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Review

Jackfruit (*Artocarpus heterophyllus* Lam.): nutritional profile, polysaccharide analysis, and opportunities for product development

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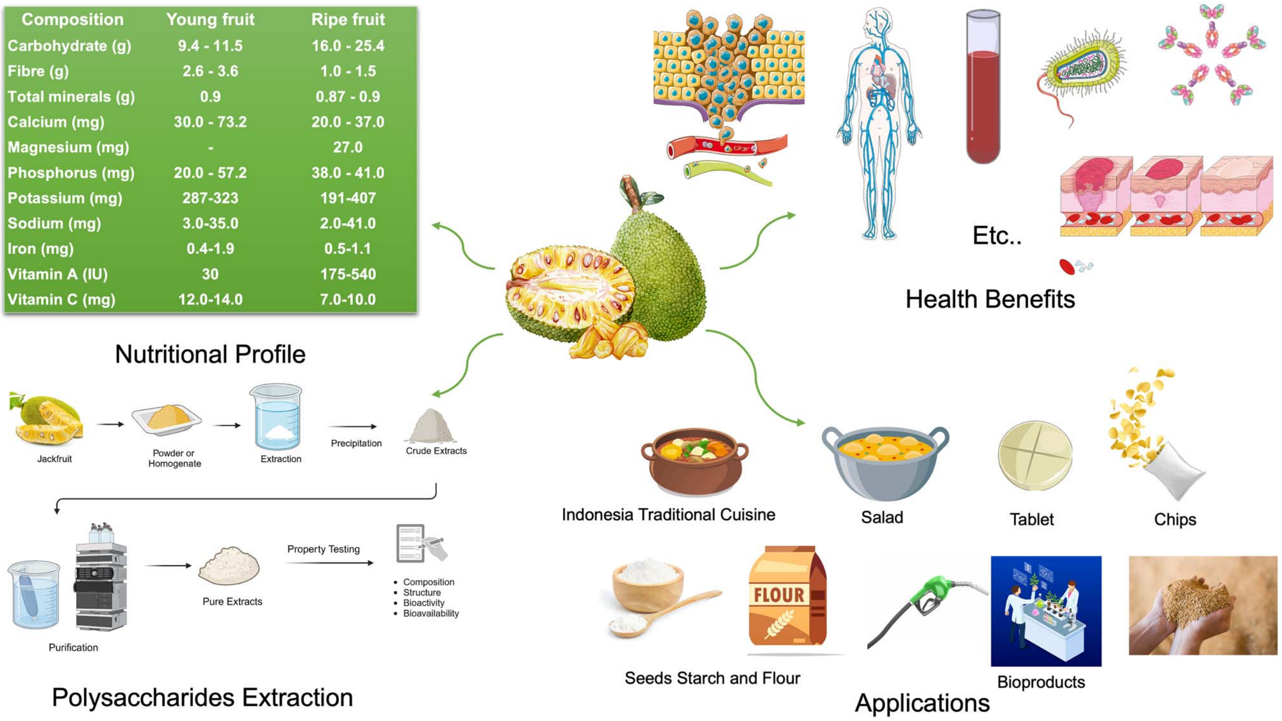
Abstract

Jackfruit (*Artocarpus heterophyllus* Lam.) has been drawing lots of attention recently due to its abundant bioactive compounds, health-promoting benefits, and wide application in the food and nonfood industry. This comprehensive review explores the nutritional profile of jackfruit, emphasising the polysaccharides, macro- and micronutrients, and bioactive phytochemicals. The health benefits of phytochemicals have been examined, including anti-inflammatory, antidiabetic, antioxidant, anticancer, antiobesity, immune effects, antimicrobial, antiviral, and wound healing. This review also extends the content of jackfruit polysaccharides extraction, bioactivity, along their research limitation. For application, this review discussed the traditional use and current product development tendency, especially in the food and nonfood industry. Due to its unique texture, jackfruit takes a place in meat analogue, which has been demonstrated in this review as well. Finally, commercial potential and challenges in jackfruit and related product development have been discussed and future research direction and market opportunities have been provided.

Keywords: jackfruit, polysaccharides, bioactivity, phytochemicals profile, product development

Graphical abstract



Composition	Young fruit	Ripe fruit
Carbohydrate (g)	9.4 - 11.5	16.0 - 25.4
Fibre (g)	2.6 - 3.6	1.0 - 1.5
Total minerals (g)	0.9	0.87 - 0.9
Calcium (mg)	30.0 - 73.2	20.0 - 37.0
Magnesium (mg)	-	27.0
Phosphorus (mg)	20.0 - 57.2	38.0 - 41.0
Potassium (mg)	287-323	191-407
Sodium (mg)	3.0-35.0	2.0-41.0
Iron (mg)	0.4-1.9	0.5-1.1
Vitamin A (IU)	30	175-540
Vitamin C (mg)	12.0-14.0	7.0-10.0

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Introduction

Jackfruit (*Artocarpus heterophyllus* Lam.) is a tropical fruit that belongs to the *Moraceae* family. It is originally from India and Malaysia, while it is widely worldwide, grown in Southeast Asia and other tropical areas including Thailand, India, Bangladesh, Australia, USA (Florida), Latin America, and the Caribbean (Jagadeesh et al., 2007; Sidhu, 2012).

Nutritionally, jackfruit is rich in carbohydrates, dietary fibre, and proteins. It contains a great amount of vitamins and minerals, including vitamin A, vitamin group B, vitamin C, calcium, iron, magnesium, potassium, and sodium (Srivastava & Singh, 2020), and other vital components compared to other common fruits (e.g., bananas, mangos, and pineapples) (Prem et al., 2015). From a phytochemical perspective, jackfruit possesses a valuable profile of bioactive compounds including polyphenols (flavonoids, tannins, phenolic acids), volatile acids, amino acids, carotenoids, and minerals. Those compounds contribute to its pharmaceutical properties, including but not limited to antioxidant, anti-inflammatory, and antimicrobial (Gupta et al., 2023). Notably, those profiles of jackfruit are significantly variable across different maturity stages. This variability has sparked growing interest among researchers to investigate the optimal harvest time for specific end-use purposes (Tiwari & Vidyarthi, 2015).

In addition to its nutritional value, jackfruit has been noted for its therapeutic potential. It has been shown to obtain antimicrobial properties against various bacteria and foodborne pathogens and antiviral properties against HIV (Human Immunodeficiency Virus) (Fu et al., 2020) and HCV (Hepatitis C Virus) (Hafid et al., 2017). Previous studies have also demonstrated its effectiveness in managing diabetes by regulating blood sugar levels and inhibiting key enzymes responsible for glucose metabolism. Related research has focused on the anticancer, obesity management, immunomodulatory (Ma et al., 2021), wound healing (Baliga et al., 2011; Gupta & Tandon, 2004), and antioxidant potential of jackfruit and its various fractions. Furthermore, jackfruit exhibited significant versatility in both processed and nonprocessed forms. Its fibrous and meaty texture makes it a popular plant-based meat substitute (Hamid et al., 2020) in culinary dishes such as curries, sandwiches, and tacos. Its neutral flavour allows a wide range of use in culinary. In addition, jackfruit concentrate has great potential to contribute to sensory qualities and nutritional benefits for the food industry (Ahiduzzaman et al., 2024). India is the largest producer of jackfruit with an area of 102 khm^2 and a production of 1,436 kilo tons (Sidhu, 2012). The following is Bangladesh, where jackfruit is cultivated in 79,000 ha of land with about 1,352,000 tons of annual fruit production (Khan et al., 2021). In addition, Malaysia, Thailand, and the Philippines are also important cultivators and producers of jackfruit. Notably, in the past 10 years, the production of jackfruit in Mexico has increased by two times with an output value of USD 3.7 million (Siap, 2015). These data indicate that the market demand for jackfruit is continuously increasing. Although jackfruit has a long growth period, there is still a need for continuous innovation and optimisation to increase yield, reduce the incidence of pests and diseases (Khan & Khan, 2020), and minimise environmental impact. Additionally, the potential threat of extreme weather events due to global climate change poses a significant risk to the cultivation and growth of jackfruit. The storage, processing, and transportation of jackfruit present significant challenges for sales. Ensuring a stable supply while maintaining the freshness and quality of the fruit is the primary issue that needs to be addressed in the commercialisation process of jackfruit. In addition, jackfruit also faces market competition issues such as how it can stand out among the many tropical fruit commercial products, such as bananas, coconuts, mangoes, and durians. This article tried to explore specific strategies to enhance jackfruit's competitiveness in the market.

This review aims to provide a comprehensive exploration of jackfruit, focusing on its nutritional and phytochemical composition, including impact of maturity stages on the composition, therapeutic potential, food applications, and commercial viability. Through systematic exploration of the current literature, this review endeavours to illuminate the diverse facets of jackfruit, from multifaceted benefits and potential to the opportunities and challenges in its utilisation and commercialisation. This review would highlight jackfruit not only as a nutritional fruit but also as a valuable commodity in the food industry.

Nutritional profile of jackfruit

Nutritionally, jackfruit is a good source of carbohydrates, dietary fibre, and proteins and a notable source of vitamins and minerals as well, including vitamin A, vitamin group B, vitamin C, calcium, iron, magnesium, potassium, and sodium (Srivastava & Singh, 2020). Comparing jackfruit to other common fruits, Prem et al. (2015) found that jackfruit has higher levels of protein, calcium, iron, vitamins, and other vital components. Phytochemically, jackfruit is rich in bioactive substances that endow jackfruit with the pharmaceutical properties, for example, antioxidant, anti-inflammatory, and antimicrobial (Gupta et al., 2023). A significant aspect of jackfruit's nutritional and phytochemical composition is its variability across different maturity stages (Tiwari & Vidyarthi, 2015).

Macronutrients

Maturity plays a key role in a jackfruit's chemical composition. For the macronutrients, young and ripe jackfruit showed different patterns. According to the summary of Ranasinghe et al. (2019), 100 g edible portion of young jackfruit contains 76.2–85.2 g water, 2.0–2.6 g protein, 0.1–0.6 g fat, 9.4–11.5 g carbohydrates, and 2.6–3.6 g fibre. That of ripe fruit is 72.0–94.0 g water, 1.2–1.9 g protein, 0.1–0.4 g fat, 16.0–25.4 g carbohydrates, 1.0–1.5 g fibre, and 20.6 g total sugars. During the maturation of jackfruit, the concentration of sugars increases, which might be because glucose is released by starch hydrolysis and glucose and fructose are released by sucrose hydrolysis (Li et al., 2017). Based on this research, acid invertase and neutral invertase might play a key role in sucrose hydrolysis during ripening. In addition to its rich nutritional profile, the particular interest is polysaccharides, which play an important role in the structure properties as well. This review would explore the analysis of polysaccharides from jackfruit in the next section.

Polysaccharides in jackfruit

Jackfruit polysaccharides are found in pulp, seeds, and some part that been seen as jackfruit waste, including peel, the core part. Unlike well-defined polysaccharides, jackfruit polysaccharides do not have a specific name, most research is based on starch, cellulose, and pectin.

Extraction methods

Polysaccharides from jackfruit can be extracted using the conventional method (Figure 1); assisted techniques would be applied to improve the yield or add functional properties. The most common are microwave and ultrasonic, while radio frequency (Naik et al., 2020), pulsed electric field (PEF) (Lal et al., 2021), and subcritical (Li

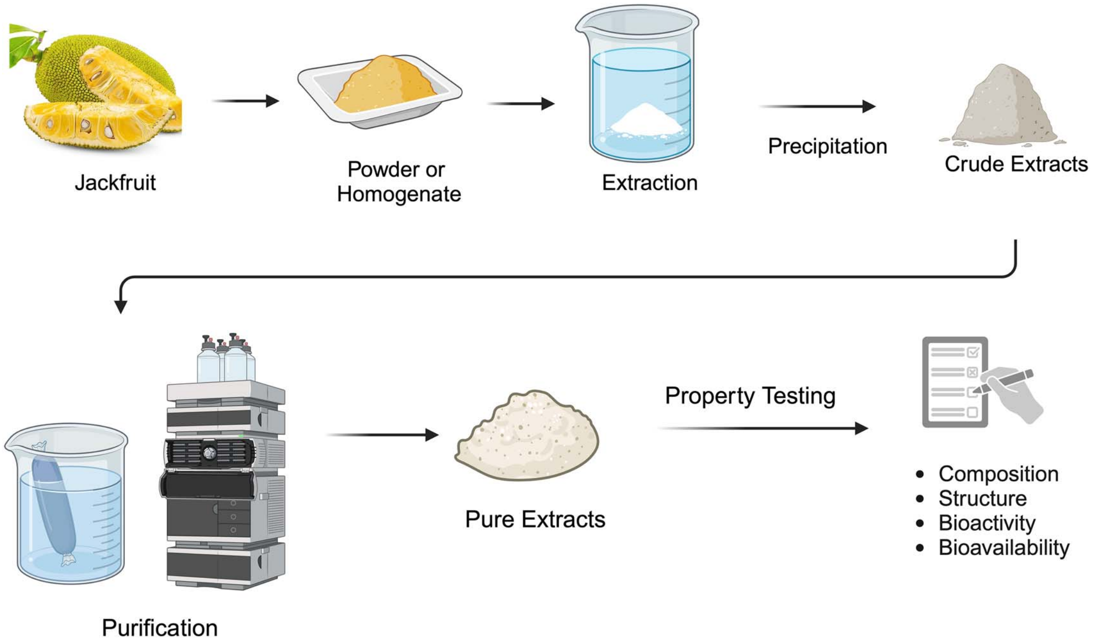

Figure 1. Conventional extraction of jackfruit polysaccharides.

et al., 2019) are added. The extraction of jackfruit polysaccharides were summarized in Table 1.

Microwave-assisted extraction could enhance the extraction efficiency. According to Thirugnanasambandham et al. (2015), the mechanism of microwave extraction for polysaccharides is as follows. One is temperature rapid increase to reduce emulsion viscosity and break the plant's outer film/organism, while other one is zeta potential, which has been neutralised by molecular rotation. However, this method would affect the physicochemical and functional properties of pectin that has been extracted (Ling et al., 2023) and the potential mechanism is unclear yet. Tran et al. (2023), using microwave-assisted extraction to extract jackfruit rags pectin, demonstrated that optimal parameters are 66 °C for 10.56 min and pectin has excellent antioxidant and antibacterial abilities. Lal et al. (2021) used pulsed electric field combined with microwave to extract the pectin of rind and the core part. The yield could reach to 29.78% with the optimised parameters.

Ultrasound-assisted extraction uses ultrasound acoustic cavitation to destroy tissue while breaking the cell and membrane of plants, which speeds up the solvent penetration ability into the plant tissue matrix to increase efficiency of plant materials, such as the cytoplasm and cell sap, into the solvent during the extraction period (Mazvimba et al., 2012). Moorthy et al. (2017) applied ultrasound to the pectin extraction of jackfruit peel. Four factors were optimised, and the optimal parameters were as follows: liquid/solid of 15:1, pH 1.6, sonication for 24 min, and extraction under 60 °C. Yield under this condition is 14.48 ± 0.11%. Another study carried out by Saurabh et al. (2023) showed that the highest pectin yield is 13.15% with 40% ultrasound power, 0.15 N oxalic acid for 10 min. Ultrasonic plus microwave-assisted extraction (UMAE) is the integration extraction of green technology; it achieves rapid, uniform, and low-temperature extraction while overcoming the drawbacks of ultrasound and microwave technology (Zhang et al., 2023). Xu et al. (2018) determined the pectin extraction efficiency of jackfruit peel by UMAE. When peel was extracted at a temperature of 86 °C and a 1:48 solid–liquid ratio for 29 min, the ultimate yield was 4.3% higher as compared to the conventional method.

Subcritical water extraction (SWE) is an efficient, green, and lower energy consumption method. During the extraction process, the condition ensures that the water remains in liquid form under high temperature and high pressure; usually, the pressure is less than 22.12 MPa and the temperature is between 100 and 374 °C (Kumar, 2020). Li et al. (2019) explored the SWE to prepare the pectin from jackfruit waste (peel) for the first time. Compared with the conventional extraction using citric acid (CTAE), pectin by SWE has a lower yield; the results are 16.83% and 14.96%, respectively. The main reason might the extraction medium; for SWE, the extraction medium is water, while that of CTAE is citric acid. In addition, pectin from SWE has more hairy regions and side chains, lower molecular weight, and lower apparent viscosity and elasticity.

Radio frequency–assisted extraction (RFAE) has numerous advantages, including but not limited to rapid heating, minimal solvent requirements, preventing burning/overheating of a sample, protecting the sample from a direct contact heating source, normal atmospheric pressure, and even heat through the sample (Jusoh et al., 2017). Previously, RFAE was applied in extracting pectin from apple pomace (Zheng et al., 2021), pomelo peel (Wang et al., 2024). Naik et al. introduced radio frequency for jackfruit pectin extraction with response surface design. The outcome is under optimal conditions, with a radio frequency time of 61.5 min, a 20.63:1 liquid–solid ratio, and a pH of 2.61; the yield is 29.05% and higher than conventional extraction (12.37%).

Bioactivity of jackfruit polysaccharides

Jackfruit polysaccharides (JFPs) have demonstrated various bioactivities that contribute to human health. Li et al. (2024) explore the anti-inflammatory effects of JFPs of pulp (JFPs-P) through an *in vivo* trial by dextran sodium sulphate–induced enteritis in rats. The results showed that purified JFPs-P alleviated the small intestine tissue damage through reduction of pro-inflammatory cytokine expression and the increase in anti-inflammatory cytokine interleukin-10 expression. In addition, JFPs could minimise the oxidative stress through restraining the antioxidant enzyme activity and decreasing the malondialdehyde

Table 1. A summary of the extraction methods of polysaccharides from jackfruit.

Type	Part	Compounds	Size	Extraction	Precipitation	Drying	Yield	Ref
Conventional	Pulp	Polysaccharides	Homogenate	Water	95% ethanol	–	–	Zhu et al. (2017)
Conventional	Seeds	Polysaccharides	Powder	Water	50%, 75%, 95% ethanol	Lyophilisation	2%–8%	Dasaesamoh and Seechamnanturakit (2014)
Conventional	Peel	Pectin	60-mesh powder	Citric acid, pH = 2	95% ethanol	Freeze-dry	16.83%	Li et al. (2019)
Conventional	Peel	Polysaccharides	–	Water	Ethanol	Freeze-dry	13.6 g/kg crude extract	Wang and Jiang (2022)
Conventional	Peel	Polysaccharides	–	Water	Acidified (pH 4) 96% ethanol	Freeze-dry	11.80%	Wiater et al. (2020)
Conventional	Seeds	Starch	homogenate, 200-mesh sieve (74 µm)	0.5 M sodium thiosulphate	Water	45 °C oven dry	18.68 ± 0.34% to 22.92 ± 0.46%	Zhang et al. (2018)
Conventional	Peel	Pectin	Powder	Hydrochloric acid, oxalic acid, tartaric acid, nitric acid, and citric acid.	95% ethanol	50 °C oven dry	22.5%–38.42%	Sundarraj et al. (2018)
Conventional	Peel	Cellulose	Powder	Acetic acid and nitric acid at 100 °C for first extract; acetic acid, sulphuric acid, and NaCl for second extract	–	–	–	Reshmy et al. (2021)
Conventional	Peel	Cellulose	20 and 80 sieve powder	Sodium chlorite	Suspend in water	Filtered and dried	20.08 ± 0.05%	Trilokesh and Uppuluri (2019)
Conventional	Peel	Cellulose	20 and 80 sieve powder	Acetic acid and nitric acid	Washed by water and 95% ethanol	50 °C dry	Around 12.5%	Trilokesh and Uppuluri (2019)
Conventional	Peel	Cellulose	20 and 80 sieve powder	Formic acid	–	–	Around 5%	Trilokesh and Uppuluri (2019)
Conventional	Seeds	Starch	Powder	Water	Sodium hydroxide	45 °C dry	24.61%	Yaowiwat et al. (2023)
Microwave-assisted	Rags	Pectin	Powder	Citric acid	Ethanol	50 °C oven dry	10.90%–29.78%	Tran et al. (2023)
Pulsed electric field and microwave-assisted	Rind and core	Pectin	80-mesh powder	1% citric acid	Ethanol	60 °C dry	13.9%–18.3%	Lal et al. (2021)
Radiofrequency assisted	Peel	Pectin	Powder	Oxalic acid	96% ethyl alcohol	55 ± 2 °C oven dry	9.6%–29.4%	Naik et al. (2020)
Subcritical water extraction	Peel	Pectin	60-mesh powder	Water	95% ethanol	Freeze-dry	125.6 ± 2.17 to 149.8 ± 1.41 g/kg	Li et al. (2019)
Ultrasonic and microwave-assisted	Peel	Pectin	Powder	Three types of mineral acids (hydrochloric acid, sulphuric acid, and nitric acid) and three types of organic acids (citric acid, tartaric acid, and lactic acid)	95% ethanol	60 °C vacuum dry	5.2% – 21.0%	Xu et al. (2018)
Ultrasonic assisted	Peel	Pectin	Powder	Oxalic acid	Ethanol	Freeze-dry	6.15%–13.15%	Saurabh et al. (2023)
Ultrasonic assisted	Peel	Pectin	40-mesh powder	Water	95% ethanol	51 °C oven dry	14.48 ± 0.11%	Moorthy et al. (2017)

content. Zhu et al. (2017) determined the antioxidant ability of purified JFPs-P; during the concentration range of 0.25–4 mg/ml, the DPPH scavenging ability is from 21.82% to 69.64%, in the concentration range of 0.5–2 mg/ml. The OH scavenging ability is dose-dependent. The result of reducing power is not ideal.

