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Food Production, Processing and Nutrition

REVIEW

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# Finding out various potentials and possibilities of jackfruit seed and its usage in the industry: a review

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## Abstract

Despite the fact that jackfruit seeds have been demonstrated to contain a variety of beneficial nutrients or bioactive components that add real value to meals, they remain underutilized due to limited commercial jackfruit production. They include a wide variety of nutrient-dense components, including as starch, fibre, phytonutrients, protein, minerals, lectins, as well as beneficial components like phenols and flavonoids. This review focuses on the significant findings regarding starch extraction techniques and different conventional and novel modification techniques and their influence on functional properties of jackfruit seed. Jackfruit seeds are primarily rich in seed starch (70–85%), which is used in food processing and other areas as thickeners, stabilizer, microencapsulating agent, coagulants, bioplastics etc. and provide significant health benefits. Applicability of jackfruit seed starch is also well established. There is a significant impact on jackfruit seed processing using different techniques in order to achieve versatile nutritional and functional components. The creation of composite films, starch, food items, bioethanol, pigments, and medical applications are the key areas of ongoing study. This paper was developed by analysing more than 150 scientific publications including recent studies of various researchers, with a primary focus on the features of jackfruit seeds.

**Keywords** Artocarpus heterophyllus, Jackfruit, Jackfruit seed, Starch, Flavonoids, Nutrients

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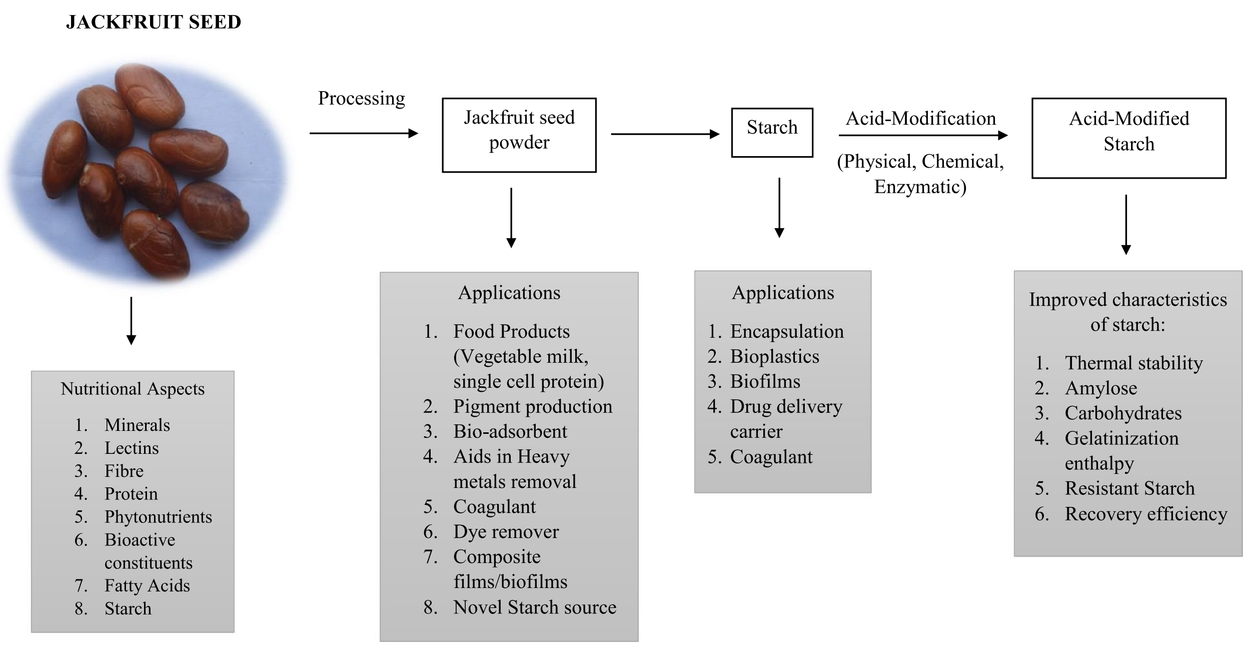
## Graphical Abstract




## Introduction

Despite being regarded as edible, jackfruit seeds are rarely used in industrial food production, with the exception of some Asian households that roast them for consumption. The seeds tend to be tossed away as waste due to their perishable nature, but they can last for about a month if they are kept in a cold, moist environment. The roasted seeds can be ground into powder and added to various goods to increase their value and shelf life. By combining it with wheat flour and other inexpensive flours, jackfruit seed powder is used as an alternative flour in baking and confectionary items. Various researches have been carried out to study the nutritional benefits and consumer acceptability of jackfruit seed flour infused food products. The seed is encased in a white aril that surrounds a thin brown endosperm that covers the fleshy white cotyledon. Jackfruit can weigh up to a maximum of 45 kg, the bulbs are the edible fractions of the fruit which surround the seed (Ranasinghe et al. 2019). Jackfruit seeds represent about 18–25% of jackfruit's total weight, and each fruit has approximately 100–500 seeds (Kumoro et al. 2020). The seeds are also discovered to contain a variety of antioxidant peptides that have the potential to be developed as dietary supplements or preservatives for protein-rich food systems (Chai et al., 2021a, 2021b). Protein isolates from Jackfruit seed were prepared to check their emulsification performance and it was seen that under neutral conditions it displayed a higher emulsifying index value (Zhang et al. 2019a, 2019b, 2019c). Supercritical extraction derived jackfruit extracts were found to have antifungal activity whereas low pressure derived extracts exhibited photoprotective activity (Tramontin et al. 2019). Such characteristics could be exploited to obtain products of natural origin for the cosmetic, pharmaceutical and food industries. Inositol, sorbitol, glucose, fructose, sucrose, maltose, and raffinose are among the compounds found in jackfruit seed flour. All of these compounds, with the exception of sucrose and maltose, increase in concentration as the fruit ages or matures (Kushwaha et al. 2021a, 2021b). The majority of jackfruit seed proteins are made up of 17–26 kDa polypeptides, and the primary secondary structures areβ-sheet and random coil (Wu et al. 2022). In general, jackfruit seed protein isolates and protein fractions showed strong foaming and emulsifying abilities. Jackfruit seed proteins therefore have the potential to be useful and nutritive food additives.

