A COMPREHENSIVE REVIEW ON THE RECENT ADVANCES IN THE VALORIZATION OF JACKFRUIT WASTE FOR THE DEVELOPMENT OF VALUE-ADDED PRODUCTS

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ABSTRACT

The jackfruit (Artocarpus heterophyllus), a particular member of the Moraceae family, is abundantly found in Asia’s tropical and subtropical regions, and it has been reported to have a range of useful properties that treat ailments. Jackfruit contains both edible fractions e.g. seed and inedible fractions e.g. peel, rags, latex, perianth, core which are generally disposed of into the environment directly as waste and thereby causing an environmental concern as it leads to bio-waste accumulation. The existence of multiple beneficial compounds in the discarded parts of fruit contributes to its usage as a raw material in various food products such as bread, cake, cookies, extruded products, etc and also in various other sectors such as the fuel, cosmetics, pharmaceutical industries etc. This literature analysis was conducted to gain a good comprehension of changing trends in the Jackfruit waste utilization scenario, shaping up into the formation of value added food products. This review paper is designed by considering some latest findings of several researchers in this area.

Contribution/Originality: About 60% and above of the jackfruit is normally discarded as waste, however researchers from all over the world has found out various ways through which the waste can be treated and utilized in order to reduce waste disposal and increase sustainability. This review paper has been designed to compile those findings in order to get a clear picture of the jackfruit waste valorization scenario.

1. INTRODUCTION

In regions where jackfruit is grown and processed, it is underutilized because of its short shelf life and lack of processing facilities. Only 35% of the jackfruit's whole fruit is edible, with 60% consisting of inedible prickly rind, rags, latex, and seeds (Ranasinghe, Maduwanthi, & Marapana, 2019). A highly perishable fruit, jackfruit flesh is often subject to flavour loss, tissue softening, and browning on the cut surface (Mondal et al., 2013). Bruising and mechanical injury are more likely to occur when the fruit is softened (Ramlı, 2009). The postharvest handling and inadequate storage facilities in the areas where jackfruit is processed and marketed result in the rapid degradation of large quantities of ripe jackfruit after harvesting (Saxena, Bawa, & Raju, 2011).

The high perishability of jackfruit reduces its cost-effectiveness because it has to be exported as whole fruits than other fruits. Due to the uncertain shape and size of the fruit, the packaging design gets very cumbersome, and the sturdy body and sticky latex make the preparation very difficult (Ramlı, 2009). Peeling is very difficult in the case of Jackfruit since it’s a large fruit. Inconsistencies in size and shape make packaging very difficult and the rough
and thick skin and the latex make preparation difficult. Furthermore, segregating jackfruit edible bulbs from the rind is a manual labor exertion process and requires loads of time, which makes it an impractical option for the metropolitan inhabitants. A great deal of inedible parts is generated in jackfruit processing industries, and they are usually used as animal feed (Akter & Haque, 2019). There have been a few studies devoted to investigating how these wastes could be converted into augmented products. The result is a sizeable load of jackfruit waste being disposed of, which has serious suggestions for waste disposal and the surroundings. For this reason, it is crucial that commercial jackfruit handling employs modern processing automation and a sustainable waste control approach.

It has only been possible to conduct limited studies on Jackfruit waste counterparts. Adan, Ojwang, Muge, Mwanza, and Nyaboga (2020) found out that the peel and fibres of jackfruit have many bioactive compounds. The latex of jackfruit which has a sticky nature and is often looked down upon has also been discovered to have antioxidants and anti-cancer properties (Samrot & Sea, 2022). The Jackfruit seeds though edible are often thrown as waste because of the lack of significant flavor. The Jackfruit rags which surround the bulb of the fruit are rich in various compounds like cellulose, protein, reduced sugar and pectin however they are discarded as waste because of the chewy texture (Dam & Nguyen, 2012).