Later research conducted by Zhu et al. (2021) showed that polysaccharides are beneficial to gut health through the mice model. Twenty-four male mice treated with different concentrations administration (50, 100, and 200 mg/kg BW), fresh faeces samples were collected after 2 weeks and DNA extraction, 16S rRNA gene amplification and sequencing, gut microbiota bioinformatics analysis and short-chain fatty acid products analysis were conducted. The outcome showed that the jackfruit polysaccharides treatment would increase operational taxonomic units (OTUs) of faecal bacteria (control and treatment groups were 711, 635, 850, and 787). Higher variation in intestinal bacteria and significant differences in bacterial communities were shown in the treatment group compared to the control group. For short-chain fatty acids (SCFAs), the concentrations of acetic acid, propionic acid, n-butyric acid, and total SCFAs in mouse faeces increased.

In addition, Li et al. (2023) using the polysaccharides from peel (PJPs) confirmed the above finding by *in vitro* digestion and faecal fermentation. The PJPs could reach the colon intact. The molecular weight of PJPs decreased during the faecal fermentation; the reason is that PJPs had been degraded during the faecal fermentation, which was caused by microbes in the intestine and also released the oligosaccharides. For α-diversity, the Chao and Shannon indices of the PJP group are lower than the control, which indicates that microbiota richness and diversity are lower. After 48 hr fermentation, the total SCFAs of PJP (25.843 ± 1.036 mmol/L) are higher than the control group (11.142 ± 1.558 mmol/L), which demonstrates that PJPs increase the amount of SCFAs and have the potential of being a prebiotic.

According to Wiater et al. (2020), water-soluble polysaccharides (WSPs) from jackfruit revealed their anticancer properties through assays performed on cell lines HT29 and SW620. The outcome of neutral red (NR) uptake assay, MTT assay, and May–Grünwald–Giemsa (MGG) staining showed that both cell lines exhibit no overall significant viability loss in the NR in treatment group with WSP, even at the highest concentration (250 μg/ml) with viability not dropping below 94%. No morphological alteration was observed in either cells treated with WSP at the highest concentration. In addition, two assays (DPPH and FRAP) were performed to determine the antioxidant capacity. The DPPH and FRAP assays showed 16.2 μg Trolox equivalent (TE)/ml and 48.4 μg ascorbic acid equivalent (AAE) at the highest WSP concentration, respectively.

The bioactivity of jackfruit polysaccharides is summarised in Table 4.

Limitations

Although jackfruit polysaccharides have attracted attention for their health benefits, commercial products, and other advantages, there are the following limitations when studying these bioactive compounds. (1) The methods of extraction, quantification, characterisation, and experiment condition are different in different studies; it is hard to compare the results, which means it is essential to establish the standardised methods (Zhang et al., 2021b). (2) The structure analysis still contains a large research gap, such as 3D structure and glycosidic linkage. Therefore, when the jackfruit polysaccharides are mentioned, there is no specific name, only general terms such as pectin, starch, and cellulose. (3) Limitation in product development. *In vivo* assays have confirmed that there are many essential properties that are related to human health, such as anticancer, anti-inflammatory, and antidiabetic. However, further trials were not carried out.

Micronutrients

Nutritional content varies based on the ripeness of the fruit and the specific part consumed, such as the flesh, seeds, or bulbs (Konsue et al., 2023) (Table 2). Jackfruit flesh is low in calories and fat while providing a valuable source of dietary fibre. It contains essential vitamins (C, A, thiamine, riboflavin, niacin, and folate) and important minerals (potassium, magnesium, manganese, and calcium) (Goswami & Chacrabati, 2016). Notably, the latest research showed the mineral profiling of 12 different genotypes of jackfruits grown in Australia, which includes the quantity elements, essential trace elements, and other elements. The result exhibited a total of 20 minerals in jackfruit pulp (Kaur et al., 2024). In the total 12 genotypes, pulp showed high concentrations of potassium (4,028 ± 16.4 to 9,559 ± 33.5 mg kg^{-1}), magnesium (1,401 ± 31.1 to 2,307 ± 6.1 mg kg^{-1}), and phosphorus (990 ± 35.1 to 1825 ± 776 mg kg^{-1}) while sodium (11.3 ± 2.5 to 36.7 ± 13.2 mg kg^{-1}) has lower concentrations.

Phytochemicals

Jackfruit is a rich source of beneficial phytochemicals, including flavonoids and carotenoids (Table 2). Flavonoids include quercetin, kaempferol, catechins, and epicatechins, which exhibit antioxidant properties (Arung et al., 2007). Carotenoids, including beta-carotene, lutein, and zeaxanthin, provide health benefits and act as the precursors of vitamin A. The jackfruit kernel has numerous carotenoids, including β-carotene, α-carotene, β-zeacarotene, α-zeacarotene, and β-carotene-5,6α-epoxide, a dicarboxylic carotenoid and crocetin. Further carotenoids present in jackfruit include all-trans-lutein, all-trans-β-carotene, all-trans-neoxanthin, 9-cis-neoxanthin, and 9-cis-violaxanthin (de Faria et al., 2009). Alkaloids, saponins, and tannins might contribute to the health benefits of jackfruit because of their diverse bioactivities (Chun-Nan & Chai-Ming, 1993; Mukprasirt & Sajjaanantakul, 2004). Terpenoids, including phytosterols, are present in jackfruit, which exhibit anti-inflammatory and anticancer properties. Lignans, resveratrol, and phenolic acids, such as ferulic acid and caffeic acid, contribute to the antioxidant potential of jackfruit (Arung et al., 2007; de Faria et al., 2009). The phytochemicals may vary in different parts of the jackfruit, and the concentration and types of the compounds are influenced by factors such as the maturity and growth conditions of the jackfruit.

Moreover, jackfruit tree wood contains flavonoids like artocarpin, brosimone, albanin A, morin, 2′,4′-dihydroxyflavone, and oxyresveratrol (Arung et al., 2007). Similarly, in twigs of jackfruit, the phenolic content is higher than the flavonoid content, having a higher concentration of vanillic acid and hydroxybenzoic acid. The root of jackfruit is rich in prenylated flavonoids, such as artonol and cyclocommunol. The phytochemical profile of the stem is distinguished by the presence of prenylated chromone and flavonoids, including cnidimol and tetramethoxy-6-C-prenylflavone (Table 3). Furthermore, betulinic acid, flavones, and tannins were mainly found in the bark (Prakash et al., 2009). Generally, leaves and stems contain sapogenins, β-sitosterol, cycloartenone, tannins, and cycloartenol (Prakash et al., 2009). The fruit encompasses carotenoids (all-trans-neoxanthin and cis-antheraxanthin), oxyresveratrol, artocarpesin, artoheterophoid, 16-dione, and artoheteronin. Fruit pulp analysis reveals the presence of uronic acid and phenolic acid. Among the extracts, methanolic fractions of the peel exhibited elevated phenolic

Table 2. The brief summary of mineral and vitamin profile of jackfruit.

Vitamin and mineral	Fruit	Seeds	Peel	Fibre	Core	Leaves
Vitamin A	30–540 IU/100 g EP	10–17 IU/100 g EP				
Vitamin B1 (Thiamine)	0.03 — 0.15 mg/100 g EP	0.25 mg/100 g EP				
Vitamin B2 (Riboflavin)	0.05–0.4 mg/100 g EP	0.11–0.3 mg/100 g EP				
Vitamin B3 (Niacin)	12.75 mg					
Vitamin B6 (Pyridoxine)						
Vitamin B9 (Folate)	52.9–83.6 µg/100 g	51.1 µg/100 g				
Vitamin C	7.0–14.0 mg/100 g EP	11 mg/100 g EP				0.99 mg/100 g
Calcium	20.0–73.2 mg/100 g EP	50.0 mg/100 g EP	4.9 mg/g DW	7.32 ± 4.099 mg/g DW	6.94 ± 2.074 mg/g DW	0.52 g/100 g
Magnesium	27 mg/100 g EP	54.0 mg/100 g EP	1.45 mg/g DW	1.24 ± 0.421 mg/g DW	0.011 ± 0.004 mg/g DW	
Phosphorus	20.0–57.2 mg/100 g EP	38.0–97.0 mg/100 g EP	–	–	–	
Potassium	191–407 mg/100 g EP	246 mg/100 g EP	23 mg/g DW	31.07 ± 17.502 mg/g DW	24.15 ± 8.105 mg/g DW	0.21 g/100 g
Sodium	2.0–41.0 mg/100 g EP	63.2 mg/100 g EP	0.47 mg/g DW	0.48 ± 0.091 mg/g DW	0.43 ± 0.079 mg/g DW	
Iron	0.4–1.9 mg/100 g EP	1.5 mg/100 g EP	–	–	–	59.5 mg/100 g
Zinc	5.2 mg/100 g	40.85 ppm	1.44 mg/g DW	0.98 ± 0.044 mg/g DW	1.9 ± 0.408 mg/g DW	5.73 mg/100 g
Cooper	0.28–0.38 mg/100 g	22 ppm	0.018 mg/g DW	0.005 ± 0.005 mg/g DW	0.018 mg/g DW	
Ferrous	1.20–4.24 mg/100 g	148 ppm	0.11 mg/g DW	0.088 ± 0.133 mg/g DW	0.051 ± 0.023 mg/g DW	
Manganese	11.75 mg/100 g	–	0.15 mg/g DW	0.01 ± 0.0025 mg/g DW	0.011 ± 0.004 mg/g DW	12.75 mg/100 g

Sources: Narasimham (1990), Soepadmo (1991), Gunasena (1996), Azad (2000), Haq et al. (2006), Ajayi (2008), Swami et al. (2012), Ranasinghe et al. (2019), Striegel et al. (2019), Adan et al. (2020), Gupta et al. (2020), Shedge et al. (2022), Gupta et al. (2023). *Note.* DW = dry weight; EP = edible portion.

content, while the highest flavonoid content was observed in fruit peels (Zhang et al., 2017).

A. heterophyllus seeds exhibit a diverse composition, containing flavonoids, isoflavones, phenols, saponins, and lignans (Fernandes et al., 2017). Likewise, seed kernels contain carotenes, zeacarotenes, dicarboxylic carotenoid, 6α-epoxide, β-carotene-5, and crocetin (Chandrika et al., 2005). *A. heterophyllus* fruit also exhibits a varied volatile profile, and a study on Malaysian *A. heterophyllus* fruit revealed 45 compounds, including esters (31.9%) (Wong et al., 1992). Similarly, 86 volatile compounds, ranging from aldehydes to carboxylic acids, were identified in different Mexican jackfruit varieties (Barros-Castillo et al., 2021).

Healthy benefits

Jackfruit offers significant therapeutic potential, as outlined in Figure 2. Packed with essential nutrients like protein and healthy fats, the seeds support overall well-being. Meanwhile, the flesh and leaves contain potent antioxidant phytochemicals, including flavonoids and carotenoids. These antioxidants help combat oxidative stress and disease—key players in jackfruit's protective abilities. Additionally, Figure 2 illustrates its potential across various health areas, including cardiovascular health, anticancer action, antimicrobial and antiviral properties, and more. The ongoing exploration of jackfruit's health benefits could revolutionise natural, holistic practices in health support and disease prevention.

Anti-inflammatory activity

Inflammation is a key factor in many chronic diseases. Researchers are actively exploring the anti-inflammatory potential of phytochemicals in jackfruit. The polyphenols extracted from the fruit of jackfruit exhibit anti-inflammatory activity by inhibiting the production of nitric oxide (NO) that leads to the downregulation of COX-2 and iNOS proteins (Fang et al., 2008). Quercetin, a flavonoid abundant in jackfruit, exerts its anti-inflammatory properties by interfering with the action of inflammatory enzymes and cytokines (Chen et al., 2016). Numerous studies have delved into the anti-inflammatory attributes of compounds from various parts of jackfruit.

Liu et al. (2020) analysed the anti-inflammatory effects of seven prenylated chromones and five prenylated flavonoids extracted from jackfruit stems and leaves. A total of 12 compounds exhibited significant inhibitory activities against NO production, showing IC_{50} values in the range of 0.48 ± 0.05 to 19.87 ± 0.21 μM, while Compounds 1–4 (prenylated chromones) exhibited lower IC_{50} than positive-control hydrocortisone (3.83 ± 0.12 μM). Their structure plays a key role in their anti-inflammatory effects; for example, the absence of the benzene ring located at C-2, C-6 has an isopentenyl derivative and C-5, C-7, and C-4′ have hydroxyl groups at the same time.

Fang et al. (2008) examined the phenolic compounds extracted from jackfruit fruits; three compounds were purified: (1) artocarpesin, (2) norartocarpetin, and (3) oxyresveratrol. Through the RAW 264.7 murine macrophage cells induced the inflammatory effect by lipopolysaccharide (LPS), the outcome demonstrated that artocarpesin (1) has the potential in inflammatory-related diseases, as it suppressed the production of NO and prostaglandin E2 (PGE2). Liu et al. (2021) explored the anti-inflammatory effects of steroids from jackfruit fruit by measuring the same cell line as Fang et al. All eight steroids showed remarkable inhibitory effects against NO production with the IC_{50} values in the range of 0.72 ± 0.07 to 5.93 ± 0.12 μM. In addition, Tao et al. (2022) discovered that seven prenylated coumarins exhibited notable inhibitory effects on NO production, showing the IC_{50} values ranging from 0.58 ± 0.06 to 6.29 ± 0.12 μM, showing comparable effects with the positive control 4.08 ± 0.11.

Meera et al. (2018) evaluated the ethanol extract from jackfruit parts such as fruit spine, skin, and rind; the skin extract demonstrated the highest anti-inflammatory response, with 71.9% of COX-1 and 70.7% of COX-2 percentage inhibition. Those of skin and rind extract were 57.4%, 56.9%, and 39.1%, 65.3%, respectively.

Yao et al. (2016) reported that Moracin C (MC) significantly inhibited the production of NO with IC_{50} 7.70 μM. The concentrations of MC were 25 and 50 μM significantly inhibited LPS-induced ROS generation. Pretreatment of MC could restrain the mRNA and protein expression of iNOS and COX-2 stimulated by LPS at concentrations of 10, 25, and 50 μM. Furthermore, 25 μM MC pretreatment could reduce the secretion of IL-1β and IL-6 and 50 μM MC reduced TNF-α by 70.6%. Moracin C could inhibit NF-κB activation by block nuclear translocation of p65, which is triggered by LPS and inhibits the MAPK pathways.

Jackfruit may hold potential in managing inflammation associated with diabetes. A study conducted on Wistar albino rats with gestational diabetes mellitus (GDM) demonstrated that ethanol extract from jackfruit seeds exhibited hypoglycaemic and anti-inflammatory properties. Although the jackfruit seed extract showed beneficial effects, its efficacy was not as pronounced as that of metformin, a standard pharmaceutical treatment for diabetes (Manurung et al., 2023). In addition, the jackfruit stem bark acetone extract has been shown to reduce IL-6, TNF-α, and NF-κB levels in diabetic rats, which also confirms the potential of jackfruit in managing anti-inflammatory effects related to diabetes (Ajiboye et al., 2020).

In conclusion, the above multiple evidence and studies indicate that jackfruit, especially its components, has anti-inflammatory properties. Future research can be directed towards investigation of the molecular mechanisms and identification of the compounds responsible for these actions, helping to provide valuable insights into the potential of jackfruit as a natural anti-inflammatory resource.

Antidiabetic capacity

Diabetes is a severe disease, which is one of the top five leading causes of death and disability in the world. As of 2019, the International Diabetes Federation projected a global prevalence of 9.3% for diabetes among adults aged 20–79, affecting 463 million people. From the statistical data of Diabetes Atlas (2021 version), projections indicate an increase to 578 million by 2023 and a further rise to 700 million by 2045. Hyperglycaemia, a common consequence of diabetes, arises from insulin resistance, inadequate insulin production, or excessive glucagon secretion (Gupta et al., 2023).

Type 2 diabetes mellitus, the most prevalent form of the disease, accounts for 85%–95% of cases and poses a significant public health concern. Jackfruit seeds comprise resistant starch, which helps regulate blood sugar levels and promotes intestinal health (Waghmare et al., 2019). Previous research has indicated that raw jackfruit, due to its high protein and fibre content, has a considerably lower glycaemic load (GL) compared to rice and wheat, making it potentially favourable for individuals with diabetes (Sreeja Devi et al., 2021). Various components of *A. heterophyllus* have been traditionally used in diabetes treatments. In recent research, the efficacy of green jackfruit powder as a medical nutritional therapy for blood sugar control can replace the equivalent amount of rice

Table 3. The brief summary of jackfruit's phytochemical composition.

