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Utilization of Jackfruit: Nutritional Composition and its Application in a Food Model System

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Abstract: Jackfruit (Artocarpus heterophyllus Lam.) is widely grown in many regions of the world. The jackfruit is distinguished by its three parts (bulb, seeds, and ripe fruit peel), is a rich source of minerals, vitamins, proteins, and carbohydrates. Numerous bioactive compounds with antifungal, antibacterial, antidiabetic, anti-inflammatory, and antioxidant qualities highlight its pharmacological potential. Beyond its therapeutic uses, jackfruit is frequently used in food preparation and is more popular in non-food sectors. Vacuum-frying and freeze-drying are two more preservation methods that increase its adaptability. The jackfruit tree's bark is also important for forestry and traditional medicine. The purpose of this review is to clarify the many uses of jackfruit, including its pharmacology, nutrition, functionality, and applications in different fields.

Keywords: Jackfruit; nutritional content; health benefits; technologies; utilization; value addition

1. Introduction

Jackfruit (Artocarpus heterophyllus Lam.), is a member of the Moraceae family. Its cultivation is extensive in Bangladesh, India, Burma, Pakistan, Sri Lanka, Malaysia, Thailand, Brazil, Australia, Africa, and America (Uddin et al., 2021).

Jackfruit trees are evergreen with short trunks and rich canopy (Gardner et al. 2018). Jackfruit is made up of a trio of components: the bulb (30-32%), the seeds (18%), and the ripe fruit peel (5-55%). Jackfruit can be eaten in both its immature and mature states. Those delicious matured jackfruits are frequently utilised in desserts. The alternative version is less sweeter but more crunchy. Large seeds of this non leguminous plant are edible but hard to digest. Jackfruit is packed with essential minerals such as iron, potassium, and calcium, along with vitamins A, B, and C, carbohydrates, and proteins (Jagdale et al., 2021). Jackfruit cotyledon contain a lot of protein and carbohydrates. Phytochemical investigations revealed that jackfruit contains a high concentration of bioactive compounds, particularly carotenoids, flavonoids, volatile acids, tannins, and lectins which are responsible for a variety of biological effects (Wiater et al., 2020). The jackfruit bulb and its parts are frequently used medicinally. Jackfruit is renowned for its antifungal, antibacterial, antidiabetic, anti-inflammatory, and antioxidant properties, as highlighted by (Ranasinghe et al., 2019). Moreover, due to these therapeutic attributes, it finds application in producing juice, jam, jelly, sweets, ice cream, candy, cake, pasta and cordial bases, as noted by (Dietz et al., 2022). In recent times, there has been a growing interest in utilizing jackfruit fiber across culinary and non-food industries. Starches are the primary source of carbohydrates in humans and are now used in a range of meals as thickening agents, stabilisers, gelatinizers, additives, absorbents, and adhesives (Liu et al., 2017). Analyzing the health advantages of jackfruit and its utilization is crucial at the industrial level.

Jackfruit pulp is sweet and pleasant; it can be used as a dessert or preserved in syrup. Candies, jams, chutneys, and jellies are made from fruits with fresh pulp, whereas dishes and beverages such as ice cream are flavored with fruitlets with mature pulp, and to prepare chips, dried pulp is used (Srivastava et al., 2020). Young, unripe fruits are used as vegetables due to their high vitamin and mineral content. Furthermore, mature jackfruit seeds were roasted, boiled, and before consumption (Sreeletha et al., 2018). Methods such as freeze-drying, vacuum frying, and cryogenic processing have emerged as innovative preservation techniques for products derived from jackfruit. The jackfruit tree is utilized in medicine for diverse purposes, with its bark being a crucial commodity within the forestry sector (Jadhav et al., 2021). Additionally, food items play a significant role in maintaining health, garnering widespread support for their contributions to disease prevention and treatment. The objective of this review is to summarise jackfruit's pharmacological, nutritional, functional, and physiological benefits and its applications.

2. Morphology of Jackfruit

Jackfruit is characterized by its evergreen tree structure, featuring a compact treetop atop a short base. It typically grows to heights ranging from 15 to 20 meters, with trunk diameters spanning 40 to 80 centimetres. Young trees typically have a conical or pyramidal canopy, whereas mature trees have a

spreading and dome-shaped canopy. It sometimes generates buttress roots. Young trees have irregularly lobed or broken leaf margins. The tree provides a deep shade. Heavy side branching frequently starts near the ground. When a tree is wounded, it produces sticky white latex from all sections (Khan et al., 2021). Fruit can weigh up to 25 kg; however, its typical weight range is between 3.5 kg and 10 kg. A conical apex and a substantial rubbery wall are present on the exterior of the jackfruit shell. The rags and the fruit's skin are bonded together along a longitudinal axis that develops as the fruit ages. The bulb, which is located in between the rags, is formed of pulp that encircles a seed. The kernels within these seeds constitute 85-95% of their weight, while the pulp makes up 35% to 70%. Approximately 65% of these non-edible parts include the exterior rind, perianth, and center core, which are usually discarded (Kalse& Swami, 2022).