2. UTILIZED PARTS OF THE JACKFRUIT

2.1. Jackfruit Seed

In general, jackfruit seeds are discarded as waste, but they are beneficial in terms of nutrition. Jackfruit seeds represent about 10-15% of the fruit mass (Hossain et al., 2014). Numerous difficulties arise during processing and storage because of its perishable nature and thus large numbers of seeds are disposed per annum. In order to acquire a shelf-stable jackfruit seed product, they are normally roasted and ground into powdered form. In bakery and confectionary industries, jackfruit seed powder is used as a substitute for wheat flour and other types of flour (Hossain et al., 2014). Alternatively, the seeds are boiled or roasted and are also used as a supplement for potatoes. The seeds of jackfruit could serve as an economically feasible protein source for malnourished people (Chowdhury, Bhattacharyya, & Chattopadhyay, 2012). Due to its capability to come up with supplementary physiological advantages alongside basic nutrition, it is a crucial functional ingredient.

2.1.1. Nutritional Profile

Detailed research is yet to be done on the nutritional assets of Jackfruit seeds. Gohain Barua and Boruah (2004) recorded the presence of Iron (Fe), Manganese(Mn) and Magnesium(Mg) through emission and Fourier transform infrared spectra.

Table 1 presents the physicochemical parameters of jackfruit seed powder.

| Parameter               | Amount (% dry matter) |
|-------------------------|------------------------|
| Crude Fat               | 1.27 ±0.01             |
| Moisture                | 6.09 ±0.01             |
| Carbohydrate            | 79.34 ±0.06            |
| pH                      | 5.78 ±0.01             |
| Protein                 | 13.50± 0.06            |
| Titratable Acidity (as lactic acid) | 1.12 ±0.03 |
| Fibre                   | 3.19 ±0.01             |
| Energy(Kcal/100g)       | 382.79 ±1.20           |
| Ash                     | 2.70 ±0.02             |

Source: Okofo, Bansu, Boutin, Adam, and Agblevor (2010).

Table 2 presents the Mineral constitution of jackfruit seed flour.
Table 2. Mineral constitution of jackfruit seed flour.

| Minerals   | Amount (% dry matter) |
|------------|-----------------------|
| Zinc       | <0.01                 |
| Manganese  | 1.12 ± 0.11           |
| Copper     | 10.45 ± 0.89          |
| Iron       | 130.74 ± 12.37        |
| Calcium    | 3087.166              |
| Magnesium  | 3380 ± 388            |
| Sodium     | 60.66 ± 2.01          |
| Potassium  | 14781 ± 256           |

Source: Ocloo et al. (2010).

Table 3 presents Functional parameters of Jackfruit flour.

Table 3. Functional parameters of Jackfruit flour.

| Parameters                             | Amount (% dry matter) |
|----------------------------------------|-----------------------|
| Fat Absorption capacity (%)            | 17.00 ± 1.37          |
| Swelling Power (g/g)                   | 4.77 ± 0.10           |
| Foaming capacity (%)                   | 25.34 ± 0.02          |
| Bulk density (g/cm³)                   | 0.80 ± 0.02           |
| Foam Stability (%)                     | 33.00 ± 0.01          |
| Water Absorption Capacity (%)          | 25.00 ± 1.67          |

Source: Ocloo et al. (2010).

2.1.2. Pre-Processing Methods of Jackfruit Seed

Various methods are involved in the pre-processing of Jackfruit seeds in order to make it suitable for further incorporation into various food products. The seeds after undergoing the processing treatments undergo various changes in their physico-chemical properties. The processed seeds are then milled to flour and are used for further applications. The seeds are mainly pre-processed by techniques such as baking, pan roasting, pressure cooking and microwave roasting. After being subjected to various pre-treatments they exhibit various changes in their physico-chemical properties which are shown in a schematic diagram down below.

Figure 1 illustrates the pre-processing methods of jackfruit seeds and their effects.

Figure 1. Pre-processing methods of jackfruit seeds and their effects.
2.1.3. Value-Added Food Products

Value addition of a food product refers to the inclusion of a certain component that is not originally present in the product, thereby improving its overall value/utility. Modern food processing technologies can be used to incorporate a new beneficial ingredient or packaging visuals can be improved to target a certain demographic. Examples of value-added products involve juices, bread, extruded products, jam, jellies, breakfast cereals, etc.

