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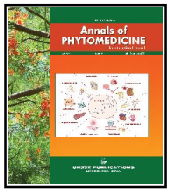

Review Article : Open Access

An overview of the nutritional assessment, clinical application and industrial utilization of jackfruit (*Artocarpus heterophyllus* Lam.)

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Abstract

Jackfruit (*Artocarpus heterophyllus* Lam.) belongs to the Moraceae family. It is native to the Western Ghats of India and is also found in parts of eastern Africa and southern Asia. It is the most consumed edible fruit in the world. It contains abundant minerals, protein, vitamins, phytochemicals, and carbohydrates. This superfruit helps lower the risk of cardiovascular disease, decreases low density lipoprotein, improves bone health, and is used in weight loss. It also exhibits antidiabetic, antiageing, anticancer, antiulcer effects. Not only the fruit but also its seeds are rich in isoflavones, lignans, and saponins. One can optimize the fruit, and its different parts into usable and culinary delights. Its pulp is used in making chutney, biscuit jelly, toffee, paste, leather, bars, and nectar and the bulb is used to make color and can be used in textile industries. Jackfruit waste can be utilized in bio-fuel, bioactive compounds, animal feed, and industrial dyes. Jacalin belongs to a group of lectins that are present in the seed of jackfruit, and contribute to the strengthening of the immune system. This review article focuses on the multifaceted applications of jackfruit with special emphasis on its health-promoting effects and its utilization to produce various products.

1. Introduction

A key component of Asia's various folk and traditional medicine systems is the jackfruit tree (Pawan *et al*., 2023). Jackfruit, the widely consumed fruit in Bangladesh also referred to as 'Poor man's Fruit' corresponds as a member of the mulberry family Moraceae. It is the national fruit of Bangladesh and is mostly devoured by rural areas of the country (Matin, 2015). A fruit native to Malaysia and the Western Ghats of India along with central and eastern Africa, it can also be found in Southeast Asia, the Caribbean, Florida, Brazil, Australia, and several Pacific Islands (Rahman *et al*., 1999). Ripe jackfruit is either consumed directly or processed. Seeds comprise between 10 per cent and 15 per cent of the fruit's weight and are high in carbohydrates and proteins (Bobbio *et al*., 1978; Kumar *et al*., 1988). Bangladesh comes at second place with a total production of 926 tons, and jackfruit has been designated as their national fruit. India is the largest producer of jackfruit, with an overall yield of 1.4 million tons. Notable producers of jackfruit include Thailand, Indonesia, and Nepal (Haq, 2006; Apaari, 2012). Bangladesh is home to a variety of cultivars, including khaja, gala, and durasha (Haque, 1993). It is a non-seasonal fruit that provided a significant amount for people and their animals when major feeding grains were short in supply (Sim *et al*., 2003). It is high in minerals, vitamins, digestible carbohydrates, and proteins. Ripe flakes contain approximately 287-323 mg potassium, 30-73 mg calcium, and 11-19 g carbohydrates per 100 g (Prakash *et al*., 2009) This fruit is high in energy and can help athletes and sports persons rebuild their strength. Recent studies discovered phytonutrients present in jackfruit have several health benefits ranging from antibacterial, antidiabetic, antiinflammatory, antioxidant, anthelminthic, and so on (Shanmugapriya *et al*., 2011). A large, evergreen tree that reaches a height of 10 to 15 meters, native to India's warmest regions, it grows in cultivated evergreen forests between 450 and 1200 meters. This plant produces milky latex with a straight, rough stem with 1.25 cm thick green or black bark. The inflorescence comprises single axillaries and cauliforous on short leafy stems. The leaves are broad, obovate, elliptic, decurrent, and hairless.

Every species of Artocarpus tree is a lactiferous tree that is gathered from stems and leaves that might yield a milky sap. The estimated weight of this fruit lies between a range of 4.5 to 30 kg (Hamid *et al*., 2020). In addition, it produces unisexual flowers, this monoecious fauna type has both sexes within the same plant. In the Indian market, jackfruit is accessible from spring through summer. Fresh fruit pulp is consumed has great nutritional content and is used in fruit salads (Sreeja *et al*., 2021). The seeds themselves are an excellent nutrient source full of vitamins, fiber, carbohydrates, and proteins. According to a recent study conducted, it was stated that the inedible portion of the fruit carries a significant amount of pectin ranging from 14.8-18.6 per cent and about 17.6-20.5 per cent (w/w) (Nandhu *et al.,* 2020) The yield of polyphenols from the jackfruit's rind is higher than other fruit peels of orange, pomegranate, pineapple, *etc.* (Brahmaand Ray, 2022). The protein isolates from jackfruit seeds, a significant lectin belonging to a class

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of glycoprotein called jacalin are associated with boosting the immune system (Kumar *et al*., 1982).

Its residue, a byproduct of the fruit extraction process, is utilized to create jackfruit rind flour. Jackfruit residue, which has a low market value, makes up about 2 per cent of the freshly grated flesh (Asquieri *et al*., 2008). In its early years, the tree develops swiftly, reaching a height of 1.5 m/year (5 ft/year). But as it ages, it slows down to roughly 0.5 m/year (20 in/year) (Kamaluddin *et al*., 1996). A valuable addition to meals since ancient times, jackfruit is one of the tropical fruits that is often underutilized, but has many positive potential effects on the human body (Aroraand Parle, 2016). Goats, pigs, and cattle may get valuable fodder from the leaves and fruit debris as they are nutritious and high in vitamins and minerals. The renowned orange-red hue of Buddhist priests' robes is achieved by the use of a dye produced from the wood chips of jackfruit. Moreover, a variety of plant parts, like the bark, roots, leaves, and fruits, have therapeutic qualities (Shyamalamma *et al*., 2008). Utilization of jackfruit is endless such as utilizing dried and treated ripe jackfruit pulp can be converted into dry powder. The processed jackfruit could be turned into pickles, juices, cookies, sauce, jams, jellies, candies, paste, leather, barriers, and syrups (Li *et al*., 2017). Lastly, there are growing appeals for using jackfruit as a meat analogue as it contains a higher amount of protein of 17.8-37.0 per cent and an abundance amount of fiber due to the presence of rind along with the fat content is also high may be due to the oil holding capacity of fibers (Lopez-Martinez *et al*., 2024).