## Nutritional aspects of jackfruit seeds

### Minerals

Jackfruit seeds possess important minerals such as magnesium, potassium, phosphorous, calcium, sodium, iron, copper, zinc, and manganese (Hajj et al. 2022). However, throughout literature the mineral composition varies from one species of Jackfruit to another. The various minerals that have been listed in Table 1.

### Lectins

Jackfruit seeds contain two lectins, namely jacalin and artocarpin (Shedge et al. 2022). Natural proteins called lectins have powerful antibacterial properties because they bind to carbohydrates on microbial surfaces (Breitenbach et al. 2018). Jacalin, a dietary lectin has been used by (Kumar et al. 2022) to inhibit the proliferation of cancer cells, they combined Jacalin with the established anti-cancer drug taxol to obtain a better effect on a triple-negative breast cancer line. (Subramaniyan et al. 2021) studied Jacalin-derived silver nanoparticles which had good antibacterial activity and it was found to have killed *Staphylococcus aureus* in less than 30 min, by inducing oxidative stress and membrane damage. (Lavanya et al. 2022) researched the effect of jacalin on the proliferation and cytokine production of peripheral blood mononuclear cells (PBMCs) and found that it had hindered tumor growth for a stipulated time point. Another lectin namely, Artocarpin derived from Jackfruit (*Artocarpus heterophyllus Lam.*) exhibits pharmacological properties and is effective against pathogenic microbes, such as *Pseudomonas aeruginosa*, which when combined with tetracycline (antibiotic) disrupted membrane permeability and lead to cell lysis and can thus be used to prevent *P. aeruginosa* infection (Septama et al. 2022). Artocarpin has antioxidant activities and inhibitory activities on α-glucosidase and α-amylase, thereby they can act as ingredients for hypoglycemic functional foods (Wang et al. 2022).

### Fibre

Jackfruit seed is rich in fibre as compared to Jackfruit pulp (Amadi et al. 2018). The fibre content in Jackfruit seed was 3.19% (Ocloo et al. 2010). Jackfruit seed is rich in dietary fiber (Babu et al. 2017). Dietary fibre has been linked to a lower risk of cardiovascular disease and mortality (Barber et al. 2020).

### Protein

A jackfruit seed isolate was isolated in an effort to discover a novel source of useful proteins with emulsifying properties (Zhang et al. 2019a, 2019b, 2019c). Jackfruit seeds have a high concentration of highly soluble protein that aids in the reduction of mental tension and anxiety (Waghmare et al. 2019). (Chai et al. 2021a, 2021b) investigated jackfruit seed protein isolates and discovered preservative properties.

### Phytonutrients

The lignans, flavones, and saponins identified in jackfruit seeds have antioxidant, anticancer, antiulcer, antihypertensive, and antiaging effects (Shedge et al. 2022). Lignans refer to a group of secondary metabolites that form when two or more phenylpropanoid units undergo oxidative dimerization; two types of antiviral lignans – podophyllotoxin and bicyclol show high potency against venereal warts and chronic hepatitis B (Cui et al. 2020). Flavones are a significant class of bioactive dietary ingredients with anti-inflammatory properties (Wang et al. 2021). Saponins are amphiphilic compounds of pharmacological importance, and the majority of their biological activities such as cytotoxicity, hemolysis, fungicide, etc. are connected to their membranolytic capabilities (Savarino et al. 2021).

### Bioactive constituents

(Olarere et al. 2020) employed liquid Chromatography-Mass spectrometry analysis to study the jackfruit seed composition after microwave extraction and found out there were a total of 90 and 148 bioactive constituents at positive and negative electrospray ionization modes which shows the medicinal and nutritional functionality of the sample. Supercritical carbon dioxide extraction was carried out to extract 0.6254 mg $g^{-1}$ polyphenols from jackfruit seed under optimum conditions of 30 g $min^{-1}$ flow rate of $CO_2$ at 175 bar pressure, 70% ethanol 5mL$g^{-1}$ ethanol dosage, 50 °C extraction temperatures, and 1.5 h of extracting time (Meng-Xia et al. 2018).

### Fatty acids

Linoleic and linolenic acids are the predominant fatty acids found (Kumoro et al. 2020). In five different jackfruit species; (Nagala et al. 2013) examined the fatty acid composition and antioxidant capacity of the oils. According to their research, jackfruit is a good source of essential

**Table 1** Elements in jackfruit seed in different varieties (Sulaiman 2019) (Abedin et al. 2012)

| Varieties | Phosphorus | Potassium | Aluminium | Calcium | Magnesium | Sodium | Zinc | Iron |
|---|---|---|---|---|---|---|---|---|
| Mastura | 0.12883 | 0.76932 | 1.67 | 40.86 | 0.10294 | 5.39 | 1.36 | 1.00 |
| Khaja | 0.139 | 1.30 | Not reported | 0.02 | 0.1507 | Not reported | 1.5 | Not reported |
| Gala | 0.1707 | 1.34 | Not reported | 0.11 | 0.1687 | Not reported | 2.333 | Not reported |
| Durosha | 0.1193 | 1.42 | Not reported | 0.38 | 0.210 | Not reported | 3.1 | Not reported |

fatty acids (EFAs) and has significant antioxidant activity. The DPPH tests revealed higher percentages for *Artocarpus integer* (98.4 ± 0.2% of inhibition 50μL$^{-1}$), *Artocarpus integrifolia* (98.2 ± 0.3% of inhibition 50 μL$^{-1}$), and *Artocarpus heterophyllus* (87.4 ± 0.2% of inhibition 50 μL$^{-1}$).