### Table 4. Value-added products developed by using jackfruit seed.

| Products          | Observations                                                                 | References                                                                 |
|-------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Bread             | Bread containing 25% jackfruit seed flour was nutritionally better than whole wheat bread because of its higher carbohydrates, fat, protein, and crude fiber content. | Hossain et al. (2014)                                                       |
| Chapatis          | With the addition of 5% jackfruit seed flour to the chapatis, overall protein content was increased by 11% as well as calorific content. | Sultana, Rahman, Islam, Rahman, and Alim (2014)                             |
| Cake              | As the jackfruit seed flour content increased, the fat content of the cake decreased. | Khan, Saqib, and Alim (2016)                                               |
| Cake              | Using 10% Jackfruit seed flour and sucrose substitute (polydextrose) the calorie content of the cake was reduced by 34%. | Faridah and Aziah (2012)                                                   |
| Buns              | A composite bun with an enhanced nutritional profile was created by adding 10% jackfruit seed flour to wheat flour. | Ngwere and Mongi (2021)                                                    |
| Bread Spread      | The bread spread had a nutritional profile of 82 Kcal and also consisted of potassium, phosphorous, calcium and magnesium, niacin and vitamin C. | Supit et al. (2018)                                                        |
| Tortilla          | Pumpkin and jackfruit seed flour was incorporated to make Tortillas with increased dietary fibre values. | Ihromi and Dewi (2021)                                                    |
| Cookies           | The protein, fat, fiber, and ash content of cookies with Jackfruit seed flour was higher than those with wheat flour. Phytate and oxalate were also found within acceptable limits. | Maskey, Subedi, and Shrestha (2020)                                        |
| Snacks            | The snacks were prepared using jackfruit seed flour and corn flour and it showed protein (11%), fibre (2.43%). The optimum product was formed from 70% seed flour and 30% corn flour and exhibited higher organoleptic properties. | Shehin, Kaur, and Gupta (2019)                                             |
| Biscuits          | Coconut milk residue and jackfruit seed flour was mixed to form baked biscuits at the temperature of 180°C and scored good in sensory evaluation. | Barge and Divekar (2018)                                                   |
| Biscuits          | A higher replacement of wheat flour with jack seed flour increased moisture, fat, crude fiber, and ash content. The sensory panelists, however, rejected the jackfruit seed flour if the amount was increased by more than 20% because the colour was black and the texture was rough. | Islam, Begum, Khatun, and Dey (2015)                                       |
| Tambah cookie     | Using Jackfruit seed flour/powder in the cookies showed the presence of calcium and phosphorous. | Hidayati, Soekopitojo, Chisibiyah, and Mareta (2019)                        |
| 3D printed cookies| The cookies showed a higher storage modulus (elasticity) than the loss modulus (viscosity/viscous behaviour). | Varghese et al. (2020)                                                    |
| Unleavened Flat Bread | The product showed dough springiness, good colour and good overall acceptability. The analysis indicated that the jackfruit seed flour boosts the nutritional profile and shall stay acceptable | Ragast, Rawson, Krishnamoorthy, and Rangaranjan (2022)                     |
| Pasta             | Jackfruit seed flour along with red amaranthus was used to make pasta, it was concluded that the protein, fibre, carotenoid value had increased. It was also seen that the amaranthus contributed to the reduction of cooking losses of the pasta. | Swathi, Lekshmi, and Sajeev (2019)                                         |
| Pasta             | Jackfruit seed and jackfruit bulb flour were used to make pasta with reduced cooking losses and higher water absorption capacity. | Lakmali and Arampath (2021)                                               |
| Extruded product  | Jackfruit seed flour(10%) along with maize grits(75%) and tapioca flour(15 %) were utilized to form an extruded product with good texture and physicochemical qualities | Thejas Gowda et al. (2021)                                                 |
| Chips             | Jackfruit seed flour based chips showed higher carbohydrate values and good organoleptic properties. | Sotiyanita and Nurhayati (2018)                                            |
| Noodles           | Jackfruit seed flour along with Broccoli was utilized for the purpose of calcium fortification in noodles. An increase in micronutrients were analyzed. | Yulia (2019)                                                              |
| Butter cake       | The butter cake’s protein and crude fibre contents increased when the amount of jackfruit seed flour was increased. However, the sensory panelists rejected the increased jackfruit seed flour, therefore it was only reduced to 12%. | Abd El-Aziz and Esmail (2016)                                              |