2. Bioactive compounds of jackfruits

Bioactive compounds are a group of physiologically active components extracted from plants or animals that provide vital elements more than basic nutrition. They are referred to as (GRAS) "generally regarded as safe", as they correspond to our living tissues giving potential health benefits (Banwo *et al.,* 2021). *A. heterophyllus* is known for its therapeutic effects containing a wide range of bioactive compounds including stilbenoids, flavonoids, lectin jacalin, aryl benzofurans along with carotenoids, tannins, and volatile acids (Tripati *et al.,* 2023). As bioactive compound, it fights against bacteria and has anti-inflammation, antioxidant, and anthelminthic properties. Zhang reported that the peels of the jackfruit contain significant amount of glycosides, prenylflavonoids, hydroxycinnamic acids with ABTS+ and DPPH scavenging capability of α-glucosidase (Zhang *et al.,* 2017).

2.1 Carotenoids

Carotenoids are a group of lipid-soluble pigments that dissolve in non-polar solvents, found in fruits, vegetables, insects, and algae (Huang *et al.,* 2022). The findings from the present study confirm that there are around 1,07,98 carotenoids present in the bulb of the jackfruit. Major carotenoids include all-*trans*-lutein (24-44%), all-*trans* -β-carotene (24-30%), all-*trans*-neoxanthin (4-19%), 9- *cis* -neoxanthin (4-9%) and 9- *cis* -violaxanthin (4-10%). Experiments showed qualitative and quantitative differences among the three different batches that were mainly related to the proportion of lutein. Batch A had all the carotenoids at significantly low levels, with a total carotenoid content as low as 34.1 µg/100 g with almost zero pro-vitamin A value. The total carotenoid content in batches B and C was from 129.0 to 150.3 µg/100 g with pro-vitamin A values of 3.3 and 4.3 µg RAE/100 g, respectively. The authors identified 14 new carotenoids in jackfruit, bringing the number up to 18 (De Faria *et al.,* 2022). Consumption of dietary intake of carotenoids has been linked with decreased risk of chronic diseases such as cancer, cardiovascular, obesity, and type 2 diabetes (Bohn *et al.,* 2021).

2.2 Flavonoids

Flavonoids are classified as water-soluble pigments belongs to a group of phenylpropanoids found in vacuoles of plant cell wall. They are comprised of two benzene rings linked with a 3-carbon heterocyclic ring having a carbon skeleton of C_6-C_3-C_6 (Liu *et al.,* 2021). Total flavonoid content varies depending on different parts of the fruit and extraction methods. According to García-Mateos, the total flavonoid content in jackfruit pulp was reported to be 9.86 mg quercetin equivalents per 100 g of fresh weight (Del Rosario *et al.,* 2021). High flavonoid content in ethanol and water extracts of jackfruit pulp correlates with considerable antioxidant activities (Jagtap *et al.,* 2010). Quercetin is a flavanol, with a molecular formula of C H O, containing multiple hydroxyl groups that posses antioxidant properties (Qi *et al.,* 2022). Surprisingly, the flavonoid content is more in peel relatively in pulp. Recent study reveals that ethyl acetate fraction had the highest level of phenols and flavonoids and strong antiradical activity approximately IC_{50} at 5.435 + 0.064 µg/ml, being comparable with ascorbic acid and tocopherols one of the most potent antioxidants. Table 1 illustrates the average total flavonoids content in the jackfruit seeds (Zubaydah *et al.,* 2021).

Table 1: The average total flavonoids present in seeds of jackfruit

S.No.	Sample	Average (g QE/100 g sample)
1	Methanol extract	59.907 ± 0.719
2	n-hexane fraction	65.228 ± 0.615
3	Ethyl acetate fraction	70.199 ± 0.458
4	Water fraction	54.234 ± 0.351

Source: Zubaydah *et al.* (2021).

2.3 Lectin jacalin

Jacalin belongs to the group of lectins a type of naturally occurring protein found in jackfruit seeds with a molecular weight of 66 kDa. Lectin is a tetrameric two-chain compound formed by linking heavy α chain and light β chains of 133 and 21 amino acids, respectively (Esch *et al.,* 2017). It will stick to specific carbohydrates and potentially lower the glycemic index. According to recent research, lectin can directly interact with human lymphocytes in many ways and succeeds in protecting CD_4 cells against human immunodeficiency virus. Although, there is currently no vaccine to prevent HIV, this research article suggests potential benefits for therapy in the future (Prashant *et al*., 2021, 13). Recent research developments have revealed that using jacalin as a drug-delivery molecule targeting carcinogenic cells could be beneficial as jacalin can bind to the Thomsen-Friedenreich antigen found in most of expressed human cancerous cells. And biomolecular interaction of jacalin and curcumin a functional compound present in turmeric show, the cytotoxic effect towards MDA-MB-231 cells, a positive cell line of breast cancer (Petrova *et al*., 2023). Extraction and purification are always an area of research where different techniques are practiced

to enhance efficiency and reduce costs. Traditionally, it was done through expensive and tedious chromatographic techniques; however, work was reported where it has been demonstrated that an AOT-based reverse micellar system can be used for the extraction of jacalin from crude jackfruit seed extract with optimized conditions, forward extraction efficiency was 88.04 ± 1.30 per cent (Mohamad *et al.,* 2020). Besides that, the immunomodulatory response of jackfruit-derived jacalin-containing oligopeptides increases cell-mediated and humoral immunity, macrophage phagocytic activity, and natural killer (NK) cell activity. This includes elevated percentages of T and Th cells, changes in serum cytokine and immunoglobulin levels (Banerjee *et al.,* 2024).