Plant part	Class	Extraction solvent	Specific compounds	Ref
Heartwoods	Flavonoids	Ethyl acetate	Cycloartocarpin, artocarpin, artocarpanone, cyanomaclurin	Septama and Panichayupakaranant (2015)
Wood	Flavonoids	Methanol	Artocarpin (1), cudraflavone C (2), 6-prenylapigenin (3), kuwanon C (4), norartocarpin (5), albanin A (6), cudraflavone B (7), brosimone I (8), and artocarpanone (9)	Arung et al. (2010)
	Phenolic compounds	Ethanol	Artoheterophyllin E (1), artoheterophyllin F (2), artoheterophyllin G (3), artoheterophyllin H (4), artoheterophyllin I (5), artoheterophyllin J (6), 2-geranyl-2′,3,4′,5-tetrahydroxy-cis-stilbene (7), 5-methoxymorican M (8), 2,3-dihydro-5,7-dihydroxy-2-(2-hydroxy-4-methoxyphenyl)-4H-1-benzopyran-4-one (9), 6-[(1S,2S)-1,2-dihydroxy-3-methylbutyl]-2-(2,4-dihydroxyphenyl)-5-hydroxy-7-methoxy-3-(3-methyl-2-buten-1-yl)-4H-1-benzopyran-4-one (10), artocarpin (11), cycloartocarpin (12), cycloartocarpesin (13), steppogenin (14), artocarpesin (15), norartocarpetin (16), brosimone I (17), isoartocarpesin (18), cyanomaclurin (19), artocarpanone (20), albanin A (21), artocarmin A (22), apigenin (23), artocarpetin (24), gemichalcone A (25), artocarpfuranol (26), morin (27), moracin M (28), artocarbene (29), cudraflavone C (30), hypargyflavones A (31), 2,4-dihydroxybenzoic acid methyl ester (32), and 2,4-dihydroxybenzaldehyde (33)	Zheng et al. (2014)
	Flavonoid	95% ethanol	Artocarpfuranol (1), dihydromorin (2), steppogenin (3), norartocarpetin (4), artocarpanone (5), artocarpesin (6), artocarpin (7), cycloar-tocarpin (8), cycloartocarpesin (9), artocarpetin (10), brosimone I (11), cudraflavone B (12), carpach-romene (13), isoartocarpesin (14), and cyanomaclurin (15)	Zheng et al. (2008)
	Flavonoids, chalcones	Methanol	Artocarmins A (1, 7.0 mg), artocarmins B (2, 5.0 mg), artocarmins C (3, 6.0 mg), artocarmins D (4, 8.3 mg), artocarmitins A (5, 5.0 mg), artocarmitins B (6, 8.5 mg), artocarmitins C (7, 5.5 mg), 3′-[γ-hydroxymethyl-(Z)-γ-methylallyl]-4,2′,4′-trihydroxychalcone (8, 8.5 mg), gemichalcone B (9, 12.0 mg), gemichalcone A (10, 6.8 mg), isogemichalcone B (11, 5.7 mg), morachalcone A (12, 7.8 mg), norartocarpin (13, 9.0 mg), cudraflavone C (14, 7.5 mg), albanin A (15, 50.0 mg), p-hydroxybenzoic acid (16, 6.5 mg), β-resorcylic acid (17, 5.g), vanillic acid (18, 6.7 mg), (goldfussinol (19, 6.5 mg), and p-coumaric acid (20, 20.8 mg)	Nguyen et al. (2012)
Twigs	Phenolic compounds	Ethanol	Artoheterophyllin A (1), artoheterophyllin B (2, 10.0 mg), artoheterophyllin C (3, 2.0 mg), artoheterophyllin D (4, 3.0 mg), dihydrophaseic acid 4′-O-β-d-glucopyranoside (5, 11.7 mg), p-counmaric acid (6, 24.2 mg), vanillic acid (7, 3.0 mg), norartocarpetin (8, 23.3 mg), 4-hydroxybenzoic acid (9, 2.0 mg), licoflavone C (10, 2.0 mg), moracin M (11, 39.2 mg), (E)-5-(6-hydroxybenzofuran-2-yl)-4-(3-methylbut-l-enyl)benzene-1,3-diol (12, 34.8 mg), artocarpesin (13, 33.0 mg), artocarpin (14, 5.6 mg), 6-prenyl-4′,5,7-trihydroxyflavone (15, 4.0 mg), artonin A (16, 14.0 mg), artonin J (17, 8.0 mg), cudraflavone B (18, 3.0 mg), cycloheterophyllin (19, 16.6 mg), and 2-(2,4-dihydroxy-6-methoxyphenyl)-5-hydroxy-7-methoxy-6-(3-methyl-l-buten-l-yl)-3-(3-methyl-2-buten-l-yl)-4H-1-benzopyran-4-one (20, 2.0 mg)	Zheng et al. (2009)

(Continued)

Table 3. Continued

Plant part	Class	Extraction solvent	Specific compounds	Ref
Root	Prenylated flavonoids	95% ethanol	6-(3-Methylbutyl-2-enyl)apigenin (1), Artonin K (2), Albanin A (3), 14-Hydroxyartonin E (4), Artoindonesianin P (5), Artonin J (6), Artelastoxanthone (7), Artobiloxanthone (8), Artonin E (9), Cyclocommunol (10), Artoindonesianin Q (11), Artoindonesianin R (12), Artonol E (13), Artoindonesianin T (14), Cycloartobiloxanthone (15), Artoindonesianin B (16), Artocarpetin A (17), Heteroflavanone C (18), Artocarpesin (19), 6-(3-Methylbut-2-enyl) Apigenin (20), Styracifolin D (21), Cycloartocarpesin (22), Artonin U (23), Norartocarpin (24), Mulberrochromene (25), Dihydroisocycloartomunin (26), Morusin (27), Heterophyllin (28), Artocarpetin B (29), Artelastofuran (30), 5’-Hydroxycudraflavone A (31), Artonin F (32), Isocycloheterophyllin (33), Artoindonesianin I (34), Artocarpin (35), Cannflavin C (36), Artonin H (37), Artonin S (38), Artonin G (39), Artonin A (40), Artonin B (41), Cudraflavone A (42), Artoindonesianin G (43), Cycloartocarpin (44), Artoindonesianin H (45), Cycloheterophyllin (46), Artelastochromene (47)	Ye et al. (2019)
Stem and leaves	Prenylated chromones	Petroleum ether and ethyl acetate	Artoheterophines A (1, 12.6 mg) and B (2, 21.8 mg), cnidimol D (3, 37.2 mg), ficuformodiol B (4, 5.8 mg), harperamone (5), perforatin B (6, 38.5 mg), 5,7-dihydroxy-8-[(2E)-4-hydroxy-3-methylbut-2-enyl]-2-methyl-4H-1-benzopyran-4-one (7, 9.7 mg)	Liu et al. (2020)
	Prenylated flavonoids	Petroleum ether and ethyl acetate	2-(4-Hydroxy-phenyl)-8-(3-methyl-but-2-enyl)-chroman-4-one (8, 23.7 mg), bracteflavone B (9, 82.3 mg), dinklagin C (10, 8.7 mg), 6-(3-methyl-(E)-1-butenyl) chrysin (11, 23.6 mg) and 5,7,3′,5′-tetramethoxy-6-C-prenylflavone (12, 49.8 mg)	Liu et al. (2020)
Leaves	Phenolic compounds	80% ethanol	Kaempferol 3-O-rutinoside (1), Kaempferol 3-O-β-d-apiofuranosyl (2), Citric acid (3), Caffeic acid (4), Quinic acid (5), Phenylalanine (6), Chlorogenic acid (7), Cistanoside (8), 3,5-dicaffeoylquinic acid (9), l-isoleucine-pentafluoropropionic- pentadecyl ester (10), Carvacrol (11), Hydroxytyrosol-hexose isomer a (12), Luteolin (13), Catechin (14), Isorhamnetin-3-O-rutinoside (15), Apigenin 8-C-xyloside-6-C-glucoside (Vicenin 3) (16), Naringin (17), Epigallocatechin (18), Penstebioside (19), β-OH-acteoside (20), Ferulic acid 4-O-glucoside (21)	Vázquez-González et al. (2020)
Stem bark	Phenolic compounds	Ethanol	Phenol, 3,4,5-trimethoxy- (1), 4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol (2), Scopoletin (3), 10,11-Dihydro-10-hydroxy-2,3-dimethoxydibenz(b,f) oxepin(16), 2,4a,8,8-Tetramethyldecahydrocyclopropa[d]naphthalene (22), 2,2,4-Trimethyl-3-(3,8,12,16-tetramethyl-heptadeca3,7,11,15-tetraenyl)-cyclohexanol (23), Vitamin E (24)	Ajiboye et al. (2016)
	Fatty acid	Ethanol	n-Hexadecanoic acid (4), Ethyl 9,12-hexadecadieno-ate (7), Ethyl oleate (8), Bis(2-ethylhexyl) phthalate (14), Butyl 9,12-octadecadienoate (17), Octadecanoic acid, 2-hydroxy-1-(hydroxymethyl) ethyl ester (18)	Ajiboye et al. (2016b)
	Aldehyde compound	Ethanol	3,5-Dimethoxy-4-hydroxycinnamaldehyde (5)	Ajiboye et al. (2016)
	Fatty acid ethyl ester	Ethanol	Hexadecanoic acid, ethyl ester (6), Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl) ethyl ester (13)	Ajiboye et al. (2016)
	Amino compound	Ethanol	Hexadecanami-de (9), 1H-Pyrido[3,4-b] indol-1-one, 2,3,4,9-tetrahydro- (10), 9-Octadecenamide, (Z)- (11), Decanamide- (12), Pyrazolo[3,4-b]thiopyrano[4,3-d]pyridin-1-1-amine,3,6,8,9-tetrahydro-8,8-dimethyl-5-phenyl (15),	Ajiboye et al. (2016)
	Phytosterol	Ethanol	Stigmast-4-en-3-one (19), Squalene (20)	Ajiboye et al. (2016)
	Ketone compounds	Ethanol	Methanone (5-hydroxy-3-benzofuryl) (2,5-dimethoxyphenyl) (21)	Ajiboye et al. (2016)

(Continued)

Table 3. Continued

Plant part	Class	Extraction solvent	Specific compounds	Ref
Fruit	Phenolic compounds	Ethyl acetate	Artocarpesin [5,7,2′,4′-tetrahydroxy-6-(3-methylbut-3-enyl) flavone] (1), norartocarpetin (5,7,2′,4′-tetrahydroxyflavone) (2), and oxyresveratrol [trans-2,4,3′,5′-tetrahydroxystilbene] (3)	Fang et al. (2008)
Jackfruit	Oxyresveratrol	Ethyl acetate	Oxyresveratrol	Li et al. (2020)
Fruit	Steroids	Petroleum ether and ethyl acetate	Artoheterophoid (1, 18.1 mg), trichiliasterone B (2, 9.7 mg), 1-methoxy-androstan-1,4-dien-3,16-dione (3, 11.5 mg), K10–0216 KA (4, 8.6 mg), K10–0216 KB (5, 23.6 mg), (Z)-Δ1,2-dehydroguggIsterone (6, 29.7 mg), 1-methoxy- pregnan-17-(S)-1,4-dien-3,16-dione (7, 32.5 mg) and 1-methoxy-pregnan-17(R)-1,4- dien-3,16-dione (8, 53.5 mg)	Liu et al. (2021)
Fruit	Prenylated coumarins	Petroleum ether and ethyl acetate	New prenylated coumarin (1, 9.8 mg), tanizin (2, 16.3 mg), anisocoumarin A (3, 12.8 mg), fipsomin (4, 53.9 mg), 6-(1ξ,2ξ,3-trihydroxy-3-methylbutyl)-7-hydroxy-2H-1- benzopyran- 2-one (5, 22.7 mg), phellodenol C (6, 32.6 mg) and isophellodenol C (7, 74.8 mg)	Tao et al. (2022)
Pulp	Odour-active compounds	Dichloromethane	Ethyl 2-methylpropanoate (1), butane-2,3-dione (2), methyl 3-methylbutanoate (3), ethyl butanoate (4), ethyl 2-methylbutanoate (5), ethyl 3-methylbutanoate (6), butyl acetateb (7), hexanal (8), 3-methylbutyl acetate (10), butan-1-ol (11), methyl hexanoate (12), 3-methylbutan-1-ol (13), 2-methylbutan-1-ol (14), ethyl hexanoate (15), octanal (16), 3-hydroxybutan-2-one (17), 1-octen-3-one (18), 2-acetyl-1-pyrroline (19), nonanal (21), acetic acid (22), 3-(methylsulfanyl)propanal (23), decanal (24), 3-isobutyl-2-methoxypyrazine (25), (2E)-non-2-enal (26), (2E,6Z)-nona-2,6-dienal (27), butanoic acid (29), phenylacetaldehyde (30), 3-methylbutanoic acid (31), hexanoic acid (37), 2-methoxyphenol (38), ethyl 3-phenylpropanoate (39), 2-phenylethanol (40), γ-octalactone (41), 4-hydroxy-2,5-dimethylfuran-3(2H)-one (42), 4-methylphenol (43), ethyl (2E)-3-phenylprop-2-enoate (44), 3-hydroxy-4,5-dimethylfuran-2(5H)-one (46), 2-phenylacetic acid (47), vanillin (48)	Grimm and Steinhaus (2019)
	Monosaccharide	Water	Glucose (Glc), xylose (Xyl), arabinose (Ara), rhamnose (Rha), galactose (Gal), galacturonic acid (GalA)	Zhu et al. (2017)
	Amino acid (polysaccharides)	–	Asparagic acid (Asp), Threonine (Thr), Serine (Ser), Glutamic acid (Glu), Proline (Pro), Alanine (Ala), Cysteine (Cys), Valine (Val), Methionine (Met), Isoleucine (Ile), Leucine (Leu), Tyrosine (Tyr), Phenylalanine (Phe), Histidine (His), Lysine (Lys), Arginine (Arg)	Zhu et al. (2017)
Jackfruit	Phenolic compounds	–	25-Hydroxycycloart-23-en-3-one (HY), Artocarpin (AR), Dadahol A (DA), Morachalcone A (MA), Artoheterophyllin B (AB), Cycloheterophyllin (CY), and Moracin C (MC)	Yao et al. (2016)

(*Continued*)

Table 3. Continued

Plant part	Class	Extraction solvent	Specific compounds	Ref
Peel	Organic acid	90% methanol	Naphthalenedicarboxylic acid-hexose, Quinic acid, Malic acid, Quinic acid isomers, Citric acid, [5-glucopyranosyloxy-2-oxo-2,3-dihydro-1H-indol-3-yl]acetic acid, Resorcylic acid-O-hexoside, Hydroxycaproic acid-O-hexoside	Zhang et al. (2017a)
	Glycosides	90% methanol	Digitoxosylhexoside, Benzyl-pentosylhexoside, Pentyl-pentosylhexoside, Pentyl-pentosylhexoside isomer I, Pentyl-pentosylhexoside isomer II, Benzylacetylpentosylhexoside, Pentyldipentosylglucuronidehexoside, Pentylacetylpentosylhexoside	
	Oxylipins	90% methanol	9,12,13-Trihydroxyoctadecadienoic acid, 9-Hydroxy-10,12,15-octadecatrienoic acid, 9-Hydroxy-10,12-octadecadienoic acid	
	Phenolic acids	90% methanol	Cis 3-Caffeoylquinic acid, Trans 3-Caffeoylquinic acid, Esculetin-O-hexoside, Esculetin-C-hexoside, 3,4-dihydroxybenzoic acidmethyl ester-C-dihexoside, Esculetin-hexoylpentoside, Feruloylglucoside, Cis 4-Caffeoylquinic acid, Caffeoylglucoside, Cis 5-Caffeoylquinic acid, Trans 5-Caffeoylquinic acid, Trans 4-Caffeoylquinic acid	
	Flavonoids	90% methanol	Procyanidin B, (Epi)catechin-Orhamnoside, Dihydromyricetin, (Epi)catechin, Phloretin-C-dihexoside, Dihydroquercetin, Prenylmethylfluorone, Prenyl-O-tetrahydroxy9,10-dihydrophenanthrene, Prenyl-O-naringenin, Butenylprenylnaringenin, Morachalcone A, Morachalcone A isome r, Chlorophorin, Pentenylisoliquiritigenin, Prenylgenistein, Pentenylnaringenin, Hexenyl-5,7,4′-Trihydroxyflavan, Pentenyl-Oisoliquiritigenin	
	Amino acids, peptides, and derivatives	90% methanol	Tryptophan, [2-Oxo-2-[(tetrahydro-2-furanylmethyl) amino] ethoxy] acetic acid, Hydroxy-1-isoquinolinonediglucuronide, Damascenine	
Seed	Organic acids[a]	Methanol	Oxalic (771.83), Aconitic (747.03), Citric (9832.67), Pyruvic (59.32), Malic (4417.61), Quinic (691.22), Shikimic (12.95), Acetic (84.28), Fumaric (562.21)	Fernandes et al. (2017)
	Amino acids[a]	Methanol	Threonine (435.2), Valine (327.97), Isoleucine (168.83), Leucine (467.82), Tryptophan (102.99), Phenylalanine (240.43), Lysine (271.63), Histidine (136.98), Aspartic acid (273.47), Glutamic acid (723.7), Asparagine (917.8), Glutamine (3,008.65), Serine (336.46), Glycine (172.63), Alanine (273.4), Proline (2780.31), Arginine (1313.86), Cysteine (543.09), Ornithine (36.92), Tyrosine (546.8)	
	Fatty acids[a]	Methanol	Dodecanoic (C12:0)(12.69), Tridecanoic (C13:0)(1.7), Tetradecanoic (C14:0)(73.55), cis-10-Pentadecenoic (C15:1n-5c)(3.43), Pentadecanoic (C15:0)(56.48), cis-9-Hexadecenoic (C16:1n-7c)(61.98), Hexadecanoic (C16:0)(1701.49), cis-10-Heptadecenoic (C17:1 n-7c)(20.46), Heptadecanoic (C17:0)(47.56), cis-9,12-Octadecadienoic (C18:2n-6c)(948.78), cis-9-Octadecenoic (C18:1n-9c)(299.23), trans-9-Octadecenoic (C18:1n-9 t)(40.93), Octadecanoic (C18:0)(436.37), cis-9,12,15-Octadecatrienoic (C18:3n-3c)(6.08), Eicosanoic (C20:0)(153.23), Heneicosanoic (C21:0)(44.92), Docosanoic (C22:0)(203.53), Tricosanoic (C23:0)(46.25), Tetracosanoic (C24:0)(150.6)	
	Phenolic compounds	Methanol	3-Caffeoylquinic acid, Feruloylglucaric acid isom, Feruloylglucaric acid isom, Feruloylglucaric acid isom, Feruloylglucaric acid isom, 5-Caffeoylquinic acid, Caffeoylquinic acid isom, Feruloylglucaric acid isom, Feruloylsinapic acid isomm, Feruloylsinapic acid isom, 4-p-Coumaroylquinic acid, 5-p-Coumaroylquinic acid, 4-Feruloylquinic acid, 5-Feruloylquinic acid, p-Coumaroyl derivative, Feruloyl derivative, Sinapoyl derivative, Feruloyl derivative	
Kernel	Carotenoids	Acetone	β-Carotene (5.6 ± 0.3 µg/g), β-carotene-5,6-epoxide (3.1 ± 0.3 µg/g), α-Carotene (1.7 ± 0.1 µg/g), β-Zeacarotene (3.1 ± 0.3 µg/g), α-Zeacarotene (3.5 ± 0.2 µg/g), Crocetin (2.1 ± 0.1 µg/g)	Chandrika et al. (2005)

[a] This is the sum of seed kernel and seed membrane, unit is mg/kg dry matter.

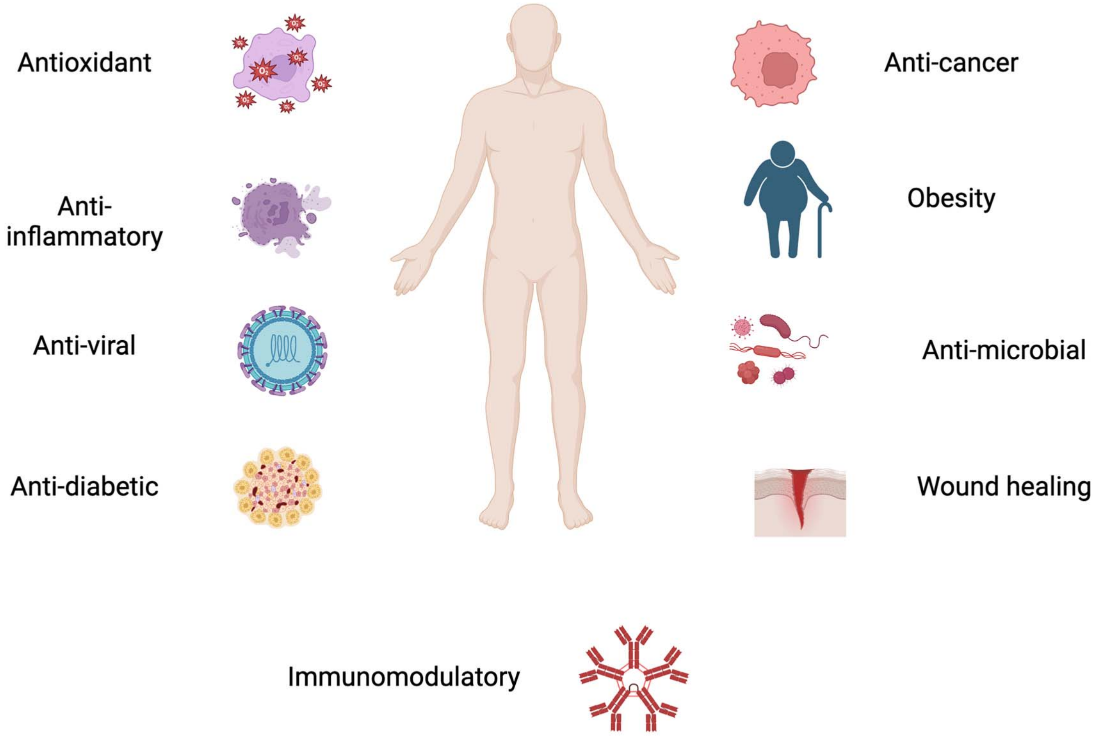

Figure 2. Outline the therapeutic potentials of the jackfruit.

or wheat flour in the daily diet (Rao et al., 2021). According to Sydney University's Glycaemic Index Research Service, porridge made by green jackfruit is 365, when carbohydrates per serving are 15 g, the glycaemic index (GI) is 65, and the GL is only 10. As comparison, the risotto rice has 69 GI and 31 GL (Anonymous, 2012).