Jackfruit seeds have a very good nutritional profile but they are underutilized and mostly go to waste. However, in recent times they are being used as a substitute for wheat flour and other types of flour in the bakery and confectionary industry (Hossain et al., 2014). Chowdhury et al. (2012) found out that the jackfruit seed flour
and its blends have exceptional water and oil absorption capabilities, and up to 1.5% (w/w) blending may be recommended for use in bread development moreover, it can also be used as a protein alternative and functional component for the purpose of improved human nutrition.

Table 4 presents the value-added products developed by using jackfruit seed.

### 2.1.4. Other Applications

Jackfruit seeds is not only used directly as a food product but can also be used in order to make other products that benefit the food industry. For e.g.: Coating material, prebiotics, nanomaterials, starch etc.

Table 5 presents the various other products that are used in the food industry but are not directly a food product.

| Products                          | Observations                                                                                         | References                                    |
|----------------------------------|-------------------------------------------------------------------------------------------------------|-----------------------------------------------|
| Smart seed starch coating        | The color change in the smart film occurred due to the release of total volatile basic nitrogen during the fish deterioration, altering the pH of the products which reacts with the anthocyanin. | Costa et al. (2020)                           |
| Prebiotics                       | Jackfruit seeds were extracted with 50% ethanol as a solvent. Based on the extraction yield and the quantity of non-reducing sugar, which is thought to contain prebiotics, the extraction efficiency was calculated. | Bhornsmithikun, Chetpattananondh, Yamsaenguang, and Prasertsit (2010) |
| Pectin from the slimy coating of a jackfruit seed | A modest 35.32% recovery was acquired by utilising oxalic acid in acidic extraction of pectin. In comparison with commercial apple and citrus pectin, the sheath displays the highest levels of antioxidant activity. | Kumar et al. (2021)                           |
| Jackfruit seed starch as raw material to make microcapsules holding in vanilla oil | A novel shell material based on the ultrasonic process, jackfruit seed starch, was used to microencapsulate vanilla essential oil. Jackfruit seed starch demonstrated a high encapsulation efficiency despite a poor yield. It outperformed other types of microcapsules in terms of storage stability and potential for gradual release. | Zhu, Zhang, Tian, and Chu (2018) |
| Jackfruit seed starch            | The jackfruit starch has the potential to compete with or supplement other commercially significant starches in some applications due to its advantages over major starches, including less particle size, more amylose and resistant starch content, good water and oil absorption capacities, and thermal stability of paste. | Zhang et al. (2021)                           |
| Jackfruit seeds as a replacement to cocoa powder | A 50 or 75 percent substitution of cocoa powder with dry jackfruit seed flour did not alter the sensory acceptability or features of the final product. Dry jackfruit seed flour can be used as an ingredient in cappuccino formulations. | Papa et al. (2018)                            |
| Protein Isolate                  | Jackfruit seed defatted flour was used with an alkaline solution which was then ultrasound treated. The Isolate had glutelins in huge amounts. | Ulloa et al. (2017)                           |
| Pigments (Food Colorant)         | Due to the substrate's buffering characteristics and the pigments' colour stability over a large variety of initial pH, this pigment can be used in a range of food applications. | Babitha, Soccol, and Pandey (2007)             |
| Silver nanoparticles             | By interacting with the bacterial cell wall or plasma membrane, bacterial DNA, and bacterial proteins, the silver nanoparticles demonstrated antibacterial property against a huge assortment of Gram positive and Gram negative bacteria. | Jagtap and Bapat (2013)                        |
| Thickener                        | Jackfruit seed starch was extracted and was utilized as a thickener and stabilizer in chilli sauce and also it scored a high overall acceptability value. | Rengsutthi and Charoenrein (2011)             |

### 2.2. Jackfruit Rags

Jackfruit rags are long filaments like structures that are found surrounding the bulb portion of the fruit and is at most times discarded as waste. They comprise approximately 25% of the fruit weight and are rich in cellulose, protein, reduced sugar, pectin (Dam & Nguyen, 2012). The presence of substances like polyphenolics including anthocyanins, coumarins, flavonoids, and substances belonging to the terpenoid, saponin, and cardiac glycoside families were also experimentally discovered, according to phytochemical screening assays (Dhwani et al., 2020).