### Starch

Jackfruit seed consists of certain amount of starch. Starch has numerous benefits, when this starch is gelatinized followed by cooking and cooling resistant starch is formed (Birkett & Brown, 2007). Resistant starch (RS) refers to all types of starch that are digested in the colon to produce short chain fatty acids but are inaccessible to human digestive enzymes. Due to its distinct physical, chemical, and functional characteristics resistant starch is used in a variety of food products and produces goods of excellent quality (Ashwar et al. 2016). It offers various health advantages. Among them are the possibility of modifying fat oxidation, management of diabetes, improvement of colon health and microbiota, reduction of glycemic index and blood cholesterol levels, decreased bilestone production, and increase in mineral absorption (Bojarczuk et al. 2022; Raigond et al. 2015). There are various ways these starches can be modified such as physical, enzymatic and chemical modifications. It is explained in further detailed in the following section.

## Jackfruit seed starch

Starches constitute the most essential carbohydrate source for humans, and they have become components for a wide range of food products, including thickening agent, stabilizers, gelatinizers, binders, superabsorbent polymers, and adhesives (Liu et al. 2017). Jackfruit seeds can be used to produce starch because they contain 63–80% carbohydrates (Tulyathan et al. 2002). Jackfruit seeds contain 70–85% total starch when dry (Madrigal-Aldana et al. 2011). Jackfruit seed starch consists of 25 to 45% amylose content and 45 to 80% amylopectin content (Mukprasirt & Sajjaanantakul 2004). As a result of its high amylose concentration, jackfruit starch is a prospective resistant and low-digestible starch; it has a round, bell, or oval form and exhibits lower granule size, swelling power, and solubility (Zhang et al. 2021a, 2021b, 2021c). Jackfruit seed starches show higher amount of resistant starch (about 75%) better swelling and water absorption capacity, and high gelatinization temperature (76–88 °C) (Kushwaha et al. 2021a, 2021b).

### Extraction of starch

Various extraction techniques are used to extract starch from Jackfruit seeds. Some of these techniques involve the usage of distilled water, alkali, and enzymes. (Noor et al. 2014) investigated the extraction of jackfruit seed starch by employing all the aforementioned techniques, the results of which are listed in Table 2. (Mukprasirt & Sajjaanantakul 2004) extracted starch from jackfruit seed using a slightly modified technique of (Bobbio et al. 1978). The cotyledons of the jackfruit were rinsed with distilled water to remove soluble sugars before being pulverized in 0.5% $NaHSO_3$ (1:1 by weight) for 2 min. The liquid and the particles were separated using centrifugation at 3500 RPM for 15 min at 20 °C. The cake was washed in 80% ethanol, distilled water, then distilled water one more, and then dried (Mukprasirt & Sajjaanantakul 2004). Jackfruit seed starch was extracted and exposed it to acid modification after which its pasting properties showed a drastic loss in viscosity that indicates the possibility that acid-thinned jackfruit starch can be utilized in confectionery fillings (Dutta et al. 2011).

### Modification

The starch that is obtained after being extracted from seeds is altered in order to enhance its functional properties. Numerous techniques have been used to modify the jackfruit seed starch. There are mainly three modification techniques used to modify native starch; physical modification, chemical modification, and enzymatic modification. Some of these are annealing (Bhattacharjya et al. 2015), acid modification (Banyal et al. 2022; Dutta et al. 2011; Le et al. 2020), acid thinning (Zuo et al. 2014), pre-gelatinization (Kittipongpatana & Kittipongpatana 2011), microwave modification (Karadbhajne et al. 2014), heat moisture treatment (Kittipongpatana & Kittipongpatana, 2015), hydroxypropylation (Naknaen, 2014), cross-linking (Kittipongpatana et al. 2011), carboxymethylation (Kittipongpatana & Kittipongpatana 2011; Van et al. 2021), oxidation (Naknaen 2014; Naknaen et al. 2017; Tung et al. 2021), partial gelatinization (Li et al. 2022; Tran et al. 2015), improved extrusion cooking technology (Li et al. 2021; Zhang et al. 2022, 2021a, 2021b, 2021c, 2019a, 2019b, 2019c), β-amylase

**Table 2** Comparison of the extraction techniques (Adapted from Noor et al. 2014)

| Extraction techniques | Inferences |
|---|---|
| Distilled water | High yield, amylose, and swelling water capacity |
| Enzyme | High water absorption index, water-soluble index |
| Alkali | Low performance compared to both techniques |

(Tran et al. 2015; Zhang et al. 2021a, 2021b, 2021c), Etherification with Propylene Oxide (Naknaen 2014), ultrasonic methods (Banyal et al. 2022). These modification techniques tend to develop resistant starch; improve gelatinization temperature, and increase thermal stability, viscosity, crystallinity, and water-holding capacity moreover it helps to raise solubility and swelling power. More details related to the various modification techniques and the impacts they cause have been listed in Table 3.

#### Comparison of jackfruit seed starch to other starches

(Wong et al. 2021) compared jackfruit seed starch to potato starch and rice starch and found three superior characteristics in comparison to the other starches i.e., heat stability, ability to form strong starch gels, and small monodispersed starch granules. (Phrukwiwattanakul et al. 2014) found that in comparison to mung bean starch, jackfruit seed starch has higher gelatinization temperature, and enthalpy of gelatinization and pasting temperature. Jackfruit seed starch possesses better gel-forming properties as compared to potato, tapioca, and waxy maize starches (Yazid et al. 2019). Jackfruit seed starch had better gelatinization temperature, enthalpy, and pasting viscosity as compared to litchi, longan, loquat, and mango kernel starch (Guo et al. 2018). In comparison to corn and cassava starch, (Ying et al. 2022) found that jackfruit seed starch had the highest amylose content, lowest particle size distribution, and highest particle size uniformity. This creates the opportunity to create original, distinctive products for the Asian and global markets using jackfruit seed starch as a novel source of starch. The above-mentioned research presents ideas for needed research to increase the comprehensive consideration of jackfruit seed starch in the food sector.

