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JACKFRUIT SEEDS AS GLUTEN-FREE FLOUR ALTERNATIVE FOR FUNCTIONAL FOODS

S u m m a r y

Background. The increasing prevalence of gluten-related disorders and growing consumer awareness regarding gluten-free diets have intensified the search for alternative, nutritionally valuable flour substitutes. Jackfruit (Artocarpus heterophyllus) seeds, often discarded as agro-industrial waste, represent a promising underutilized resource rich in protein, dietary fiber, minerals and bioactive compounds. Their potential application in gluten-free and functional food formulations aligns with current trends in sustainable food production and waste valorization. Therefore, this integrative review aims to synthesize existing knowledge on the nutritional composition, functional properties, technological applications and sustainability potential of jackfruit seed flour (JSF).

Results and conclusions. The literature analyzed indicates that jackfruit seed flour exhibits favorable nutritional and functional characteristics, including significant protein content, beneficial amino acid profile and improved textural properties when incorporated into gluten-free products. Various processing methods effectively reduce antinutritional factors, enhancing its suitability for food applications. Studies demonstrate acceptable sensory properties of products partially substituted with JSF, particularly in bakery and snack formulations. Moreover, the utilization of jackfruit seeds contributes to sustainable food systems by reducing agro-waste and promoting value addition. Overall, JSF shows strong potential as a functional, gluten-free ingredient; however, further research is needed to optimize substitution levels, assess long-term consumer acceptance and explore its broader industrial applications.

Keywords: jack fruit seed, gluten–free flour, functional food, sustainable food, nutritional composition

Introduction

Jackfruit (**Artocarpus heterophyllus** *L.*) is a well-known tropical tree belonging to the Moraceae family. It is originally native to the forests of Southwestern India but has spread widely across Asia. Today, jackfruit is commonly found in countries such as Thailand, Indonesia, the Philippines, Malaysia and China, among others. Its broad

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distribution highlights its importance as both a traditional food source and a crop of growing interest in different regions [16, 35]. Despite its importance as a traditional food source, a large portion of jackfruit seeds – representing 8 ÷ 15 % of the fruit's weight – are discarded due to their high moisture content (≈55 %), which limits preservation and contributes to post-harvest waste [35]. Yet, these seeds can be cooked, toasted or processed into flours for use in breads, cookies, cakes and pasta, offering opportunities for sustainable food innovation [22]. Jackfruit seed flour not only reduces production costs, but also enhances nutritional value with carbohydrates, proteins, fiber and bioactive compounds such as phenolics and antioxidants [42]. Beyond nutrition, it also exhibits antibacterial, antifungal and anticarcinogenic properties linked to lectins like jacalin and artocarpine, underscoring its potential as a functional ingredient [36].

Gluten related disorders (GRD) are an umbrella term which represents conditions caused by the ingestion of gluten containing cereals in genetically or immunologically susceptible individuals. It includes celiac disease, dermatitis herpetiformis, non-celiac gluten sensitivity, wheat allergy and gluten ataxia that is prevalent in about 5 % of the global population as per a survey documented by the National Institute of Health in 2020 [43]. Individuals nowadays have become aware and seek gluten free alternatives to combat gluten related disorders. This demand and interest of consumers have resulted in a significant surge in the manufacturing of gluten-free products.

Celiac disease is an autoimmune disorder which affects genetically prone individuals who eat gluten. The disease causes an immune reaction that leads to inflammation and damage in the lining of the small intestine, including the flattening of the intestinal villi. Over the time, it can cause digestive problems such as bloating, diarrhea, nausea, poor appetite, stomach pain and weight loss [2]. About 1.4 % of women and 0.7% of men are affected with celiac disease and there are around 17 new cases per 100,000 women and 8 new cases per 100,000 men every year [8].

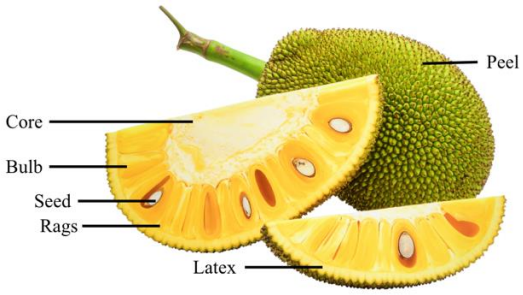

Figure 1. Structure of the jackfruit (Artocarpus heterophyllus L.)

The graph (Figure 2 and Figure 3) illustrates the high prevalence of nutritional deficiencies and systemic complications in patients with untreated celiac disease, highlighting its multisystem involvement. Iron deficiency affects a substantial proportion of patients, often occurring even before anemia gets diagnosed. Deficiencies of folic acid and vitamin B_{12} are more common in adults than in children due to their long-term poor absorption of nutrients. Bone problems such as low bone mineral density (BMD) and osteopenia increase the risk of fractures in patients with celiac disease. Among vitamins, deficiencies of vitamin E and vitamin B_1 are the most common, while vitamin K and B_6 deficiencies are less frequent but still important [8].