A study explored the α-glucosidase activity inhibitory effect of methanolic extractions from different parts of jackfruit (peel, seed, pulp, and flake) with the 0–20 mg/ml concentration. The peel extract demonstrated the highest inhibition effects (IC_{50}: 0.05 ± 0.00 mg DM/ml), followed by the seed (IC_{50}: 1.79 ± 0.15 mg DM/ml), pulp (IC_{50}: 6.81 ± 0.52 mg DM/ml), and flake (IC_{50}: mg 10.52 ± 0.73 DM/ml) extraction, while the peel extract also showed the highest total phenolic content, which is 48.04 ± 4.57 mg GAE/ml. This suggests that there is an association between the inhibition effect of α-glucosidase and the total phenolic content of the extracts (Zhang et al., 2017).

In the context of diabetes, medicinal plants should possess the ability to inhibit the enzymes α-amylase and α-glucosidase. In the study conducted by Ajiboye et al. (2016), it was observed that the ethanolic extract of *A. heterophyllus* stem bark, which contains polyphenolic compounds, demonstrated a concentration-dependent inhibition of α-amylase and α-glucosidase actions *in vitro*; the IC50 is 4.18 ± 0.01 and 3.53 ± 0.03 mg/ml, respectively. These findings suggest that the extract has the potential to regulate carbohydrate metabolism by inhibiting the enzymes responsible for the breakdown of complex carbohydrates into simpler sugars.

In another research conducted by Ajiboye et al. (2020), they conducted both *in vivo* and *in vitro* assays to determine the acetone extract of jackfruit stem bark potential for antidiabetic ability. For *in vitro*, α-amylase and α-glucosidase inhibitory activity were determined. The outcome showed that both free and bound phenols have inhibitory effects in a dose-dependent manner. Notably, the bound phenol has higher inhibitory activity, even higher than standard acarbose. For *in vivo*, 50 male Wistar rats introducing diabetes by a single streptozotocin (STZ) injection were used; then, they were orally administered 400 mg/kg free and bound phenols extract and 5 mg/kg metformin. Fasting blood glucose levels decreased after 14 days of administration compared with diabetic rats. After 28 days of administration, there was no significant weight difference between rats with phenolic (both free and bound) treatment and normal rats, while the diabetic control group lost weight from 167.48 ± 4.11 to 120.67 ± 6.10 g. There was significant increase in liver glycogen concentration, HOMA-β, hexokinase activity, and glucose transporter 2, while the concentration of MDA, glucose-6-phosphatase activity, antioxidant enzyme activities of SOD, CAT, and GPx, and levels of IL-6, TNF-α, and NF-κB decreased.

Ajiboye conducted the studies on the ethanolic extract of jackfruit stem bark, to analyse the anti-diabetic ability in alloxan-induced diabetic rats. The diabetes rats received the treatment of 50, 100, 150 mg/kg body weight ethanol extract (Ajiboye et al., 2017). The outcome demonstrated that after 3-week treatment, the blood sugar decreased significantly compared with the diabetic rats (308.12 ± 1.10 mg/dl); the results were 94.30 ± 1.10, 88.40 ± 1.12, and 84.20 ± 1.46, respectively. The insulin and HOMA-β levels decreased in alloxan-induced diabetic rats (50.48 ± 0.28 and 4.71 ± 0.16) compared with the normal rats (143.44 ± 1.50 and 81.93 ± 2.20), while the HOMA-IR increased in diabetic rats (5.36 ± 0.03) compared with the normal rats (4.16 ± 0.01). All the treatment groups showed an increase in insulin and HOMA-β and a decrease in HOMA-IR. In another study (Ajiboye et al., 2018), compared with the normal rats, the alloxan-induced diabetic rats showed significant body weight loss. Haematological parameter determination, serum lipid profiles, atherogenic and coronary indices, and even liver and kidney function indices also showed significant ($p < .05$) abnormalities. Notably, all these abnormal

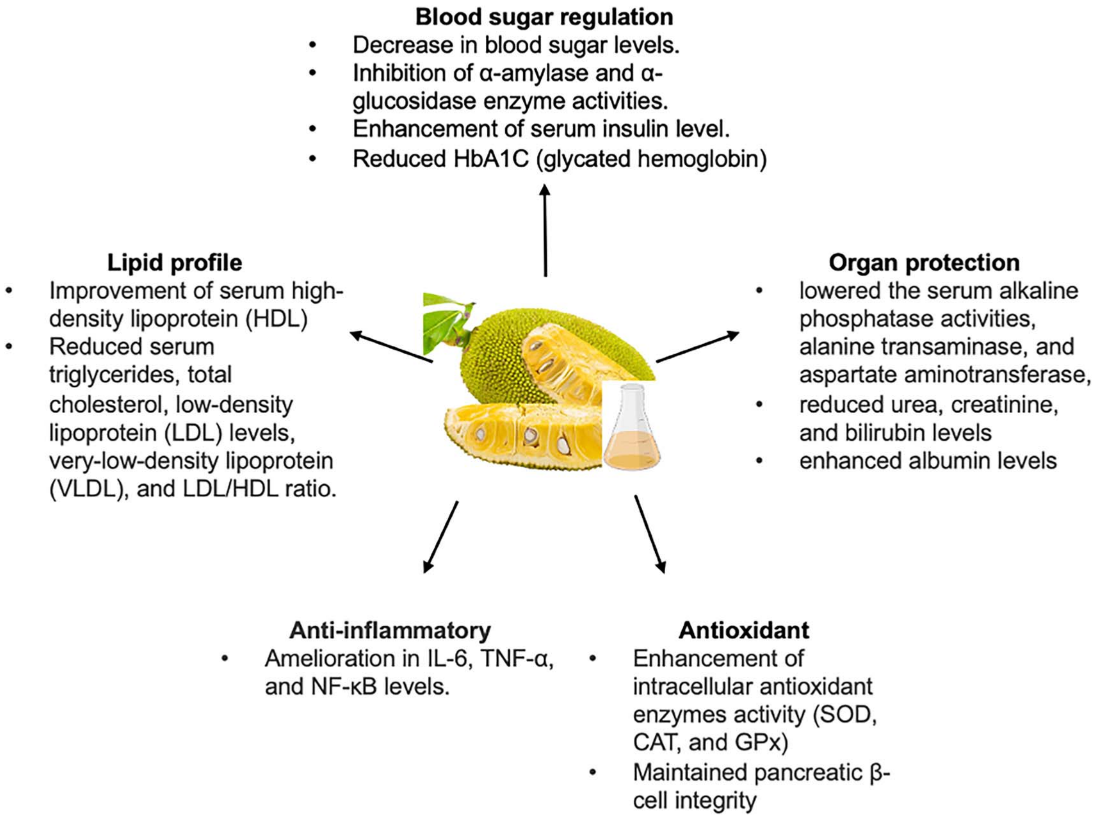

Figure 3. Antidiabetic mechanistic action of jackfruit.

symptoms were reverted to normal after different doses of ethanol extract of *A. heterophyllus* stem bark treatment and there is dose dependency, as 150 mg/kg body weight, which exhibited no significant ($p > .05$) difference with nondiabetic rats.

Earlier, Kotowaroo et al. (2006) investigated the α-amylase inhibitory activity of aqueous leaf extracts of *A. heterophyllus* compared with six other traditional medicinal plants. Only the extract from *A. heterophyllus* exhibited the significant inhibition of α-amylase activity in rat plasma. When the concentration of 1,000 μg/ml, the inhibitory activity reached the highest value (27.20 ± 5.00%). Although this assay tested the different concentrations of *A. heterophyllus* extraction, there is no dose dependency been observed.

Another study by Chackrewarthy et al. (2010) explored the impact of ethyl acetate (EA) fraction from jackfruit leaf on glycaemic responses through normoglycemic rats and STZ-induced diabetic rats. For normoglycemic rats, reduction in serum glucose is 18.9%, 26.4%, and 35.9% for rats with 10 mg/kg, 20 mg/kg extracts and 0.6 mg/kg glibenclamide, respectively. After 5 weeks of treatment, diabetic rats with jackfruit leaf extracts (20 mg/kg) had 39% less serum glucose, 23% lower serum total cholesterol and 40% lower serum TG levels, and 11% higher body weight. This study confirmed that the EA fraction of jackfruit has the potential for future diabetic treatment.

Omar et al. (2011) investigated the hyperglycaemic and hyperlipidaemic effects of ethanol (JFEE) and n-butanol (JFBE) extracts from jackfruit leaves in STZ-diabetic rats. The administration of JFEE or JFBE to diabetic rats significantly reduced fasting blood glucose, lipid peroxide–glycosylated haemoglobin A1C, triglycerides, total cholesterol, low-density lipoprotein cholesterol (LDL-C), very-low-density lipoprotein cholesterol (VLDL-C), and LDL/high-density lipoprotein (HDL) ratio while increasing insulin, total protein content, high-density lipoprotein cholesterol (HDL-C), and protein.

Figure 3 exhibits the mechanism of jackfruit in antidiabetics.

Antioxidant potential of jackfruit

Oxidative stress is a by-product that causes a variety of diseases. Antioxidants, including natural antioxidants and synthetic antioxidants, are effective in preventing the production of free radicals (Caleja et al., 2017). Phenolic compounds exhibit numerous benefits for the human body, including but not least inhibiting reactive oxygen and nitrogen species, transferring electrons to free radicals, activating antioxidant enzymes, and alleviating oxidative stress (Cheng et al., 2024). Jackfruit peel, pulp, and seeds contain abundant phenolic compounds that provide its antioxidant potential, showcasing its ability to combat oxidative stress–related conditions. Additionally, jackfruit is a source of carotenoids, particularly beta-carotene, contributing to its vibrant colour (Maoka, 2020) and playing a crucial role in preventing oxidative damage to lipids and proteins (Swapnil et al., 2021). Jackfruit is rich in antioxidants, and including jackfruit in the diet may be associated with a reduced risk of chronic diseases, which is consistent with the broader health-promoting effects of a plant-based diet.

Zhang et al. (2017) used the methanolic extraction from different parts of jackfruit, including peel, pulp, seed, and flake, to explore the antioxidant capacity by DPPH and ABTS assays. The outcome is that peel has the highest antioxidant capacity; the IC_{50} of DPPH is 1.25 ± 0.14 mg/ml, while that of pulp, flake, and seed are all over 10 mg/ml. The IC50 of ABTS is 0.23 ± 0.02 mg/ml; that of pulp, flake, and seed is 5.70 ± 0.37, 8.21 ± 0.25, and 7.62 ± 0.13 mg/ml, respectively.

Ajiboye et al. (2016) explore the antioxidant ability from the ethanolic extract of jackfruit stem bark by DPPH, FRAP, hydroxyl radical scavenging, and Fe^{2+}-chelating ability with different sample concentrations (1–5 mg/ml). The results demonstrated that all four assays show a dose-dependent tendency and a higher standard control group. The highest value of each assay is when the concentration of sample is 5 mg/ml. However, there are no specific data shown in the paper, but the values are around 85%, 85%, 95%, and 70% for DPPH, FRAP, hydroxyl radical scavenging, and Fe^{2+}-chelating ability, respectively.

Jagtap et al. (2010) conducted an *in vitro* analysis of the antioxidant activity of jackfruit pulp. Their findings indicated that the methanolic extract had promising DPPH radical scavenging activity with an IC_{50} of 0.4 mg/ml. for FRAP, 5 mg/ml concentration showed 1.7 mM TEAC/g for methanolic and 1.4 mM TEAC/g for water extract; for DMPD, the IC_{50} was as follows: 3.43 mg/ml for methanolic extract, 3.6 mg/ml for ethanolic extract, and 3.9 mg/ml for water extract.

Likewise, Loizzo et al. (2010) investigated the antioxidant properties of *Artocarpus heterophyllus* leaf total water extraction, and aqueous and ethyl acetate fractions. For assays, DPPH, FRAP, ABTS, and Fe^{2+}-chelating activity had been determined. Total water extract has the highest phenolic content, which is 523.2 ± 1.1 mg catechin per gram dry extract. Different antioxidant assays have different patterns for each fraction; for DPPH and Fe^{2+}-chelating assays, the ethyl acetate fraction has the highest IC_{50}, which are 235.8 ± 2.9 and 251.8 ± 3.3 μg/ml, respectively. Total water extract has the highest value in FRAP and ABTS assays, which are 565.8 ± 2.5 μM Fe (II)/g and 34.8 ± 1.03 Trolox equivalent value.

A subsequent investigation by Jagtap et al. (2011) checked the antioxidant activity of jackfruit extract-based wine (JFW) and observed an increase in the DPPH radical–scavenging activity of the JFW from 28% to 69% when concentration was increased from 100 to 500 μl, while the absorbance value of FRAP was from 0.123 ± 0.041 and 0.316 ± 0.004 for 100 and 300 μl of JFW. N, N-dimethyl-p-phenylenediamine (DMPD)–scavenging capacity showed 32.60 ± 2.19% at 10 μl and 78.45 ± 0.05% at 50 μl, and nitric oxide (NO) exhibited the highest 62.46 ± 0.45% at 500 μl of JFW.

Daud et al. (2017) conducted the antioxidant potential of jackfruit in different fractions like rind and rachis with three different extraction techniques: soxhlet, percolation, and maceration. Throughout the three antioxidant assays, the rind extracts consistently exhibited stronger antioxidant efficacy than the rachis, while the maceration showed higher antioxidant efficacy among the three different extraction methods. There was the outcome from rind extracted by maceration, 94.4 ± 0.1% DPPH inhibition rate, 26.4 ± 0.7 μM TE/ml of FRAP, and 59.0 ± 1.0% β-carotene bleaching.

In a study conducted by Zhu et al. (2017), the water-soluble polysaccharide extracted from *A. heterophyllus* fruit pulp was found to exhibit notable DPPH and OH activities. When the concentration of polysaccharides is from 0.25 to 4 mg/ml, the scavenging abilities of DPPH were from 21.82 to 69.64%. The OH-scavenging abilities of 1 mg/ml concentration are 68.30%. These two assays are all dose dependent. However, an observed decrease in reducing activity was noted with increasing extract concentrations may be because they utilised polysaccharides instead of polyphenols. In another study by Zhu et al. (2019), the antioxidant potential of *A. heterophyllus* fruit pulp polysaccharides were assessed through *in vitro* saliva, gastric, and intestinal digestion; the outcome exhibited that OH-scavenging activities were time dependent that after the digestion of intestine for 1, 2, and 4 hr, the value continuously increased to 79.4 ± 2.25%, 86.99 ± 1.36% and 95.09 ± 2.13%, respectively. That of superoxide anion radical scavenging abilities were 42.68 ± 2.36%, 49.98 ± 2.78%, and 54.68 ± 2.98%, respectively. The outcome of DPPH was 2.18 ± 0.29%, 4.14 ± 1.71%, and 7.09 ± 0.27%, separately, and the reducing power ability is very low.

Zhang et al. (2021a) obtained nonextractable polyphenols from the dietary fibre of jackfruit pulp by alkaline, acidic, and enzymatic hydrolysis and conducted *in vitro* antioxidant activity. The alkaline extract exhibited superior ABTS scavenging, around nine and four times higher than that of acidic and enzymatic extracts. Same tendency was observed in peroxyl radical–scavenging and oxygen radical–scavenging capacities results.

In a separate study, Calderón-Chiu et al. (2021) observed that the *A. heterophyllus* leaf protein demonstrated notable DPPH and ABTS radical–scavenging activities. Interestingly, when hydrolysed with pancreatin and pepsin, the leaf protein concentrate exhibited varying radical quenching activities, with pancreatin hydrolysis showing superior effects. The values for $DPPH^+$ and $ABTS^+$ were 72.38% at 0.1 mg/ml and 98.20% at 0.8 mg/ml, respectively. When the proteolysis time is 240 min, the IC_{50} reached the highest; for pancreatin, the IC_{50} of ABTS and DPPH are 0.206 ± 0.005 and 0.025 ± 0.003 mg/ml, respectively.

Conclusively, jackfruit, rich in flavonoids, phenolic acids, and carotenoids, exhibits significant antioxidant potential, with variations observed in different parts such as pulp, leaves, and stem bark. Extraction methods influence antioxidant efficacy, highlighting the diverse health-promoting properties of distinct jackfruit components.

Anticancer action

Cancer, a complex and multifaceted disease, poses a significant global health challenge, and exploring effective strategies for its management is crucial. Plant polyphenols, bioactive compounds found in fruits, vegetables, and herbs, have emerged as promising agents for anticancer effects by modulating cell cycle signalling, neutralising carcinogenic agents, activating antioxidant enzymes, inducing apoptosis, and arresting the cell cycle (Briguglio et al., 2020).

Zheng et al. (2014) examined the antiproliferative effect of 33 compounds present in jackfruit wood extract through three cancer cell lines (MCF-7, SMMC-7721, and NCI-H460 cells). They found that artocarpin and cudraflavone C exhibited a stronger inhibitory effect on cancer cell growth, in the SMMC-7721 cell line, the IC_{50} is 15.85 and 12.06 μM, respectively. In the NCI-H460 cell line, cudraflavone C (IC_{50} 5.19 μM) exhibited higher cytotoxicity. Liu et al. (2020) reported that 12 prenylated chromones isolated from jackfruit exhibited significant antiproliferative effects against various cancer cell lines (MCF-7 cell line, SMMC-7721 cell line, HL-60 cell line, SW480 cell line, and A-549 cell line), with IC_{50} values ranging from 0.36 ± 0.02 to 22.09 ± 0.16 μM.

Morrison et al. (2021) enriched 84% artocarpin from methanolic extraction of jackfruit wood pulp, which exhibited the irreversible inhibition kinetics against P450 CYP2C enzymes, with an IC_{50} value of 0.46 μg/ml by *in vitro* analysis. Through the AOM/DSS colitis–induced cancer mice model, the mice with jackfruit extract treatment exhibited a threefold reduction in *Cyp2c37* gene expression. Likewise, Sun et al. (2017) reported that artocarpin present in jackfruit exhibited a dose-dependent manner in exhibiting potent cytotoxicity against human colon cancer cells and the IC_{50} values at around 15 μmol/L artocarpin induced apoptosis and autophagy, which has been supported by poly(ADP-ribose) polymerase (PARP) cleavage and the up-regulation of LC3B expression. In addition, artocarpin induced G1 phase cell cycle arrest. In the mice model, oral administration of artocarpin for 16 weeks significantly increased the survival rate and reduced the multiplicity of colonic neoplasms by 56%.

One of the promising phytochemicals in jackfruit, brosimone-I, induced cell cycle, G1 cycle, apoptosis, cell growth inhibition, ER stress, and cytotoxicity (Zhao et al., 2019), which was determined through *in vitro* in human colon cell line, HCT116 and CCD-841CoN. Brosimone-I, in HCT116 cell line, in suppressing cell viability with IC_{50} about 14 μM, increased the percentage of cells in the G1 phase in a dose-dependent manner, exhibited the cell apoptotic response, increased the level of phosphorylated AMPK, and induced cytotoxicity by increasing the cytosolic Ca^{2+} level and ER stress.

Through human breast cells T47D, artocarpin showed the induction of cell apoptosis (Arung et al., 2010a). Different concentrations of artocarpin (5.7, 11.5, 20, and 28.7 μM) were dissolved into dimethyl sulfoxide (DMSO) and incubated for 24 hr to analyse the cell viability. The outcomes showed that the IC_{50} is 12.6 μM. Based on this result, cell and nuclear morphology, sub-G1 apoptosis, and the apoptotic signalling pathway were conducted with the concentrations of 5.7, 12.6, and 20 μM. The cell morphology changed with the 12.6 μM treatment, and the percentage of cell in sub-G1 increased with increased concentration of artocarpin; the percentages were 0.89%, 25.71%, and 82.86%, respectively. The cleaved-caspase 3 and 8 increased with the concentration increase, and the caspase 10 decreased.

Jackfruit pulp extract also demonstrated antiproliferative activity, according to the research by Ruiz-Montañez et al. (2015). Two maturity stages of jackfruit were used, and three solvents (acetone, methanol, and hexane) were used to extract and partition. Methanol–hexane commercial jackfruit extract has significant antimutagenicity activities, which exhibit a dose-dependent manner and a revision rate achieved by 500 ng AFB1 and chosen for further fraction by HPLC. Four fractions were obtained: F1, F2, F3, and F4. Subfraction F1 ($IC_{50} = 49.2$ μg/ml) showed the highest antiproliferative activity in the cell line M12.C3.F6. Cancer cell lines PC-3, NCI-H460, and/or A549 were inhibited from proliferating by bioactive substances, artocarmitin B, artocarpin, and cudraflavone C, found in *A. heterophyllus* leaves (Wang et al., 2017).