#### Application of Jackfruit seed starch

Jackfruit seed starch has a wide range of applications, and multiple researchers have been striving to maximize its potential. The different types of study that researchers have conducted over the years are described in Table 4.

## Health benefits

There are numerous health benefits that have been recorded throughout various literatures upon consumption of jackfruit seeds that can be attributed to its possession of various nutritional components. Because they aid in digestion, have anti-carcinogenic qualities, and reduce the appearance of wrinkles on the skin, jackfruit seeds are very healthy to consume (Chhotaray & Priyadarshini 2022). A presence of minerals calcium, magnesium, phosphorus, sodium, iron, copper, zinc, potassium, and Manganese were detected (Hajj et al. 2022). They perform a wide range of tasks, including serving as our bones' building blocks, affecting muscle and nerve activity, and balancing the body's water levels (Weyh et al. 2022).The seeds of the jackfruit are high in carbohydrate and have a protein content of 10% to 15% also due to its high amylose and protein concentrations, jackfruit seed flour or starch has the potential to be used in functional food formulations when compared to commercially available modified starches (Suzihaque et al 2022). Seeds also contain two lectins (Artocarpin & Lectin) which impart immunological properties (Gat, Sharma & Rafiq. 2022). It was also found to have dietary fibre in adequate amounts (Astuti et al. 2022). Increased intake of dietary fibre has been found to lower blood pressure and other cardiometabolic risk variables, and is related with a lower risk of developing cardiovascular disease (Reynolds et al. 2022). Figure 1 shows the various health benefits linked to the functional components prevalent in Jackfruit seed.

## Processing of Jackfruit seeds

Jackfruit seed is normally processed to turn it into its powdered form shown in Fig. 2. Different processing methods are utilized to process the jackfruit seeds into powdered or flour form. Jackfruit seeds are autoclaved, boiled, dried, germinated, microwaved, baked, and roasted in order to process them for increasing their various functional properties or characteristics. (Borgis & Bharati 2020; Ejiofor et al. 2014) investigated the effects of all the processing methods on the various nutritional or functional properties of jackfruit seed. The significant changes observed in the jackfruit seed composition have been diagrammatically represented in Fig. 2. Roasting prior to flour production gave the best results as compared to other processing methods since it increased the protein content, and water absorption capacity with a reduced oil absorption capacity (Ejiofor et al. 2014). Similar experiments were conducted on three types of jackfruit seed flour; raw jackfruit seed flour, germinated seed flour, and thermal jackfruit seed flour (Oven dried at 60–80 °C) and found that the thermal jackfruit seed flour gave the best results based on protein content, essential amino acids, dietary fibre, and vitamin C (Zuwariah et al. 2018).

## Application

Jackfruit seed is gradually being commercially produced in recent times and can be found at a few stores and e-commerce platforms. With increasing research, the potential of jackfruit seed is now getting

**Table 3** Modification techniques employed to improve the functionality of jackfruit seed

| MODIFICATION | TREATMENT | IMPACT | REFERENCES |
|---|---|---|---|
| Annealing (Physical modification) | Single stage: 10 g starch heated with 50 mL distilled water at 45ºc, 50ºC, 55ºC, and 60ºC for 72 h<br>Double stage: Involved additional heating step at a temperature that was 10ºC lower the stipulated temperature for the same duration | Increase in peak viscosity<br>Increase in thermal stability<br>Decrease in swelling power<br>Decrease in solubility | (Bhattacharjya et al. 2015) |
| Acid (Chemical modification) | Acid hydrolysis<br>25 g of dry starch in Hydrochloric acid with ethanol or methanol followed by heating and neutralizing with 1N NaOH | Increase in amylose content<br>Increase in water absorption capacity<br>Increase in solubility<br>Increase in carbohydrates<br>Decrease in oil absorption capacity<br>Decrease in swelling power<br>Decrease in dispersibility<br>Decrease in protein & Fat | (Banyalet al. 2022)<br>(Le et al. 2020) |
| Pre-gelatinization (Physical modification) | 100 g jackfruit seed starch in 350 mL distilled water, heated at 80ºC for 15 min with slow addition of 200 mL methanol and continuous stirring | Increase in gelatinization enthalpy<br>Increase in water solubility<br>Increase in viscosity<br>Increase in swelling power<br>Increase in water uptake<br>Decrease in crystallinity | (Kittipongpatana & Kittipongpatana 2011) |
| Microwave (Physical modification) | 450 W, 5 min, and 50ºC | Increase in thermal stability | (Olalere et al. 2020) |
| Heat Moisture (Physical modification) | Initially, 10.3% moisture content was adjusted to 20, 25, 30, and 35% by water addition and was thus heated in a hot air oven at 80, 90, 100, 110, and 120ºC for 6, 12, and 16 h | Increase in resistant starch<br>Increase in gelatinization<br>Increase in swelling power | (Kittipongpatana & Kittipongpatana 2015) |
| Hydroxypropylation (Chemical modification) | Jackfruit seed starch (100 g) was suspended in 120 mL 1g$L^{-1}$ NaOH with 15 g $Na_2SO_4$and after 10 min, 12 mL of propylene oxide was added and heated at 40ºC for 24 h | Increase in swelling power<br>Increase in water solubility<br>Increase in thermal stability | (Kittipongpatana & Kittipongpatana 2011) |
| Cross-linking (Chemical modification) | Jackfruit seed starch (100 g) was suspended in 250 mL distilled water, with 15 g of sodium sulphate and 2.5 g of sodium trimetaphosphate. The pH of suspension was adjusted to 10.5 by adding 50g$L^{-1}$ aqueous sodium hydroxide | Increase in crystallinity<br>Increase in water uptake<br>Decrease in flowability | (Kittipongpatana & Kittipongpatana 2011) |
| Carboxymethylation (Chemical modification) | Alcoholic Solvents:<br>Methanol, 1-propanol, and 2-propanol | Increase in water uptake<br>Increase in viscosity | (Kittipongpatana & Kittipongpatana, 2011) |
| Oxidation (Chemical modification) | 40 g starch was mixed in distilled water, using sulphuric acid and NaOH to adjust pH value. Copper sulphate was added as a catalyst and 2% Hydrogen peroxide ($H_2O_2$) was added as an oxidizing agent, pH-9, and temperature of 40ºC<br>Starch was stirred at 35ºC, pH-9.5 with 2 M NaOH. Sodium hypochlorite (NaOCl) mixed with 1% active chlorine was slowly added within 30 min and continuously stirred for 50 min at the same pH and temperature | Decrease in grain surface smoothness<br>Increase in recovery efficiency<br>Increase in whiteness<br>Increase in paste clarity<br>Increase in thermal stability<br>Increase in storage stability<br>Increase in solubility | (Tung et al. 2021)<br>(Naknaen et al. 2017) |
| Partial gelatinization (Physical modification) | Starches were gelatinized by using 4 M Calcium chloride ($CaCl_2$) | Increase in amylose content<br>Increase in resistant starch<br>Increase in gelatinization temperature | (Li et al. 2022) |