Table 6 exhibits Value-added products prepared by using jackfruit rags.
Table 6. Valuable-added products prepared by using jackfruit rags.

| Products                      | Observations                                                                 | References                     |
|-------------------------------|-----------------------------------------------------------------------------|--------------------------------|
| Corned milkfish               | The raw material is immersed in salt as part of the corning preservation technique to enhance flavour and prolong shelf life. A corned product made from milkfish, which is common in the Philippines, and rags from jackfruit received a 55 percent approval rating overall. | Gipolan and Tabinas (2022)     |
| Fermented Beverage           | The mixture made from jackfruit rags was transported into fermentation containers and pectinase was added. 11°Brix, pH 4.35, 1.28 percent total acids, and 5.5% (v/v) ethanol were the end product's parameters. | Dam and Nguyen (2012)          |
| Vinegar                      | Jackfruit rag comprises 20% carbohydrates, which are enzymatically broken down into reducing sugar and used as a starting point for the creation of vinegar. | Photphisutthiphong and Vatanyoopaisarn (2019) |

Table 7 exhibits various products prepared by using jackfruit rags.

Table 7. Other products prepared by using jackfruit rags.

| Products                          | Observations                                                                 | References                        |
|-----------------------------------|-----------------------------------------------------------------------------|-----------------------------------|
| Amylase                           | The enzyme exhibited functional activity at pH 6-7, making it useful for the food industry's production of dough, the processing of juice and fruit, baking, and the brewing business. Additionally, a lower incubation time and less expensive substrates may enable the production of amylase at a cheap cost, making the procedure both commercially and economically viable. | Weerasoooriya and Piyarathe (2019) |
| Natural Photo-sensitizer         | The natural dye extracted from Jackfruit rags was used in the dye-sensitized solar cells, which demonstrated promising photovoltaic performance and led to the creation of minimal cost photo-sensitizers for energy harvesting functions. | Ashok et al. (2018)               |
| Single-slope solar still         | The trials generated a promising yield of 9.8% rate of increase of potable water compared to traditional stills employing Jackfruit rags and Azadirachta indica gum insulation. | Balachandran et al. (2021)        |
| Porous Carbon N-doped (PNC)      | Without using any chemical or physical activation, PNC materials were created from rags from jackfruit using a simple calcination procedure in an argon environment. When employed as the anode of sodium-ion batteries, the hierarchical NPC made from jackfruit rags at 800 °C (NPC-800) had the best cycling performance and rate capability. | Zhao, Ding, and Wen (2019)        |
| Jackfruit rags utilized as meat extender and phosphate binder | The resulting meat loaf had a moisture content of 50.91%, a crude fibre content of 7.27%, a crude protein content of 30.56%, and an ash content of 10.69%. | Braga and Galvez (2018)           |
| Glucose syrup                    | Cellulose from rags were hydrolysed by Hydrochloric acid to produce glucose syrups. | Sari (2019)                      |
| Acrylonitrile Butadiene Styrene Thermoplastic | The Jackfruit rags are reinforced with ABS (Acrylonitrile Butadiene Styrene) using compression moulding technique to form a natural fibre reinforced polymer. The resulting polymer exhibited commendable tensile and flexural properties. | Arun Sankar et al. (2021)        |
| Antibacterial Component         | For a wide range of laboratory and clinical strains of gram-positive and gram-negative bacteria, the rags extracts caused zones of inhibition which were visible in the agar well disc diffusion assay. According to analysis of bacterial cell pictures taken under an electron microscope, rag extracts induce cell death by rupturing the bacterial cell wall and eventually causes intracytoplasmic clumping. | Dhwani et al. (2020)             |
| Biosurfactant                    | The only media used in this work for the generation of microbial biosurfactants was isolated from jackfruit waste i.e. rags. In in-vitro tests, the final product showed strong antifungal efficacy against Alternaria solani, suppressing fungal growth by up to 83%. The nontoxicity of rhamnolipids generated from jackfruit waste suggests that they have potential for use in cosmetic and medicinal products. | Patowary et al. (2022)           |
Table 8. Value-added products prepared by using jackfruit rags.

