions from organic decay.

Talukder (2021) emphasizes that the annual production of jackfruit in countries like Bangladesh and India is substantial, yet its seeds remain grossly underexploited. Valorizing these seeds through flour production can reduce post-harvest waste by up to 20%, offering a cost-effective and environmentally friendly alternative to conventional grain flours.

Reduced Pressure on Conventional Crops:

The growing reliance on conventional cereal grains like wheat and corn has led to intensive monoculture, excessive pesticide use, and unsustainable water consumption. Introducing JSF as a substitute in gluten-free formulations reduces the dependence on resource-intensive crops. Unlike wheat, jackfruit trees require minimal agrochemical inputs and are resilient to climatic stress, making them a more sustainable crop choice in the face of global climate variability (Islam *et al.,* 2020). Furthermore, jackfruit trees have a long lifespan and contribute to biodiversity, soil stabilization, and carbon sequestration in agroforestry systems. Promoting the utilization of jackfruit seeds thus indirectly supports ecological balance and reduces the agricultural carbon footprint.

Low-Impact Processing:

The processing of jackfruit seeds into flour involves relatively low environmental impact compared to other protein sources such as soy or animal-based ingredients. Standard operations include cleaning, drying, roasting, milling, and packagingall of which can be conducted with minimal energy inputs if localized and scaled appropriately (Talukder, 2021). Moreover, solar drying or biomass-powered dryers can be incorporated to further reduce the energy footprint of the drying phase, which is typically the most energy-intensive step.

By contrast, the carbon and water footprint of wheat and animal proteins is substantially higher. JSF offers an energy-efficient alternative that can be produced in decentralized units, promoting rural employment and reducing transportation-related emissions.

Socioeconomic and Sustainability Synergies:

From a socio-environmental perspective, JSF production fosters inclusive development. Since jackfruit is a common backyard and smallholder crop in rural areas, encouraging its utilization creates income opportunities for local farmers, women entrepreneurs, and cottage industries. (Islam *et al.,* 2020) highlight that community-based enterprises can be established to handle seed collection, drying, and flour production, creating sustainable livelihood models that are also environmentally conscious.

Integrating these enterprises with local markets and institutional buyers (e.g., schools or public nutrition programs) ensures a reliable outlet while fostering sustainable procurement models. Such grassroots valorization strengthens food sovereignty and reduces the environmental cost associated with importing specialty gluten-free flours.

Packaging and Shelf -Life Considerations:

Sustainable packaging plays a critical role in the commercialization of JSF. Due to its low -fat content, JSF has relatively good shelf stability compared to oil-rich flours, reducing the need for plastic-heavy vacuum packaging or artificial preservatives (Zuwariah *et al.*, 2018). Compostable or recyclable packaging solutions can further enhance the eco-profile of these products.

Additionally, using JSF in food products extends their shelf life due to its antioxidant properties. This reduces food spoilage and waste in the supply chain another indirect contribution to environmental sustainability.

Alignment with Sustainable Development Goals (SDGs):

The valorization of jackfruit seed flour strongly supports multiple United Nations Sustainable Development Goals (SDGs), including:

- **SDG 2 (Zero Hunger):** By enhancing food availability and nutritional quality.
- **SDG 12 (Responsible Consumption and Production):** Through waste reduction and resource efficiency.
- **SDG 13 (Climate Action):** By promoting low-emission food systems.
- **SDG 8 (Decent Work and Economic Growth):** Via rural employment and value chain development.

Phanthurat *et al*. (2023) and Talukder (2021) advocate for public policy incentives, such as grants or subsidies, to support sustainable processing, market development, and farmer training programs that will scale this innovation responsibly.

Challenges and Future Perspectives:

The valorization of jackfruit seed flour (JSF) as a functional ingredient in gluten-free and high-protein foods presents immense promise. However, despite its nutritional value, functional properties, and sustainability benefits, several challenges limit its large-scale application. Addressing these obstacles while exploring new directions for innovation is essential for the future of JSF in food systems.