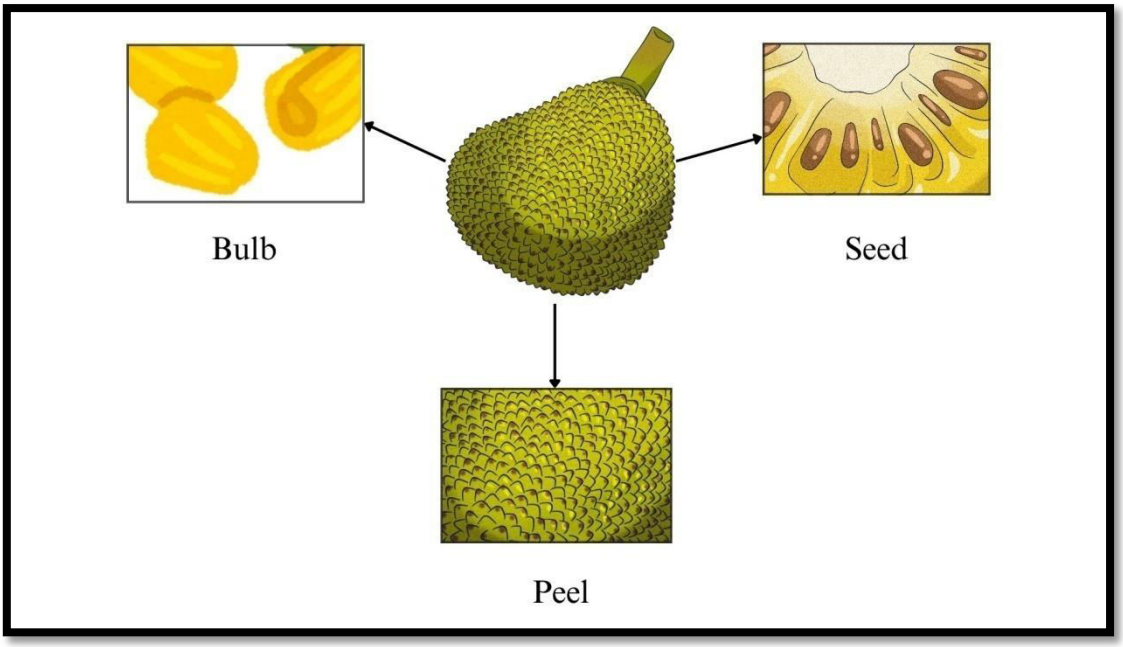

Figure 1. Parts of jackfruit

2.1. Peel

Peel is the exterior layer of the fruit, which bears a pattern similar to spikes. It is not edible and is typically utilized as fertilizer or dumped as waste (Tran et al., 2021). Unsystematic dumping of peel presents a significant environmental burden. Proper utilisation of by-products raises their economic worth and reduces disposal costs. Jackfruit contains 54% of rind. Jackfruit peel contains around 27% cellulose, 7% pectin, 6% protein, and 4% starch (Akter et al., 2019). Alkaloids, glycosides, tannins, phenolic compounds, steroids, triterpenoids, saponins, alkaloids, glycosides, flavonoids, proteins, and carbohydrates are among the functional components found in jackfruit peel (Sundarraj & Ranganathan, 2018). Due to its frequent contact with the extrinsic domain,

jackfruit peel contains more polyphenols than other fruits. The synthesis of polyphenols is triggered by abiotic stress factors such as climate, sunshine, and UV radiation. To assist the body in repairing the harm caused by oxidation reactions, bioactive antioxidant components promote chemical processes. Peels are an excellent source of polysaccharides since they have between 8.94 and 15.14% pectin in their dry composition (Xu et al., 2018). Pectin is commonly utilised in the pharmaceutical industry as a binding agent in pill formulations and a delivery medium for drugs in capsules. Jackfruit peel is used in a variety of industries, including food, biofuels, pharmaceuticals, paper, paint, and optics (Sundarraj et al., 2018).

2.2. Bulb

A tree produces many cylindrical shaped fruits. The skin has a leathery texture, a yellowish, greenish, or brownish colour, and unique hexagonal nubs. A jackfruit contain 29% of pulp (Swami et al., 2018). In the ripe condition, the gap between the epidermis and its centre fibrous peduncle is filled with a combination of thin, tight ribbons and many seeds. Each seed is surrounded by a fleshy, juicy pulp that is yellow and has a nice flavour. The aroma of ripened jackfruit pulp includes sweet, fruity, and creamy elements. The pulp is primarily consumed fresh, though it can also be processed into jam, syrup, dried pulp, or canned pulp (Khan et al., 2021).

2.3. Seed

The seeds are light brown and spherical. They are surrounded by a thin, white membrane. Seeds can be stored for up to one month in cool, moist conditions (Gardner et al., 2018). The seed coat comprises a thin, and waxy husk with a brownish, membraneous tegmen. The cotyledons are typically uneven in size, with scant endosperm. A jackfruit contain 12% of seeds. Jackfruit seeds contain 13% protein and 79% carbohydrates (dry basis). The nutrient content of the seeds depends on the species and location. The fruit seeds include a variety of triterpenes and flavonoids. It contains alkaloid compounds, phenols, saponins, tannins, steroids, and so on. Jackfruit seed is an excellent source of vitamin B2 (Arpit & John, 2015). Roasted seeds may be crushed into powder and used in other products to increase their value and shelf life. Malnutrition, caused by low protein consumption, is one of India's major challenges. Jackfruit seeds might be utilized as a low-cost protein alternative to alleviate malnutrition. The increasing consumer knowledge of the connection between nutrition and disease has increased the demand for jackfruit seeds (Waghmare et al., 2019).

3. Nutritional and antinutritional content

Jackfruit is abundant in various minerals such as vitamin A, vitamin C, thiamin, riboflavin, calcium, potassium, iron, sodium and zinc (Srivastava et al., 2020). The potassium content in jackfruit is high, with 100 gm containing 848 mg

(Kamdem et al., 2023). Research has demonstrated that foods high in potassium can lower blood pressure. The consumption of jackfruit also has the added benefit of being a good source of vitamin C. The antioxidant vitamin C helps the body fight free radicals, boosts immunity, and maintains healthy gums (Sultana, 2019). The phytonutrients found in jackfruit, such as isoflavones, lignans and saponins, offer a range of beneficial health effects. These phytonutrients have anti-ageing, anticancer, and antihypertensive effects. Jackfruit phytonutrients have been shown to reduce blood pressure, aid in the treatment of stomach ulcers, and protect skin-supporting cells from premature ageing. Additionally, they may inhibit the growth of cancerous cells. Niacin, also known as vitamin B3, is another compound present in jackfruit, playing a crucial role in hormone synthesis, neuron health, and energy metabolism (Srivastava et al., 2020).

Table 1. Nutritional and anti-nutritional content of jackfruit

Nutrition content	Jackfruit Peel	Jackfruit Bulb	Jackfruit Seed	Reference
Energy (kcal/100 g)	337.26	351.08	332.23	Swam et al., (2012)
Protein (g/100 g)	12.64	18.35	21.66	
Fat (g/100 g)	0.78	0.6	0.43	
Fiber (g/100 g)	3.5	3.6	3.94	Kamdem et al., (2023)
Carbohydrates(g/100 g)	62.39	54.39	49.01	
Vit A (IU)	30	175	17	
VitB1(Thiamine) (mg)	0.015	0.09	0.25	Ramya et al., (2020)
VitB2(Riboflavin) (mg)	0.02	0.4	0.3	
Vit C (mg)	14	10	11	
Ca (mg)	30	84	132	Verma et al., (2020)
Mg (mg)	-	27	54	
K (g/100 g)	303	407	246	
P (g/100 g)	57.2	43.22	97	
Na (g/100)	35	41	63	

3.1. Phytonutrients

Phytonutrients are organic substances that give fruits their distinctive flavor, color, and aroma. (Kaur et al., 2023) reported that these chemicals not only protect humans but also serve as part of the plant's immune system. Jackfruit

contains a high concentration of phytonutrients like phenolic compounds, carotenoids, volatile chemicals, and antioxidants. Many phytonutrients are demonstrated to provide additional health benefits in addition to their ability to prevent cancer (Ranasinghe et al., 2019). Phytoestrogens are polycyclic phenols that occur naturally in numerous plants. They have estrogenic qualities when consumed and mild estrogenic effects after being metabolised. Isoflavones and lignans are two major groups of phytoestrogens found in jackfruit pulp.