Most patients with celiac disease show improvement within one year of gluten-free diet. Extensive research has been conducted by the researchers due to increasing diagnosis and awareness in response to the growing demand for nutritionally improved gluten-free food products. As a result, the food industry has come up with alternative gluten-free ingredients from underutilized agricultural by-products such as jackfruit seeds, okara or soy pulp, etc. and fruit-based banana flour, plantain flour, pumpkin flour, etc. Currently, the complete dietary exclusion of gluten is the primary therapeutic approach. Gluten-free flours play a critical role in managing celiac disease and gluten intolerance by preventing intestinal mucosal damage, reducing inflammatory responses and alleviating gastrointestinal symptoms [15].

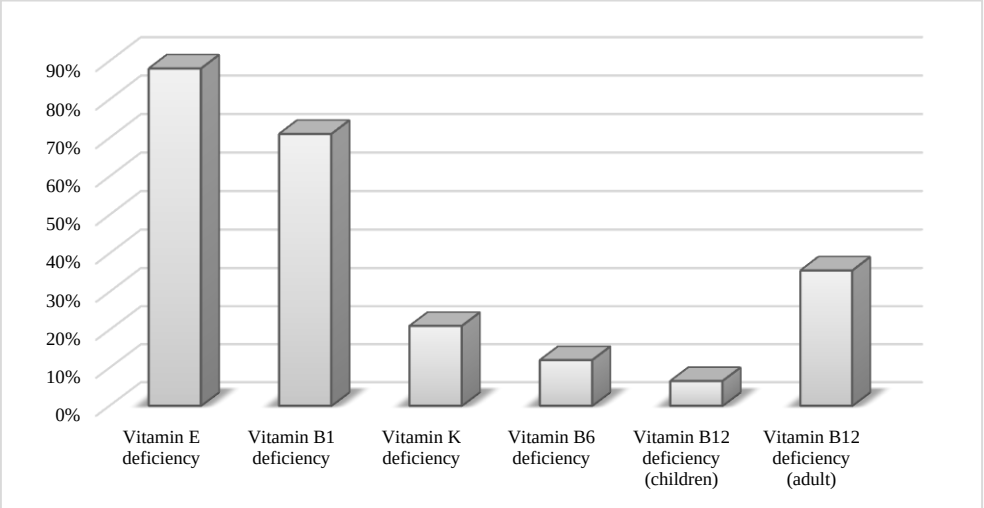

Figure 2. Nutrient deficiencies and complications in untreated celiac disease

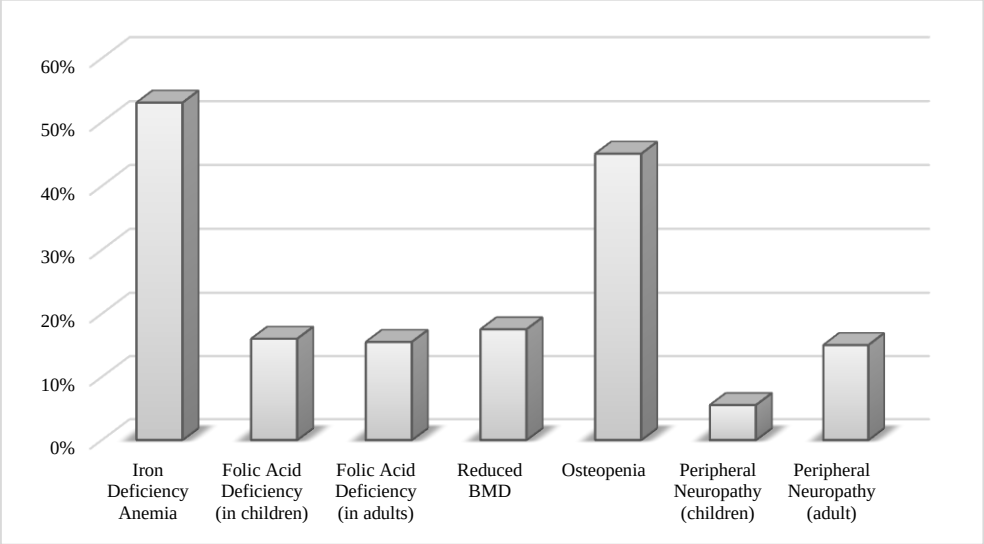

Figure 3. Nutrient deficiencies and complications in untreated celiac disease

It is difficult to identify if gluten-free products available in the market are nutritionally adequate, as they are often low in dietary fiber, protein and micronutrients [23]. Therefore, fruit-based gluten-free flours such as banana, plantain, pumpkin and jackfruit seed flour have gained attention due to their starch content, dietary fiber, minerals and functional properties suitable for food formulation [3]. The edibility and nutritional composition of jackfruit seeds have been demonstrated in several studies [9, 42, 50]. The value-addition of jackfruit seeds in various food products after drying and grinding it into fine powder makes it a better alternative of wheat flour, meanwhile improving the nutritional value of food and providing various health benefits.