2.4 Volatile compounds

Jackfruit has a wide array of volatile compounds known for its unique odor and flavor. Several volatile compounds have been determined by different extraction and analytical techniques. These include prominent groups such as limonene, pentyl 3-methyl butanoate, 1-butanol, butyl 3-methyl butanoate, butanal, and β-cyclocitral, which occur at relatively high levels (16). The aroma of ripe jackfruit is a complex mixture of sweet, fruity, malty and cheesy notes. Researchers identified 19 major volatile compounds in jackfruit, which are mainly esters and alcohols. The studies were carried out in Malaysia, Brazil, Thailand, and Mexico, which indicate global interest in understanding the volatile profile of jackfruit. They exist in both free and glycosidically bound forms, where the bound fraction is eight times higher than the free fraction indicating the significance of precursors of aroma in the case of jackfruit (Katherinatama *et al.,* 2024). A study performed by Spada *et al.* (2017) demonstrated that sensory properties of jackfruit seeds, showing that such seeds, once fermented and roasted in a manner similar to that used for cocoa beans, yield a specific smell of chocolate. This conversion is due to the synthesis of pyrazines, odor-active volatiles, whose formation depends on amino acids composition and bioavailability of sugars during fermentation. Pyrazines are the main odor-active compounds in flours of roasted jackfruit seeds as well as in cocoa beans and cocoa powder. Further studies on jackfruit volatiles may lead to a better flavor development in food products as well as to a possible substitute for the aroma of chocolate.

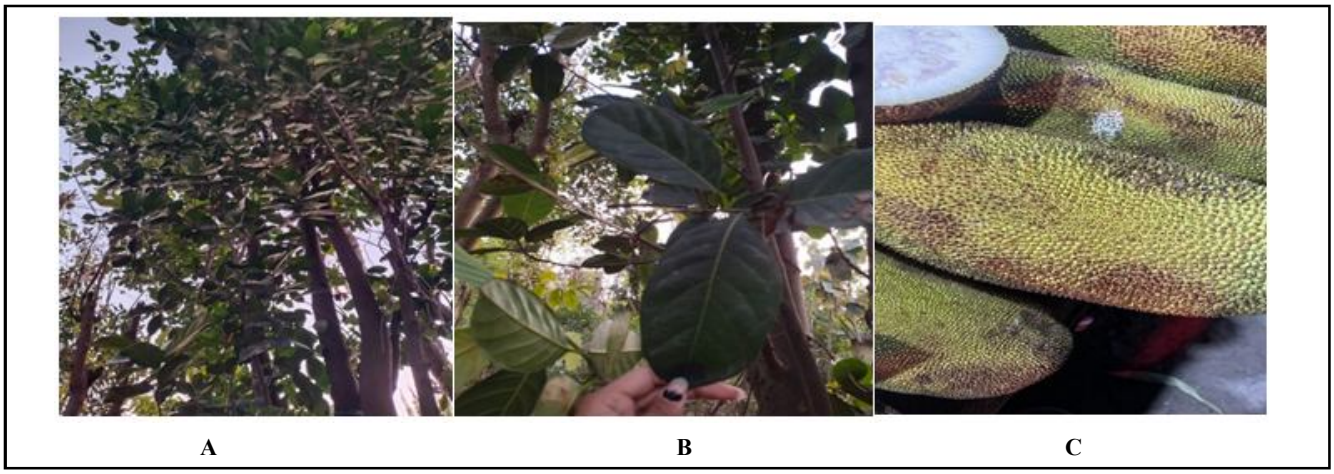

Figure 1: (A) Jackfruit tree, (B) Leaves, and (C) Jackfruit bulbs.

3. Pharmacological uses of jackfruit

Jackfruit is a rich source of several high-value compounds with potentially beneficial physiological effects such as phytonutrients including isoflavones, lignans, and isoflavones, and is known for its antiulcer, antihypertensive, and antiaging effects. An increased ratio of LDL to HDL in the blood is one of the major risk factors for the development of coronary artery disease and the oxidation of LDL associated with atherosclerosis and inflammatory-oxidative changes occur within the arterial wall. Free radicals accumulation causes tissue injuries. Antioxidants are compounds that can delay or prevent oxidation processes. They protect the body and biomolecules from damage caused by excess free radical production. Jackfruit contains many carotenoids and other phytonutrients, that can act as an antioxidant to mitigate this oxidative stress. Jackfruit is also beneficial in lowering blood pressure and improving heart health due to its high potassium content. While vitamin B_6 reduces homocysteine levels, which further reduces the risk of heart disease, it plays an important role in skin health by protecting and promoting collagen production. Studies indicate the potential for chemoprotection with jackfruit's high dietary fiber content helps in aiding digestion and promotes good intestinal health. It also contains essential minerals such as magnesium, iron, and copper, which support bone health along with the prevention of anemia and thyroid. The seeds and pulp of the jackfruit are a cooling tonic, and it has been found that the wood of jackfruit can inhibit the biosynthesis of melanin because of the presence of prenylated, flavones-based polyphenols. Additionally, an example of antifungal properties is jacalin, a lectin that can inhibit the growth of fungi such as *Fusarium moniliforme*. Studies have also demonstrated that jackfruit leaf extract has been shown to increase glucose tolerance with various parts of the plant having antibacterial and necrotizing properties. Use of jackfruit seeds promotes tooth remineralization, counteracts the effects of demineralization and improve overall teeth health. It can be a natural and effective alternative approach to improve teeth health. Demonstrated that when jackfruit latex extract, which has a high flavonoid and alkaloid content, was evaluated for its antibacterial and antifungal effects, it performed very well and had an important relationship with popular antibacterial and antifungal drugs. Studies concluded that this data

offers jackfruit latex and resin, or both, several significant applications. It can be used as a low-cost cementing medium, a denture cleaning solution, an irrigation solution (a stream of fluid that is used for cleaning a wound or cavity in the body), as well as potential dental filling materials (Rao *et al.,* 2021).