| Products                      | Observations                                                                 | References                                                                                           |
|-------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Antioxidants                  | Antioxidant activity in the aqueous extract of the jackfruit latex have been found | Samrot and Sea (2022)                                                                                  |
| Anticancer components         | Jackfruit latex inhibited breast cancer cell proliferation and migration. Extract killed all cancer cells and inhibited cell proliferation, migration at higher concentration | Prakash and Gupta (2013)                                                                             |
| Protease                      | Artocarpin protease was extracted from Jackfruit latex and it indicated presence of proteolytic activity against casein. | Prasad and Virupaksha (1990)                                                                          |
| Protease                      | Protease was isolated which involves human blood coagulation factors          | Siritapetawee, Thumanu, Sojikul, and Thammasirirak (2012)                                            |
| Mucoadhesive tablet           | Jackfruit latex has the potential to act as a natural binder in mucoadhesive solid dosage form (tablet) and can also be used to formulate tablets, according to research in the form of in-vitro dissolution studies, comparative mucoadhesion studies, compatibility studies with the selected formulation, stability studies, etc. | Gohain and Sahu (2017)                                                                               |
| Natural rubber                | Jackfruit latex increases a tire's wet skid resistance (WSR). Additionally, it enhances carbon black's dispersion in rubber compound. In order to improve the dispersion of carbon black in rubber compounds and to improve WSR for tyres, it can be utilised as a low molecular weight natural resin rather than as a direct replacement for natural rubber. It can also be utilised as vulcanizable low molecular weight natural resin in a variety of vulcanizable elastomeric products, such as rubber rollers, matting, hot water bags, O rings, rail pads, conveyor belts, boats, dock fenders, and tyres. The peculiarity of this substance is that it comes from a natural source, is vulcanizable like natural rubber, enhances filler dispersion, and raises tyre wet skid resistance. | Bhadra, Mohan, Parikh, and Nair (2019)                                                               |
| Natural Rubber/LDPE/Waste Polyethylene Composites | Latex composites improve tensile, swelling properties and gel content. | Sandaruwan, WDM, Edirisinghe, and Sudusingha (2020)                                                  |
| Binder                        | Jackfruit latex was used as binder for fabric dyes                             | Kabir, Kim, and Koh (2018)                                                                            |
| Bimetallic Silver-Gold nanoparticles | The flavonoids, phenolics, and tannins included in the latex extract secondary metabolites are thought to be surface-active chemicals stabilising the bimetallic nanoparticles. Proteins and tannins may help in the bioreduction of metal ions to produce Ag-Au nanoparticles. The production of bimetallic nanoparticles was demonstrated using spectroscopic and surface morphological approaches. | Krishnan Sundarajan and Pottail (2021)                                                               |
| Polyisoprenes                 | The majority of the chemicals in the extracts, including polyisoprenes (89%), were lipophilic compounds, according to the proximate chemical analysis. Polyisoprene extracts have physicochemical and technofunctional characteristics that suggest they could be employed in emulsions or electrohydrodynamic encapsulation procedures. | Ramos-Martínez, González-Cruz, Calderón-Santoyo, and Ragazzo-Sánchez (2022)                           |
| Glycoprotein                  | Jackfruit latex was exposed to heat precipitation and Ion-exchange chromatography in order to obtain a heteromultimeric glycoprotein which had an inhibitory effect on the blood coagulation. | Siritapetawee and Thammasirirak (2011)                                                               |
2.3. Jackfruit Latex