Several studies have reported the functional, physicochemical and nutritional properties of jackfruit seed flour, highlighting its use in the preparation of various items in bakery and confectionary and other food products [1, 5, 12, 14, 26]. However, the nutritional composition and functionality of the jackfruit seed flour can be altered by various processing methods such as boiling, roasting, frying, drying or oven-drying [15, 32, 38, 49].

This review paper aims to highlight the value-addition of jackfruit seeds as a result of sustainable utilization and reduction of agro-food waste, assesses its potential as a gluten free ingredient and explores its application in developing functional foods, estimates nutrients elements and examines sensory traits.

Material and methods

This study adopted the form of an integrative review, which allows for the synthesis of knowledge from diverse sources, including empirical studies (quantitative and qualitative), theoretical analyses, conceptual models and institutional documents. This method was chosen due to the complex and multidimensional nature of the analyzed issue: the use of jackfruit seed flour (JSF) as an ingredient in gluten-free and functional foods, taking into account nutritional, technological and environmental aspects. The aim of the study was not merely to organize the available data, but to critically analyze and integrate them to demonstrate the current state of knowledge, identify research gaps and suggest potential directions for further research and practical applications. Due to the exploratory and theoretical nature of the work, the formal PRISMA guidelines, appropriate for systematic reviews, were not applied. Instead, a flexible methodological approach was adopted, allowing for the analysis of heterogeneous sources and their interpretation within a common analytical framework.

A literature search was conducted using electronic databases, including PubMed, Scopus, Web of Science and Google Scholar. Only articles published in English between 2015 and 2025 were considered. Following the screening and eligibility assessment, 48 studies were ultimately included in the review.

Publications published between 2015 and 2025 were included. The search process was conducted between August 2025 and January 2026. Studies focusing on the use of jackfruit seed flour in food products, both as a primary ingredient and as a partial substitute for conventional flours, were included. Studies examining various processing methods (drying, roasting, fermentation, cooking) and their impact on the nutritional composition, functional properties, texture, flavor and overall product quality were included. Both gluten-free and blended formulations were considered, provided they addressed product development and the assessment of its technological properties. Animal studies and in vitro analyses not directly related to food applications were excluded. During the selection process, particular attention was paid to the methodological quality of the studies and the reliability of the sources. Peer-reviewed publications, systematic reviews, meta-analyses and experimental studies with clearly described methodology were preferred.

The selected publications were subjected to thematic analysis to identify key research areas and trends. The extracted data included nutritional composition and comparative analyses, preparation methods and product development, functional and sensory properties, and the aspects of sustainable raw material use and the potential for reducing food waste. The results were synthesized in a narrative format, enabling the integration of data from various studies and the identification of existing gaps in the literature. The literature search, source selection and data extraction were conducted independently by the authors of the manuscript. Any discrepancies were resolved

through discussion and consensus, aiming to increase the reliability and consistency of the analysis. The use of an integrative review is associated with certain limitations. Greater methodological flexibility may increase the risk of subjective data interpretation. Furthermore, the heterogeneity of the analyzed studies (methodological differences, different product formulations or levels of JSF substitution) may limit the direct comparability of results. Therefore, the conclusions should be interpreted in the context of the adopted methodological assumptions.

Results

Preparation of Jackfruit Seed Flour

The reviewed literature indicates that several methods have been developed for the preparation of jackfruit seed flour (JSF). Although processing techniques vary slightly across studies, the general procedure follows a similar sequence of cleaning, peeling, drying, grinding and storage. Jackfruit seeds are collected after separation of the edible arils and represent approximately $11 \div 15$ % of the total fruit weight [13, 14]. Despite their nutritional potential, these seeds are often discarded as processing waste. After collection, the seeds are washed to remove adhering pulp and impurities. They are then cut into smaller pieces to facilitate uniform drying. Several pre-treatment techniques have been reported to reduce antinutritional factors and improve functional properties. These include boiling, roasting, autoclaving, germination and lye treatment. Autoclaving at 121 °C for 10 minutes significantly reduces antinutritional compounds, while roasting has been shown to decrease tannin and cyanide content [14, 31]. Germination further reduces phytic acid and oxalates, enhancing nutritional quality and safety. Lye peeling using sodium hydroxide ($0.05 \div 3$ %) is frequently applied to soften and remove the seed coat, followed by thorough washing to ensure safety. After peeling, seeds are sometimes soaked in potassium metabisulfite ($0.05 \div 0.2$ %) to prevent browning and microbial growth before drying. Drying temperatures reported in the literature range from 50 °C to 100 °C, depending on the method used [1, 18]. The dried seeds are then milled into flour, sieved to obtain uniform particle size and stored in airtight containers under dry conditions to maintain quality.