3.1 Anticancer

Cancer is a group of illnesses that show abnormal cell growth and spread in the body. If treatment is not received, it might have serious physiological implications (Sharma and Muhammad, 2023). Cancer is a group of disease in which cells abnormally divide and invades surrounding tissues, leading to development of malignant tumor (Brown *et al*., 2023). Colon cancer, one of the other cancers also referred to as colorectal cancer occurs in the rectum or colon in the large intestine. Symptoms include bowel movements and blood in faeces, diarrhea, and constipation. Studies done earlier have reported jackfruit as a potential anticancer activity demonstrating functional food. Additionally, the seeds of jackfruit are reported to have the strongest anticancer properties. The phytonutrients available in jackfruit such as isoflavones, saponins, and lignans add to its anticancer properties (Gupta *et al*., 2023). Other compounds such as jacalin, artocarpin and artinM alsodecrease the risk of cancer development. Previous researches indicate the role of jacalin, a dietary lectin in inhibiting the cell proliferation in certain cancers such as non-small lung carcinoma cells (H1299), breast cancer cells (MCF7), and colorectal adenocarcinoma cells (HCT-15). This effect is due to jacalin's capability to recognize antigen and suppress the proliferation of human colon cancer cells (Razak *et al*., 2022). Study performed by Ghosh *et al*. (2023) reported jacalin in inhibiting proliferation of MDA-MB-468 cell proliferation and observed cellular recovery after the removal of lectin. Another study performed by Petrova *et al*. (2024) explores the potential of jacalin interaction with for the treatment of prostate cancer cell line PC3. Another compound found in jackfruit is namely artinM. It is reported that artinM has been proven to inhibit the growth of cancer cells and induces apoptosis through autophagy-associated pathways. Furthermore, Morrison *et al*. (2021) performed study on mouse to demonstrate the potential anticancer effects of artocarpin. Oral administration of *A. heterophyllus* extract was done in mouse which induced colon tumorigenesis, minimized tumor formation and decreased expression of protumorigenic and proinflammatory genes which resulted in inhibited synthesis of proinflammatory cytokines IL-1β and TNF-α for the treatment of colitis-associated tumorigenesis. Another study performed by Nik Mat Daud *et al*. (2023) explored the effects of artocarpin in the inhibition of cancer stem cells by modulating the β-Catenin signalling pathway. The results confirm artocarpin as a potential therapeutic agent for the inhibition of stem cells regeneration in lung cancer mediated through the WNT/β-Catenin signalling pathway by inhibiting TCF-4/β-Catenin complex formation.

3.2 Antidiabetes

One of the most prevalent chronic illnesses is diabetes (Sury and Rishabh, 2022). Diabetes is a collection of conditions that cause high blood sugar levels that, if left untreated, can cause problems (Divya *et al*., 2023). Many people around the world suffer from diabetes. Diabetes is a state of the body where the pancreas cannot produce enough insulin for the carbohydrates consumed through food. Studies previously proved jackfruit plays an important role in reversing diabetes by bringing down HbA 1e (glycosylated haemoglobin), and fasting blood glucose levels. With its vitamin A, vitamin C, potassium, calcium, and iron content, jackfruit is considered an important antidiabetic functional food (Rao *et al.,* 2021). Rutin, a citrus flavonoid glycosidevis significantly present in jackfruitis reported to have benefits, such as powerful antioxidants, radical scavenging effects, antidiabetic effects, and anti-inflammatory effects. This antioxidative effect of rutin is important in preventing diabetes mellitus. Multiple studies have demonstrated that rutin suppresses enzymes which stimulates the degradation of carbohydrates, α-glucosidases, and α-amylase. Inhibition of these enzymes prevents the small intestine from absorbing glucose molecules and therefore preventing sharp increase in blood glucose levels (Maradesha *et al*., 2022; Sok Yen *et al*., 2021). Study performed by Manurung *et al*. (2023) on wistar albino rats reported reduction in blood sugar levels. Another research performed by Rao *et al*. (2021) explored the effects of green jackfruit flour as an alternate to traditional flour in diets of patients suffering from type 2 diabetes. The results showed a significant reduction in HbA1c levels, fasting blood glucose (FPG), and postprandial glucose (PPG) after 12 weeks of treatment. The research confirms the anti-diabetic potential of jackfruit. Study performed by Fernando *et al*. (1991), observed that the hot water extract of jackfruit leaves substantially improved glucose tolerance in both the heaalthy individuals and diabetic patients when investigated at oral doses equivalent to 20 g/kg.

3.3 Improved bone health

Jackfruit is a great source of numerous vitamins and minerals such as vitamin A, vitamin C, potassium, magnesium, calcium. Jackfruit is significantly high in magnesium, around 0.07-0.09 milligrams per serving which is important for improving bone health as it enhances the absorption of calcium (Tripathi *et al*., 2023). Moreover, vitamin B_6, sodium, potassium present in jackfruit proved to have muscle and nerve function improving effects (Hussain *et al*., 2020; Ranasinghe *et al.,* 2019). Additionally, flavonoids present in jackfruit demonstrated IC_{50} values ranging from 1.4 to 93.9 iM, and plays a crucial role in osteoclast mediated bone resorption and inhibits the activity of protein cathepsin-K (Singh *et al*., 2022; Kumar *et al*., 2022).

3.4 Antiulcer

Ulcer disease is a break or sore in the inner lining of the stomach and parts of small intestine which affects the overall wellbeing of an individual. Studies performed proved that flavonoids present in jackfruit are reported to have antiulcer activity. Different parts of fruits are reported to have different activity, whereas ripe fruit have the ability to treat or prevent ulcers (Bhattacharjee, 2006). Prakash *et al*. (2015) performed study on Indomethacin-induced ulcer model in albino rats to investigate the antiulcer effects of jackfruit. The results observed were reduction in gastric acidity, increased pH. These results might be attributed to flavonoids and phytochemicals present in leaves extract which enhance mucosal defense and hence confirms jackfruit to have potential antiulcer activity.

