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THERAPEUTIC POTENTIAL OF JACKFRUIT WASTE: A COMPREHENSIVE REVIEW

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Therapeutic Potential of Jackfruit Waste: A comprehensive review

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ABSTRACT

Jackfruit (Artocarpus heterophyllus) is drawing attention for its nutritional value and its potential medicinal use based on its byproducts. Medicinal potential of jackfruit waste and the bioactive chemicals present in seeds, peels and other byproducts is also reviewed in this review study. Similar to other natural foods, jackfruit waste is rich in carbs, proteins, antioxidants, and phytochemicals, including flavonoids and phenolic compounds, which have been shown to possess anti-cancer effects and act as anti-lifestyle sickness. It highlights methods of conversion of jackfruit waste into useable items, such as biofuels, functional food additives, and bioplastics. It also explores the environmental impacts of employing jackfruit waste material for bioremediation and how it can be used as a low-cost adsorbent for color removal in wastewater. Jackfruit waste is the focal point of this research that addresses sustainable ways to utilize and recover the bioactive components with the aim to highlight its wide number of applications in the health and environment policy and to support the development of a circular economy.

Keywords- Jackfruit, jackfruit waste, bioactive compounds, phytochemicals, waste valorization, circular economy.

1. INTRODUCTION

The jackfruit is a big fruit which is edible, a tree bear fruit, which belongs to the Moraceae family with scientific name Artocarpus heterophyllus [1]. The plant Artocarpus heterophyllus commonly called jackfruit is also called Panas in Hindi, Chakka in Malayalam, Palaa in Tamil, Kathal in Bengali and Phanas in Gujarat [2]. Jackfruit consists of proteins, vitamins, minerals, antioxidants, flavonoids and digestible starch which offer nutritional value to diet reproduction [3,4]. Jackfruit specially thrive in regions that are warm, with high humidity and veggies in coastal areas with plenty of annual rainfalls [5]. Jackfruit is a fruit that is grown in abundance in India, and the country has the highest production records, a total of 1.4 million tons. Jackfruit is the national fruit of the country Bangladesh and stands second in the total production of the fruit with 926 tons. Some of the other associated countries include Thailand, Indonesia, and Nepal [6,7]. Failure to either consume or preserve jackfruit results in the product reaching a state of ridiculously poor quality over the course of several days after being harvested [8]. In general, it is an underutilized crop, though its nutritional importance has contributed to an emerging market [9]. The research reveals that out of 100 fruits, only 25-35% are suitable for human consumption and the rest 75-65% is all waste [10]. This fruit has a seed in the middle, outer covering, and petals which are not part of the pulp [11].

The latex, peel and seed of jackfruit contains a large amount of waste which is produced by industries which process jackfruit. The wastes, when not procured appropriately or disposed of, have been known to bring about large-scale problems like greenhouse gas effusions, asphyxia, obnoxious stench, water poisoning. The most important of all is the fact that the bioactive compounds from these waste materials can be used for their potential applications such as a flavoring, coloring, antioxidizing and stabilizing agent. Certain wastes are produced in the form of solid in various unit activities like peeling and coring have nutritional value and might be used to fed animals. The unit processing the fruits is considered productive if it can turn fruit waste into several value-added products. The part of the fruit that is consumed is the bulb, which is sweet and cooling; it cures constipation, increases sexual desire and is rich in nutrients [10]. 60% of the fruit is discarded as; outer skin and interoperating and central core which are considered unfit for human consumption. These waste products of fruit pose a dilemma for both fruit processing enterprises and environmental regulators. The nature of waste hence calls for their conversion into other byproducts – for instance the peel may be utilized to produce pectin, activated carbon, or as a raw material for bio-hydrogen production, among others. The seed has several applications, including food coloring, ethanol production, calf feed, and fast-dissolving tablets. The fruit's latex may be used for a variety of purposes, including dental health.