**Table 3** (continued)

| MODIFICATION | TREATMENT | IMPACT | REFERENCES |
|---|---|---|---|
| Extrusion cooking (Physical modification) | Starch is cooked in a sealed barrel under high pressure, high temperature, and high mechanical shearing force in short time | Increase in rapid digestibility of Starch | (Zhang et al. 2022) |
| β-amylase (Enzyme modification) | Starch was modified by using 8% of β-amylase, pH-5.5, which is heated at 50-60ºC | Increase in water holding capacity | (Tran et al. 2015) |
| Etherification with Propylene Oxide (Chemical modification) | Propylene oxide to modify starch for 24 h at 40ºC | Decrease in crystallinity<br>Increase in molecular substitution<br>Increase in swelling power<br>Increase in solubility | (Naknaen 2014) |
| Ultrasonication (Physical modification) | Ultrasonic waves were passed through the starch for the purpose of functional modification | Increase in high purity starch<br>Increase in antibacterial properties | (Banyal et al. 2022) |
| Cold plasma (Physical modification) | Jackfruit seed flour was treated with varying plasma voltages of 170, 200, and 230 V for 5–15 min | Increase in water solubility<br>Increase in absorption<br>Increase in swelling power<br>Increase in water holding capacity<br>Decrease in pH<br>Decrease in moisture | (Joy et al. 2022) |

acknowledged, and in-depth research projects are being undertaken to investigate its nutritional properties or characteristics. Jackfruit seeds are rich in dietary fibre and B-complex vitamins and due to their high fibre content, they help lower the risk of heart disease, prevent constipation and limit adipogenesis (Waghmare et al. 2019). It was examined that the starch composition of jackfruit seeds in soft and hard jackfruit seeds contain 92.8% and 94.5% starch, respectively (Madruga et al. 2014). It is because of these qualities that jackfruit seeds have been utilized in many types of research and are also being used as alternatives for other types of flour. Significant research works have been carried out in order to utilize jackfruit seed in food and various other sectors. These works have been listed in a tabulated form in Table 5.

Jackfruit seed can be utilised in a number of other industries besides the food industry, including bioadsorbents, dyes, electronics, and pharmaceuticals. Table 6 lists the many studies that have been conducted by scholars over the years and most lately.

## Focused areas of research

There are a few research areas that use jackfruit seeds as the starting point but have distinct ends in mind. Jackfruit seed has been used for years to create bioabsorbents, composite films, bioplastics, starch, and other things. In the Table 7 below, each of these is listed in proper detail.

## Future scopes

Various conventional and non-conventional techniques have been utilized to extract various nutritional properties or qualities of jackfruit seeds. However, further research is required to understand the full potential of Jackfruit seeds. There are numerous research opportunity areas such as 1) Essential oil in jackfruit seeds 2) Carotenoid assay of the jackfruit seeds 3) Comparison of the various processing techniques on jackfruit seeds and their physicochemical and nutritional studies 4) Research on various types of physical, chemical, and enzymatic modification techniques for improving the yield of jackfruit seed starch and improvement of recovery of various functional components. Moreover, there are numerous types of jackfruits that can exhibit different physicochemical/nutritional/quality attributes, and all these breeds or types of jackfruits if studied can make a breakthrough in the current research scene of jackfruit seed.

## Conclusion

After an enormous review, it has been observed that jackfruit seed has a high degree of adaptability and it requires little input for cultivation, making it a potential source of abundant, affordable, and sustainable carbohydrates in tropical and subtropical areas. As a dietary supplement, it is known to contain nutrients which are essential in combating malnourishment and can be used as immune-modulators. The presence of phytonutrients further enhances the opportunities