In a study conducted by Braz et al. (2016), observed that administration of ArtinM at a dose of 50 μg/kg resulted in a reduction in the number of preneoplastic lesions and a decrease in proliferating cell nuclear antigen (PCNA)–positive cells in DEN (diethyl-nitrosamine)-induced Wistar rats. In addition, these rats decreased the proliferating cell nuclear antigen (PCNA), increased nuclear p21 and p27 staining, heightened the expression of p53 and p21, and upregulated the p42/44 MAPK pathway, which are involved in apoptosis and stress response. Additionally, there is increased expression of TNFα and IFNγ genes, indicating an inflammatory response.

Similar findings were also observed by Carvalho et al. (2011) who demonstrated by human myelocytic leukaemia cell lines NB4, K562, and U937. NB4 showed the highest intensity of ArtinM binding, which may be the result of higher levels of N-acetylglucosaminyltransferase V transcripts, IC_{50} of NB4, K562, and U937 cells were 10 (±1), 14 (±1), and 84 (±1.5) μg/ml. The mechanism is ArtinM treatment induced reactive oxygen species generation and autophagy, which is due to ArtinM recognising the trimannosyl core of N-glycans that have a β1,6-GlcNAc branch connected to α1,6-mannose.

These findings suggest that jackfruit constituents possess a variety of anticancer properties and may hold potential for the development of novel cancer therapies. Further research is warranted to fully elucidate the mechanisms of action and clinical efficacy of these compounds.

Obesity and associated complications

Obesity stands as a major contributor to a spectrum of health issues, with a particularly pronounced connection to cardiovascular complications. The increased adiposity associated with obesity often leads to an unfavourable lipid profile, characterised by elevated levels of triglycerides, low-density lipoprotein cholesterol (LDL-C), and reduced levels of HDL-C, collectively known as dyslipidaemia. This dyslipidaemia, coupled with the chronic low-grade inflammation that accompanies excess adipose tissue, contributes to the development of atherosclerosis (Bays et al., 2024). Atherosclerosis, characterised by the plaque build-up in the arteries, leads to narrowed and hardened arteries, raising the risk of cardiovascular events such as heart attacks and strokes (Lusis, 2000). Large-scale prospective research has suggested that hypertension, dyslipidaemia, diabetes, and other comorbidities play a major role in mediating the relationship between obesity and cardiovascular disease (Powell-Wiley et al., 2021).

Studies have shown that jackfruit has potential benefits for lipid profile management and weight management. As a low-fat fruit that is rich in dietary fibre, jackfruit contributes to a feeling of fullness and promotes weight control by reducing calorie intake (Parihar et al., 2021). The dietary fibre content also plays a key role in regulating blood cholesterol levels. Additionally, jackfruit contains carotenoids, which help to prevent chronic degenerative diseases such as cardiovascular disease (Ranasinghe et al., 2019). More research is needed in the future to fully understand the mechanism of jackfruit on lipid profiles and weight management through animal model and clinical trials.

Similarly, Rao et al. (2021) found that replacing rice or wheat flour with green jackfruit flour in daily meals significantly reduced plasma glucose levels in type 2 diabetes mellitus (T2DM) patients. Those supplemented with jackfruit flour exhibited a notable decrease in HbA1c at Week 12, in contrast to a slight increase in the placebo group (−2.73 mmol/mol (−0.25%) versus 0.22 mmol/mol (0.02%), $p = .006$). Fasting and postprandial glucose levels were significantly lower in the jackfruit flour group at week 12 ($p = .001$). Continuous glucose monitoring (CGM) indicated reduced blood glucose levels in the jackfruit flour group, but a general decrease was observed in both groups, potentially influenced by a CGM placebo effect.

Koh et al. (2023) carried out a study to compare SCOBY jackfruit drinks made by pulp and leaves with orlistat for weight management in high-fat diet–fed obese mice. The jackfruit drink significantly reduced body weight (18.5%–20.2%) without negative effects on blood composition or inflammation. Gene expression related to metabolism and inflammation in adipose tissues was also reduced. These drinks also positively influenced gut microbiota composition.

Zhang et al. (2021d) used 16S rRNA and shotgun metagenomic sequencing to study the effects of jackfruit seed–sourced resistant starch (JSRS) on mice gut microbes and hyperlipidaemia. The findings indicated that a 10% JSRS diet did not have a significantly preventive effect on body weight and serum lipid levels. In a 16s rRNA high-throughput sequencing analysis, adding JSRS would correct the dysbiosis of intestine caused by high-fat diet. High-throughput 16s rRNA sequencing and an *in vitro* experiment showed that *Bifidobacterium pseudolongum* is the dominant species in the mouse gut, and it could grow by using JSRS as the primary carbon source.

Aulia et al. (2019) evaluated the impact of jackfruit peel extract on the lipid profile of rats subjected to a high-fat diet. Using an experimental post-test-only control group design, male white Wistar rats were divided into negative control, positive control, and treatment groups receiving jackfruit extract at doses of 500 mg/200 gBW/day and 750 mg/200 gBW/day for 14 days. The study revealed significant differences in cholesterol, triglyceride, LDL, and HDL parameters ($p < .05$) with dose-dependent but was less effective than simvastatin. Overall, both doses of jackfruit peel extract were found to decrease the lipid profile in rats fed a high-fat diet.

Supplementation of jackfruit seed powder (JSP) effectively prevents excessive body weight gain and bulimia induced by high-sugar diets (HSDs) in mice (Goswami et al., 2021). Six-week-old Swiss albino male mice were used in the experiment, the HSD addition increased the food intake, and this was reversed by JSP (HSD is 42.50 ± 4.57 g, HSD + JSP is 36.00 ± 1.73 g), and the body weight of mice with JSP treatment is lower than the HSD group, which are 33.25 ± 0.75 g and 41.75 ± 3.94 g, respectively. The blood sugar also decreased with JSP addition (221.83 ± 20.94 mg/dl), compared with the HSD group (333.25 ± 24.43 mg/dl), although it is not as same as normal control (187.40 ± 10.85 mg/dl). In addition, JSP significantly reduced the serum total cholesterol (TC) and triglyceride (TG) levels.

In summary, jackfruit has great potential in antidiabetic and antiobesity areas, especially the jackfruit seed flour (JSF) and starch that have been the commercial products in market. Further research would be focus on the clinical trial and commercial product development.

Immunomodulatory effects

Plant polyphenols, a diverse group of bioactive compounds found in fruits, vegetables, tea, and other plant-based foods, have immunomodulatory effects (Scalbert et al., 2005). Polyphenols possess the ability to modulate the immune system, affecting both innate and adaptive immune responses. Studies have demonstrated that plant polyphenols can enhance the activity of immune cells such as macrophages, natural killer cells, and T lymphocytes, thereby improving defence mechanisms against infections and diseases (Mamun et al., 2024).

In addition, plant polyphenols regulate cytokine production and interfere with the regulation of immune cells and gene expression to exhibit the anti-inflammatory property (Yahfoufi et al., 2018). The immunomodulatory effects of polyphenols have implications for various health conditions, including autoimmune disorders, allergies, and inflammatory diseases. Furthermore, the antioxidant properties of plant polyphenols play a role in reducing oxidative stress, contributing to overall immune system health (Rudrapal et al., 2022). While the mechanisms underlying the immunomodulatory effects of plant polyphenols are complex, more and more research highlights their potential as natural agents to support and regulate immune function, such as flavonoids (García-Lafuente et al., 2009).

Jackfruit has gained attention because of its potential immunomodulatory properties, which are attributed to its rich content of bioactive compounds such as polyphenols and peptides. Studies have explored the immunomodulatory effects of jackfruit components, revealing their ability to modulate immune responses and enhance defence mechanisms. Ma et al. (2021) analysed the cofermented collagen peptide–jackfruit juice (FPJ) on immune response in immunosuppressed mice. After the FPJ treatment, the thymus and spleen indexes increased to 2.27 ± 0.15 mg/g and 5.33 ± 0.12 mg/g, respectively. It also alleviated the pathological damage symptom that the model group mice have, including fewer goblet cells and mucins. Treatment of FPJ led to a significant increase in cytokines and immunoglobulins, including IFN-γ, TNF-α, IL-2/6/17, IgA/M/G.

Hao et al. (2020) explore the immunomodulatory effects of oligopeptides derived from jackfruit pulp and seeds (JOPs) through intragastric administration to female BALB/c mice with different concentrations (0.20, 0.40, and 0.80 g per kg BW). The results exhibited that JOPs did not influence the body weight and thymus index but has the spleen index significantly increased. 0.40, and 0.80 g per kg BW treatment significantly enhanced the ConA-stimulated proliferation of splenic lymphocytes and the footpad thickness of mice. JOPs enhanced humoral immunity through two assays, IgM-plaque-forming cell (IgM-PFC) test and serum haemolysin level. The outcomes exhibited that at doses of 0.40 and 0.80 g per kg BW, JOPs increased IgM-PFC by 27.67% and 24.11%, while HC50 values increased by 13.18% and 16.76%, respectively. Compared with the vehicle group, there were carbon clearance index growths of 16.10%, 29.03%, and 32.21%, while the phagocytic rate was increased by 23.93%, 50.61%, and 42.54% for 0.20, 0.40, and 0.80 g per kg BW, respectively. 0.40 and 0.80 g per kg BW treatment significantly improved the activity of NK cells by 55.53% and 57.37%, respectively. The value of $CD3^+$, $CD4^+CD25^+/CD4^+$, and $CD3^+CD4^+$significantly increased with 0.40 and 0.80 g per kg BW JOP treatment. In addition, IL-1α, IL-10, TFN-α, serum IgM, IgA, and SIgA levels increased with the IFN-γ level decreased. These results indicate that JOP treatment might be a good way to address immune dysfunction.

Additionally, ArtinM, a lectin isolated from jackfruit seeds, has shown the potential in modulating immune responses. Leandro Peixoto Ferreira de Souza et al. (Ramos et al., 2016) investigated the immunostimulatory effects of ArtinM against *Toxoplasma gondii*-induced toxoplasmosis by using female B57BL/6 mice. The study revealed that ArtinM treatment at different concentrations significantly enhanced the viability of bone marrow-derived macrophages. Moreover, ArtinM stimulated the production of nitric oxide (NO) in macrophages and modulated the production of interleukin-10 (IL-10) and interleukin-12 (IL-12), while ArtinM treatment significantly increased the survival rate of infected mice compared to nontreated mice.

Ruas et al. (2018) explored the effects of ArtinM lectin from jackfruit seeds on peripheral blood cells of patients with paracoccidioidomycosis (PCM) and the healthy individuals' blood cells that infected by fungal yeasts (*Paracoccidioides brasiliensis*) *in vitro*. After 18-hr treatments with ArtinM, neutrophils infected with *P. brasiliensis* were observed TNF-α production increment. ArtinM can also stimulate TNF- α and IL-8 in neutrophils from patients with PCM, and the IL-8 level was even eight times higher than the unstimulated cells. Notably, the stimulation of ArtinM did not rely on Dectin-1, which is a β-glucan receptor that participates in the cell response of fungal recognition. In addition, ArtinM enhanced the dextran internalisation of neutrophils and increased the killing capacity of neutrophils and macrophages.

Antimicrobial property

Microorganisms have a significant impact on health; from a negative aspect, microorganisms lead to various diseases through direct infection or through body immune response to their presence.

Vázquez-González et al. (2020a) investigated the antifungal potential of jackfruit leaf extracts using hexane, ethanol, ethyl acetate, acetone, methanol, and water solvents. Two milligrams per millilitre showed the highest percentages of inhibition. Ethanolic extract against *Colletotrichum gloeosporioides* with 83.78 ± 1.25% inhibition rate and methanolic extracts has 66.45 ± 5.92% inhibition rate against *Penicillium italicum*. Using 80% ethanol to explore the antifungal effects of different extraction methods, the outcomes exhibited that high hydrostatic pressure has the highest inhibition rate; for *C. gloeosporioides*, 5 mg/ml has the highest inhibition percentage, which is 55.41 ± 2.44%. For *P. italicum*, 2 mg/ml has the highest value (46.49 ± 6.49%).

In another study by Loizzo et al. (2010), total water extract, ethyl acetate, and aqueous fraction of leaf extracts were evaluated. All the samples can inhibit the *E. coli*, *Listeria monocytogenes*, *Salmonella typhimurium*, *Salmonella enterica*, *Enterococcus faecalis*, and *Staphylococcus aureus*. In addition, total water extract exhibited the highest inhibitory activity against *S. aureus* (15 ± 1 mm). That of ethyl acetate fraction is against *S. enterica* (13 ± 1 mm), while for the aqueous fraction, there is a significant inhibition against *L. monocytogenes* (15 ± 1 mm) and *E. faecalis* (13 ± 1 mm).

Septama and Panichayupakaranant (2015) explore the antibacterial effects of jackfruit heartwood extract. Four compounds were purified. The first one is cycloartocarpin, which has moderate antibacterial activities with MIC and MBC values of 35.9 to 143.6 μM. The second is artocarpin, and it exhibited the strongest antibacterial activities against *Streptococcus mutans*, *S. pyogenes*, *Bacillus subtilis*, *S. aureus*, and *S. epidermidis* with MICs and MBCs of 4.4–17.8 and 8.9–17.8 μM. Artocarpanone showed strong antibacterial activity against *S. mutans*, *S. pyogenes*, and *B. subtilis* with MIC values of 25.8 μM and MBCs of 51.6–103.2 μM. The last one is cyanomaclurin, and it showed strong antibacterial activity against *S. mutans* and *E. coli*; the MIC values of Compound 4 were 6.8 and 27.2 μM, and MBCs were 54.4 and 54.4 μM.

Additionally, jackfruit seed extracts showed antibacterial efficacy (Eve et al., 2020). Ethanolic and hexane extraction has the inhibition ability against methicillin-resistant *S. aureus* (MRSA), methicillin-susceptible *S. aureus* (MSSA), and multidrug-resistant *P. aeruginosa* (MDR PA). There is no dose dependency; the 500 mg/ml has no significant difference with the 1,000 mg/ml. The mean inhibition zone diameters of ethanolic against MRSA, MSSA, and MDR PA were 15.0 ± 1.0, 15.0 ± 2.0, and 11.0 ± 1.0 of 1,000 mg/ml concentration. That of hexane extract were 16.5 ± 0.5, 16.0 ± 1.0, and 9.0 ± 1.0, respectively. The MIC of ethanolic and hexane against MRSA, MSSA, and MDR PA were 62.5, 31.25, and 125 and 125, 62.5, and 125 mg/ml, respectively. That of MBC were 250, 125, and >500 and 250, 250, and >500 mg/ml.

Additionally, Septama et al. (2017) investigated the interaction between artocarpanone, a compound from jackfruit, and tetracycline, ampicillin, and norfloxacin. The MIC value of artocarpanone against *E. coli*, *P. aeruginosa*, and MRSA were 7.8, 500, and 125 μg/ml, respectively. Interaction between artocarpanone (125 μg/ml) and norfloxacin (0.9 μg/ml) has the additive effect against *P. aeruginosa*, 125 μg/ml. Artocarpanone (3.9 μg/ml) exhibited an additive effect on the antibacterial activity of tetracycline (1.9 μg/ml) against *E. coli*. Notably, the interaction between artocarpanone (31.2 μg/ml) and tetracycline (31.2 μg/ml) and ampicillin (15.6 μg/ml) showed additive effects against MRSA, while the interaction between artocarpanone and artocarpanone (3.9 μg/ml) exhibited synergistic effects.

These findings collectively underscore the antibacterial and antifungal potential of different jackfruit extracts and compounds, suggesting their potential applications in the pharmaceutical and food industries.

Antiviral property

Viruses are infectious agents that rely on host cells to replicate. Researchers have investigated the antiviral potential of jackfruit concerning specific viruses.

Fu et al. (2020) evaluated the antiretroviral activity of prenylated compounds derived from ripe jackfruit pulps against human immunodeficiency virus-1 (HIV-1) reverse transcriptase. Twelve prenylated chromones showed significant anti-HIV activities with EC_{50} values ranging from 0.09 to 9.72 μM, especially for the artocarheterones A (0.09 μM) and cnidimol D (0.26 μM) that might be the oxidised isopentenyl group connected to C-6.

Jackfruit leaf extracts with different solvents (ethanol 80%, hexane, dichloromethane, and methanol) had been explored for their antiviral effect (Hafid et al., 2017). The dichloromethane extract exhibited strong anti-HCV activity with an IC_{50} value of 1.5 ± 0.6 μg/ml; the mechanism is that these extracts kill the viral and target host cells by time-of-addition assay.

Another study (de Sousa et al., 2020) explored the antiherpesvirus effect for different processes (dry and fresh) of jackfruit leaves with different extract solvents (methanol, ethanol, and hexane). Fresh leaves extraction, even in high concentrations of 1,000 μg/ml, caused less than 10% haemolysis, while dry leaves caused 85% haemolysis at 1,000 μg/ml. Fresh ethanolic extract showed highest inhibition percentage (IP) (76.01%) against equine alfa herpesvirus 1 (EHV-1), dry methanolic extract has the highest inhibition ability against alfa herpesvirus 1 (SuHV-1), with the IP value of 94.38%, and fresh methanolic extract exhibited the highest IP (99.2%) against bovine alfa herpesvirus 1 (BoHV-1).

In an *in vitro* study by Permanasari et al. (2021), the antiviral potential of dichloromethane extracts from *A. heterophyllus* leaves was investigated, focusing on four fractions and seven subfractions. The researchers conducted a comprehensive assessment, including virucidal activity testing and examination of viral adsorption. Notably, subfraction FR3T3 demonstrated remarkable anti-HCV activity in Huh7it-1 cells with the least toxicity, displaying an IC_{50} of 4.69 ± 0.95 μg/ml. Mode-of-action analysis revealed that FR3T3 primarily targeted postviral entry stages, inhibiting events such as HCV NS3 protein expression and HCV RNA replication, with minimal impact on the viral entry stage. Intriguingly, when the dichloromethane leaf extract (1.5 μg/ml) was combined with various antiviral drugs, including ribavirin, cyclosporin, or simeprevir, synergistic effects were observed. This study sheds light on the potential of *A. heterophyllus* leaf extracts, particularly subfraction FR3T3, as a promising candidate for antiviral interventions against HCV, and highlights the synergistic effects when used in combination with existing antiviral drugs. Further studies are needed to confirm the efficacy of this extract in clinical settings, in order to develop therapeutic agents that could be effectively used in the treatment of HCV.

Wound healing

Polyphenols, abundant in various plant sources, including *A. heterophyllus*, are a crucial factor in wound healing (Zhao et al., 2023). These bioactive compounds exhibit antioxidant, anti-inflammatory, and antimicrobial properties, contributing to their beneficial effects on the wound-healing process. Jackfruit, known for its rich polyphenolic content, may offer unique advantages in wound healing. Specific polyphenols found in jackfruit, such as flavonoids and tannins, have been associated with wound-healing properties. Flavonoids, one of the families of polyphenols, possess anti-inflammatory, angiogenesis, re-epithelialisation, and antioxidant effects contributing to wound-healing properties (Zulkefli et al., 2023).

Previous research found that the methanolic bark extract of *A. heterophyllus* has a comparable effect to standard (Betadine) ointment for the excision model with rats (Raghuvanshi et al., 2010). After 16 days of treatment, the negative control animals group showed 10.66 ± 5.33 of wound area whereas the Betadine-treated group showed 0.1 ± 0.200 wound areas and the extracts treated exhibited 3.9 ± 1.137 wound areas. The *p*-value is <.001, which means there is a significant difference between the control and the extract treatment group. Another study explores the wound-healing effect of the jackfruit leaf ethanolic extract gel (JLEEG) after tooth extraction by using a diabetic rat model. The result, 15%, was thought to be the most beneficial concentration for reducing inflammation and speeding up the healing process of tooth extraction wounds in diabetes rats (Amin[1] & Pamasja, 2021).