Technological and Processing Limitations:

One of the critical concerns in JSF application is inconsistency in processing, which affects flour properties such as particle size, moisture content, and gelatinization behavior. As reported by (Zuwariah *et al.,* 2018), variations in drying and milling parameters significantly influence functional attributes like water absorption capacity and swelling index. Ensuring uniformity in processing is essential for commercial scalability. Additionally, jackfruit seeds are highly perishable and susceptible to microbial spoilage if not processed promptly (Talukder *et al.,* 2021). Adoption of improved post-harvest techniques—such as solar drying, blanching, and moisture-controlled storage—can improve shelf life and product quality (Yusof *et al.,* 2022).

Sensory and Acceptability Issues:

Despite flavorable nutritional profiles, higher incorporation levels of JSF can negatively affect sensory characteristics of food products. For instance, Phanthurat *et al.* (2023) observed that gluten-free pasta formulations with increased JSF levels exhibited darker coloration, astringency, and reduced textural appeal. Such sensory changes could hinder consumer acceptance. Da Silva *et al.* (2023) suggest that pre-treatment techniques like enzymatic modification or flour blending with rice or corn flours may improve mouthfeel and flavor balance. Future innovations must also consider cultural taste preferences to enhance acceptance across diverse consumer segments.

Allergenicity and Safety Concerns:

Although jackfruit seeds are generally safe, they belong to the *Moraceae* family, and there is limited data on potential allergenicity. Zuwariah *et al.* (2018) suggest that comprehensive toxicological and allergenic assessments are required before widespread use, especially for vulnerable groups like children and immunocompromised individuals. Establishing rigorous food safety protocols and regulatory approval will be essential to ensure consumer protection.

Supply Chain and Seasonal Dependency:

The seasonal nature of jackfruit poses a significant limitation in ensuring uninterrupted supply of raw seeds for flour production. According to Talukder *et al.* (2021), the limited harvest window and lack of organized seed collection strategies lead to raw material shortages during off-season periods. Rahman *et al.* (2020) propose that establishing community-level seed banks and decentralizing collection hubs could enhance seed availability throughout the year. Investment in cold storage and drying facilities at the farm level could also mitigate supply volatility**.**

Regulatory and Commercial Barriers:

At present, jackfruit seed flour is not widely listed in major food regulatory databases (e.g., GRAS in the USA or EFSA in Europe)is noted by Da Silva *et al.* (2023). This lack of regulatory recognition can hinder its entry into international markets. Establishing quality standards, nutrient profiles, and safety assessments through academic-industry collaborations will be crucial for obtaining necessary approvals and certifications.

Additionally, awareness among food manufacturers and product developers remains low. Effective knowledge transfer through academic journals, conferences, and industry outreach can accelerate its adoption into mainstream product development.

Future Perspectives:

Despite these challenges, the potential of jackfruit seed flour remains high, especially in light of global trends flavoring sustainable, plant-based, and gluten-free food innovations. Several future directions can be envisioned:

Functional Food and Nutraceutical Development:

Jackfruit seed flour is rich in resistant starch, antioxidants, and polyphenols (Islam *et al.,* 2020). These properties position it as an excellent candidate for the development of functional foods targeting diabetes management, digestive health, and weight regulation. Further clinical studies are needed to validate these health claims and support functional food positioning.

Bioprocessing and Fermentation Technologies:

Advanced bioprocessing technologies such as enzymatic hydrolysis, fermentation, and extrusion cooking can be employed to reduce antinutritional factors and enhance bioavailability of nutrients in JSF. Zhou *et al.* (2023) reported that enzymatic modification improved solubility and digestibility in plant-based flours, which could be replicated with JSF to enhance its application in diverse food formats.

Smart Packaging and Product Innovation:

Yusof *et al.* (2022) emphasized the importance of moisture-resistant packaging to maintain flour quality during storage. Further innovation could explore biodegradable and active packaging solutions that enhance shelf stability. Product diversification such as incorporating JSF into protein bars, meal replacements, or infant cerealsmay broaden consumer appeal, particularly in health-conscious markets.

Expansion into International Markets:

With increasing interest in novel tropical ingredients, JSF has significant potential as an exportable, functional super food. Standardizing its composition, establishing traceability, and securing certifications such as HACCP and ISO 22000 will facilitate international trade. Branding efforts that highlight its sustainability and nutritional profile could elevate its global marketability (Rahman *et al*., 2020).