**Table 4** Application potential of jackfruit seed starch in various sectors

| Application | Findings | References |
|---|---|---|
| Thickener and Stabilizer in chilli sauce | Jackfruit seed starch when incorporated with chilli sauce showed better consistency and low serum separation | (Rengsutthi & Charoenrein 2011) |
| Coagulant aid for treatment of wastewater | Positive turbidity and Chemical oxygen demand removals were observed in the systems | (Choy et al. 2017)<br>(Yunus & Azaha 2021) |
| Jackfruit seed plasticized with glycerol to make starch-based bioplastics | The bioplastics had low opacity, better water vapor permeability, and high mechanical stability, by using glycerol in the gelatinized starch dispersions | (Santana et al. 2018) |
| Novel flavor microcapsules containing vanilla oil | Results of peroxide value and the aroma intensity demonstrated that it had good storage stability and slow-releasing potential with a shelf life of 250 days | (Zhu et al. 2018) |
| Bioethanol | Jackfruit seed starch was able to produce 13–19% of ethanol | (Ginting et al. 2020) |
| Smart film as an indicator of fish freshness | The film exhibited a high tensile strength | (Costa et al. 2020) |
| Rice bran oil encapsulation using jackfruit seed starch | Increased encapsulation efficiency of 85.90% was observed after the incorporation of jackfruit seed starch | (Murali et al. 2017) |
| Jackfruit seed starch-based bioplastics using sorbitol as a plasticizer and chitosan as a filler | The bioplastic showed good tensile strength 13,524 MPa with a smooth fracture surface | (Lubis et al. 2017) |
| Jackfruit seed starch-alginate mucoadhesive beads of metformin Hydrochloric acid | In alloxan-induced diabetic rats, the optimised beads demonstrated good mucoadhesivity and a strong hypoglycemia impact for an extended period following oral delivery | (Nayak & Pal 2013) |
| Microencapsulated anthocyanin-rich powder using soy protein isolate, jackfruit seed starch, and an emulsifier | Encapsulation efficiency was found to be 89–90%. Studies on storage to determine the anthocyanin half-life in the microcapsule at room temperature (37 °C) showed improved stability, i.e., 63 days when stored under an amber-colored vial compared to just 35 days when stored under a clear glass vial | (Patel et al. 2020) |
| Plasticized jackfruit seed starch as an alternative to petroleum-based polymer blends | Improved thermal stability as well as tensile properties | (Kahar et al. 2019) |
| Superdisintegrant to design fast-dissolving tablets of irbesartan | Formulations were stable and showed fast disintegration of tablets and drug release | (Suryadevara et al. 2017) |
| Jackfruit seed starch-based bioplastic reinforced with microcrystalline cellulose from cocoa pod husk using glycerol as a plasticizer | Tensile strength of 0.637 MPa was observed | (Lubis et al. 2018) |
| Jackfruit seed starch used as a coating material in 'Palmer' mango fruit | The coating sources were effective in maintaining quality and delayed fruit skin yellowing | (Rodrigues et al. 2020) |
| Jackfruit seed sourced resistant starch along with *Bifidobacterium pseudolongum* subsp. *Globosum* (synbiotics) to suppress hyperlipidemia in Mice | Maintained the homeostasis of the intestinal microbes by correcting the damaging effects of a high-fat diet on gut microbes. Synergistic effects were seen in order to treat and prevent hyperlipidemia | (Zhang et al. 2021a, 2021b, 2021c) |
| Jackfruit seed starch-PVA blend polymer electrolyte along with Zinc oxide nanoparticles | The maximum ionic conductivity at an ambient temperature of $1.10 \times 10^{-6}$ S $cm^{-1}$ was obtained in the film and it is attributed because of the high amorphous content | (Raihan et al. 2022) |
| Jackfruit seed starch based composite films | Showed improved material strength, apparent viscosity, dynamic moduli, enhanced ultraviolet, water vapor barrier properties, and thermal stability | (Santhosh & Sarkar 2022) |
| Jackfruit seed starch-based bioplastics | Good tensile strength of 5.12 MPa | (Nguyen et al. 2022) |
| Jackfruit seed starch-based thermoplastic films along with glycerol | The maximum strength, 4.40 MPa, was attained by starch film plasticized with 10% glycerol, which also created stable hydrogen bond contacts with the starch molecules | (Seed 2018) |

**Table 4** (continued)

| Application | Findings | References |
|---|---|---|
| Jackfruit seed starch-based films containing carvacrol | The film effectively controlled the growth of *Staphylococcus aureus* in cheese stored at 28 °C with a tensile strength of 12.03 MPa | (Saturos et al. 2021) |
| Thiolated Jackfruit seed starch as a colonic drug delivery carrier | High drug release rate at pH 7.4 | (Das et al. 2019) |
| Jackfruit seed starch used as a coagulant for the leachate treatment process | Addition of the jackfruit seed starch succeeded in reducing 33.3% the usage amount of polyaluminium chloride in the treatment | (Suffianyusoff et al. 2016) |