3.2. Polyphenols

They are secondary metabolites made up of phenolic compounds, tannins, and flavonoids. These chemicals affect the flavour, colour, and antioxidant properties of fruits. Endogenous and exogenous elements can all influence a plant's total phenolic content (Kaur et al., 2023). Jackfruit contains phenolic compounds such as ferulic acid, gallic acid, and tannic acid, along with flavonoids like rutin, catechin, and myricetin (Anaya et al., 2018). Immature fruits have an astringent flavour due to higher TPC levels, which decrease with development (Redondo et al., 2021).

3.3. Antioxidants

Antioxidants inhibit oxidation processes (Hasan et al., 2021). Fruits contain flavonoids, phenolics, anthocyanins, and carotenoids, which act as free radical scavengers and reduce cellular damage (Hussain et al., 2020). Jackfruit contains powerful antioxidants that protect against free radicals, reactive oxygen, and oxidative enzymes. Antioxidants are categorized into two types: enzymatic antioxidants, which encompass thiols, thioredoxin, and enzymes like glutathione reductase, catalase, guaiacol peroxidase, and ascorbate peroxidase; and nonenzymatic antioxidants, which comprise phenolic compounds, flavonoids, ascorbic acid, and anthocyanins (Kaur et al., 2023). Jackfruit contains numerous provitamins and vitamins that aid in fighting against free radical damage. Jackfruit pulp has high levels of nonenzymatic antioxidants, including tocopherol and vitamin C, which are helpful to the body.

3.4. Carotenoid

They are the primary dietary source of vitamin A in humans (Alvarez et al., 2014). Fruits have a yellow, orange, or reddish color because of their natural pigments. These substances defend against degenerative conditions such as cataracts, macular degeneration, macular edema, cancer and cardiovascular disease. Jackfruit contains a large number of carotenoids, which act as antioxidants. Jackfruit contains beta-carotene, beta-carotene-5, and beta-carotene-6-epoxide). Carotenoids in jackfruit play an important role in the prevention of several chronic degenerative disorders, cancer, inflammation, cardiovascular disease, and cancer. The main carotenoids found in jackfruit include all-trans-lutein, all-trans-carotene, all-trans-neoxanthin, 9-cis-neoxanthin,

and 9-cis-violaxanthin (Tripathi et al., 2023).

4. Health benefits of jackfruit

Jackfruit is recognized as a valuable source of various high-value compounds with potential beneficial physiological activities. It is renowned for its antioxidant, antibacterial, antifungal, antidiabetic, and anti-inflammatory properties (Ahlawat et al., 2023). Many phytonutrients, including carotenoids, which can act as antioxidants, are found in jackfruit. The total flavonoid and phenolic contents of jackfruit flesh extracts correlate with their antioxidant activity. Fresh jackfruit seeds and flesh exhibit significant levels of ascorbic acid, with antioxidant activities equivalent to 27.7 and 0.9 gallic acid equivalent phenolic contents, respectively. These compounds are believed to contribute to approximately 70% of the total antioxidant activity (Mridula et al., 2019). Jackfruit has medicinal compounds that can aid with cardiovascular disease, stroke, high blood pressure, and bone loss. It can improve the functioning of muscles and nerves and lower blood levels of homocysteine (Swami et al., 2016). Moreover, the abundance of potassium in jackfruit helps in lowering blood pressure and counteracting the negative effects of sodium. Sodium tends to elevate blood pressure and can have detrimental impacts on blood vessels and the heart. Consequently, loss of bone, heart disease, stroke, and reduced nerve and muscle function are all avoided. Jackfruit's vitamin B6 content reduces blood homocysteine levels, lowering the risk of cardiovascular disease (Jagdale et al., 2021). The phytonutrients found in jackfruit, such as lignans, isoflavones, and saponins, play a role in its anticancer, antihypertensive, antiulcer, and anti-ageing properties (Saha et al., 2022). They guard against the development of stomach ulcers and stop the growth of cancerous cells in the body.