2. BIOCHEMICAL COMPOSITION OF JACKFRUIT AND ITS WASTE

Jackfruit due to its significant phytonutrient and phytochemical content is widely regarded by food industry, researchers and consumers [10, 12] About 70–80% of them are inedible according to Akter and Haque [13] and roughly 60% of them are waste since they are the jackfruit's outer rind, perianth and central core. The biochemical makeup of jackfruit and its associated waste demonstrated that the fruit is both a healthy food source and an environmentally favorable raw material for the creation of numerous high-value bioproducts. The components found in jackfruit peels are cellulose, protein, starch, and pectin, in that order [14]. According to Kumar et al., 1988 dried jackfruit seeds contain 2.1% lipids, 17.8% protein, and 76.1% carbohydrates [15]. Additionally, a number of lignin, phytonutrients, isoflavones, saponins and some additional significant nutrients have been found with jackfruit seeds, added by Sumathy et al., 2007 [16]. Likewise, Fernandes et al., 2011 stated that jackfruit seeds are a great way to get vitamins like riboflavin and thiamine [17]. Among the solid wastes generated during the processing of jackfruit are peels, seeds, and latex, all of which harm the environment [18]. The fruit wastes may be a sustainable resource for a variety of products because waste biomass chemistry makes biomass valuable for development of the bioproduct. From the analysis, it has been discovered that there is a sustainable way to utilize the jackfruit peel as an alternate origin of commercial pectin, biofuels, and other bioproducts [18]. From the research of Sundarraj and Ranganathan [19] revealed that only the two dominant states producing jackfruits, Karnataka and Kerala, may be estimated to generate approximately 20,000 million Indian rupees value of jackfruit waste. Notably, India fails to market and process its jackfruit products, that leads to 75% of them being wasted due to negligence, insufficient marketing, and the absence of processing centers. However, by using a number of technologies for bioconversion, the waste which from the inedible parts of the jackfruit can be efficiently utilized. For instance, the peel of jackfruit is thick which can be utilized as cattle feed enriched with nutrients, for the purpose of biofuel extraction or as nano porous absorbent for the removal of dyes, etc. The research also showed that the fruit waste can also be exploited as a good source of food and feed. While there are several papers on investment products from the edible portions of jackfruit, reuse and conversion of the jackfruit waste into new different value-added products using advanced technologies is comparatively scarce. Therefore, to fill this knowledge gap, it is highly imperative to generate a review, which concentrates on the collection of a significant amount of jackfruit waste both before and after the harvest process and the application of this waste for generating energy with the help of new technologies to reduce waste to zero.

3. JACKFRUIT PEEL AND PEEL EXTRACT

The first layer of fruit is called jackfruit skin which has a texture similar to that of spiky pattern. It is not edible and is considered to be the fruit's deficiency; it is discarded or used for composting [20]. It is mostly used in feeding cattle within the community because of the rich source of protein, carbohydrates, and fibers having 8.7%, 24%, and 17.3% respectively [21]. Some of the found structural constituents and functional components in jackfruit peel are flavonoids, proteins, carbohydrates, alkaloids, glycosides, steroids, triterpenoids, saponin, tannin, and phenol compounds [19]. The polyphenol content of peel of jackfruit may have been influenced by the higher interaction with the extrinsic domain. Temperature stress originating from both high and low temperatures, UV radiation, and daylight all elicit polyphenol formation through the walk of the peel. Bioactive chemicals assisting in the chemical reactions that protect the body from the destructive effects of oxidation reactions come from antioxidants. The peel can be a good source of pectin since it has an average composition of 8.94 and 15.14% of the dry matter. Pectins has versatile application and are used as agents: emulsifier, binder, stabilizer in the food industry as well as in medicines and cosmetics industries [22]. It has claimed that taking this polysaccharide will decrease chances of developing cancer, blood sugar level issues, ulcers and poor cholesterol and at the same time maintain good immune balance [23]. Pectin is employed in pharmaceutical manufacturing as a binder for diverse forms of the pill and also as multi-purpose carrier for encapsulated drug [24]. Jackfruit peel find utilization in pharmaceutical, paper, paint, optical, environmental, bio fuel, and food sectors. This polysaccharide is used used to keep a healthy immune response, prevent as well as control cancer, blood sugar troubles, ulcers and low cholesterol levels, [23]. Pectin is extensively used in the pharmaceutical industry to provide encapsulated drugs a multiple delivery system and also as a binder for pills of various composition [24]. Besides the food sector, jackfruit peel has applications in paper and paint industries, in pharmaceuticals and optician, for environmental conservation, as well as in biofuel production.