White male rats were used to determine the ethanolic extract of jackfruit leaves, with 1%, 2%, and 3% concentrations. The positive control is brand X ointment (Maria Erista et al., 2024). Unfortunately, the concentration of 1% and 2% did not show significant change on wound area recovery (from 1 to 0.3 cm) while 3% concentration showed a less significant change (from 1 to 0.2 cm).

Another study used the Sprague–Dawley rats to explore the activity of ethanolic extract from jackfruit leaves on burn wounds showed different results (Solihah et al., 2024). Medical standard, Lanakeloid cream, treatment was used as a positive control. Different concentrations of extract, 94, 188, 376 mg/kg body weight, were the test group. The outcome was presented as burn wound area (cm^2), recovery on day 14th (%), recovery rate each day (%), and time recovery (day). All the parameters showed that the leaf extract had a significant effect on burn wound recovery, with dose dependency. The highest doses, 376 mg/kg BW, reached the 100% recovery on 14th, compared with the Lanakeloid cream 89.91 ± 5.18%.

However, further research is warranted to elucidate the specific mechanisms and identify the key polyphenolic compounds responsible for the observed effects. Nonetheless, the wound-healing perspective of polyphenols, particularly in the context of jackfruit, underscores the potential therapeutic applications of plant-derived compounds in promoting efficient and effective wound recovery.

Current and potential application in product development

Traditional use of jackfruit

Medical use is one of the traditional applications for jackfruit, including the treatment of inflammation, diarrhoea, and diabetes mellitus. The following research revealed that jackfruit contains numerous bioactive compounds, such as flavonoids, stilbenoids, aryl benzofurans, and lectin jacalin, which bring the biological activity to jackfruit (Tripathi et al., 2023).

Jackfruit seeds, rich in protein, are often cooked or roasted and consumed as a snack or incorporated into savoury dishes (Khan et al., 2023). The seeds are dried to create seed flour, which has a higher nutraceutical value and can be used in various meals, such as yoghurt, sweets, ice cream, and marmalades (Fabil et al., 2024).

Young jackfruit is used in cooking a variety of dishes in central Java (Indonesia), including *sayur lodeh*, *sayur megana*, *oseng-oseng gori*, and *jangan gori* (Yudhistira, 2022). In addition, jackfruit can be used as meat alternative in Asian-style curry (Khan et al., 2023b).

Jackfruit leaves are employed for wrapping and steaming food items. Leaves also have a positive effect in activating women's and animals' milk, while it is a source to treat syphilis and vermifuge. Furthermore, leaves position a role in the wound-healing area, such as leaf ash for ulcer wounds (Balbach & Boarim, 1992; Jagtap & Bapat, 2010).

The heartwood of jackfruit is used as dye to colour robes of monks, and they redye the robe instead of washing. This kind of robe has an antifungal property (Jagtap & Bapat, 2010).

Current product and potential development

Jackfruit (*A. heterophyllus* Lam.) has gained prominence in various food applications due to its diverse and versatile nutritional composition. The fruit, seeds, and leaves of jackfruit are utilised in a range of culinary contexts. The nutritional richness of jackfruit, including its protein, dietary fibre, vitamins, and minerals, contributes to its appeal in food applications (Ranasinghe et al., 2019). Jackfruit also offers versatile applications in processed foods, leveraging its various parts for culinary innovation.

General food and nonfood applications

Jackfruit seeds, rich in protein, are utilised in the production of flour and can be incorporated into baked goods, including bread and cookies, providing a nutrient-dense and gluten-free option, but, for achieving gluten-free option, further improvement in sensory value is needed. The technique of making flour from jackfruit seeds involves drying and grinding into flour and storing them in hermetically sealed containers (Akter, 2018). The JSF has great potential in the bakery. A combination of JSF and wheat flour increases the nutritional value of paste (Abraham & Jayamuthunagai, 2014). The colour and texture of bread and biscuit recipes with 10% and 20% JSF were better. The ash and crude fibre content of biscuits manufactured with JSF was higher, but the carbohydrate content was lower (Butool & Butool, 2015). By combining JSF and wheat flour in varying amounts for toasted bread, it indicates that using JSF in place of bread is the best choice (Hossain et al., 2014). Latest research demonstrated that cookies made by JSF and wheat flour with a 25:75 ratio maintained comparable quality to the control sample (100% wheat flour) over the 15-day period and most preferred acceptability. However, 50% and 100% JSF had slight differences in texture and taste as compared to the control sample and 100% jackfruit cookie had received neutral ratings in the hedonic sensory test, suggesting that full replacement of wheat with JSF might affect texture and flavour, which impacted consumer satisfaction (Nordin et al., 2024). The use of JSF in cookies not only lowers waste from jackfruit seeds but also lowers baking costs, according to recent research on the development of JSF and its usage in cookie manufacturing (Binti Nordin et al., 2024). Jackfruit seeds contain a notable amount of starch and protein. Recent research has highlighted the potential of jackfruit seed starch in the pharmaceutical industry, such as pharmaceutical biopolymeric raw materials (Nayak et al., 2022).

Additionally, young jackfruit, with its mild taste and ability to absorb seasonings, is employed in the creation of processed savoury products like canned curries, soups, and ready-to-eat meals, contributing to the growing market for convenient and plant-based food options (Khan et al., 2023a). The culinary versatility of jackfruit, showcased in a range of processed foods, highlights its potential as a sustainable and nutritious ingredient in the evolving landscape of plant-based and alternative protein products. This would be discussed more specifically later.

Table 4. Summary of jackfruit's healthy benefits.

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antibacterial	Heartwoods	Cycloartocarpin (1), artocarpin (2), artocarpanone (3), and cyanomaclurin (4)	Ethyl acetate	Purified compound	Disc diffusion method	Cycloartocarpin: moderate antibacterial activities with MIC and MBC values of 35.9–143.6 μM; Artocarpin: exhibited the strongest antibacterial activities against *Streptococcus mutans*, *S. pyogenes*, *B. subtilis*, *S. aureus*, and *S. epidermidis* with MICs and MBCs of 4.4–17.8 and 8.9–17.8 μM, respectively; artocarpanone: strong antibacterial activity against *S. mutans*, *S. pyogenes*, and *B. subtilis* with MIC values of 25.8 μM, and MBCs of 51.6–103.2 μM; cyanomaclurin: strong antibacterial activity against *S. mutans* and *E. coli* with MIC values of 6.8 and 27.2 μM, and MBCs of 54.4 and 54.4 μM, respectively	Septama and Panichayupakaranant (2015)
Antibacterial	Seeds	Tannins, flavonoids, reducing sugars, cardiac glycosides, saponins, and steroids	Ethanol and hexane	500 and 1,000 mg/ml	*In vitro*, microbial cultures	Ethanolic and hexane extraction has the inhibition ability against methicillin-resistant *S. aureus* (MRSA), methicillin-susceptible *S. aureus* (MSSA), and multidrug-resistant *P. aeruginosa* (MDR PA). There is no dose dependency, the 500 mg/ml has no significant difference with the 1,000 mg/ml. Mean inhibition zone diameters of ethanolic against MRSA, MSSA, and MDR PA were 15.0 ± 1.0, 15.0 ± 2.0 and 11.0 ± 1.0 of 1,000 mg/ml concentration. That of hexane extract were 16.5 ± 0.5, 16.0 ± 1.0 and 9.0 ± 1.0, respectively. The MIC of ethanolic and hexane against MRSA, MSSA, and MDR PA were 62.5, 31.25, 125, and 125, 62.5, 125 mg/ml, respectively. That of MBC were 250, 125, >500 and 250, 250, >500 mg/ml	Eve et al. (2020)
Antibacterial	Heartwoods	Artocarpanone	Ethyl acetate	31.25 μg/ml	*In vitro*, microbial cultures	The MIC value of artocarpanone against *E. coli*, *P. aeruginosa*, and MRSA were 7.8, 500, and 125 μg/ml, respectively. Interaction between artocarpanone and norfloxacin has an additive effect against *P. aeruginosa*, 125 μg/ml. Artocarpanone (3.9 μg/ml) exhibited an additive effect on the antibacterial activity of tetracycline (1.9 μg/ml) against *E. coli*. Notably, the interaction between artocarpanone (31.2 μg and tetracycline (31.2 μg/ml) and ampicillin (15.6 μg/ml) showed additive effects against MRSA, while the interaction between artocarpanone and artocarpanone (3.9 μg/ml) exhibited synergistic effects	Septama et al. (2017)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antibacterial	Leaves	Phenolic contents	Water and ethyl acetate	NA	Disc diffusion assay, minimum inhibition concentrations (MICs)	All samples are able to inhibit *E. coli*, *Listeria monocytogenes*, *Salmonella typhimurium*, *Salmonella enterica*, *Enterococcus faecalis*, and *S. aureus*	Loizzo et al. (2010)
Antibrowning	Wood	NA	95% ethanol	0.03% and 0.05%	Fresh-cut apple	0.03% or 0.05% of *Artocarpus heterophyllus* extract with 0.5% ascorbic acid did not undergo any substantial browning reaction after storage at room temperature for 24 hr	Zheng et al. (2008)
Anticancer	Wood	Phenolic compounds	95% ethanol	10, 25, and 50 μM	Microculture tetrazolium technique for cell viability (MCF-7, H460, and SMMC-7721 human cancer cell lines)	Artoheterophyllins I, artocarpin, cycloartocarpin, and cudraflavone C significantly reduced the cell viability of these cell lines Artocarpin and cudraflavone C resulted in more potent cytotoxicity than the positive control, 5-fluorouracil (5-Fu), in the SMMC-7721 cell line, with IC50 values of 15.85 and 12.06 μM Cudraflavone C exhibited more potent cytotoxicity than 5-Fu in NCI-H460 cell line, with an IC50 value of 5.19 μM Artocarpin and cudraflavone C have anticancer potential *via* MAPK pathways	Zheng et al. (2014)
Anticancer	Leaf	2″-O-β-D-xylosylvitexin	80% ethanol	0–400 μM	Human HepG2 heptoma cancer cells and human MCF-7 breast cancer cells	2″-O-β-D-xylosylvitexin had no significant cytotoxicities to HepG2 and MCF-7 cell	Wen et al. (2017)
Antidiabetic	Leaves	Starch	Water	125–2,000 μg/ml	*In vitro*, α-amylase	Aqueous leaf extract significantly ($p < .05$) inhibited α-amylase activity in rat plasma. The highest inhibitory activity (27.20 ± 5.00%) was observed at a concentration of 1,000 μg/ml. No dose dependency	Kotowaroo et al. (2006)
Antidiabetic	Stem bark	Phenolic compounds	80% acetone	0–100 μg/ml	*In vivo* (Wistar male rats introduce diabetes by streptozotocin injection) and *in vitro* (α-amylase and α-glucosidase inhibitory assays)	Significant ($p < .05$) increases in the inhibitory effects of both free and bound phenol against α-amylase and α-glucosidase in a concentration-dependent manner. The bound phenol has higher inhibitory activity, even higher that standard acarbose.— for *in vivo* experiment, fasting blood glucose levels, body weight, liver glycogen, concentration of insulin, HOMA-IR, HOMA-β, SOD, CAT, GPx, MDA, Carbohydrate Metabolism Enzymes, Glucose Transporter 2 were analysed. All these parameters the diabetic rats with phenol extract from the stem bark of A heterophyllus were trending towards the normal rats. The bound phenol has better effects compared to the free phenols, and even better than the standard medicine (5 mg/kg metformin)	Ajiboye et al. (2020a)

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Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antidiabetic	Leaves	NA	Ethyl acetate	10 and 20 mg/kg	*In vivo*, treptozotocin (STZ)-induced diabetic rat model	In normoglycemic rats, 20 mg/kg of the EA fraction resulted in a significant ($p < .05$) reduction in the fasting blood glucose concentration and a significant improvement in glucose tolerance ($p < .05$), compared to the controls In STZ-induced diabetic rats, chronic administration of the EA fraction of *A. heterophyllus* leaves daily for 5 weeks resulted in a significant lowering of serum glucose, cholesterol, and triglyceride (TG) levels. Compared to control diabetic rats, the extract-treated rats had 39% less serum glucose, 23% lower serum total cholesterol, and 40% lower serum TG levels and 11% higher body weight at the end of the fifth week	Chackrewarthy et al. (2010)
Antidiabetic	Stem bark	NA	Ethanol	50, 100, 150 mg/kg	*In vivo*, male Wistar rats induced diabetes by alloxan of 150 mg/kg body weight	Diabetic control rats showed significant ($p < .05$) weight reduction, abnormal haematological parameters, high serum lipids (except high-density lipoprotein) concentrations, increased creatinine, bilirubin, and urea levels with a decrease in albumin level when compared with nondiabetic control rats. All these alterations were reverted to normal after being administered with different doses of ethanol extract of *A. heterophyllus* stem bark, most especially at 150 mg/kg body weight, which exhibited no significant ($p > .05$) difference with nondiabetic rats	Ajiboye et al. (2018)
Antidiabetic	Stem bark	NA	Ethanol	50, 100, and 150 mg/kg	*In vivo*, male Wistar rats induced diabetes by alloxan of 150 mg/kg body weight	The blood sugar decrease significantly compared with the diabetic rats (308.12 ± 1.10 mg/dL), the results were 94.30 ± 1.10, 88.40 ± 1.12, and 84.20 ± 1.46, respectively. The insulin and HOMA-β levels decreased in alloxan-induced diabetic rats (50.48 ± 0.28 and 4.71 ± 0.16) compared with the normal rats (143.44 ± 1.50 and 81.93 ± 2.20), while the HOMA-IR increased in diabetic rats (5.36 ± 0.03) comparing the normal rats (4.16 ± 0.01). All the treatment groups showed an increase of insulin and HOMA-β and a decrease of HOMA-IR	Ajiboye et al. (2017)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antidiabetic	Leaf	Isoquercitrin	Ethanol (EE), n-butanol (BE), water (WE), chloroform (CE), and ethyl acetate (EAE) extract	0.2, 0.4, and 0.6 mg/ml	*In vivo*, male Wistar rats induced diabetes by streptozotocin with 60 mg/kg	Jackfruit leaf EE and BE extraction have shown appreciable results in decreasing FBG, lipid peroxides, HbA1C, TC, LDL-C, and TG levels and increasing insulin, HDL-C, and protein content.	Omar et al. (2011)
Antidiabetic	Peel	Phenolic compounds	90% methanol	0–20 mg/ml	a-Glucosidase inhibitory activity	Peel extract demonstrated the highest inhibition effects (IC50: 0.05 ± 0.00 mg DM/ml), followed by the seed (IC50: 1.79 ± 0.15 mg DM/ml), pulp (IC50: 6.81 ± 0.52 mg DM/ml), and flake (IC50: mg 10.52 ± 0.73 DM/ml) extraction	Zhang et al. (2017b)
Antidiabetic	Stem bark	Phenolic compounds	70% ethanol	1–5 mg/ml	α-Amylase and α-glucosidase inhibition capacity	The IC_{50} of α-amylase and α-glucosidase are 4.18 ± 0.01 and 3.53 ± 0.03 mg/ml, respectively	Ajiboye et al. (2016b)
Antidiabetic	Seeds	Ethanolic extract	Ethanol	100 mg/kg BW per day and 400 mg/kg BW per day	*In vivo* Wistar albino rats with gestational diabetes mellitus induced by streptozotocin, blood sugar level, HOMA-IR check, insulin check, MDA check, and interleukin-6 check	Reduce blood sugar levels with a dose of extract 400 mg/kg BW	Manurung et al. (2023)
Antidiabetic	Na	Flour	NA	30 g per day	A randomised, double-blind, placebo-controlled study	Those supplemented with jackfruit flour exhibited a notable decrease in HbA1c at week 12, in contrast to a slight increase in the placebo group (−2.73 mmol/mol (−0.25%) versus 0.22 mmol/mol (0.02%), $p = .006$). Fasting and postprandial glucose levels were significantly lower in the jackfruit flour group at week 12 ($p = .001$)	Rao et al. (2021)
Antidiabetic	Seeds	Starch	NA	10% jackfruit seed starch with normal/high-fat diet	*In vivo* 4-week-old C57BL/6 J male mice	10% JSRS diet did not have a significantly preventive effect on body weight and serum lipid levels. In a 16 s rRNA high-throughput sequencing analysis, adding JSRS would correct the dysbiosis of intestine caused by a high-fat diet. High-throughput 16 s rRNA sequencing and *in vitro* experiment showed that *Bifidobacterium Pseudolongum* is the dominant species in the mice gut and it could grow by using JSRS as the primary carbon source	Zhang et al. (2021f)
Antidiabetic	Peel	NA	NA	500 mg and 750 mg/200gBW/day	*In vivo*, male white Wistar rats	Dose-dependent, but not as efficient as simvastatin. Significant differences in cholesterol, triglyceride, and LDL and HDL parameters ($p < .05$)	Aulia et al. (2019)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antidiabetic	Seeds	NA	NA	20% (wt/wt)	*In vivo*, 6-week-old Swiss albino male mice	A high-sugar diet was reversed by the addition of jackfruit seed powder, the body weight of mice with JSP treatment is lower than the HSD group, which are 33.25 ± 0.75 g and 41.75 ± 3.94 g, respectively. The blood sugar also decreased with JSP addition (221.83 ± 20.94 mg/dL), compared with the HSD group (333.25 ± 24.43 mg/dL), although it is not as same as normal control (187.40 ± 10.85 mg/dL). In addition, JSP significantly reduced the serum total cholesterol (TC) and triglyceride (TG) levels	Goswami et al. (2021)
Antifungal	Leaves	Phenolic compound	Hexane, ethanol, ethyl acetate, acetone, methanol, water	0.5, 2, and 5 mg/ml	*In vitro*, mycelial growth	Two milligrams per millilitre showed the highest percentages of inhibition. Ethanolic extract (83.78 ± 1.25%) against *Colletotrichum gloeosporioides* and methanolic extracts (66.45 ± 5.92%) against *Penicillium italicum*	Vázquez–González et al. (2020b)
Antifungal	Leaves	Phenolic compound	80% ethanol	0.5, 2, and 5 mg/ml	*In vitro*, mycelial growth	High hydrostatic pressure has the highest inhibition ratel for *C. gloeosporioides*, 5 mg/ml has the highest inhibition percentage, which is 55.41 ± 2.44%. For *P. italicum*, 2 mg/ml has the highest value 46.49 ± 6.49%	Vázquez–González et al. (2020c)
Anti-HCV	Leaves	NA	n-Hexane, dichloromethane	100 mg/ml	*In vitro*, virucidal activity test, viral adsorption examination, and pretreatment of cells with the drug	Subfraction FR3T3 as possessing the most robust anti-HCV activity with an IC50 value of 4.7 ± 1.0 μg/ml	Permanasari et al. (2021)
Antiherpesvirus	Leaves	Phenolic compounds	Ethanol, fraction with fractionated with hexane, chloroform, ethyl acetate, and methanol	10 mg/ml	*In vitro*, three animal alpha herpesviruses	Fresh leaf extraction, even in high concentrations of 1,000 μg/ml, caused less than 10% hemolysis, while dry leaves caused 85% hemolysis at the 1,000 μg/ml. Fresh ethanolic extract showed highest inhibition percentage (IP) (76.01%) against equine alfa herpesvirus 1 (EHV-1), dry methanolic extract has the highest inhibition ability against alfa herpesvirus 1 (SuHV-1), with the IP value of 94.38% and fresh methanolic extract exhibited the highest IP (99.2%) against bovine alfa herpesvirus 1 (BoHV-1)	de Sousa et al. (2020)

(*Continued*)