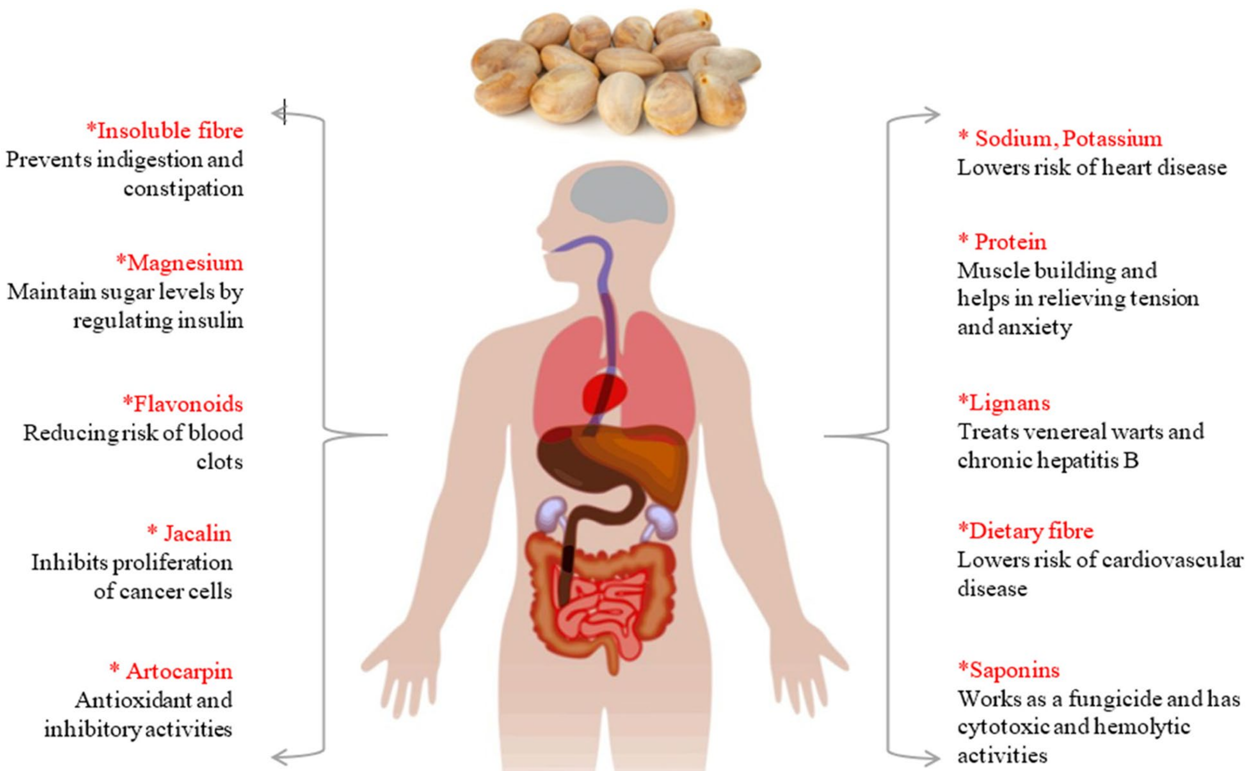



**Fig. 1** Health benefits of jackfruit seeds

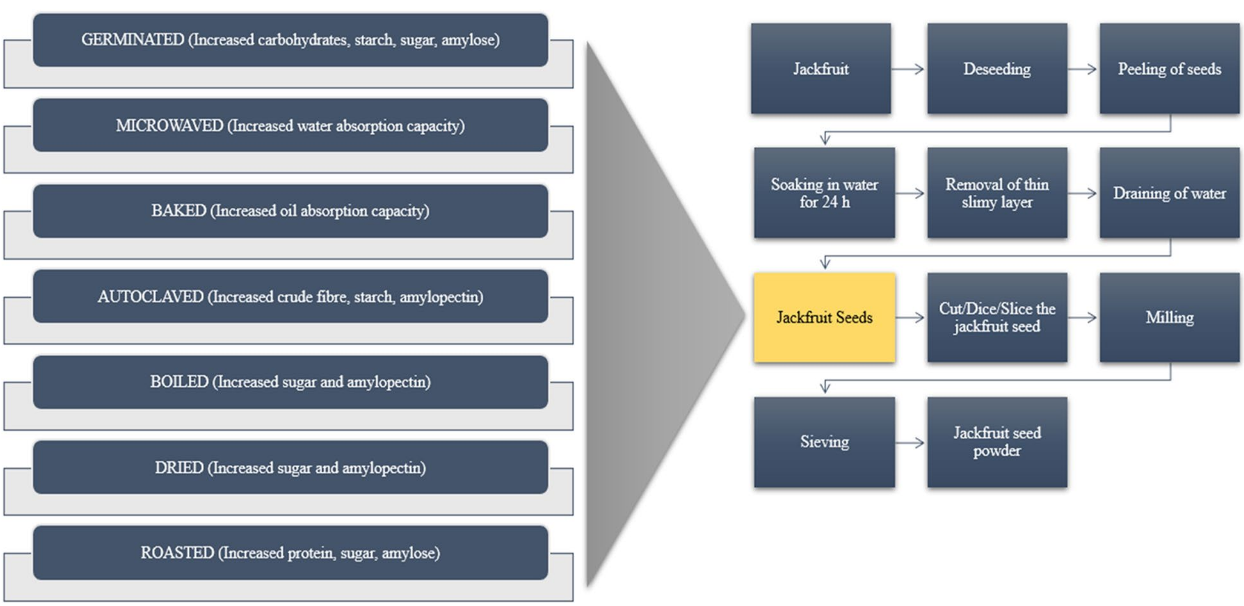



**Fig. 2** Processing steps for conversion of jackfruit seed to jackfruit seed powder and the impacts of the pre-processing techniques on the flour

**Table 5** Application of jackfruit seed in food sectors

| Finding | Inferences | References |
|---|---|---|
| Single-cell Protein | Supplementation of jackfruit seed with inorganic nitrogen sources and glucose as a carbon source enhanced single-cell protein production | (Chakraborty & Bhowal 2022) |
| Xylanase & Endoglucanase | *Penicillium roqueforti* carried out the solid-state fermentation | (Marques et al. 2019)<br>(Marques et al. 2020) |
| Vegetable milk | Plant-based milk using jackfruit seed had 2–3% protein, 1% fat and an overall good mouth-feel | (Hartati 2022) |
| Preservative | Essential oil extracted from jackfruit seed had enough radical scavenging activity which could scavenge the free radicals during the oxidation of meat | (Ramli et al. 2021) |
| Animal feed | Significant nutrient intake, digestibility, and nitrogen balance were shown by the jackfruit seed-based feed when fed to the West African dwarf goats | (Eyoh & Udoh 2020) |
| β-cyclodextrin | Jackfruit seed was used to extract β-cyclodextrin which led to a seven-fold production compared to other substrates | (Silva et al. 2020) |

for development of value-added products and nutraceutical developments. From the extensive review, we can conclude that Jackfruit seed has a high nutrient profile; starch being the most important product derived from it which can be used for making thickeners, tablets, and drug delivery carrier etc. It can further be raised in quality by making modifications which improves its overall thermal stability. Other than starch, Jackfruit seeds can also be used in making other ingredients such as biodiesel, composite films, absorbents etc. which have been the focus of research in the recent years.