Conclusion:

The valorization of jackfruit seed flour (JSF) represents a promising avenue in the development of sustainable, nutritious, and functional food products. Historically considered a waste by-product, jackfruit seeds are now recognized for their rich nutritional profile, including high levels of starch, protein, dietary fiber, and beneficial bioactive compounds. This recharacterization underscores the transformative potential of JSF in addressing contemporary dietary and food system challenges, particularly in the gluten-free and high-protein food segments.

Jackfruit seed flour offers an excellent alternative to conventional cereal flours for individuals with gluten intolerance or celiac disease. Its gluten-free nature, coupled with substantial protein and fiber content, makes it a suitable base for creating nutrient-dense food products such as pasta, bread, cookies, and extruded snacks. Studies have shown that JSF can enhance the nutritional profile and improve the functional properties of composite flours used in bakery and pasta production (Phanthurat *et al.,* 2023; Zuwariah *et al.,* 2018). Moreover, when processed correctly, it can retain desirable attributes such as water absorption capacity, swelling power, and emulsification properties critical for high-quality food manufacturing (Talukder, 2021).

Processing methods such as roasting, fermentation, blanching, and fine milling are instrumental in improving the sensory acceptability and functional behavior of JSF. These techniques help in reducing bitterness, modifying texture, and increasing shelf life. However, despite these advances, challenges remain in standardizing processing techniques, ensuring year-round availability of raw material, overcoming consumer sensory barriers, and navigating regulatory frameworks.

From an environmental perspective, jackfruit seed utilization contributes to waste reduction and circular economy practices by converting agro-waste into value-added food ingredients. This aligns with global sustainability goals and resonates with the increasing consumer demand for eco-friendly, plant-based alternatives (Islam *et al.*, 2020). Commercial viability can be enhanced through policy support, farmer engagement, and strategic marketing emphasizing the health and ecological benefits of JSF-based products.

Looking forward, integrating JSF into functional food formulations, ready-to-eat meals, and sports nutrition could widen its appeal. There is also significant potential for further research in clinical validation of its health benefits, exploration of advanced processing techniques like enzymatic modification, and development of globally accepted food standards for JSF.

REFERENCES

Ahmed, J., Almusallam, A.S. and Al-Senaidy, A.M. (2016). Rheological and thermal characterization of water chestnut starch–whey protein isolate based composite films. *Internat. J. Biological Macromolecules*, **84** : 395–406.

Arun, K.B., Madhavan, A., Reshmitha, T.R. and Anilkumar, K.R. (2021). Nutritional and phytochemical characterization of jackfruit seed flour and its potential application in bread. *J. Food Sci. & Technol.*, **58** (3) : 1096–1105.

Bobbio, F.O., El-Dash, A.A., Bobbio, P.A., Rodrigues, L.R. and Oliveira, J.E. (1978). Isolation and characterization of the physicochemical properties of the starch of jackfruit seeds (*Artocarpus heterophyllus*). *Cereal Chemistry*, **55** (4) : 505–511.

Chavan, J.K., Kadam, S.S. and Salunkhe, D.K. (2015). Dietary fiber and dietary protein in legumes. CRC Press.

Da Silva, J.C.F., Barbosa, M.I.M.J., Pimentel, T.C., Silva, H.L. A. and Freitas, M.Q. (2023). Sustainable gluten-free flours from unconventional tropical seeds: A review. *Curr. Res. Food Sci.,* **6**, 100541.

Foschia, M., Horstmann, S., Arendt, E.K. and Zannini, E. (2016). Nutritional therapy – Facing the gap between coeliac disease and gluten-free food. *Internat. J. Food Microbiol.*, **239** : 113–124.

Gopalan, C., Ramasastri, B.V. and Balasubramanian, S.C. (2004). Nutritive Value of Indian Foods. National Institute of Nutrition, Indian Council of Medical Research.

Islam, M.A.I., Haque, M.A. and Rahman, M.M. (2020). Functional and physicochemical properties of jackfruit seed flour and its utilization in food products. *J. Food Processing & Technol.*, **11** (2) :1000812.