Nutritional composition

Jackfruit seeds are still being studied, but they are already known to be a good source of protein, fiber and starch [11]. They have potential health benefits, especially due to their antioxidant properties. Several studies [12] reported that jackfruit seeds contain $37.4 \div 42.5$ % of carbohydrates and $5.3 \div 6.8$ % of protein, depending on the variety. They are also rich in minerals like nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, zinc and copper. A literature search was conducted using elec-

tronic databases, including PubMed, Scopus, Web of Science and Google Scholar. Only articles published in English between 2015 and 2025 were considered. Jackfruit seed flour provides approximately 356 kcal per 100 g and contains essential nutrients, including vitamins and dietary fiber components such as pectin. During processing, moisture reduction leads to a concentration of nutrients, increasing the overall nutritional density of flour. Based on reported mineral composition, jackfruit seed flour is rich in potassium (705.71 mg/100 g), calcium (115.85 mg/100 g) and magnesium (96.75 mg/100 g), which are present in higher amounts compared to other minerals. These values refer specifically to flour and may vary depending on processing conditions and raw material characteristics. Importantly, the sodium-to-potassium ratio in jackfruit seed flour is relatively low (< 1), which is considered favorable in the context of electrolyte balance and cardiovascular health. A lower Na:K ratio has been associated with improved blood pressure outcomes compared to sodium or potassium levels alone. Due to its calcium content, jackfruit seed flour may also contribute to bone health. The potassium content contributes to dietary intake; however, its nutritional impact should be considered in the context of total daily consumption and individual health status. Such levels are generally considered safe for healthy individuals when consumed as part of a balanced diet. Importantly, these properties suggest a potential role in the prevention and dietary management of hypertension rather than its treatment [40, 44].

Although jackfruit seeds are a standout ingredient due to their distinctive nutrient density, they are a part of a vibrant movement of varied, gluten-free substitutes. Comparing the nutritional profiles of several gluten-free flours can help determine how jackfruit seed flour contrasts with other popular wheat alternatives.

Table 1. Proximate composition of jackfruit seed flour and other commonly used gluten-free flours

Food ingredient [%]	Jackfruit seed flour [35]	Chest nut flour [40]	Sorghum flour [10]	Ragi flour [35]	Rice flour [5]	Maize flour [5]
Carbohydrates	76.15	79.70 ± 0.22	54.6 ÷ 77.2	78.32	82.41 ± 5.25	74.41 ± 3.25
Protein	13.90	6.71 ± 0.12	7.8 ÷ 19.0	7.80	5.74 ± 0.17	10.48 ± 2.37
Fat	1.44	3.79 ± 0.20	1.6 ÷ 5.0	1.78	0.48 ± 0.23	4.41 ± 1.48
Dietary fiber	NR	NR	8.5 ÷ 26.3	2.36	3.36 ± 1.93	6.26 ± 1.25
Ash	0.96 ± 0.02	2.79 ± 0.10	0.9 ÷ 2.8	0.98 ± 0.02	1.23 ± 0.76	2.41 ± 0.92
Moisture	6.50 ± 0.07	7.42 ± 0.12	NR	8.76 ± 0.02	7.08 ± 0.46	10.95 ± 3.92
Crude fiber	1.05	9.30 ± 0.15	NR	NR	NR	NR

Explanatory notes: NR- not reported in the cited study/brak danych w cytowanej publikacji

Table 1 presents a comparative analysis of the proximate composition of jackfruit seed flour and other gluten-free flours that are commonly used. It can be seen that JSF contains higher amount of carbohydrates (76.15 %) as compared to other gluten-free flours, indicating that it can be a good source of energy-rich ingredients. It also shows higher protein content (13.9 %), suggesting better nutritional quality in terms of protein. Fat content of JSF is lower (1.44 %) when compared to other flours, with the highest contained in maize (4.41 ± 1.48), making JSF suitable for low fat food products. The fiber and crude fiber of JSF is lower than of chestnut and sorghum flour but still contributes to dietary fiber intake. The ash content and also moisture content is lower in JSF making it more shelf stable than many other flours.

Health benefits

Jackfruit seed flour offers significant health benefits due to its gluten-free nature and rich nutritional composition. As a naturally gluten-free ingredient, it can be safely incorporated into the diets of individuals affected by celiac disease, as well as those with non-celiac gluten sensitivity, wheat allergy, dermatitis herpetiformis and gluten ataxia, without inducing gastrointestinal effects [13, 26, 21]. It may also be beneficial in the dietary management of diabetes mellitus. The presence of dietary fiber and resistant starch contributes to delayed carbohydrate digestion and glucose absorption, thereby supporting glycemic control. Studies have demonstrated that the incorporation of JSF into gluten-free food products improves fiber and protein content, making such products suitable for diabetic-friendly diets [44].