Jackfruit produces latex from the fruits, stem, bark, leaves. The latex is white in colour and has a sticky nature i.e. it has gum-like properties. It tends to coagulate when in contact with air and has a characteristic fruity smell. The chemical composition of jackfruit is that it is rich in lipid-derived waxy substances, proteins, secondary plant metabolites like flavonoids, alkaloids and tannins (Krishnan Sundarrajan & Pottail, 2021). It grabs very less interest in terms of commerce or market but it has high potential because it has antioxidant properties which is highly beneficial to human health (Samrot & Sea, 2022). According to Swami, Thakor, Haldankar, and Kalse (2012), pharyngitis, snakebites and glandular swellings can also be cured by the jackfruit latex. Not much scientific activities have been found regarding the jackfruit latex and its usage in the food industry but it definitely has an impact in the medicinal or pharmaceutical industry.

2.3.1. Profile of Jackfruit Latex

According to Samrot and Sean (2021) latex extract exhibited the presence of 1,2-benzoldicarbonsaure, nonpolar compounds and antioxidant activities.

Table 8 presents the value-added products prepared by using jackfruit rags.

2.4. Jackfruit Peel

Jackfruit peels consists of various beneficial compounds such phenols and flavonols (Zhang et al., 2017). They also contain various other compounds such as ascorbic acid, polyphenols (catechins and chlorogenic acid) and β-carotene (Sharma, Gupta, & Verma, 2015).

They are also a rich source of pectin; consists about 8-15% of pectin in dry matter (Xu et al., 2018). Cellulose is also predominantly present in a range of 20-30% in the peel. Adan et al. (2020) found out that jackfruit peel had abundant minerals, such as potassium, magnesium, zinc, manganese, sodium, copper, calcium through Atomic Absorption spectrometry (AAS).

Table 9 exhibits the value-added products prepared by using jackfruit peel.

Table 9. Value-added products prepared by using jackfruit peel.

| Products         | Observations                                                                 | References                  |
|------------------|------------------------------------------------------------------------------|-----------------------------|
| Healthy meat analogue | Jackfruit peel powder was mixed in a wheat gluten ratio to produce a meat analogue | Hamid et al. (2020)         |
| Bread            | When combined with other ingredients to make bread, peel powder (5%) increased the amount of fibre, the ability to hold oil and water, and the pasting capabilities. | Felli, Yang, Abdullah, and Zzaman (2018) |
| Cookies          | Cookies obtained after utilization of rind powder had high carbohydrates and fibre content and also had high overall acceptance. | Ramya, Anitha, and Ashwini (2020) |
| Wine             | Wine from Jackfruit peel has a TSS (Total Soluble Solids) of 5 and a good overall acceptance. | Cagasan et al. (2021)       |
| Vinegar          | Vinegar was prepared from Jackfruit peel and had a protein content of 2.45%. | Constance et al. (2021)     |

Table 10 presents the value-added products prepared by using jackfruit peel.
Table 10. Value-added products prepared by using jackfruit peel.