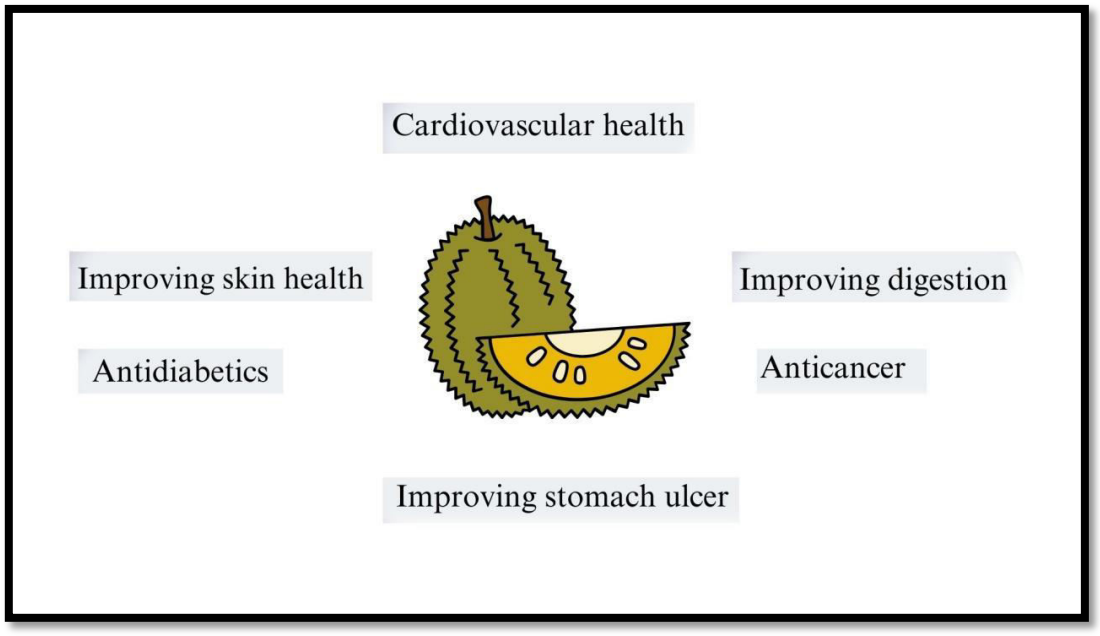

Figure 2. Functions of jackfruit

4.1. Cardiovascular health

Cardiovascular health is the condition of the heart and blood arteries (Yang et al., 2018) discovered a correlation between high or low levels of low-density lipoprotein cholesterol (LDL-C) and high or low levels of high-density lipoprotein cholesterol (HDL-C) in the blood. The oxidation of low-density lipoprotein (LDL) is believed to contribute to the development of atherosclerosis and cardiovascular disease. This is because oxidized LDL is more easily absorbed by macrophages via scavenger receptors, which makes the lipoproteins atherogenic (Khatana et al., 2020). The therapeutic benefits of jackfruit encompass lowering blood pressure, preventing heart disease and stroke, improving muscle and nerve function, preventing bone loss, and reducing blood homocysteine levels. Studies have revealed that potassium in jackfruit can aid in reducing blood pressure and counteracting the impact of sodium, which elevates blood pressure and has adverse effects on the heart and blood vessels. Heart disease and stroke can be prevented (Ranasinghe et al., 2019).

4.2. Skin health

Skin ageing is a complex process that involves both intrinsic and extrinsic ageing. The natural ageing process leads to skin damage, exacerbated by prolonged sun exposure (Chen et al., 2021). Jackfruit offers the advantage of being a rich source of vitamin C. Given that the human body cannot synthesize vitamin C on its own, incorporating vitamin C-rich foods like jackfruit into our diet can enhance overall health benefits. Because jackfruit contains casein and is gluten-free, it has anti-inflammatory effects on the skin throughout the body. In addition to flavonoids, vitamin C, flavonoids, potassium, magnesium, fiber, and antioxidants are present in jackfruit (Adan et al., 2020).

4.3. Stomach ulcers

Stomach ulcers are a form of peptic ulcer. Duodenal ulcers are among the most common types of peptic ulcers. Stomach ulcers are often caused by infection caused by the bacterium Helicobacter pylori (Ranasinghe et al., 2019). Polysaccharides, phenols, and flavonoids found in jackfruit are associated with gastroprotective properties due to their substantial antioxidant activity and ability to reduce inflammatory responses (Wang et al., 2022). Few research has focused on jackfruit's gastroprotective potential, but it has been established that it also has anti-inflammatory, antioxidant, gut microbiota composition regulation, and other bioactive properties that may assist in curing ethanol-induced gastric lesions (Zeng et al., 2022). Collagen peptide is another key element in FPJ, exhibiting anti-inflammatory and antioxidant properties (Chotphruethipong et al., 2021). Furthermore, collagen peptides, which are the fundamental blocks of

collagen, can aid in reshaping the extracellular matrix and enhance tissue repair in gastric lesion healing (Lu et al.,2022).

4.4. Improving digestion

Jackfruit is known for its ability to hold a large amount of dietary fiber. Studies have indicated that the fiber content of fruits ranges from 0.3% to 0.5%, and there are no notable differences in fiber content among various parts of the fruit at different ripening stages (Amadi et al., 2018). The natural fiber present in jackfruit and its seeds acts as a natural laxative, helping to prevent constipation by promoting a healthy digestive process. Research has shown that the dietary fibers contained in jackfruit and its seeds can promote a prolonged feeling of fullness and stimulate more frequent bowel movements. (Sowmyashree et al., 2022). The elevated fiber content in jackfruit aids in preventing constipation and facilitating regular bowel movements. Additionally, it protects colon membranes by eliminating cancer-causing substances from the colon (Shedge et al., 2022).

4.5. Anticancer

Phytonutrients present in jackfruit demonstrate anticancer effects by combating harmful free radicals, which are implicated in cancer and other chronic diseases. These nutrients inhibit the initial development of cancer cells. Saponins, specifically, are potent anticancer agents; a study showed their ability to prevent colon cancer and induce mitotic arrest in leukaemia cells (Oktavia et al., 2017), potentially aiding in remission. Saponins interact with the outer coats of cancer cells. Additionally, isoflavones and lignans, the primary forms of phytoestrogens in jackfruit pulp, help reduce the risk of endometrial cancer (Swami et al., 2012).

4.6. Antidiabetics

Jackfruit is regarded as a promising fruit for managing diabetes due to its low glycemic index (GI) and high fiber content. Studies have suggested that consuming low-GI foods like jackfruit can help regulate blood sugar levels by slowing down the release of sugar into the bloodstream. Furthermore, the significant fiber content in jackfruit aids in better blood sugar control by slowing digestion and sugar absorption (Srinivasan et al., 2016). However, it's crucial to incorporate jackfruit into a balanced diet and seek personalized dietary advice from healthcare professionals or dietitians for effective diabetes management.

5. Technological uses of jackfruit

Jackfruit is being explored for various technological applications beyond its culinary use. Its fibrous husk, seeds, and peel are potential sources of eco-friendly packaging materials, offering a sustainable alternative to traditional plastics (Shah et al., 2019). Additionally, jackfruit waste such as peels and seeds can be utilized for bioenergy production, particularly ethanol, due to the high

starch content in the seeds (Ali et al., 2021). Furthermore, ongoing research on compounds derived from different parts of the jackfruit plant for their medicinal properties suggests potential applications in pharmaceuticals and healthcare. Jackfruit has demonstrated diverse technological applications within the food industry, showcasing its adaptability beyond traditional consumption. Unripe jackfruit, known for its fibrous texture and mild taste, is increasingly utilized as a plant-based meat substitute in dishes like tacos, burgers, and stir-fries (Nakorn, 2018). Furthermore, jackfruit seeds are processed into gluten-free flour, offering a nutritious alternative for gluten-sensitive individuals and imparting a unique flavor to baked goods (Hettiarachchy et al., 2018). Extracts and compounds derived from jackfruit, such as polyphenols and antioxidants, serve as natural food additives to enhance nutritional profiles and extend the shelf life of various food products (Nair et al., 2020). Ongoing research also explores jackfruit's potential as a functional food ingredient due to its high fiber content and beneficial compounds, potentially providing health benefits like improved digestion and antioxidant support (Saxena et al., 2021). These technological advancements highlight jackfruit's versatility and its contribution to innovative and sustainable food solutions.