In relation to cardiovascular health, it contains appreciable levels of potassium and exhibits a low sodium-to-potassium ratio, which is associated with the regulation of blood pressure. Additionally, bioactive compounds such as flavonoids present in jackfruit seeds may contribute to improved vascular function and reduce risk of cardiovascular diseases [13, 41, 48]. Its high dietary fiber supports gastrointestinal health by promoting regular bowel movements and maintaining gut integrity. Fiber and phytochemicals present in flour may aid in reducing toxin accumulation in the colon and lowering the risk of colon-related disorders [46]. Experimental studies have also indicated the potential anticancer activity of jackfruit seed flour against human colon cancer cell lines, suggesting its possible role in colon cancer prevention [11, 41]. It also contributes to the bone health due to its mineral content, particularly calcium, magnesium and phosphorus, which are essential for bone formation and maintenance. Regular dietary intake may support skeletal health and help reduce the risk bone-related disorders such as osteoporosis. Furthermore, it may assist in the management of obesity and metabolic disorders. Its low-fat content, combined with high fiber levels, promotes satiety and may aid in regulation energy intake. These properties make JSF a suitable ingredient for the development of functional foods aimed at weight manage-

ment [13, 48]. And it also exhibits antioxidant and antimicrobial properties attributed to the presence of phenolic compounds, flavonoids, saponins and tannins. These bioactive constituents may enhance immune function and provide protection against microbial contamination, thereby supporting both human health and food safety [13].

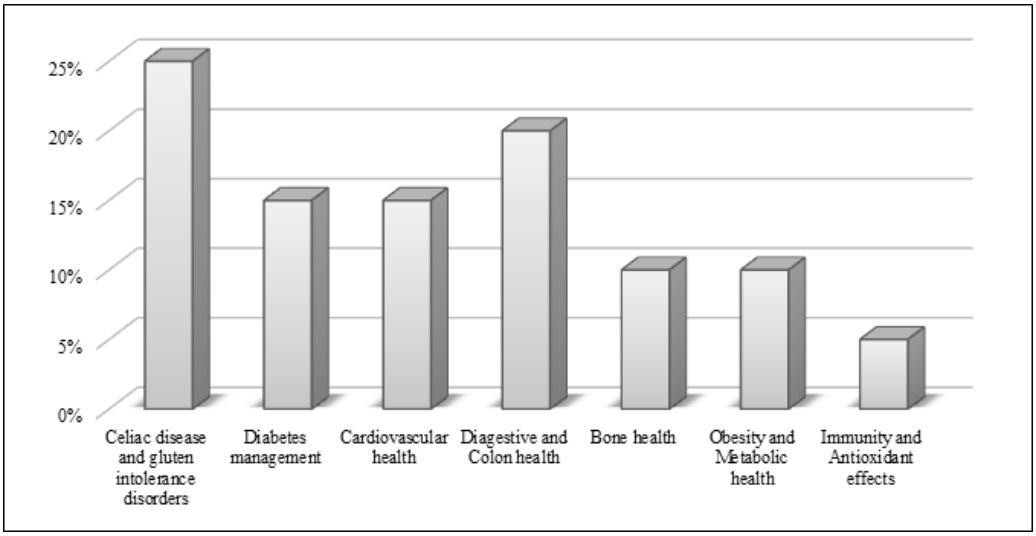

Figure 4. Distribution of health benefits associated with jackfruit seed flour

The percentage values shown in figure 4 were developed by carefully reviewing the existing literature and observing how frequently different health benefits of jackfruit seed flour were discussed. The largest share was given to celiac disorders (25 %), as many authors repeatedly describe as a safe and suitable gluten-free option for people who must avoid gluten in their daily diets [13, 21, 26]. Benefits related to digestive and colon health (20 %) were also widely reported, particularly the role of dietary fiber in improving gut function and the potential protective effects against colon-related disorders, including cancer [32, 46, 48]. Support for diabetes management (15 %) came from studies showing that fiber and resistant starch in jackfruit seed flour help control blood sugar levels and make food products more suitable for diabetic diets [11, 44, 48]. A similar proportion was assigned to heart and blood-pressure related benefits (15 %), based on research highlighting the high potassium content and the presence of natural compounds that support cardiovascular health [13, 41, 48]. Smaller but still important proportions were given to bone health (10 %), supported by reports on calcium and magnesium content that help maintain strong bones [11, 41, 45] and weight and metabolic health (10 %), as some studies note that the low fat and high fiber content of jackfruit seed flour can promote fullness and support weight management [13, 48]. The

remaining 5 % was linked to immune support and antioxidant activity, since fewer studies focused mainly on this area, even though antimicrobial and antioxidant properties have been clearly reported [13, 32, 38].