**Table 6** Application of jackfruit seed in allied sectors

| Finding | Inferences | References |
|---|---|---|
| Production of Red pigments by Monascus purpureus in solid state fermentation | High yield; Due to the substrate's ability to act as a buffer, the pigments' hue is stable throughout a wide range of starting pH | (Babitha et al. 2007) |
| Bioabsorbents for chromium removal from wastewater | 92% of chromium removal | (Giri et al. 2021) |
| Bio-adsorbent for cadmium removal from wastewater | 97% of cadmium removal in 1 h at 120 rpm and pH 7.6 | (Prasad et al. 2020) |
| Biochar for removal of heavy metals | 75–98% removal of heavy metal ions | (Khadem et al. 2022) |
| Modified ion exchange jackfruit seeds resin for removal of selected trace heavy metal ions | Adsorption of lead, copper, and cadmium ions was carried out by resins successfully | (Ndung'u et al. 2021) |
| Natural coagulant | Reduced 50% turbidity and 70% of suspended solid after water treatment<br>Reduced 70% turbidity | (Mahmood & Zaki 2019)<br>(Putra & Sinta 2022) |
| Supercapacitor electrode from chemically activated carbon of jackfruit seeds | High capacitance and low resistance | (Mathew et al. 2020)<br>(Chaudhary et al. 2020) |
| Fluorescent nitrogen-doped carbon dots | High solubility in water, high photoluminescence quantum yield, photostability, and longer storage stability and low cytotoxicity | (Raji et al. 2019) |
| Dye-remover | 73% of novacron blue dye was removed within 60 min of contact time | (Miah et al. 2022) |
| Bio-ethanol | 58% of bioethanol was produced under optimum fermentation conditions using *Saccharomyces cerevisiae*<br>24% of ethanol using *Aspergillus oryzae* and *Saccharomyces cerevisiae* | (Arif et al. 2018)<br>(Minh 2022) |
| Corncob waste briquettes | Jackfruit seed adhesives were used to make briquettes with a calorific value of 6241.81 cal $g^{-1}$ | (Ghofur et al. 2021) |
| Calcium and phosphate ions alternatives for tooth enamel remineralization | Vickers Hardness Number test displayed positive results and jackfruit seed paste was effective in increasing enamel surface hardness | (Nugroho 2021) |

**Table 7** Areas of research focus utilizing jackfruit seeds

| Research | Explanation | References |
|---|---|---|
| Bioabsorbent | Biosorption is a low-cost and environmentally benign method for removing heavy metals like arsenic ($As^{5+}$), cadmium($Cd^{2+}$), chromium($Cr^{6+}$), copper($Cu^{2+}$), zinc($Zn^{2+}$) and Nickel($Ni^{2+}$) from aqueous environments.Also, dye from textile wastewater is removed by this process | (Maity et al. 2022), (Giri et al. 2021), (Prasad et al. 2020), (Choy et al. 2017), (Khadem et al. 2022), (Kannan & Veemaraj 2010)<br>(Kooh et al. 2018), (Zahrim et al. 2018), (Ibrahim et al. 2017), (Yunus & Azaha 2021), (Ndung'u et al. 2021), (Dahri et al. 2016) |
| Composite films/Bioplastics | Composite films or bioplastics are made to increase the shelf-life of food by utilizing it as food packaging materials | (Costa et al. 2020), (Santhosh & Sarkar 2022), (Seed 2018), (Retnowati et al. 2015), (Raihan et al. 2022), (Saturoset al. 2021), (Wahidin et al. 2021), (Sarifuddin et al. 2018), (Jayakumar et al. 2019), (Lothfy et al. 2018), (Santana et al., 2018), (Lubis et al. 2017), (Nguyen et al. 2022), (Oupathumpanont et al. 2016), (Maysarah, 2020), (Widhiantari & De Side 2021), (Mahardiani et al. 2022), (Putri Putri R. D. A., &Fitrianto 2020), (S Castro et al. 2023) |
| Starch | The primary food resource of plants, starch, is produced commercially from grains and tubers.A blend of two polysaccharides makes up starch (glucans). They are crucial as sizing and finishing agents in paper and textiles for non-food usage, whereas they are utilised in foods to thicken, gel, or otherwise control texture | (Mukprasirt & Sajjaanantakul 2004), (Noor et al. 2014), (Tulyathan et al. 2002), (Dutta et al. 2011), (Madruga et al. 2014), (S Castro et al. 2023), (Zhang et al. 2021a, 2021b, 2021c) |
| Food products | Jackfruit seeds are used for making various food products such as extruded products (cookies, noodles, etc.), drinks etc | (Brahma & Ray, 2022), (Kumari et al. 2022), (Chakraborty et al. 2022), (Ortega-González et al. 2022), (Yudhistira 2022) |
| Bioethanol | Bioethanol is an alcohol created through microbial fermentation, primarily from carbohydrates provided by sugar- or starch-bearing plants such as corn, sugarcane, sweet sorghum, or lignocellulosic biomass | (Ginting et al. 2020), (Bahlawan et al. 2022), (Arif et al. 2018), (Roy et al. 2015), (Ochaikul et al. 2012), (Kumar et al. 2011), (Minh et al. 2022), (Chongkhong et al. 2012) |
| Oil/Biodiesel | Oil/Biodiesel has been utilized throughout the years as a cooking fuel and vehicle fuel | (Babu et al. 2017), (Rengasamy et al. 2017), (Jeyakumar & Narayanasamy 2020), (Nagala et al. 2013), (Ramli et al. 2021) |
| Drugs and pharmaceuticals | Jackfruit seed has many benefits and it can be used as a carrier for delivering various essential components essential for human health | (Sivamaruthi et al. 2022), (Hasnain et al. 2023), (Nallasamy et al. 2022), (Sanjoy et al. 2019) |
| Pigments | Jackfruit seed powder is used as a substrate for Monascuspurpureus to produce pigments by the help of solid-state fermentation (SSF) | (Babitha et al. 2007), (Subhasree et al. 2011), (Panesar et al. 2015), (Hamdiyati et al. 2016), (Oliveira et al. 2018), (Soccol et al. 2007), (Mishra et al. 2019), (Ignatius et al. 2021) |

## Novelty of the review

This review was designed to emphasize the utilization of jackfruit seed in the coming years as a part of agro-waste valorization in various ways. Numerous emerging research areas, where experiments are being carried out by researchers across the globe have been described in the paper. After thorough literature survey of several research publications, a few research gaps have been identified and addressed new insights into previously unexplored areas as described in Sect. 8. As an under-utilized fragment of jackfruit, it has no such adverse effect to the environment but provides significant nutritional and functional constituents which could be exploited for value added food product development. Therefore, the readers of this review paper can find the scope of future research related to jackfruit seed valorization into value added constituents for future applications.

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RB formulated and researched the scientific publications related to the topic and prepared the manuscript. SR supervised and proofread the manuscript.

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