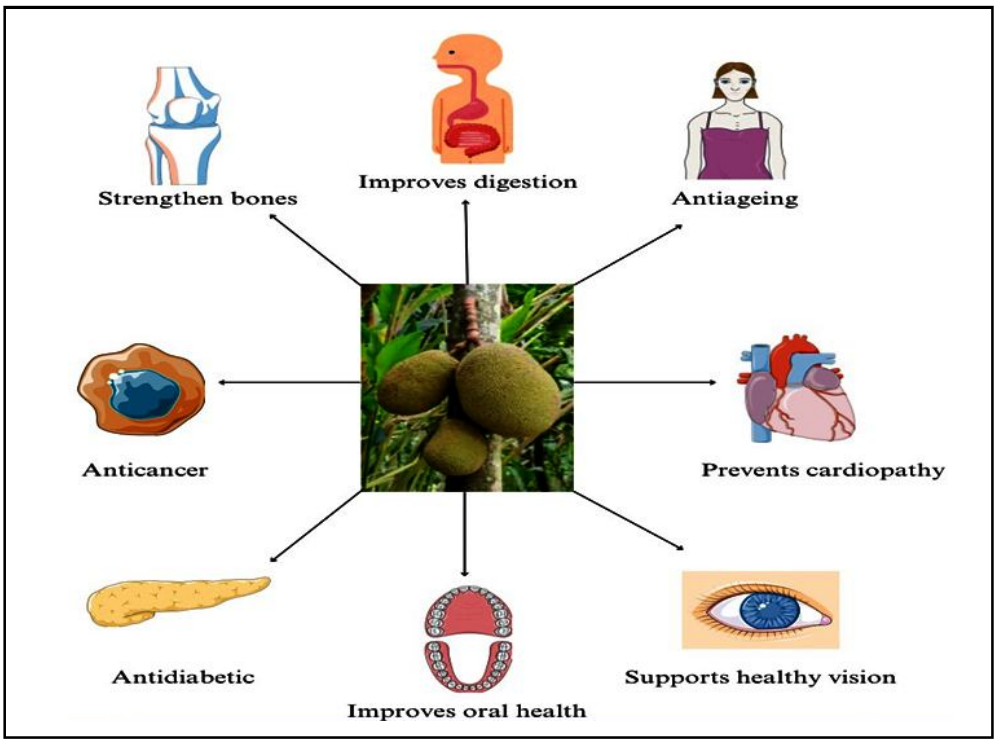

Figure 2: Health benefits from jackfruit.

3.5 Cardiovasculardiseases

Raw jackfruit is an excellent source of this important mineral nutrient known as potassium. Potassium balances fluids with sodium inside the cells for proper muscles and heart contraction. Atherosclerosis and coronary heart disease have long been linked to elevated blood cholesterol levels (Jyoti *et al*., 2023). By lowering blood pressure, the potassium present in jackfruit helps prevent heart disease and stroke. Additionally, jackfruit's fiber content can help decrease cholesterol. Potassium is necessary for sustaining and coordinating muscular activity, including that of the heart muscles. About 10% of our daily potassium needs are met by the good potassium content of jackfruit. Maintaining fluid equilibrium, or electrolyte balance, requires the optimal potassium level. Potassium regulates muscular contraction, sodium regulation, and electrolyte balance. Because of all these functions, potassium is a particularly beneficial diet for lowering blood pressure and preserving heart health (Ranasinghe *et al*., 2019). Study performed by Hathcock *et al*. (1997) focuses on a 55-year-old male with a medical history of hypertension and coronary artery disease (CAD). The patient, a vegetarian, expressed interest in incorporating more variety into his diet, including tropical fruits like jackfruit, due to its high nutrient content and potential cardiovascular benefits. Consumption of around 1 cup jackfruit (150-200 g) per serving was done by patient in his breakfast routine three to four times weekly. After three months of regular jackfruit intake, the patient's blood pressure decreased to an average of 138/85 mmHg, and LDL cholesterol showed mild reduction of around 5-7 per cent, possibly due to the dietary fiber and potassium in jackfruit, which support vascular health. Blood markers for inflammation, such as C-reactive protein (CRP), showed a slight decline, which could be attributed to the antioxidants in jackfruit. Reduced inflammation is beneficial for heart patients, as it helps mitigate the risk of further arterial damage. This case suggests that incorporating jackfruit into the diet of a heart patient, when done in moderation, may support cardiovascular health by improving blood pressure and cholesterol levels, possibly due to its fiber, potassium, and antioxidant profile. However, there are considerations to keep in mind. All these roles make potassium a very healthy food for arresting high blood pressure and maintaining health.

3.6 Improved eyesight

Jackfruit's high nutritional content have a number of advantages for eye health. For instance, jackfruit contains vitamin A, which is essential for preserving retinal health and avoiding night blindness, which can result from a lack of vitamin A (Sommer, 2008). Jackfruit also includes antioxidants called lutein and zeaxanthin, which are known to shield the eyes from blue light and oxidative stress. One of the main causes of vision loss, age-related macular degeneration (AMD) that can be prevented with the help of these substances (Ma and Lin, 2010). Vitamin C in jackfruit has been linked to reduced cataract formation by decreasing oxidative damage to the eye lens. This effect is especially relevant for patients at risk of age-related cataracts (Taylor *et al*., 1995). Vitamin C also supports collagen synthesis, which is essential for maintaining the structure of the cornea and blood vessels in the eye, contributing to eye health (Nusrianto *et al*., 2019). Jackfruit's composition also includes beta-carotene, which contributes to retinal health by providing antioxidant protection against oxidative stress (Swami *et al*., 2012). Beta-carotene, a precursor of vitamin A, can be especially helpful in supporting visual acuity and may help slow the progression of retinal disorders by enhancing macular health (Bernstein *et al*., 2001). Ma and Lin, (2010) performed study on a 62-year-old woman with

early-stage age-related macular degeneration (AMD) and mild cataracts was advised to incorporate foods rich in antioxidants and essential nutrients for eye health into her diet. She began adding jackfruit to her diet three times a week to explore potential benefits for her vision. With her current medications such as standard multivitamin with an additional eye-health supplement containing lutein and zeaxanthin. After six months, her vision was stable, with some improvement in night vision reported. This may be attributed to the vitamin A and beta-carotene in jackfruit, which support low-light vision and retinal health. The patient's macular pigment density, a protective factor against AMD, remained stable. Lutein and zeaxanthin, found naturally in jackfruit and supplemented, can help filter harmful blue light and support retinal health, potentially contributing to this stabilization. Jackfruit plays avital role in overall eye health.