Table 4. Continued

Property	**Part**	**Compounds**	**Extraction solvent**	**Concentration**	**Assay**	**Key findings**	**Ref**
Anti-HIV	Fruit	Prenylated Chromones	Petroleum ether and ethyl acetate	NA	*In vitro*, MTT	Twelve prenylated chromones showed significant anti-HIV activities with EC_{50} values ranging from 0.09 to 9.72 µM, especially for the artocarheterones A (0.09 µM) and cnidimol D (0.26 µM) that might be the oxidised isopentenyl group connected to C-6	Fu et al. (2020)
Anti-HIV	Fruits	New prenylated coumarin 1, tanizin (2), anisocoumarin A (3), fipsomin (4), 6-(1ξ,2ξ,3-trihydroxy-3-methylbutyl)-7-hydroxy-2H-1- benzopyran- 2-one (5), phellodenol C (6) and isophellodenol C (7)	90% ethanol	Purified compound	Anti-HIV-1 reverse transcriptase (RT) activities in the light of the inhibition assay for the cytopathic effects of HIV-1 (EC50)	Anti-HIV-1 reverse transcriptase (RT) activities possessing EC_{50} values in the range of 0.18–9.12 µM	Tao et al. (2022)
Anti-inflammatory	Stems and leaves	Prenylated chromones and flavonoids	Methanol	NA	*In vitro,* RAW 264.7 cells	A total of 12 compounds exhibited significant inhibitory activities against NO production, showing IC_{50} values in the range of 0.48 ± 0.05 to 19.87 ± 0.21 µM	Liu et al. (2020b)
Anti-inflammatory	Fruits	Artocarpesin (1), norartocarpetin (2), and oxyresveratrol (3)	Methanol	0–100 µM	MTT assay with RAW 264.7 cells, Measurement of nitric oxide/nitrite and prostaglandin E2 (PGE2), ROS production	Artocarpin (1) suppressed the LPS-induced production of nitric oxide (NO) and prostaglandin E2 (PGE2) through the downregulation of inducible nitric oxide synthase (iNOS) and cyclooxygenase 2 (COX-2) protein expressions	Fang et al. (2008c)
Anti-inflammatory	Fruits	Steroids	90% ethanol	NA	*In vitro* by measuring the inhibitory effect against NO production induced by lipopolysaccharide in mouse macrophage RAW 264.7 cells.	Remarkable inhibitory effects against NO production with the IC_{50} values in the range of 0.72 ± 0.07 to 5.93 ± 0.12 µM	Liu et al. (2021c)
Anti-inflammatory	Fruits	new prenylated coumarin 1, tanizin (2), anisocoumarin A (3), fipsomin (4), 6-(1ξ,2ξ,3-trihydroxy-3-methylbutyl)-7-hydroxy-2H-1- benzopyran- 2-one (5), phellodenol C (6) and isophellodenol C (7)	90% ethanol	Purified compound	*In vitro* by measuring the inhibitory effect against NO production induced by lipopolysaccharide in mouse macrophage RAW 264.7 cells.	Notable inhibitory effects, the IC_{50} values in the range of 0.58 ± 0.06 to 6.29 ± 0.12 µM	Tao et al. (2022)

(Continued)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Anti-inflammatory	Jackfruit	Moracin C (MC)	NA	Commercial compound	*In vitro*, RAW 264.7 cells with nitrite assay, cell viability assay, ROS measurement, cytokine quantification, RT-PCR, Western blot analysis	MC significantly inhibited LPS-activated ROS and NO release without marked cytotoxicity, effectively reduced LPS-stimulated up-regulation of mRNA and protein expression of inducible nitric oxide synthase (iNOS), cyclooxygenase-2 (COX-2), and several pro-inflammatory cytokines (interleukin-1β [IL-1β], interleukin-6 [IL-6], and tumour necrosis factor α [TNF-α]). The anti-inflammatory effect of MC was associated with the activation of the mitogen-activated protein kinases (MAPKs) and nuclear factor-κB (NF-κB) pathways, especially reducing the nuclear translocation of NF-κB p65 subunit as revealed by nuclear separation experiment and confocal microscopy	Yao et al. (2016)
Anti-inflammatory	NA	Flavonoids: cycloartomunin (1), cyclomorusin (2), dihydrocycloartomunin (3), dihydroisocycloarto-munin (4), cudraflavone A (5), cyclocommunin (6), and artomunoxanthone (7), and cycloheterohyllin (8), artonins A (9) and B (10), artocarpanone (11), artocarpanone A (12), and heteroflavanones A (13), B (14), and C (15)	NA	NA	*In vitro* by determining their inhibitory effects on the chemical mediators released from mast cells, neutrophils, and macrophages.	Dihydroisocycloartomunin significantly inhibited the release of β-glucuronidase and histamine from rat peritoneal mast cells stimulated with P-methoxy-N-methylphenethylamine Artocarpanone significantly inhibited the release of lysozyme from rat neutrophils stimulated with formyl-Met-Leu-Phe (fMLP) Cycloheterohyllin, artonins B, and artocarpanone significantly inhibited superoxide anion formation in fMLP-stimulated rat neutrophils, while cyclomorusin, dihydrocycloartomunin, cudraflavone A, and cyclocommunin evoked the stimulation of superoxide anion generation Artocarpanone exhibited significant inhibitory effect on NO production and iNOS protein expression in RAW 264.7 cells	Wei et al. (2005)
Anti-inflammatory	Spine, skin and rind	Ethanolic extract	Ethanol	100, 200 μg/ml	*In vitro* by assessing the extent of COX inhibition, human RBC membrane stabilisation, and egg albumin denaturation. The *in vivo* anti-inflammatory activity was screened by the method of carrageenan-induced paw oedema in Wistar albino rats.	Percentage inhibition of COX-1 (71.9%) and COX-2 (70.7%) was the highest with spine extract	Meera et al. (2018)
Anti-inflammatory	Pulp	Polysaccharides	Water	Purified, 50, 100, and 200 mg/kg	*In vivo*, male SD rats	Alleviated inflammatory injury in the small intestine and maintained cytokine homeostasis by inhibiting the activation of the TLR4/MAPK pathway	Li et al. (2024)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Anti-inflammatory	Seed	Flour	50% ethanol	NA	*In vitro,* simulated gastrointestinal digestion, *in vivo,* Cell culture and MTT assay, nuclear factor-κB activation, and TNF-α levels	Fjs-D affects cell viability when the concentration is 300 μg ml^{-1} ($p > .05$) and showed 58% reduction of NF-κB activation	Spada et al. (2023)
Anti-inflammatory	Pulp	Phenolic compounds	95% ethanol	5–20 μg/ml	*In vivo,* zebrafish model, embryo acute toxicity test, tail amputation of zebrafish larvae	The NO inhibitory rates of five jackfruit extracts at 250 μg/ml were 78.44% (T5), 77.68% (M1), 71.29% (M7), 67.81% (M3), and 55.10% (M2). T5 extract at doses of 5, 10, and 20 μg/ml significantly reduced the number of neutrophils transplanted to the tail of transgenic zebrafish embryos in a dose-dependent manner	Pu et al. (2023)
Anti-inflammatory	Stem bark	Phenolic compounds	80% acetone	400 mg/kg	NA	Diabetic rats administered the polyphenolic-rich extract of A heterophyllus stem bark have lower IL-6, TNF-α, and NF-κB levels, compared to the diabetic rats control group	Ajiboye et al. (2020)
Antimutagenic	Pulp	β-Carotene and other carotenoids	Methanol, hexane, or acetone	0.5–500 mg/ml	*S. Typhimurium* tester strains TA98 and TA100	Methanol-hexane commercial jackfruit extract has significant antimutagenicity activities, which has a dose-dependent manner and a revision rate achieved by 500 ng AFB1 and chosen for the further fraction by HPLC	Ruiz-Montañez et al. (2015)
Anti-obesity	Pulp, leaves	NA	NA	Orlistat (10 mg/kg), pulp and leaves beverage (2 ml/kg)	*In vivo,* mice model	High-fat diet–fed obese mice treated with SCOBY jackfruit beverages showed great improvement in weight management control and significant body weight loss (18.5%–20.2%) compared to a commercial anti-obesity drug, Orlistat (11.3%), without adverse reaction	Koh et al. (2023)
Antioxidant	Pulp	Phenolic compounds	95% ethanol	0.3125–5 mg/ml	DPPH, ABTS, FRAP	Extraction from Thailand 5 jackfruit has the highest antioxidant capacity among the total five jackfruit cultivars for three assays, ABTS, DPPH, and FRAP	Pu et al. (2023)
Antioxidant	Peel	Phenolic compounds	90% methanol	156.25 μg/ml–10 mg/ml	DPPH, ABTS	Peel has the highest antioxidant capacity, the IC 50 of DPPH is 1.25 ± 0.14 mg/ml, while that of pulp, flake, and seed are all over 10 mg/ml. The IC50 of ABTS is 0.23 ± 0.02 mg/ml, that of pulp, flake, and seed are 5.70 ± 0.37 mg/ml, 8.21 ± 0.25 mg/ml, 7.62 ± 0.13 mg/ml, respectively	Zhang et al. (2017c)
Antioxidant	Stem bark	Phenolic compounds	70% ethanol	1–5 mg/ml	DPPH, FRAP, hydroxyl radical scavenging and Fe2+-chelating ability	All four assays show a dose-dependent tendency, and a higher standard control group. The highest value of each assay is when the concentration of sample is 5 mg/ml	Ajiboye et al. (2016)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antioxidant	Stem bark	Phenolic compounds	80% acetone	0–100 μg/ml	FRAP, DPPH, hydrogen peroxide scavenging	Dose-dependent, the bound phenols showed higher antioxidant ability than free phenol	Ajiboye et al. (2020)
Antioxidant	Pulp	Phenolic compounds	Acetone, methanol, ethanol, and water	1–5 mg/ml	DPPH, FRAP, DMPD (N, N-dimethyl-p-phenylendiamine)	Water and ethanol are the best solvents to extract the phenolic and flavonoids from jackfruit pulp. For DPPH, IC50 value was from 0.4 to 0.7 mg/ml for methanolic extract; for FRAP, 5 mg/ml concentration showed 1.7 mM TEAC/g for methanolic and 1.4 mM TEAC/g for water extract; for DMPD, IC50 were as follows: 3.43 mg/ml for methanolic extract, 3.6 mg/ml for ethanolic extract and 3.9 mg/ml for water extract	Jagtap et al. (2010)
Antioxidant	Leaves	Phenolic contents	Water and ethyl acetate	25–400 μg/ml (DPPH), 1 μg/ml (FRAP)	DPPH, FRAP, ABTS, Fe^{2+} chelating activity	IC 50 of DPPH and Fe2+ chelating activity are 73.5 ± 1.8 to 235.8 ± 2.9 μg/ml and 222.6 ± 2.5 to 251.8 ± 3.3 μg/ml, respectively. The FRAP is from 72.0 ± 2.9 to 565.8 ± 2.5 μM Fe (II)/g. The outcome of ABTS is from 5.9 ± 0.09 to 34.8 ± 1.03 Trolox value	Loizzo et al. (2010)
Antioxidant	Pulp	Polysaccharides	Water	0–4 mg/ml	DPPH, OH, reducing power	The concentration of polysaccharides is from 0.25 to 4 mg/ml; the scavenging abilities of DPPH were from 21.82% to 69.64%. The OH scavenging abilities of 1 mg/ml concentration is 68.30%. These two assays are all dose-dependent. However, an observed decrease in reducing activity was noted with increasing extract concentrations	Zhu et al. (2017)
Antioxidant	NA	Wine	NA	100–500 and 10–50 μl	DPPH, FRAP, DMPD (N, N-dimethyl-p-phenylendiamine) and NO	DPPH radical–scavenging activity from 28% to 69% when the concentration was increased from 100 to 500 μl, while the absorbance value of FRAP was from 0.123 ± 0.041 and 0.316 ± 0.004 for 100 and 300 μl. DMPD scavenging capacity showed 32.60 ± 2.19% at 10 μl and 78.45 ± 0.05% at 50 μl, and NO exhibited the highest 62.46 ± 0.45% at 500 μl	Jagtap et al. (2011)
Antioxidant	Rind and rachis	Phenolic contents	70% ethanol	1.0 mg of samples into 1.0 ml 70% ethanol	DPPH, FRAP, β-carotene bleaching	Three different extraction methods, maceration, percolation, and Soxhlet, were used. For rind, the DPPH range from 38.0 ± 0.1 to 94.4 ± 0.1%, FRAP is range from 15.6 ± 0.2 to 26.4 ± 0.7 μM Trolox equivalent/ml and 20.0 ± 0.5 to 59.0 ± 1.0% of beta-carotene bleaching	Daud et al. (2017)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antioxidant	Pulp	Polysaccharides	Water	NA	DPPH, FRAP, hydroxyl radical and superoxide anion scavenging activity	After the digestion of intestine for 1, 2, and 4 hr, the OH scavenging activities' value continuously increased to 79.4 ± 2.25%, 86.99 ± 1.36% and 95.09 ± 2.13%, respectively. That of superoxide anion radical–scavenging abilities were 42.68 ± 2.36%, 49.98 ± 2.78% and 54.68 ± 2.98%, respectively. The outcome of DPPH was 2.18 ± 0.29%, 4.14 ± 1.71% and 7.09 ± 0.27%, separately, and the reducing power ability is very low	Zhu et al. (2019)
Antioxidant	Pulp	Polyphenols	Alkaline, acid, and enzymatic hydrolysis		ABTS, ORAC, PSC	The alkaline extract exhibited superior ABTS scavenging, around 9 and 4 times higher than that of acidic and enzymatic extracts. Same tendency in peroxyl radical scavenging and oxygen radical scavenging capacities	Zhang et al. (2021e)
Antioxidant	Leaf	Protein	Alkaline condition	DPPH 0.015–0.1 mg/ml, ABTS 0.3–1 mg/ml	DPPH, ABTS	$ABTS^+$ for H-Pep and H-Pan was 85.97% in 1 mg/ml and 98.20% in 0.8 mg/ml, while the radical scavenging activity by DPPH+ was 64.88 and 72.38% in 0.1 mg/ml, respectively	Calderón-Chiu et al. (2021)
Antioxidant	Seeds	Petites	NA	purified	ABTS	From the crude trypsin protein hydrolysates to fraction SCX-F12, there is 11.8-fold increase in the radical-scavenging potential	Chai et al. (2021)
Antioxidant	Leaf	NA	Ethanol (EE), n-butanol (BE), water (WE), chloroform (CE), and ethyl acetate (EAE) extract	0.2, 0.4, and 0.6 mg/ml	DPPH, ferrous ion (Fe++) chelating activity	The scavenging rates of JFEE having the highest value to DPPH· were 21, 32, and 51% at concentrations of 0.2, 0.4, and 0.6 mg/ml, respectively. The percentages were 65, 76, and 77% in the case of JFBE (highest one) at concentrations of 0.2, 0.4, and 0.6 mg/ml, respectively	Omar et al. (2011)
Antioxidant	Pulp	β-C arotene and other carotenoids	Methanol, hexane or acetone	NA	ABTS, DPPH	Methanol and hexane commercial extraction had done the further fraction by HPLC and obtained four fractions: F1, F2, F3, and F4. Subfraction F1 showed the highest DPPH (42.18 ± 1.43%) and ABTS (33.42 ± 0.33%) scavenging ability	Ruiz-Montañez et al. (2015)

(Continued)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antioxidant	Leaf	2″-O-β-D-xylosylvitexin	80% ethanol	DPPH 0–120 μM; OH 0–2.0 mM	ORAC, DPPH, OH	For ORAC, the ORAC-fluorescein is 5.75 ± 0.50 μmol TE/μmol, and the ORAC-pyrogallol red is 0.55 ± 0.07; for DPPH, the IC50 is 68.88 ± 1.30 μM and the IC 50 of hydroxyl radical is 1.72 ± 0.10 mM	Wen et al. (2017)
Antioxidant	Leaf	2″-O-β-D-xylosylvitexin	80% ethanol	0–400 μM	HepG2 cells for cellular antioxidant activity assay	Dose-dependent, better cellular antioxidant activity than the aglycone, apigenin	Wen et al. (2017)
Antioxidant	Fruit	Polysaccharides	Water	25–250 μg/ml	DPPH, FRAP	DPPH, the activity of the highest WSP concentration (250 μg/ml) corresponded to 16.2 μg/ml of Trolox, while in the case of the FRAP method, it was equivalent to 48.4 μg/ml of ascorbic acid	Wiater et al. (2020)
Antiproliferative	Stems and leaves	Prenylated chromones and flavonoids	Methanol	NA	MTT assay for five human tumour cell lines, namely, breast cancer MCF-7 cell line, human hepatocarcinoma SMMC-7721 cell line, human myeloid leukaemia HL-60 cell line, human pancreatic carcinoma SW480 cell line, and lung cancer A-549 cell line	A total of 12 compounds displayed significant inhibitory effects against various human cancer cell lines with IC50 values ranging from 0.36 ± 0.02 to 22.09 ± 0.16 μM	Liu et al. (2020c)
Antiproliferative	Wood	Artocarpin	n-hexane and methanol	NA	CYP P450 enzyme assays, human colon adenocarcinoma cell line HCT116 (ATCC, CCL-247), and normal cell line CCD-18Co (ATCC, CRL-1459), azoxymethane and dextran sulphate sodium (AOM/DSS) colitis-induced cancer mice model	Irreversibly inhibited the activity of human cytochrome P450 CYP2C9. In *vitro* evaluations on heterologously expressed microsomes, revealed irreversible inhibitory kinetics with an IC50 value of 0.46 μg/ml. Time- and concentration-dependent cytotoxicity was observed on human cancerous HCT116 cells with an IC50 value of 4.23 mg/L in 72 hr. AOM/DSS induced the mice revealed that the enriched extract suppressed tumour multiplicity, reduced the protein expression of proliferating cell nuclear antigen, and attenuated the gene expression of proinflammatory cytokines (Il-6 and Ifn-γ) and protumorigenic markers (Pcna, Axin2, Vegf, and Myc)	Morrison et al. (2021)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antiproliferative	Wood	Artocarpin	95% ethanol	0–25 μM for cell line assays	Human colon cell lines (CCD-18Co, DLD1, HCT116, HCT15, HT29, and SW480) and mouse colitis–associated colon carcinogenesis model	Artocarpin has a dose-dependent manner in exhibiting potent cytotoxicity against human colon cancer cells and the IC50 values at around 15 μmol/L. artocarpin induced apoptosis and autophagy, which has been supported by PARP cleavage and the up-regulation of LC3B expression. In addition, artocarpin induced G1 phase cell cycle arrest. In the mice model, oral administration of artocarpin for 16 weeks significantly increased the survival rate and reduced the multiplicity of colonic neoplasms by 56%	Sun et al. (2017)
Antiproliferative	Wood	Brosimone I	NA	0–30 μM (cell viability), 0–25 μM (cell growth inhibition),	Cell culture (HCT116 and CCD-841CoN), cell cycle analysis, apoptosis assay	Brosimone-I, in the HCT116 cell line, in suppressing cell viability with IC50 about 14 μM, increased the percentage of cells in the G1 phase in a dose-dependent manner, exhibited the cell apoptotic response, increased the level of phosphorylated AMPK, and induced cytotoxicity by increasing the cytosolic Ca2+ level and ER stress	Zhao et al. (2019)
Antiproliferative	Wood	Artocarpin	NA	5.7, 11.5, 20, and 28.7 μM	Cell culture (T47D cells)	The outcomes showed the IC50 is 12.6 μM. Based on this result, cell and nuclear morphology, sub-G1 apoptosis, and the apoptotic signalling pathway were conducted with the concentrations of 5.7, 12.6, and 20 μM. The cell morphology changed with the 12.6 μM treatment, and the percent of cell in sub-G1 increased with the concentration of artocarpin increased, the percentages were 0.89%, 25.71%, and 82.86%, respectively. The cleaved-caspase 3 and 8 increased with the concentration increase and the caspase 10 decreased. Negligible changes in mitochondrial membrane potential (Δψm) due to artocarpin treatment	Arung et al. (2010)
Antiproliferative	Pulp	β-carotene and other carotenoids	Methanol, hexane, or acetone	3.125–100 μg/ml, 12.5–100 μg/ml, 50–400 μg/ml	MTT assay (cancer cell line M12.C3.F6)	Methanol and hexane commercial extraction had done the further fraction by HPLC and obtained 4 fractions: F1, F2, F3, F4. Subfraction F1 (IC50 = 49.2 μg/ml) showed the highest antiproliferative activity in the cell line	Ruiz-Montañez et al. (2015)