Table 2 summarizes food products formulated with jackfruit seed flour (JSF) or enriched with its addition, including their key technological advantages, nutritional characteristics and principal research outcomes.

Table 2. Applications of jackfruit seed flour (JSF) in food products and associated technological and nutritional outcomes

Types of product	Key benefit	Research findings	References
Bread	Dough stability	JSF improved water absorption, made the dough more stable and boosted its fiber content. The bread also scored well in taste, texture and overall appeal during sensory tests.	[17, 25]
Protein bars	Sustained energy	JSF is rich in protein and resistant starch, making it ideal for energy and protein bars. It provides slow-release carbs for lasting Energy.	[26, 31]
Noodles	Texture and flavor	Noodles made with jackfruit seed and soy flour had higher protein, fat, fiber and ash content. Over 60 days of storage, these nutrients gradually declined due to natural processes like fat oxidation and moisture absorption.	[27]
Chapatti	Extended shelf life	Up to 25 % of wheat flour in chapatti can be replaced with jackfruit seed flour without affecting taste or texture. With added preservatives, the shelf life extended to 3 ÷ 4 days at room temperature and up to 30 days when refrigerated.	[1, 41]
Cookies	Fiber enrichment	Developed biscuits using 10 ÷ 20 % jackfruit seed flour, which gave them a darker brown color and slightly increased the content of ash and fiber. The biscuits were well-received in taste tests.	[1, 9]
Snack foods (crackers)	Increases crispiness	Combined with 70 % wheat and 30 % JSF, increases crispness and antioxidant activity; improves bulk density and water holding capacity.	[47]
Jackfruit seed laddus	Gluten-free	Developed using jackfruit seed as base, jaggery for sweetness and grated coconut for texture; overall gluten-free, sugar-free, high in energy and protein.	[24]
Breakfast flakes	Fiber enrichment	Made from 15 % JSF and different proportions of Green Banana Flour and Corn Flour. Flakes made from higher Green Banana Flour improves the taste, texture, crunchiness and overall acceptability.	[7]
Pasta	Flavor and texture	Pasta developed with incorporation of 10 % JSF was well accepted for its flavor and texture. A higher addition of flour (40 %) from JSF resulted in moderate consumer acceptance.	[4, 33]

Chin chin	Oil reduction and extended shelf life	A fried snack from Nigeria. Incorporation of 80 % JSF reduces the fat content and 20 % JSF reduced the moisture content and hence increased the shelf life of the product.	[28]
Nutrient bar	Nutrient density	JSF combined with uncommon seeds such as watermelon seeds, winged bean and pumpkin seeds had more moisture and fiber, looked better and had better mouthfeel.	[39]
Breadsticks	Anti-nutritional reduction	The product made from pressure-cooked 50% of JSF and 50 % of all-purpose flour reduced anti-nutritional factors (oxalates, phytin, saponin and tannin) and improved the taste, nutrition, and overall acceptability of the product	[37]
Buns	Optimal nutrient improvement	Incorporation of 10 % JSF into wheat flour improved nutrition, taste and allowed for acceptability as the normal wheat buns. However, 20 ÷ 30 % buns were darker in color and were less acceptable.	[29]
Pizza	Improved nutrient content	30 % of JSF can be incorporated into 70 % wheat flour without changing it.	[30]
Puttu mix	Increased protein content	South Indian traditional food. Incorporation of 50 % rice flour, 30 % JSF, 20 % fat reduced coconut flour, had higher moisture content, higher protein and fiber and overall acceptability.	[20]
Tortilla	Balanced micro-nutrients	Incorporation of 50 % JSF and 50 % pumpkin was accepted as the best for balanced nutrition and sensory quality. Higher JSF gave better color and crunch.	[34]
Cakes	Higher nutrients and shelf life	Cakes incorporated with JSF contained higher levels of nutrients compared to the ones made with 100 % wheat. Moisture content also reduced increasing the shelf life.	[19]
Rice Paper	Gluten-free	Combining 33 % rice flour, 33 % JSF and 33 % tapioca flour resulted in higher protein, good texture and taste. Overall, it is a good alternative to gluten containing flours.	[6]

Explanatory notes: JSF- jackfruit seed flour

Studies show that adding JSF to different food products improves the qualities in food like dough stability, texture, crispiness and shelf life. It also increases its nutritional value. Products made with JSF have better moisture retention, reduced oil absorption and improved mouhfeel. It also reduces anti-nutritional factors, making it a valuable ingredient for developing healthier and functional foods.

Discussion and future perspectives

This integrative review provides a comprehensive overview of the nutritional, functional and technological potential of jackfruit seed flour (JSF), while also identifying key research gaps and future directions.