3.7 Antiageing

Jackfruit contains antioxidants such as vitamin C, flavonoids, and carotenoids that combat free radicals, which can cause oxidative stress leading to premature ageing. These antioxidants help protect skin cells from damage and reduce signs of aging like wrinkles and fine lines (Swami *et al*., 2012). Vitamin C, abundant in jackfruit, aids in collagen production, which maintains skin firmness and elasticity, two key factors in youthful-looking skin (Nusrianto *et al*., 2019). Jackfruit's antioxidants, particularly carotenoids, may offer some protection against UV damage, which is a leading cause of premature ageing. While not a replacement for sunscreen, the antioxidants in jackfruit can help protect skin cells from UV-induced oxidative stress (Ma and Lin, 2010).

3.8 Digestive health

Jackfruit is rich in dietary fiber, which has been shown to promote regular bowel movements and relieve constipation by adding bulk to the stool (Barrett *et al*., 2016). Dietary fiber intake is critical in managing constipation and ensuring smooth digestive function (Chua *et al*., 2017). Jackfruit aids healthy digestion and an effective excretion which keeps the gastrointestinal tract clean and healthy. This fiber is actually converted to important and significant amount of roughage. Dietary fiber makes laxative which adds bulk to stools and softens them. Both of these factors make it easy for the body to push them through during defecation, thus improving digestion and preventing constipation. Jackfruit contains prebiotics that nourish beneficial gut bacteria, promoting a healthier microbiome. A balanced gut flora contributes to reduced bloating and improved digestive comfort, as shown in studies on prebiotic-rich tropical fruits (Smith *et al*., 2021). Ripe jackfruit provides digestive enzymes like amylase and protease, which assist in breaking down carbohydrates and proteins, making digestion easier (Mukherjee *et al*., 2019). These enzymes aid in the efficient digestion of food and may reduce the burden on the stomach and intestines (Johnson *et al*., 2019). Jackfruit's fiber and enzyme content have been linked to a reduction in bloating among people with mild digestive discomfort (Brown and Lee, 2018). This effect is attributed to improved bowel regularity and a more balanced gut microbiome (Smith *et al*., 2021). The antioxidants in jackfruit, like vitamins A and C, help reduce inflammation in the digestive tract, potentially preventing or easing symptoms of digestive discomfort (Barrett *et al*., 2016).

This study explores the effects of incorporating jackfruit into the diet of individuals suffering from mild digestive issues such as constipation, bloating, and irregular bowel movements. The study assesses the impact of jackfruit on digestion, using a group of participants with similar digestive complaints over a four-week period. 20 adults aged 25-55 experiencing mild to moderate digestive issues. Common symptoms include constipation, bloating, and irregular bowel movements. Participants were asked to consume a portion of ripe jackfruit (about 100-150 g) 3-4 times a week. The portion size was chosen to avoid potential digestive discomfort from excessive fiber intake, 75 per cent of participants reported increased stool frequency and softer stools and 60 per cent reported improvements in regularity by the second week. Digestive enzymes such as amylase and protease in jackfruit aid in carbohydrate and protein digestion, making it easier for participants to process other foods (Mukherjee *et al*., 2019; Chua *et al*., 2017).

4. Utilization of different parts of jackfruit and its byproducts

Jackfruit is extremely versatile both people and animals benefit from every aspect of its tree and fruits. Fruits are not only edible, but they also produce wood for furniture. Jackfruit pulp can be processed in diverse ways, including juice, cookies, pickles, sauces, jellies, and ice cream. The green fruit's roots and seeds are commonly used in cooking, while the leaves are excellent fodder and contain a significant amount of nutrients. The wood is used for household furniture, and there are ways to use leftover jackfruit and wood byproducts to make biogas, briquettes, and charcoal that farmers may use in their fields. The use of jackfruit bulbs in the culinary sector raises the standard of the meal. The popularity of bakery items is rising since they are affordable, easily accessible, come in a variety of tastes and textures, and have a high nutritional content. The multipurpose jackfruit plant yields industrial, medical, food, fuel, and fodder products. Jackfruits consist of hard-shelled brown seeds encased in yellow berries. The berries are edible, and the seeds and peels of the jackfruit are categorized as feedstocks for slow pyrolysis. They concluded that jackfruit seeds and peels may be used to make charcoal. It was discovered that the biochar made from activated jackfruit peel was particularly good at removing heavy metals from aqueous solutions. This study demonstrated that jackfruit peel was a practical and affordable way to remove heavy metals from aqueous solutions, including Cd, Pb, Cu, Fe, and Mn. Functional groups in the biochar allowed metal ion binding. Peel and seeds were used to create biochar, which were used to remove copper metal ions from water (Abid *et al*., 2019). Snacks are typically consumed in between meals as it offers a substantial energy savings in comparison to a typical meal. Processed foods have longer shelf-lives and are easy to use. The food-processing sector is becoming more and more focused on developing innovative items that are easy to make and liked by consumers. Typical snacks and other dishes such as cereal bars, jamun, chapati, chocolate shake that have been enhanced with jackfruit seed flour. The cereal bars having 30 per cent and 40 per cent jackfruit seed meal were similar to other bars sold in stores in terms of their dietary advantages, improved sensory features, and high levels of fiber (Samakradhamrongthai *et al*., 2021).