5.1. Minimally Processed Products

Fully ripened jackfruit can be sold either whole or in convenient, ready-to-eat packaging such as polyethylene or polypropylene containers. Nonetheless, their shelf life is relatively short, ranging from 3 to 15 days (Farheen et al., 2016). Effective processing methods are essential to maintain freshness, and quality, and ensure microbial and enzymatic stability during storage (Ekanayaka et al., 2015). Minimally processed products are fruits and vegetables that have been physically modified from their initial state yet remain fresh. MPPs are also known as freshly cut, minimally processed, partially processed, or prepared items. Freshness, health advantages, and availability have increased the demand for a variety of items, namely, jackfruit and other tropical fruits (Ramli et al., 2017). The duration of the shelf life of MPP varies depending on the product, packaging, and storage environment (Adiani et al., 2014).

5.2. Modified atmosphere packing (MAP)

The application of modified atmosphere packaging (MAP) can be advantageous in preventing water loss, postponing browning, preserving the color, and reducing microbiological populations (Siddiq et al., 2020). The main changes in water activity, color, and the development of sugar crystals on the surface are observed in dry fruits kept under ambient settings. The examination of Modified Atmospheric Packaging (MAP) revealed no statistically significant variances between the treatment and standard storage conditions concerning alterations in the fruit's total soluble solids, titratable acidity, and firmness (Rifath et al., 2021). Fruit color can alter as a result of several chemical and biological

processes that occur during drying and storage. fruit phenolic components undergo oxidation and then further polymerize resulting in brown color when stored. Depending on the length of storage and the ambient conditions in the storage area, dried fruits gradually lose their quality. Consequently, the enzymatic and non-enzymatic oxidation process may be slowed down by storing dry fruits and vegetables at low pressure, high CO2, N2, or low O2 content (Prasantha et al., 2020). In other cases, MAP and lower temperatures did not extend the lifespan of jackfruit bulb due to severe physical and mechanical stress caused during processing (Pinto et al., 2020).

5.3. Edible Coating

Edible coatings and films can be applied to less processed fruits to extend their shelf life. They operate as a barrier, reducing metabolic activities, preventing dehydration, and delaying senescence by establishing a minimal O2/high CO2 microclimate. They are also suitable for antibacterial and antibrowning applications (Torres et al., 2017). Before adding a chitosan coating to the jackfruit bulb. Jackfruit has emerged as a promising candidate for the development of edible coatings in the food industry, offering a natural and sustainable alternative to synthetic coatings. Studies indicate that these coatings, derived from jackfruit components, can effectively enhance the shelf life of fruits and vegetables by reducing moisture loss, slowing down ripening processes, and inhibiting the growth of microbes (Tirado-Gallegos et al., 2020). The polysaccharides, antioxidants, and antimicrobial compounds found in jackfruit contribute to the efficacy of these coatings in maintaining food quality and safety. Furthermore, jackfruit-based coatings have been observed to improve sensory attributes like texture, appearance, and taste in coated products. This innovative use of jackfruit underscores its potential role in promoting food preservation and sustainability within the food industry.

5.4. Ultraviolet treatments

UV technology is commonly used to reduce vegetative organisms in food products and replace the need for chemical sterilization. UV treatments have been explored as a postharvest technique to enhance the quality and extend the shelf life of jackfruit. Research indicates that UV-C irradiation effectively reduces microbial growth and slows down ripening processes in jackfruit, leading to improved storage stability and preservation of fruit quality (Thangavelu et al., 2017). UV treatments are thought to activate defense mechanisms in fruits, such as enzyme induction and secondary metabolite production, which enhance resistance against pathogens and oxidative stress. Additionally, UV irradiation maintains the nutritional content of jackfruit while improving its sensory attributes, making it a promising non-chemical method for postharvest management.

5.5. Drying treatments

Drying treatments for jackfruit involve various methods such as sun drying, solar drying, and oven drying, which are aimed at reducing the moisture content to enhance preservation and storage. Sun drying, a traditional method, involves placing jackfruit slices or chunks on mats under direct sunlight until they reach the desired moisture level. Solar drying utilizes solar energy to dry jackfruit, often using solar dryers that control temperature and airflow. Oven drying, on the other hand, involves placing jackfruit in an oven at low temperatures for an extended period. These drying methods have been studied and optimized for efficiency and quality, contributing to the development of value-added jackfruit products (Sachindra et al., 2011). Dried jackfruit offers high commercialization potential; hence, the authors focused on these materials (Wong & Tan 2017). The study on the impacts of hot air drying temperatures (50, 60, and 70 °C) on jackfruit layers. The effects of pretreatments in addition to a blend combined with freeze-drying and hot air-drying procedures to produce dried and crisp jackfruit bulb. The samples subjected to the combined drying method had an 8-month increase in shelf life, while maintaining excellent sensory characteristics, particularly crispness (Saxena et al., 2015).

6. Utilization of jackfruit wastes

Fruit waste is one of the world's most pressing environmental issues. The food industry has increasingly focused on utilizing jackfruit waste to develop innovative products and reduce waste. Jackfruit seeds, often discarded, are rich in nutrients and can be processed into flour, which can then be used in various food formulations such as bakery products, snacks, and noodles, adding nutritional value and fiber content (Chang et al., 2019). Additionally, jackfruit rinds and peels contain bioactive compounds like antioxidants and dietary fiber, making them valuable as ingredients in functional foods, supplements, and food additives. Consequently, one of the most crucial methods for making use of jackfruit waste is to use the valorization process to create several valuable bioproducts. However, to successfully and effectively valorize such wastes, pretreatment and extraction techniques are critical steps (Castro et al., 2021). Fruit waste may be converted into useful goods through the biotransformation process (Pathak et al., 2022). By incorporating these waste materials into food products, the food industry not only minimizes waste but also enhances product diversity and nutritional benefits, aligning with sustainable and eco-friendly practices.