Nutritional and functional properties

The integrative review highlights the strong potential of jackfruit seed flour (JSF) as a sustainable, gluten-free ingredient for functional food development. Although jackfruit seeds are often discarded due to their high moisture content, studies show that they are nutrient-rich and can be effectively valorized through appropriate processing methods. Reported preparation techniques such as lye peeling, heat processing and mechanical peeling consistently involve peeling, drying, grinding and storing, while pre-treatments like boiling, roasting, autoclaving and germination reduce antinutritional compounds and improve flour quality. These methods ensure that JSF is safe, stable and suitable for incorporation into diverse food formulations. The gender wise prevalence graph shows that celiac disease is more prevalent in women than in men, indicating higher susceptibility among females. The nutrient deficiency graph highlights that individuals with celiac disease commonly suffer from deficiencies of vitamin D, vitamin B12 and iron along with reduced bone mineral density and bone disorders such as osteopenia. These findings suggest that intestinal damage caused by celiac disease significantly reduces nutrient absorption, leading to multiple deficiencies and related health complications. Nutritional composition analyses confirm that JSF is a valuable source of carbohydrates, proteins and dietary fiber, along with essential minerals such as potassium, calcium, magnesium and iron. The comparative proximate analysis demonstrates that JSF contains higher protein (13.9 %) than rice and maize flours, while maintaining lower fat content (1.44 %), making it suitable for low-fat food products. Its carbohydrate content (76.15 %) also indicates a strong energy contribution. Although its fiber levels are lower than in chestnut and sorghum flours, JSF still contributes meaningfully to dietary fiber intake. The lower ash and moisture content further enhances its shelf stability compared to other gluten-free flours. These findings suggest that JSF not only matches, but in some cases surpasses the nutritional quality of commonly used gluten-free alternatives.

Health-related implications

Health-related evidence strongly supports the incorporation of jackfruit seed flour (JSF) into gluten-free diets. The distribution of health benefits, as illustrated in the pie chart, shows its wide-ranging impact: celiac and gluten-related disorders (25 %), diabetes management (15 %), cardiovascular health (15 %), digestive and colon health (20 %), bone health (10 %), obesity and metabolic regulation (10 %), and immunity

and antioxidant effects (5 %). Resistant starch and dietary fiber contribute to glycemic control, making JSF suitable for diabetic-friendly foods. Its favorable sodium-to-potassium ratio supports blood pressure regulation, while calcium and magnesium strengthen bone health. Dietary fiber promotes gastrointestinal function and reduces colon-related risks, and bioactive compounds such as phenolics and flavonoids provide antioxidant and antimicrobial protection. These properties collectively position JSF as a functional ingredient capable of supporting multiple aspects of human health.

Technological applications and future perspectives

Applications of JSF across food products have been widely studied with encouraging results. Incorporation into breads improved dough stability and fiber content, while chapatti formulations demonstrated extended shelf life. Cookies and cakes enriched with JSF showed higher nutrient density and acceptable sensory qualities, despite darker color. Noodles and pasta benefited from enhanced protein and texture, while snack foods such as crackers and laddus highlighted its versatility in both traditional and modern formulations. Products like breakfast flakes, tortillas, nutrient bars and rice paper further demonstrate their adaptability across diverse culinary contexts. Importantly, consumer acceptance remained adequate across most studies, even when substitution levels reached $20 \div 30$ %. Despite these promising outcomes, the review identifies clear research gaps. Most studies have focused on partial substitution rather than complete replacement of wheat flour, leaving the full potential of JSF underexplored. Very limited work has been carried out on confectionery applications, particularly traditional Indian sweets such as laddoos, halwa, peda and burfi. This represents a strong opportunity for future research to expand JSF use beyond bakery items. Another promising direction is the development of baby food products, especially in regions where jackfruit seeds are already part of traditional diets. Such innovations could reduce reliance on refined flours and commercial baby food. Partial or complete substitution with JSF would not only enhance the nutritional profile of these products, but also reduce dependence on refined flours, aligning with current consumer demand for healthier alternatives. Collectively, the findings of this review confirm that jackfruit seed flour is a promising gluten-free ingredient with significant nutritional, functional and health benefits. Its incorporation into a wide range of food products improves nutrient density, extends shelf life and supports disease management, while also contributing to sustainability by reducing food waste. Future research should focus on optimizing formulations, expanding applications into confectionery and baby foods and exploring consumer acceptance at higher substitution levels. By combining traditional knowledge with modern food science, JSF can be established as a sustainable and versatile ingredient for innovative functional foods, ultimately promoting healthier dietary practices and advancing food security.