(Continued)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antiproliferative	Stem and leaves	Prenylated chromones and flavonoids	Petroleum ether and ethyl acetate		*In vitro*, MTT assay for five human cancer cell lines	Twelve compounds exhibited antiproliferative activity with IC50 values ranging from 0.36 ± 0.02 to 22.09 ± 0.16 μM	Liu et al. (2020)
Antiproliferative	Leaf	Phenolic compounds	95% ethanol	NA	MTT assay (PC-3, NCI-H460, and A549 cancer cell lines)	Artocarmitin B, artocarpin, and cudraflavone C exhibited cytotoxicity against the A549 cells	Wang et al. (2017)
Antiproliferative	Fruit	Polysaccharides	Water	NA	Neutral red (NR) uptake assay, MTT assay, and May–Grünwald–Giemsa (MGG) Staining	The cells of both HT29 and SW620 human colon tumour lines did not show signs of viability loss in the NR uptake test after culture with A. *heterophyllus* WSP at concentration values up to 250 μg/ml. The viability did not drop below 94%. No morphological changes in the cells of both lines after incubation with the WSP at a concentration of 250 μg/ml	Wiater et al. (2020)
Antiproliferative	Seeds	ArtinM	10 mM PBS	50 μg/kg	*In vivo*, administered diethyl-nitrosamine (DEN) in Wistar rats; histological analysis, western blotting, and RT-PCR	Reduction in the number of preneoplastic lesions and a decrease in proliferating cell nuclear antigen (PCNA)–positive cells in DEN (diethyl-nitrosamine)-induced Wistar rats. Decreased the proliferating cell nuclear antigen (PCNA), increased nuclear p21, and p27 staining, heightened expression of p53 and p21, and upregulated the p42/44 MAPK pathway; increased expression of TNFα and IFNγ genes, indicating an inflammatory response	Braz et al. (2016)
Antiproliferative	Seeds	ArtinM	NA	0 to 100 μg/ml	Myelocytic leukaemia cells (NB4, K562, and U937), MTT assay, assessment of apoptosis, mitochondrial membrane potential (mΔΨ), flow cytometry, and morphology, accumulation of ROS, Western blot, electrophoretic analysis, binding and competition binding assay, fluorescence microscopy, and real-time PCR	NB4, K562, and U937 cells IC50 of 10 (±1), 14 (±1), and 84 (±1.5) μg/ml	Carvalho et al. (2011)
Antitumour	Pulp	Phenolic compounds	95% ethanol	0.75, 1.00, 1.25, 1.50, and 1.75 mg/ml	CCK-8 assay in HeLa cells	T5 had the strongest inhibitory effect on cell proliferation, and the inhibition rate was 80.31% at a concentration of 1.75 mg/ml, followed by M3 (72.10%), M7 (57.52%), M2 (51.26%), and M1 (37.15%)	Pu et al. (2023)

(Continued)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Antiviral	Leaves	NA	Ethanol 80%, hexane, dichloromethane, and methanol	100 mg/ml	*In vitro*, MTT	The dichloromethane extract exhibited strong anti-HCV activity with an inhibitory concentration (IC_{50}) value of (1.5 ± 0.6) μg/ml	Hafid et al. (2017)
Gut microbiota modulation	Pulp	Polysaccharides	Water	50, 100, and 200 mg/kg BW	*In vivo*, mice model, DNA extraction, 16S rRNA gene amplification, and sequencing, Bioinformatics analysis of gut microbiota profiles, SCFA production	The outcome showed that the treatment of polysaccharides would stimulate the faecal gut microbiota composition, increased the OTU numbers of faecal bacteria, cause higher variation in intestinal bacteria, cause significant differences in bacterial communities, modulated the composition of gut microbiota, and increase the concentrations of acetic acid, propionic acid, n-butyric acid, and total SCFAs in mouse faeces	Zhu et al. (2021)
Gut microbiota modulation	Peel	Polysaccharides	Water	NA	*In vitro* upper digestion and faecal fermentation	The PJPs could reach the colon intact. The molecular decreased during the faecal fermentation, as degraded during the faecal fermentation, which was caused by microbes in the intestine and also released the oligosaccharides. For α-diversity, the Chao and Shannon indexes of PJP group are lower than the control, which indicates that microbiota richness and diversity are lower. After 48-hr fermentation, the total SCFAs of PJP (25.843 ± 1.036 mmol/L) are higher than the control group (11.142 ± 1.558 mmol/L) that demonstrated that PJP increases the amount of SCFAs and has the potential to be a prebiotic	Li et al. (2023)
Gut microbiota modulation	Pulp, leaves	NA	NA	Orlistat (10 mg/kg), pulp and leaves beverage (2 ml/kg)	*In vivo*, mice model	COBY jackfruit beverages had altered the gut microbiota composition with the enhanced growth of beneficial gut microbes in those treated mice relative to all control groups.	Koh et al. (2023)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Immunomodulatory	Fruit and seeds	Oligopeptides	NA	0.20, 0.40, and 0.80 g per kg BW	*In vivo*, 200 female BALB/c mice	The results exhibited that JOPs did not influence the body weight and thymus index but has the spleen index significantly increased. 0.40, and 0.80 g per kg BW treatment significant enhance the ConA-stimulated proliferation of splenic lymphocytes and the footpad thickness of mice. JOPs enhanced humoral immunity through two assays, IgM-plaque-forming cell (IgM-PFC) test, and serum hemolysin level. Carbon clearance index growths, the phagocytic rate was increased. 0.40 and 0.80 g per kg BW treatment significantly improved the activity of NK cells. The value of CD3+, CD4 + CD25+/CD4+ and CD3 + CD4 + significantly increased with 0.40 and 0.80 g per kg BW JOP treatment. In addition, IL-1α, IL-10, TFN-α, serum IgM, IgA, and SIgA levels increased as the IFN-γ level decreased	Hao et al. (2020)
Immunomodulatory	Seeds	ArtinM	NA	1.0; 0.33; 0.11; 0.037; 0.012; 0.004; 0.00013; and 0.00004 μg/ml for MTT, 1 μg for survival analysis	*In vivo*, female inbred C57BL/6 mice	*Synadenium carinatum* Latex (ScLL) or ScLL plus ArtinM treatment induced production of pro-inflammatory and anti-inflammatory cytokines, showing differential but complementary profiles	Ramos et al. (2016)
Immunomodulatory	Seeds	ArtinM	NA	2.5 or 5 μg/ml	*In vitro*, paracoccidioidomycosis patient peripheral blood cell	ArtinM increased neutrophils infected with *P. brasiliensis* was observed TNF-α production, stimulated TNF- α and IL-8 in neutrophils from patients with PCM, and IL-8 level even eight times higher than the unstimulated cells. Stimulation of ArtinM not reply on the Dectin-1, ArtinM enhanced the dextran internalisation of neutrophils and increased killing capacity of neutrophils and macrophages	Ruas et al. (2018)
Immunomodulatory	Leaf	Isophytol, squalene, and cyclotrisiloxane	NA	1% of the feed	*In vivo*, straight-run day-old broiler chicks of "Cobb" strain	In immunised chickens, jackfruit leaf powder significantly boosted growth and immunity, performing as well as levamisole (a standard immune-boosting drug). In immunosuppressed chickens, jackfruit leaf powder worked better than the untreated group, improving immunity and growth	Raja et al. (2020)

(*Continued*)

Table 4. Continued

Property	Part	Compounds	Extraction solvent	Concentration	Assay	Key findings	Ref
Immunomodulatory	Pulp	NA	Water	10 ml/kg BW	*In vivo*, female 8-week-old specific pathogen-free (SPF) BALB/c mice	Thymus and spleen indexes increased to 2.27 ± 0.15 mg/g and 5.33 ± 0.12 mg/g, respectively. Alleviated the pathological damage symptom that model group mice have, including fewer goblet cells and mucins. Treatment of FPJ led to a significant increase in cytokines and immunoglobulins, including IFN-γ, TNF-α, IL-2/6/17, IgA/M/G	Ma et al. (2021)
Tyrosinase inhibitory activity	Wood	Morachalcone A	Methanol	100, 50, 25, and 10 µg/ml	Tyrosinase inhibitory assay	IC50 is 0.013 ± 0.002 µM, which is 3,000 times more active than a positive-control kojic acid.	Nguyen et al. (2012)
Wound healing	Bark	NA	Methanol	5% wt/wt	*In vivo*, male albino mice model	After 16 days of treatment, the negative-control animal group showed 10.66 ± 5.33 of wound area, whereas the betadine-treated group showed 0.1 ± 0.200 wound areas and the extracts treated exhibited 3.9 ± 1.137 wound areas. When compared with the controls, the activity of extract was found to be highly significant ($p < .001$)	Raghuvanshi et al. (2010)
Wound healing	Leaves	NA	Ethanol	5%, 10%, and 15%	*In vivo*, diabetic mice model	Fifteen percent was thought to be the most beneficial concentration for reducing inflammation and speeding up the healing process of tooth extraction wounds in diabetes rats	Amin[1] and Pamasja (2021)
Wound healing	Leaves	NA	Ethanol	94, 188, and 376 mg/kg body weight	*In vivo*, Sprague–Dawley rats.	376 mg/kg BW had the quickest burn healing time and the highest percentage of recovery, even better than the medical standard: Lanakeloid cream	Solihah et al., 2024
Wound healing	Leaves	NA	Ethanol	1%, 2%, and 3% extract	*In vivo,* white male rats	Only 3% extract showed less significant change in wound area	Maria Erista et al. (2024)

Starch is the primary storage carbohydrate in plants and is globally produced at an annual rate between 88.1 and 97.7 million tons in 2020 (Vilpoux & Junior, 2023). It finds extensive industrial applications in the production of various products, including food, textiles, paper, adhesives, and pharmaceuticals. Starch exhibits properties such as thickening, gelling, and film formation. The extracted starch from jackfruit seeds is utilised as a super-disintegrant in the formulation of fast-dissolving tablets (FDTs) (Tripathi et al., 2023). The FDT technology allows tablets to dissipate or disintegrate in the mouth without requiring the consumption of additional water. The key principle behind FDT development is the utilisation of super-disintegrants, which promote rapid tablet disintegration upon placement on the tongue, consequently liberating the drug into the saliva. Orodispersable tablets are designed to dissolve or disintegrate quickly through the use of superdisintegrants (Chiranjib & Bhowmik, 2009).

Jackfruit waste can be utilised to produce several significant bioproducts, including biofuels, functional meals, animal feed, biomaterials, bakery products, medications, and food additives. Fruit wastes might be transformed by biotransformation into useful goods (Aswin et al., 2022; Muzaffar et al., 2022; Pathak et al., 2022).

The fruit pulp can be utilised to create homemade and commercial jams. The pulp of ripe jackfruit is used to produce dehydrated jackfruit, which is a healthy snack food. It has a chewy texture, a sweet and sour flavour, and a colour ranging from golden yellow to orange (Diamante, 2009).

Jackfruit products can be enhanced in taste by incorporating synthetic flavouring agents like ethyl or n-butyl ester of 4-hydroxybutyric acid. Fermented beverages, particularly fruit wine, and vinegar, can be produced using biotechnology and food processing methods from ripe jackfruit. Jackfruit wine, with an alcohol content of 7%–8% (vol/vol), is consumed by people living in eastern hilly regions of India (Sekar & Mariappan, 2007). Jackfruit wine also can be produced using temperature-controlled fermentation (Baidya et al., 2016). Fermented fruit retains its vitamin C content and offers a significant amount of this powerful antioxidant (Gupta et al., 2023).

Jackfruit chips can be prepared by slicing the bulbs, blanching them, and then drying and deep-frying them. The chips retain the natural colour, flavour, and texture of jackfruit and are high in vitamin E, y-oryzanol, and phytosterols (Gupta, 2021; Molla et al., 2008).

Jackfruit leather, made from dried fruit pulp sheets, has a sweet taste and a soft, rubbery texture. It can be consumed as a snack and used as an ingredient in ice cream, biscuits, cakes, and other baked goods (Kumar et al., 2020). These various food applications of jackfruit highlight its versatility and the potential to utilise different parts of the fruit to create a range of nutritious and flavourful dishes.

As a significantly underestimated tropical fruit, jackfruit holds enormous applications in other fields. Jacalin, a typical lectin extracted from jackfruit seeds and showing high affinity to the Thomsen–Friedenreich disaccharide antigen (Galβ1-3GalNAc) (Swami et al., 2012), raises the hope for a new drug delivery strategy to attack colon cancer (Arya et al., 2019; Cruz-Casillas et al., 2021). Jackfruit pectin could be used to prepare a bio-nanocomposite that is a potential material for bone healing (Kalse & Swami, 2022). Jackfruit seed starch has been explored in microcapsules, fast-dissolving tablets, packaging film, food colour, and other areas. Additionally, the waste of jackfruit, such as peel and latex, can be utilised as an attractive source for sustainable products. Even in the cosmetic industry, jackfruit pectin has been fabricated into nanoparticles with emulsifying capabilities (Jin et al., 2019).

Plant-based products

The fleshy arils are commonly employed as a meat substitute in vegetarian and vegan dishes owing to their fibrous texture and ability to absorb flavours (Hamid et al., 2020).

Hamid et al. (2020) utilised the jackfruit by-product (rinds, rags, and seeds) to make a meat analogue with wheat gluten, starch, vegetable oil, and soy protein. A seven-point hedonic scale was used to evaluate four different formulations; the outcome is 58% jackfruit by-products, and 20% vital wheat gluten reached the highest value of overall acceptability (5.14 ± 1.17).

Mishal et al. (2022) found that the formulation of 26% jackfruit, 26% soy protein, 3% meat flavour, and 4.3% wheat gluten received the highest score through a nine-point hedonic scale. Taikerd and Leelawat (2023) explored the potential of young jackfruit to make chicken meat analogue with wheat gluten and soy protein isolate. Seven formulae were created with different ratios of jackfruit, wheat gluten, and soybean isolate; according to the sensory evaluation, 40.64% young jackfruit, 20.32% wheat gluten, and 1.35% soy protein isolate obtained the highest overall acceptability score.

de Jesus González-Regalado et al. (2024) conducted the steaming (121 °C, 5–15 min) and boiling (90–100 °C for 5–15 min) effects for the core, cortex, and perianth of young jackfruit. The results demonstrated that all jackfruit sections exhibited similar texture parameters to meat references under the above treatment.

Aizul Azri Azizan et al. (Azizan et al., 2024) used peeled unripe jackfruit with konjac tofu and seasoning to make nugget analogue. Twenty-five percent unripe jackfruit and 75% konjac-tofu was the best formulation with a high sensory evaluation score based on a nine-point hedonic scale, 7.28 ± 1.578 of appearance, 6.48 ± 1.502 of aroma, 6.14 ± 1.852 of taste, and 6.52 ± 1.717 of texture, and the overall acceptance is 6.72 ± 1.4. The outcome of this research confirmed that unripe jackfruit nuggets would be developed as a new and healthy convenience food product as meat alternatives for vegan and vegetarian consumers.

To sum up, jackfruit, even its by-products, has a significant potential as a meat alternative. The unique texture and nutritional profile make it an excellent plant-based food, which would satisfy the requirement of people with specific dietary requirements.

Commercial potential

Genetic engineering

Genetic variability means the genetic difference within or between populations, which is essential for plant selection. Jackfruit contains an abundant genetic diversity because of propagation of seeds, which benefits the conservation and breeding when understanding genetic diversity combined with population structure (Bhaskaran et al., 2025). The research based on the jackfruit cultivated in both Kenya and Uganda showed that significant genetic variability exists, which would be utilised in developing high-yielding varieties for jackfruit breeders (Ojwang et al., 2022). Another research conducted in India (Debnath & Deb, 2022) presented that yield, fruit productivity, fruit stalk length, and fruit core weight had a high genotypic coefficient of variation, heritability, and genetic advance; all these parameters represented that these traits were influenced by genetic factors rather than environmental factors. In the past decades, using superior clone selection for developing cultivars in jackfruit cultivation countries has made big progress. For example, "Golden Nugget," "Black Gold," "Honey Gold," "Lemon Gold," "Cheena," "Chompa Gob," "Galaxy," "Nahen Kapa," etc., were cultivars reported from Australia (Mitra, 2020). Therefore, continuing and firmly applying this genetic engineering way to develop jackfruit with superior traits will still be a major direction for future development and provide fundamental support for jackfruit commercialisation.

Intelligent system in cultivation, storage, and transport

The potential threat of extreme weather would cause damage of crops, which brings reduced yield and quality and affects the farm and related profit. An Internet of Things (IoT) cultivation system could be one of the solutions. Chang et al. (2021) developed an IoT-enabled greenhouse system for lettuce. The greenhouse has the environmental sensing modules to monitor the temperature, humidity, CO_2, light intensity, and daily light integral, while during the growth of lettuce, some parameters were recorded, including net photosynthesis rate, transpiration rate, number of leaves (LN), contour area of the leaves (LA), and dry weight. Three models, fuzzy logic (FL), neural-fuzzy (NF), and neural network (NN), were trained based on the data mentioned above. NN model used to predict the dry weight, which is consistent with the result of the experiment; FL performed well in the net photosynthesis rate and transpiration rate, while NF achieved the prediction of harvest and plant quality. Another research (Ramírez-Pérez et al., 2018) was conducted in cucumber mineral absorption in leaf, stem, fruit, and root, the differences between experimental results and model-simulated data for N, P, and K were 10%, 11%, and 0.11%, respectively. Currently, digital management in jackfruit is still lacking and this would improve the efficiency and precision of jackfruit cultivation.

Time–temperature indicators (TTIs) are an innovative tool in food packaging, which provide the temperature information through monitoring, recording, and translating. It is a reliable device in monitoring and optimising spoilage of certain chilled foods (Koutsoumanis & Gougouli, 2015). Adiani et al. (2021) developed a colourimetric TTI based on phenol oxidation and used in pineapple, pomegranate, and jackfruit to monitor the microbial spoilage. A good correlation ($R^2 \geq 0.7$) was observed between TTI colour change and microbial growth in all three tested fruits and the microbial count with an error of ± 1 $\text{Log}_{10}\text{CFU g}^{-1}$. In addition, a consumer attitude towards TTI was conducted in Europeans (Pennanen et al., 2015); the outcome showed that consumers appreciated and understood TTI technology, although not all requirements of consumers were met. TTI could be used to establish an efficient, transparent, and traceable supply chain to simplify the process of jackfruit from farm to restaurant/market. This not only ensures a stable and reliable supply but also improves supply efficiency and product quality. In addition, it reduces the risks associated with supply and demand imbalances and prevents price fluctuations due to supply and demand issues.

Sustainable applications

Around 60% of ripe jackfruit is inedible, including peel, core, and flake (Ranasinghe et al., 2019). Incorrect disposal of this waste would cause environmental issues; thus, utilisation of this waste is essential. The application of peel includes pectin, activated carbon, adsorbent, and bio-hydrogen production (Kalse & Swami, 2022). In addition, peel contains high levels of carbohydrate, protein, and fibre, making it suitable for animal feed (Pathak et al., 2022), while the core and flake parts have potential in livestock as well (Subburamu et al., 1992). The peel and core parts could be used to extract pectin, which is a better way to utilise them (Lal et al., 2021). Flake through microbial fermentation to obtain value-added products has been confirmed (Suo et al., 2024). Jackfruit seed is technically not waste as it contains 60%–80% starch (Zhang et al., 2021) and has commercial products seed flour and starch. Effective utilisation of jackfruit waste would build a sustainable development system and is also a future direction.

Conclusion

In conclusion, jackfruit is a tropical fruit rich in minerals, vitamins, amino acids, protein, and dietary fibre, as well as phytochemicals, with great potential for promoting health and preventing disease. It is important to note that the content and variety of bioactive ingredients in jackfruit vary during maturity and different parts, highlighting the need to consider maturity when unlocking its full potential. The existing literature reveals a wide range of pharmacological properties, including anti-inflammatory, antioxidant, antidiabetic, anticancer, obesity, antimicrobial, immunomodulatory, antiviral, and wound healing. Further preclinical and clinical studies are necessary to fully grasp the mechanisms behind its multiple potential. Considering the current shift towards plant-based diets and the growing interest in sustainable food sources, combined with the unique flavour and special texture of jackfruit, makes it a meat substitute in a variety of culinary applications. The relevant applications of jackfruit in food and nonfood industries are also explored, and the potential for commercialisation of jackfruit is briefly discussed. From the large literature and research explored and discussed, the biggest fruit in the world could be considered as a treasure trove of bioactive compounds with high value, which brings great benefits to human health.

Data availability

Data available on request from the authors.

Author contributions

Shujun Ye (Conceptualization, Writing—original draft, Investigation), Ali Imran (Writing—review & editing, Supervision), Osman Tuncay Agar (Writing—review & editing, Supervision), Dakshina Yadav (Writing—review & editing, Resources, Project administration, Validation), Chelsea Moore (Resources, Project administration, Validation), and Hafiz A.R. Suleria (Conceptualization, Investigation, Resources, Writing—review & editing, Supervision, Funding acquisition, Project administration, Validation)

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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