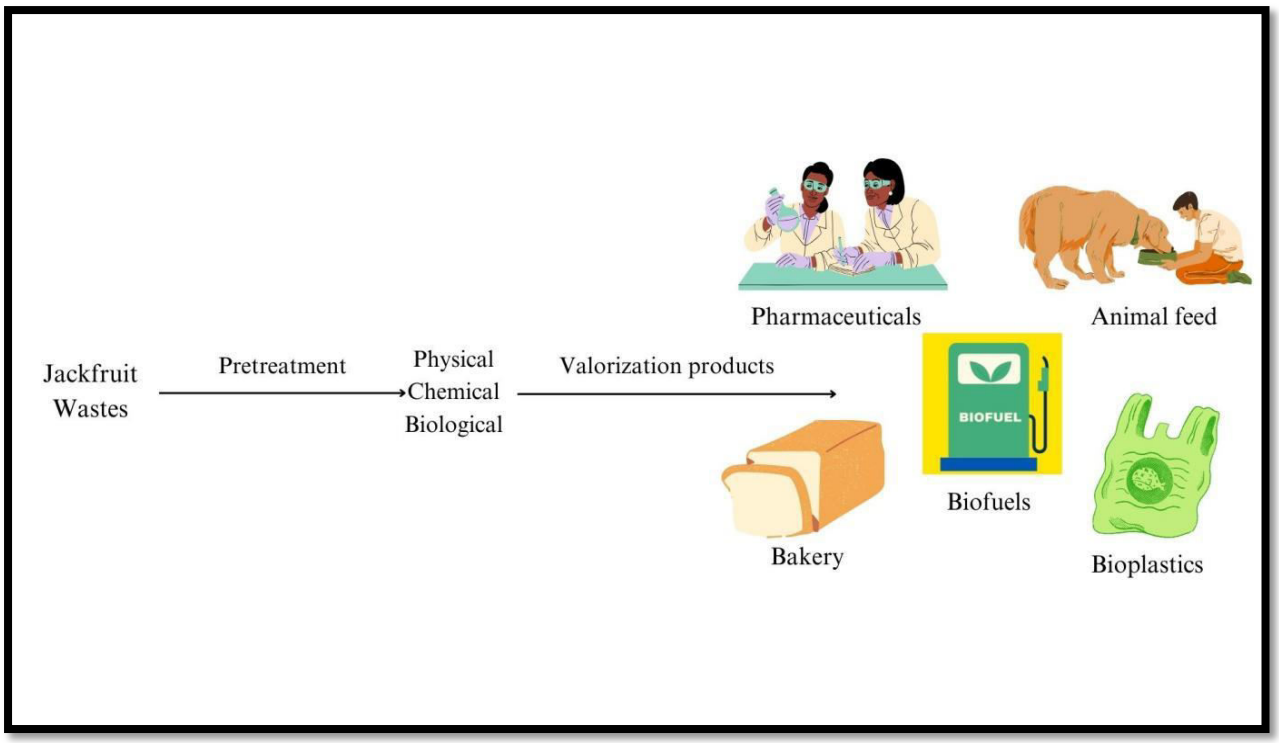

Figure 3. Jackfruit waste and its applications

6.1. Jackfruit waste as an adsorbent

Environmental pollutants can be effectively removed using modern biological remediation techniques. Many researchers have reported the use of jackfruit peel to remove dyes from aquatic environments (Tran et al., 2021). The removal of methylene blue dye from jackfruit peel has been examined. The results demonstrated that jackfruit waste biomass may be converted into a low-cost adsorbent substance. Jackfruit peel has been identified as an effective adsorbent for eliminating rhodamine from water bodies (Tran et al., 2021). This qualifies it as a prospective option for removing dyes in an eco-friendly manner. (Ahmed & Nasar, 2021) reported that jackfruit peels are a viable, inexpensive adsorbent. Even though physicochemical procedures are frequently employed to treat wastewater, some colors can still be difficult to remove. Jackfruit seeds may be used to decolorize the textile dye novacron blue (Miah et al., 2022). They discovered that increasing the dye level had a negative impact on how much dye was removed. Therefore, it is crucial to identify a conveniently accessible, reasonably priced adsorbent material to remove dye color from polluted locations, such as jackfruit peels.

6.2. Bakery products

Baked goods including cookies, cakes, buns, doughnuts, muffins, and biscuits are typically made with wheat flour, which includes proteins that interact with one another when mixed with water to generate gluten (Palamthodi et al., 2021). Jackfruit seeds have been used to make flour according to several researchers. Jackfruit seed flour is produced through a drying method that

involves grinding the dehydrated seeds and then storing them in tightly sealed containers (Akter et al., 2018). (Abraham &Jayamuthunagai, 2014) developed pasta using a combination of jackfruit seed and wheat, while adding composite flour to the pasta increased its nutritious content. (Butool, 2015) described making bread and biscuits with jackfruit. The color and texture of bread and biscuits made with 10% and 20% were found to be superior.

6.3. Pharmaceuticals

Jackfruit seeds are a plant-derived natural starch with potential usage as excipients in several medicinal compositions (Nayak et al., 2015). The protein and starch of jackfruit seeds could be used to make medicines. Jackfruit latex may help treat various dental issues because it is high in resin (Jitendra et al., 2014). The traditional use of jackfruit leaves, fruit, and bark in medicine is attributed to their natural healing properties, including anti-carcinogenic, antimicrobial, antifungal, and anti-inflammatory effects. They also show hypoglycemic effects. Jackfruit pectin has been used as a polymer framework to build biocomposites with superior antibacterial, anticoagulant, anti-inflammatory, biodegradability, and cytocompatibility (Govindaraj et al., 2018). (Mandhare et al., 2020) examined the health benefits of jackfruit extract and its nutritional benefits.

7. Value-added products prepared by incorporating jackfruit

Value-added products made with jackfruit provide consumers with a wide range of unique and healthful options as mentioned in Table 2. Jackfruit, which originated in South Asia, is well-known around the world for its variety and nutritional value. Jackfruit's major commercial product is its fruit, which might be mature or immature. Jackfruit has a meat like texture which is an excellent vegetarian meat substitute (Hamid et al., 2020). (Kumar et al., 2018) highlighted the growth of value-added products such as jackfruit flour, fries, jams, and jellies. These products highlight the fruit's particular flavor and provide additional nutritional benefits due to jackfruit's high vitamin, mineral, and antioxidant content. Jackfruit seeds are ground to make flour and consumed after being roasted, boiled, and dried (Akter & Haque 2018). The peel and leaves of jackfruit are rich in therapeutic qualities. Leaves can be used to make nutritious tea. There are numerous health benefits associated with jackfruit rind. Rind fibres can be chopped and dried before being used in polymer composites (Pathak et al, 2022).

Value-added products made with jackfruit flour are becoming increasingly popular due to their unique flavor and nutritional benefits. One such product is jackfruit flour muffins, which are not only delicious but also gluten-free and rich in fiber, making them a healthy choice for those with dietary restrictions or health-conscious consumers (Arpit &John , 2015). Another creative use of jackfruit flour is in yogurt, where it adds sweetness and a creamy texture, enhancing the overall

taste and nutritional profile of the yogurt (Hossain et al., 2023). Extruded snacks made with jackfruit flour offer a crunchy and flavorful snack option that is not only tasty but also packed with nutrients like vitamins and minerals (Gat &Ananthanarayan, 2015). Jackfruit flour can also be used to make patties, adding a distinct taste and texture to these savory treats (Felli et al., 2018). Additionally, incorporating jackfruit flour into bread recipes results in loaves that are not only soft and moist but also have a unique flavor that sets them apart from traditional bread (Ramya et al., 2020). Overall, value-added products made with jackfruit flour provide consumers with innovative and healthy alternatives to traditional snacks and baked goods, making them a popular choice in the food industry.