4.1 Jackfruit peel

Peels are the non-edible part of the fruit that is rich in carbohydrates (24%), fiber (17.3%), and protein (8.7%). It is often used as fertilizer or could be used as feedstock for cattle because of its enriched nutrients. The exposure of peels to stresses such assunlight, UV rays, and weather conditions induces a higher concentration of polyphenols making it as agood source of antioxidants for the body, which prevents damage from oxidative stress.The peel is a valuable source of pectin. Its dry matter content ranges from 8.94 per cent to 15.14 per cent. Pectin is important in the food sector and is used as an emulsifier, binder, and stabilizer in medicines and cosmetics. Supports immune function and helps reduce cancer. blood sugar Stomach ulcer and bad cholesterol in pharmaceutical formulations Pectin serves as a binder for tablet formulations and as a delivery vehicle for encapsulated drugs (Yamin *et al.,*2021). Using jackfruit for active packaging by creating bilayer films by mixing peels with fish gelatin forming solution. Likewise employing solid fermentation of peels with *S.cerevisiae* produces an animal feed protein supplement. In other sectors such as converting peel waste into biofuels can be eco-friendly and be an alternative to diesel in VCR engines with less emission of hydrocarbons. Jackfruit bark extract was used to synthesize iron nanoparticles (FeNps) with good catalytic ability and dye removal efficiency. Activated charcoal obtained from jackfruit bark has shown the ability to absorb lead (Brahma and Ray, 2022).The peel, rind, or skin of jackfruit refers to its outer layer of protection. The outer layer of the ripe jackfruit is approximately half its size (Santos *et al*., 2011). The ecology is severely harmed when the peel is disposed of improperly. On the other hand, products derived can alleviate constipation and increase economic worth when used properly. Additionally, resistant starch found in jackfruit seeds supports both intestinal health and blood sugar management. Rich in the B vitamins thiamine and riboflavin, it supports healthy skin, eyes, and hair as well as the process of converting food into energy. Additionally, an antioxidant, riboflavin aids in shielding cells from the harm caused by free radicals. The production of red blood cells, strong bones, and immunological function all depend on minerals including zinc, iron, calcium, copper, potassium, and magnesium. The body needs potassium to the development of powerful bones, correspondingly. The human body needs magnesium to control blood sugar and potassium to maintain healthy blood pressure. levels under control. Consuming jackfruit seeds exposes one to a variety of phytochemicals, which are plant-based compounds that may have antioxidant properties. Among these are polyphenols. Flavonoids, which may lower the risk of blood clots, and saponins, which may have some anticancer qualities, are additional chemicals present in jackfruit seeds (Maurya, 2016).

4.2 Jackfruit seeds

Seeds contain excessive amounts of free radicals that disrupt biomolecules and are important to increase cytoprotective effects. Studies have shown that it is rich in antioxidants such as polyphenols, and carotenoids. Anthocyanins act as excellent scavengers to lower oxidative stress and cell damage. The seeds also contain lignans, isoflavones, and saponins (Butool and Butool, 2022). Along with this it is incorporated in different food products such as biscuits, cakes, breads, jam, jelly, noodles, *etc*. Foods developed incorporating jackfruit seed flour are reported to have increased level of protein, and decreased fat content (Arpit and John, 2015).

4.3 Jackfruit wood

Over the whole Indian subcontinent, jackfruit trees constitute a significant supply of lumber. The wood has a mahogany-like appearance and is easily seasoned. It takes polish quite well, and the right equipment may provide a smooth surface. As the wood ages, it often turns from yellow to orange to a rich crimson color. It falls into the medium hardwood category. The timber has a very high natural resistance to germs, fungi, and termites (Soyza, 1973). In several Asian countries, jackfruit timber is in high demand; India is the country that exports the timber to Europe, second only to teak. Wood from trees that are four to seven years old is frequently used for building houses, furniture, and other wooden goods including musical instruments, doors, masts, and seats. The wood is prized in Indonesia for use in the palaces of chieftains, and in Indochina, it is frequently utilized in the construction of temples. Smallholders in Sri Lanka consider the jackfruit tree's many purposes when choosing which plants to put in their backyard gardens. Although, many jackfruit trees are utilized on farms without a permit, the jackfruit tree is classified as a unique economic categoryin that nation, and it is officially required to obtain one in order to move or cut 24 jackfruit trees. In the local market, jackfruit wood is fairly priced, selling for around the same as mahogany but less than teak (Taraie*t al*., 2017).

5. Industrial applications

Utilizing jackfruit seeds as an adsorbent to counteract malachite green, a dye that is frequently employed in the textile sector because of its frequent uses. The results of their investigation showed that the dye could be adsorbed by seeds without causing a pH change or being impacted by changes in temperature or salt. This approach was also demonstrated to be an affordable solution because seeds could be repurposed by utilizing base and water (Nsubuga *et al.,*2021). Jackfruit peels and seed varieties have been reported as materials for anaerobic breakdown and slow pyrolysis. They discovered that the peels and seeds of jackfruit can be categorized as possible feedstocks for slow pyrolysis. Seeds and peels in a gradual pyrolysis process. They concluded that jackfruit seeds and peels could produce charcoal. Environmental pollutants can be effectively removed using biological techniques in recent remediation approaches (Bala *et al*.,2022). The results showed that jackfruit waste biomass might be used to create an affordable adsorbent material (Jayarajan *et al.,* 2011). A cheap and effective adsorbent for eliminating methylene blue from aqueous solutions is jackfruit peels. The textile sector is required to remove harmful dyes from their discharged water using an acceptable treatment procedure. While physicochemical methods are widely employed in wastewater treatment, their efficacy in eliminating some dyes is limited (Al-Tohamy *et al.,* 2022).