| Products                               | Observations                                                                                                                                                                                                                                                                                                                                 | References                                                                                                                                 |
|----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Antimicrobial packaging films          | Tapioca starch and thymol were used to prepare jackfruit peel-based films as a filler and antimicrobial substance, respectively.                                                                                                                                                                                                        | Shukor, Nordin, Tawakkal, Talib, and Othman (2021)                                                                                             |
| Potassium, sodium, calcium, Magnesium, | Analyzed by Atomic absorption flame emission spectrometry                                                                                                                                                                                                                                                                               | Adan et al. (2020)                                                                                                                            |
| Zinc, Copper, Manganese                |                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                |
| Pectin                                 | Jackfruit peel was subjected to Radio frequency-assisted extraction to obtain pectin                                                                                                                                                                                                                                                   | Naik, Rawson, and Rangarajan (2020)                                                                                                           |
| Cellulose and spherical cellulose     | By sulphuric acid hydrolysis, Jackfruit peel derived cellulose and spherical cellulose nanocrystals were isolated                                                                                                                                                                                                                     | Trilokesh and Uppuluri (2019)                                                                                                                  |
| nanocrystals (CSCN)                    |                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                |
| Steroids, Triterpenoids, saponins,     | Jackfruit peels were treated with ethanol and methanol as extraction solvents                                                                                                                                                                                                                                                       | Sundarraj and Ranganathan (2018)                                                                                                               |
| alkaloids, glycosides, tannins and    |                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                |
| polyphenols, flavonoids, proteins,     |                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                |
| carbohydrates                          |                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                |
| Dye Remover                            | Jackfruit peel was used for activated carbon preparation and utilized for Red 2BN dye removal                                                                                                                                                                                                                                       | Ramasamy and Miranda (2022)                                                                                                                    |
| Biodegradable plastics                 | Pure nanocellulose was extracted from the peel through acid hydrolysis. Thin films were formed using nanocellulose as prime constituent.                                                                                                                                                                                              | Reshmy et al. (2021)                                                                                                                             |
| Binder in pharmaceutical tablets       | Jackfruit peels were treated in order to extract pectin which was used as a binder                                                                                                                                                                                                                                                     | Khedmat, Izadi, Mofid, and Mojtahedi (2020)                                                                                                   |
| Water purifying agent                  | Jackfruit peel derived biochar was used for copper metal ions elimination from water.                                                                                                                                                                                                                                                  | Abid, Ibrahim, and Zulkifli (2019)                                                                                                              |
| Bioethanol                             | Fermentation was carried by using filtrates of treated Jackfruit peel extract with *Sacharomyces cerevisiae*                                                                                                                                                                                                                      | Soumya, Gupta, Vikas, and Pradeep (2019)                                                                                                        |
| Bio-insecticide                        | The maceration of jackfruit peels in 70% ethanol and their use as a pesticide enabled rice weevils to die after 20 minutes                                                                                                                                                                                                              | Acero (2019)                                                                                                                                   |
| Bionanoparticles                       | Jackfruit peel was used in the fabrication of the P/HA bionanoparticles which possesses bone healing properties                                                                                                                                                                                                                        | Govindaraj, Rajan, Hatamleh, and Munusamy (2018)                                                                                               |
| Bio-oil                                | Jackfruit peel was used as the raw material in pyrolysis to obtain bio-fuel                                                                                                                                                                                                                                                                 | Soetardji, Widjaja, Djojorahardjo, Soetaredjo, and Imsadj (2014)                                                                             |

3. CONCLUSIONS AND FUTURE PERSPECTIVES

This literature study revealed that there are various potential applications of jackfruit waste and there are numerous benefits of each waste part of this seasonal fruit. Thus, using it as a raw material can serve as a major step toward environmental waste remediation. The various waste parts of jackfruit have nutrients that can serve as a good source for industrial applications. Jackfruit seeds mostly have been the most researched upon, out of all the waste parts, being rich in carbohydrates and phenolic compounds it can serve as an excellent food source. Jackfruit peel has also been found to be rich in carbohydrates, fibres and pectin. The pectin derived from the jackfruit peel has been found to have properties which can compete with the commercial grade pectin found in the market (Begum, Aziz, Yusof, Saifullah, & Uddin, 2021). Jackfruit rags possess cellulose, protein and reduced sugar (Dam & Nguyen, 2012). Lastly, jackfruit latex has antioxidant properties (Samrot & Sca, 2022). Investigations also led to finding that the rags can serve as a binder for formulating tablets (Gohain & Sahu, 2017). Putting all the above points together we can come to a conclusion that although Jackfruit comprises of 60% inedible parts, all those waste parts have their own benefits and are rich in physico-chemical composition.
However, Jackfruit being a perishable product attracts less interest from the industrial eye and because most of the fruit parts are considered inedible they are almost neglected despite having various nutritional properties and benefits. Thus, more attention and studies are required to develop appropriate post-harvest and processing methods, reduce post-harvest and production losses, and turn jackfruit waste into value-added products so that jackfruit cultivation, consumption, and waste management in jackfruit processing industries can become more widespread.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study.

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