Table 2. Value-added products prepared by incorporating jackfruit

Ingredients	Product	Outcome	Reference
Jackfruit seed & Wheat	Chocolate cake Muffins	Resulted in an increase in the protein and ash contents and a decrease in the fat content. Specific gravity increased and viscosity decreased	Arpit & John (2015)
Jackfruit seed & Rice	Extruded snacks	The nutrimental and nutraceutical properties of extrudates were improved by the incorporation of jackfruit seed flour into the rice. Increase in nutritional and phytochemical properties	Gat &Ananthanarayan (2015)
Jackfruit seed & Milk	Yogurt	The most satisfying result was obtained by introducing 6% JSPI into the yoghurt, which resulted in higher protein content while preserving acceptable sensory qualities. The ideal enrichment rate for yogurt obtained 747 mg JSF mineral concentrate per 100 g.	Hossain et al., 2023

Jackfruit seed & Milk	Nutri spreads	The jackfruit seed flour based nutri spreads were enriched by skimmed milk powder (SMP) is developed. All nutri spreads obtained high scores for organoleptic qualities. Highly acceptable, nutritionally superior and shelf stable nutri spreads developed successfully based on jackfruit seed flour without adding any preservatives.	Molu et al., 2022
Jackfruit bulb & Wheat	Patty	The product had significantly higher ($p<0.05$) protein content, higher fiber content, etc. as compared to the commercial product.	Felli et al., 2018
Jackfruit bulb & milk	Ice cream	The best quality icecream prepared with 8.00±0.10, 8.05±0.06, 8.28 ±0.08 and 8.22±0.04 Score for flavour, colour and appearance, body and texture, and overall acceptability	Gaikwad et al., 2020
Jackfruit bulb & Jackfruit seed	Inatantpayasam mix	The study was conducted to develop jackfruit based instant vermicelli payasam mix by using jackfruit flour and jackfruit seed flour had good sensory characteristics with an overall acceptability was 8.62. The market potential of jackfruit can be promoted if the fruits are made available to the consumer in a ready to cook form throughout the year.	Ajisha et al., 2020

Jackfruit rind & Wheat	Bread	The incorporation of jackfruit flour in different ratios had a significant influence on bread volume and texture attributes.	Feili et al., 2013
Jackfruit rind & Wheat	Cookies	Developed jackfruit-based high fiber cookies by utilizing jackfruit rind flour in cookies formulation, and to characterize physical properties of produced high fibre cookies. The incorporation of JRF caused significant influence on sensory, physical and chemical attributes.	Ramya et al., 2020

7.1. Jam

Jackfruit pulp offers great gelling properties for creating jam. Jackfruit jam tends to be more durable and less susceptible to microbial contamination due to the fruit's low pH. Jackfruit jam contains minimal calories and is high in natural sugars. It has been established that the jam stored at a low temperature remains free of microbial attack for a year at room temperature while maintaining increased sensory attributes (Kaur et al., 2023). Additionally, when jackfruit jam was kept at room temperature and under refrigeration, researchers found that the amount of lycopene, protein, and ascorbic acid decreased while the amount of total sugar increased (Arshad et al., 2018). Under ambient storage conditions, changes in physicochemical properties were more noticeable.

7.2. Fermented beverages

Jackfruit juice has been recognized as a favourable substrate for fermentation, particularly for wine production, due to its high sugar concentration (Muhialdin et al., 2021). The fermentable sugars found in jackfruit in significant proportions can be utilized to make wine and vinegar. Antioxidants found in jackfruit wine are a great form of defense against DNA damage caused by radiation (Panda et al., 2016). (Baidya et al., 2018) made wine with an alcohol content of 8–10% using jackfruit, mango, and pineapple. (Shraddha et al. 2021) showed that adding 15% amla juice to jackfruit juice increased the sensory score of jackfruit wine.

7.3. Squash

Squash is a strong syrup that is typically made from a mixture of fruit juice, water, and sugar (Akubor et al., 2017). The study found that the preservative and

packaging material significantly improved the shelf life of jackfruit squash. The squash remained acceptable for 90 days in terms of colour, flavour, aroma, mouth-feel, and overall acceptability, and could be stored for up to 3 months under refrigeration (Ranganna et al., 2018).

7.4. Chips

As a value-added jackfruit product, chips have considerable potential. The jackfruit bulb slices were pre-partial dried, resulting in the vacuum fried chips with the lowest moisture level. During the frying process, JF bulb slices absorbed nearly the same amount of oil as control and pre-frozen samples. Jackfruit chips were made using explosive puff drying in combination with different pre-drying treatments: hot air drying, freeze drying, infrared drying, microwave drying, and vacuum drying. The FD-EPD reduced color fading and resulted in a color more comparable to fresh jackfruits. FD-EPD dried chips also had a low hardness and showed a puffy structure and crispy texture. Additionally, the FD-EPD dried chips retained rather significant levels of ascorbic acid, phenolics, and carotenoids. The sensory evaluation results indicated that the FD-EPD combination was a better choice since it improved the overall quality of jackfruit chips (Yi et al., 2016).

7.5. Leather

Jackfruit leather refers to the dried sheets of jackfruit pulp. The sheet has a rubbery, squishy touch (International Centre for Underutilized Crops, (Rauk et al., 2019). Fruit leather is made by simmering fruit pulp or a combination of fruit juice extract and other ingredients, which is then dried on a non-stick surface and rolled (Kurniadi et al., 2022). This technology enables the creation of leathers from a variety of fruits, including guava, papaya, jackfruit, and durian. Fruit leathers, which are typically eaten as snacks, provide a handy and delicious method to ingest fruits. They can, however, be blended with water to make beverages or sauces. Fruit leather can also be used as an ingredient in baked products and breakfast cereals. Fruit leathers have been developed in several places around the world, including Africa, despite their popularity in North America (Offia-Olua et al., 2015).

7.6. Ice cream

Ice cream is a popular and nutritious snack enjoyed by people of all ages. It is made using pasteurised milk products, sugars, emulsifiers, stabilisers, flavourings, and water. To accomplish the demand for ice cream and highlight the nutritional value of jackfruit, a jackfruit pulp-based ice cream was developed. This is offered in the local region throughout the summer months. Ice cream was prepared by using buffalo milk and jackfruit pulp and reported that this particular recipe received the highest sensory rating for color, flavor, and appearance (Gaikwad et al., 2020). According to (Lumbantobing et al., 2020), ice cream made

from milk derived from jackfruit seeds is high in fiber and low in fat and a viable substitute for ice cream made from dairy products. In addition, those who are lactose intolerant can drink jackfruit seed-based ice cream, which includes dietary fiber for healthy bowel function, to avoid constipation and lower the risk of colon cancer (Lumbantobing et al., 2020).