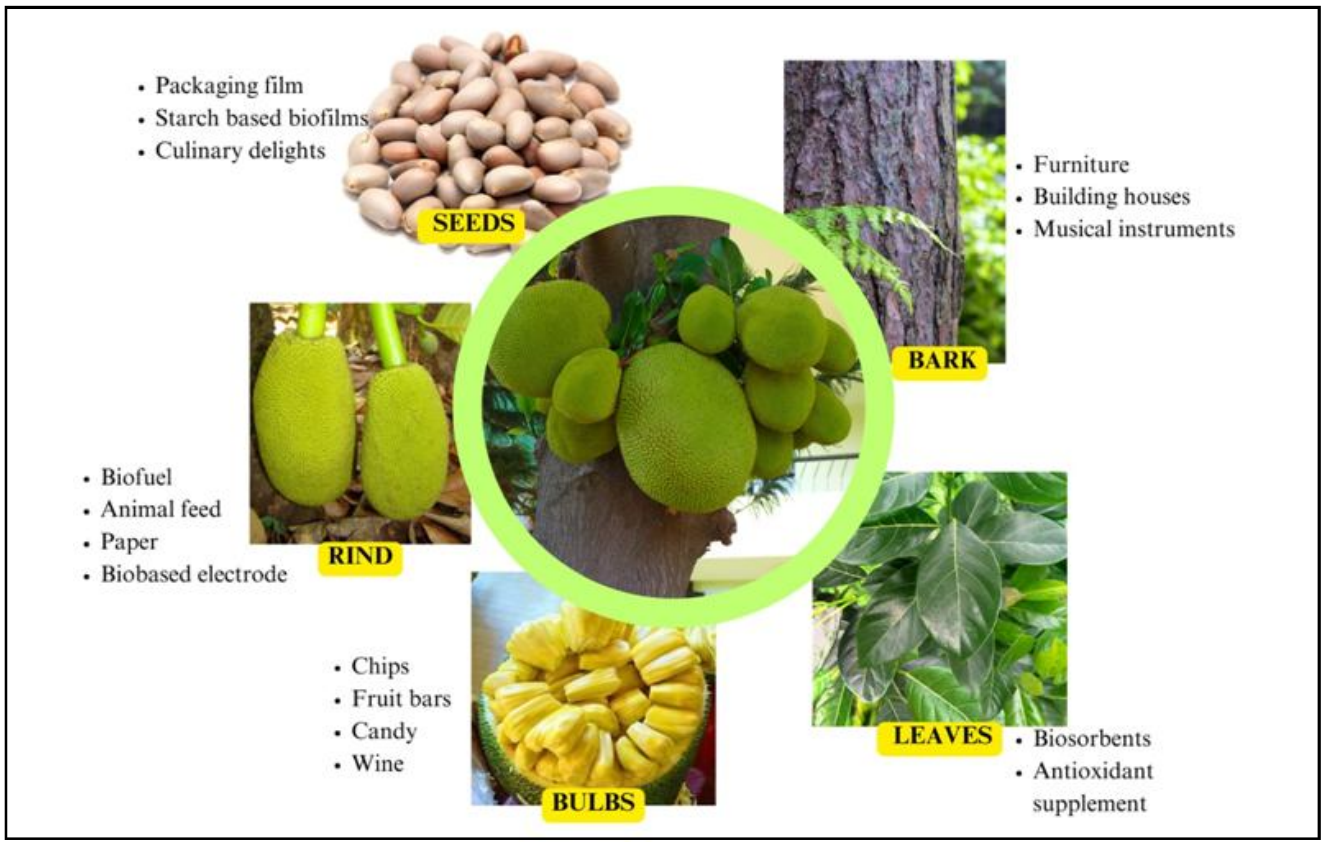

Figure 3: Utilization of different parts of the jackfruit.

6. Utilization of jackfruit waste

Approximately 35 crore jack sulphuric acid and sodium hexametaphosphate are reportedly wasted annually by the Kerala State in an attempt to determine whether they may be used as a substitute resource for economically valuable pectin fruits. Sodium hexametaphosphate. Out of all the solvents used, extraction produced the greatest yield. Still, it has the lowest solubility and high ash content (Begum *et al.,* 2014). Pectin was isolated from jackfruit wastes with the help of a microwave at power levels of 450, 600, and 800 W. Using a water-based extraction procedure, the usual isolation extraction duration was followed. The two methods that yield the most pectin are microwave isolation (17.63%) and conventional isolation (14.59%). Microwave isolation is better than traditional isolation at separating the pectin quality from jackfruit residues (Noranizan, 2014). Pectin, yielding 10.33 per cent for mangos and 7.33 per centfor jackfruit waste. In numerous food manufacturers, pectin extracted from the peels of *Magnifera indica* and Artocarpus heterophyllus is primarily used as a gelling agent and stabilizer. Methoxyl, anhydrouronic acid, and esterification degree assays, both qualitative and quantitative, were conducted on powdered pectin.It was discovered that the peels of mangos and jackfruits were good sources of typical isolation (Lokhande *et al.,* 2016).

7. Conclusion

Jackfruit (*A. heterophyllus)* is abundant in compounds with beneficial health benefits and numerous applications in industry. Studies have revealed its anticancer, antidiabetic, antioxidant and anti-inflammatory effects. The fruit is high in phytonutrients that serves as antioxidants prevents formation of free radicals which is responsible for oxidative stress and proinflammatory responses. Functional components present in seeds, rind, and leaves has the potential to reduce high blood sugar, stroke, bone loss and reduce risk of cardiovascular diseases. Jacalin a group of lectins present in the fruit is known for its immune boosting effects. Additionally, the adaptability of jackfruit being utilized both in ripe and unripe form was tremendous such as jellies, candy, bread, jams, *etc.* Not only in the field of food industry but its versatility is remarkable in creating dyes and biofuels further promoting its value. It is used as a super tonic for individuals suffering from diarrhea, fever indicating its therapeutical potential. Scientist are finding ways for further exploration of integrating jackfruit into various domains including fortification induced food products, nutraceuticals and other ecofriendly dyes. Jackfruit hold a promising future both contributing to human health and sustainability.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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