Islam, M.A., Begum, M.M. and Uddin, M.J. (2020). Physicochemical, functional, and antioxidant properties of jackfruit seed flour. *Internat. J. Food Properties,* **23**(1) : 1793–1804.

Jagtap, D.D. and Waghmare, R.G. (2018). Development and quality evaluation of cookies prepared from jackfruit seed flour and wheat flour. *Internat. J. Chemical Studies*, **6** (2) : 2856–2859.

Kumar, M., Tomer, V., Kaur, A., Kumar, V. and Gupta, K. (2021). Health promoting functional ingredients from jackfruit: A review. *Trends Food Sci. & Technol.*, **112** : 536–547.

Ocloo, F.C.K., Bansa, D., Boatin, R., Adom, T. and Agbemavor, W.S. (2010). Physicochemical, functional and pasting characteristics of flour produced from jackfruits (*Artocarpus heterophyllus*) seeds. *Agric. & Biol. J. North America*, **1** (5) : 903–908.

Phanthurat, N., Tungtrakul, P., Phantratanamongkol, L. and Phetkhut, J. (2023). Proximate composition and sensory attributes of gluten-free pasta made from jackfruit seeds. *Functional Foods Health & Disease*, **13** (1) : 1–10.

Prabhanjan, D.G., Ramaswamy, H.S. and Raghavan, G.S.V. (1997). Microwave-assisted convective air drying of thin layer carrots. *J. Food Engineering*, **25** (2) : 283–293.

Prasad, S. and Banerjee, R. (2019). Studies on nutritional composition and utilization of jackfruit seed flour in bread preparation. *J. Pharmacognosy & Phytochemistry*, **8** (1) : 2233–2236.

Rahman, M.A., Roy, M. and Saha, S. (2020). Nutritional and functional aspects of underutilized fruits in Bangladesh: An exploratory study. *Bangladesh J. Agric. Res.,* **45**(2) : 123–135.

Rajeswari, S., Prabha, S. and Brindha, R. (2019). Development and sensory evaluation of value-added food products from jackfruit seed flour. *Internat. J. Food and Nutri. Sci.*, **8**(2) : 19–24.

Sathya, T. and Premavalli, K.S. (2016). Physico-chemical and functional characteristics of resistant starch from jackfruit seed. *Internat. J. Adv. Res.*, **4** (6) : 1083–1092.

Sharma, A. and Chauhan, E.S. (2020). Formulation and evaluation of value-added biscuits developed using jackfruit seed flour. *Internat. J. Curr. Microbiol. & Appl. Sci.*, **9** (6) : 1798–1806.

Suzihaque, M.U.A., Azrina, A., Zulkapli, R. A. and Noor, Z.M. (2022). Nutritional and functional properties of jackfruit seed flour for food application: A review. *J. Functional Foods*, **85**: 104675.

Swami, S.B., Thakor, N.J., Haldankar, P.M. and Kalse, S.B. (2012). Jackfruit and its many functional components as related to human health: A review. *Comprehensive Reviews in Food Sci. & Food Safety*, **11** (6) : 565–576.

Talukder, M.A.I. (2021). Nutritional composition and utilization of jackfruit seeds: A mini review. *Food Res.*, **5**(2) : 71–76.

Talukder, M.A.I. (2021). Protein and amino acid composition of jackfruit seed flour and its supplementation to cereal-based products. *Internat. J. Food Sci. & Nutrition*, **6** (3) : 55–60.

Yusof, S., Phan, L. D. and Ismail, A. (2022). Storage stability and microbiological safety of jackfruit seed-based gluten-free formulations. *Asian Food Sci. J.,* **21**(3) : 25–35.

Zhou, X., Wang, L. and Zhang, Y. (2023). Improvement of functional properties of plant-based flours through enzymatic treatment. *LWT - Food Sci. & Technol.,* **187**, 115332.

Zuwariah, S., Chin, N.L. and Yusof, Y.A. (2018). Physicochemical and functional properties of jackfruit seed flour and its application in baking. *Food Res.*, **2** (6) : 567–573.

Zuwariah, Z., Norziah, M.H. and Aziah, A.A.N. (2018). Physicochemical and functional properties of flour produced from mature jackfruit seeds. *Food Res. Internat.,* **106** : 532–539.

****