7.7. Meat analog

Plant-based meat substitutes meet customer needs and contribute to global food security. Meat analogs have many health benefits, such as low fat intake, high fiber intake, prevention of animal diseases, reduced caloric intake, and reduced greenhouse gas emissions (Ismail et al., 2020). (Keerthana Priya et al.,2021) developed vegan sausage by using raw jackfruit and banana florets. The result obtained is acceptable and favor is siilar to the control so it could be a good alternative to meat. Extrusion process used to create a meat-like product at room temperature. The main ingredients were jackfruit and cashew nut flour, along with flaxseed, pea protein, spices, binding agents, and natural colour. The current study found that proximal and sensory analysis yielded higher values and colour characteristics compared to the control group and these substances also provided adequate nutrition (Ghangale et al., 2022).

8. Future research directions

Future research directions for the utilization of jackfruit may include a diverse approach. Investigating its health benefits & bioactive components will offer insight into its medicinal uses and functional dietary potential. Exploring novel processing processes could improve its nutritional profile, flavour, and shelf life, helping to drive product development in a variety of food categories such as plant-based alternatives and snacks. Sustainability studies would evaluate the impact on the environment, while consumer acceptance studies and market analysis would inform commercialization efforts. Further nutritional analysis, allergic potential evaluations, and food safety rules would ensure the product's safety and quality. Finally, a global view on jackfruit utilisation, taking into account regional variances and traditional applications, would encourage cross-cultural culinary creativity and widespread adoption.

9. Conclusion

Jackfruit is a tropical fruit abundant in carbohydrates, dietary fiber, vitamins, and minerals. Its unique composition makes it a valuable source of energy and essential nutrients. One of the key nutritional aspects of jackfruit is its carbohydrate content. It is a natural source of sugars, primarily fructose and sucrose, providing a sweet flavor profile that can be utilized in various food applications. Furthermore, jackfruit contains a notable amount of dietary fiber, promoting digestive health and aiding in maintaining healthy cholesterol levels. Regarding vitamins and minerals, jackfruit is particularly rich in vitamin C, which

supports immune function and collagen synthesis. It also contains essential minerals like potassium, magnesium, and manganese, which play vital roles in various bodily processes. The utilization of jackfruit in food model systems has demonstrated its versatility and potential as an ingredient in both sweet and savory dishes. In sweet applications, jackfruit can be utilized fresh or dried to add natural sweetness and a unique tropical flavor to desserts, beverages, and snacks. Its fibrous texture also makes it suitable for inclusion in jams, preserves, and fruit-based spreads. In savory applications, jackfruit serves as an excellent meat alternative for vegetarian and vegan dishes. This fruit's ability to resemble meat textures without the associated cholesterol and saturated fat content makes it a possible meat substitute for vegetarian and vegan diets. The nutritional composition and versatility of jackfruit make it a valuable addition to both traditional and innovative food systems.

Jackfruit is considered an underutilized fruit on a commercial basis because the greater proportion of inedible portions of the fruit leads to additional waste generation and difficulties in processing. Therefore, additional research should focus on identifying potential jackfruit industrial applications and managing waste produced during jackfruit processing. The incorporation of jackfruit, which is widely accessible and high in nutrients, into the diet can help maintain good health. Jackfruit is rich in phytonutrients, dietary fiber, vitamins, minerals, and numerous other substances with therapeutic benefits. As a result, this fruit can be thought of as a complete fruit with a wide range of qualities and health advantages; nonetheless, jackfruit continues to fall under the category of underutilized fruits because the majority of the fruit throughout its season is lost. The fruit and its value-added products are not entirely commercialized. Further research and development in processing techniques, flavor profiles, and culinary applications are warranted to fully unlock the potential of jackfruit as a mainstream food ingredient.

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Credit authorship contribution statement

Anaghasree: Conceptualization, Original draft writing, Editing. **Sourabh Kumar:** Project administration, Resources, Supervision. **Maanas Sharma:**Validation, VisualizationWriting – review & editing.**Praveen Kumar Dubey:** Visualization, Resources. **Nilesh Balasaheb Kardile:** Formal analysis, Resources. **Sandip T Gaikwad:** Formal analysis, Resources. **Mohammed Nayeem:** Methodology, Investigation, **Vinay Kumar:** Methodology, Visualization.

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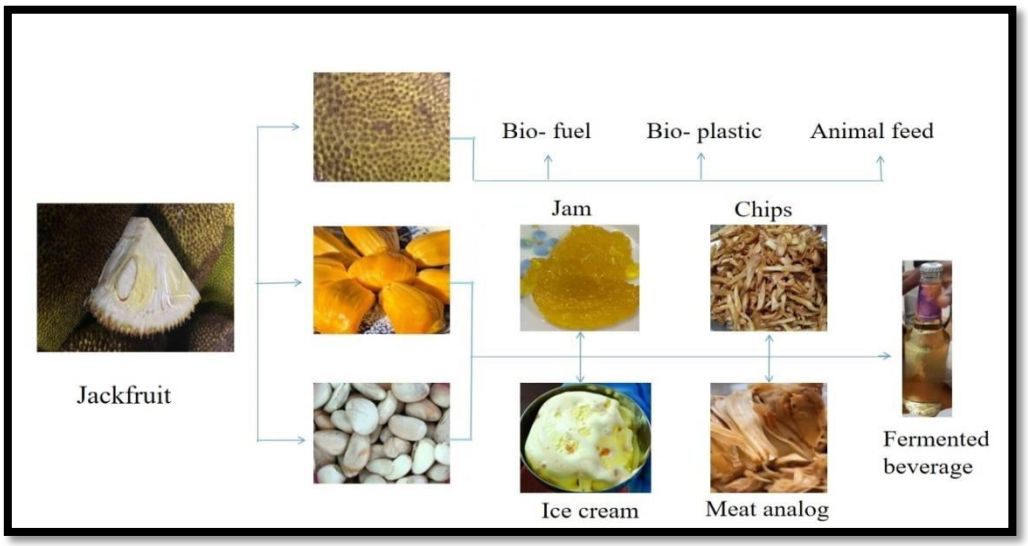
Conflict of Interests

The authors declare that there are no conflicts of interest related to this work. The authors also declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.



Graphical abstract

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