Conclusions

In conclusion, the findings highlight that jackfruit seed–derived flour is a promising alternative for developing gluten-free and functional foods. The review clearly emphasizes that this underutilized resource, often discarded as waste, can be transformed into a nutrient-rich ingredient through appropriate processing methods that reduce antinutritional compounds and enhance stability. A comparative nutritional analysis shows that the flour provides higher protein and carbohydrate levels than many other gluten-free substitutes, while maintaining low fat and moisture content, which supports both energy contribution and shelf life. The evidence also emphasizes its broad health-promoting potential. Resistant starch and dietary fiber aid in regulating blood sugar and digestion, while minerals such as calcium, magnesium and potassium contribute to bone strength and cardiovascular balance. Bioactive compounds including phenolics and flavonoids further add antioxidant and antimicrobial properties, strengthening its role as a functional food component. The distribution of health benefits, as illustrated in the review, demonstrates contributions across multiple areas of wellness, from metabolic regulation to immune support. Applications across different food categories confirm that the flour can improve texture, stability and nutrient density without compromising consumer acceptance. However, most studies have focused on partial substitution, leaving its potential as a complete replacement largely unexplored.

From the literature reviewed, it is clear that jackfruit seed flour (JSF) has been tested in bakery products such as bread, biscuits and cakes, but its use as complete flour remains very limited. Most studies only combined JSF with other flours, which means its full potential is still underexplored. In particular, very little research has been carried out on the application of JSF in confectionery products, especially traditional Indian sweets like laddoos, halwa, peda and burfi. This gap presents a strong opportunity for future studies to develop and evaluate JSF-based confectionery items. Using JSF as whole flour could significantly improve the nutritional profile of food, especially in terms of protein, fiber and mineral content. At the same time, challenges such as changes in texture, flavor and color may influence consumer acceptance. Partial or complete substitution with JSF could enhance the nutritional quality of sweets and processed food, while reducing dependence on refined flour.

In the North-Eastern region of India, jackfruit seeds are already part of traditional diets, often used in chutneys and other local preparations [9, 51]. This indigenous knowledge can be scientifically extended by developing jackfruit seed flour-based products. For example, instead of relying on commercially available baby food such as cerelac, JSF could be used to formulate nutritious, gluten-free baby food products. Regular consumption from early childhood may support better growth and overall health in infants. Overall, jackfruit seed flour holds strong potential for value addition, functional

food development and the promotion of healthier dietary practices. By combining traditional knowledge with modern food science, future research can unlock new applications of JSF, making it a sustainable and nutritious ingredient for innovative food products.

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NASIONA JACKFRUTÓW JAKO BEZGLUTENOWA ALTERNATYWA MĄKI W ŻYWNOŚCI FUNKCJONALNEJ

S t r e s z c z e n i e

Wprowadzenie. Rosnąca częstość występowania zaburzeń związanych z glutenem i rosnąca świadomość konsumentów w zakresie diet bezglutenowych zintensyfikowały poszukiwania alternatywnych, wartościowych pod względem odżywczym zamienników mąki. Nasiona jackfruita (Artocarpus heterophyllus), często wyrzucane jako odpady rolno-przemysłowe, stanowią obiecujący, niewykorzystany surowiec bogaty w białko, błonnik pokarmowy, minerały i związki bioaktywne. Ich potencjalne zastosowanie w recepturach żywności bezglutenowej i funkcjonalnej wpisuje się w obecne trendy w zrównoważonej produkcji żywności i waloryzacji odpadów. Dlatego niniejszy przegląd ma na celu syntezę istniejącej wiedzy na temat składu odżywczego, właściwości funkcjonalnych, zastosowań technologicznych i potencjału zrównoważonego rozwoju mąki z nasion jackfruita (JSF).

Wyniki i wnioski. Przeanalizowana literatura wskazuje, że mąka z nasion jackfruita wykazuje korzystne właściwości odżywcze i funkcjonalne, w tym znaczną zawartość białka, korzystny profil aminokwasowy i ulepszone właściwości teksturalne, po dodaniu do produktów bezglutenowych. Różne metody przetwarzania skutecznie redukują czynniki antyodżywcze, zwiększając jej przydatność do zastosowań spożywczych. Badania wykazują akceptowalne właściwości sensoryczne produktów częściowo zastąpionych JSF, szczególnie w produktach piekarniczych i przekąskach. Ponadto wykorzystanie nasion jackfruita przyczynia się do zrównoważonego systemu żywnościowego poprzez redukcję odpadów rolnych i promowanie wartości dodanej. Ogólnie rzecz biorąc, JSF wykazuje duży potencjał jako funkcjonalny

składnik bezglutenowy; konieczne są jednak dalsze badania w celu optymalizacji poziomów substytucji, oceny długoterminowej akceptacji konsumentów i zbadania jego szerszego zastosowania przemysłowego.

Słowa kluczowe: pestki jackfruita, mąka bezglutenowa, żywność funkcjonalna, żywność zrównoważona, skład odżywczy