It was also evident that total flavonoid and phenolic content was higher in the extract of the peel of Jackfruit than the pulp and seeds. They also observed that the extract possess 53 different chemical compositions, where HPLC-QTOF-MS/MS was used to analyze. The compounds found were 8 organic acids, 8 glycosides, 12 phenolic acids, 18 flavonoids, 3 oxylipins ad 4 other compunds [25]. After Sharma and his colleague's study in 2015, it was found that ascorbic acid, β-carotene and polyphenols (catechin and chlorogenic acid) exist in the peel extract of jackfruit [26]. Table 1 presents the chemical composition and antioxidant activity of jackfruit peel extract.

Table 1. Compounds found in jackfruit peel extracts using the HPLC-QTOF-MS/MS identification technique (Zhang et al., 2017).

Category	No. of Compounds	Compounds
Organic Acids	8	Naphthalenedicarboxylic acid-hexose, Quinic acid, Resorcylic acid-O-hexoside, Hydroxycaproic acid-O-hexoside, Citric acid, [5-glucopyranosyloxy-2-oxo-2,3-dihydro-1H-indol-3-yl] acetic acid, Quinic acid isomers, Malic acid
Glycosides	8	Digitoxosylhexoside, Benzyl-pentoylhexoside, Pentyl-pentosylhexoside, Pentyl-pentosylhexoside isomer I, Pentyl-pentosylhexoside isomer II, Benzyl-acetylpentosylhexoside, Pentyl-dipentosylglucuronide-hexoside, Pentyl-acetylpentosylhexoside
Phenolic Acids	12	Cis 3-Caffeoylquinic acid, Trans 3-Caffeoylquinic acid, Esculetin-O-hexoside, Esculetin-C-hexoside, 3,4-dihydroxybenzoic acid methyl ester-C-dihexoside, Esculetin-hexoylpentoside, Feruloylglucoside, Cis 4-Caffeoylquinic acid, Caffeoylglucoside, Cis 5-Caffeoylquinic acid, Trans 5-Caffeoylquinic acid, Trans 4-Caffeoylquinic acid
Flavonoids	18	Procyanidin B, (Epi)catechin-O-rhamnoside, Dihydromyricetin, (Epi)catechin, Phloretin-C-dihexoside, Dihydroquercetin, Prenyl-O-tetrahydroxy-9,10-dihydrophenanthrene, Prenyl-O-naringenin, Prenylmethylfluorone, Butenylprenylnaringenin, Morachalcone A, Morachalcone A isomer, Chlorophorin, Pentenylisoliquiritigenin, Prenylgenistein, Pentenylnaringenin, Hexenyl-5,7,4′-Trihydroxyflavan, Pentenyl-O-isoliquiritigenin
AminoAcids, Peptides, and Derivatives	4	Tryptophan,[2-Oxo-2-[(tetrahydro-2 furanylmethyl)amino]ethoxy] acetic acid, Hydroxy-1-isoquinolinone-diglucuronide, Damascenine

Oxylipins	3	9,12,13-Trihydroxy-octadecadienoic acid, 9-Hydroxy-10,12,15-octadecatrienoic acid, 9-Hydroxy-10,12-octadecadienoic acid

4. JACKFRUIT PEEL PROCESSING METHODS

Jackfruit peel waste can only be used for research or experimentation after having undergone some initial treatments. Nevertheless, the attributes of the peel are that it is changeable depending on the pre-processing done on it. Some of the pre-processing techniques involves Physical and chemical treatments among others. Cleaning, drying, and heating the jackfruit peel are called mechanical pre-processing techniques. Chemical pre-processing aims primarily at changing the conductivity, hydrophilic/hydrophobic nature of the cellulose-based materials used in the production of the electrode. Chemical activation is mostly done with the prerequisites containing a certain proportion of activated chemicals like particularly, H_3PO_4, NaOH, $ZnCl_2$, and KOH [27]. Thus, phosphoric acid (H_3PO_4) is the most efficient activation agent since it induces formation of both microspores and meospores in the target [28]. Additional pre-processing procedures include exposing cellulosic tissues to supercritical CO_2 at temperatures of 800°-1100°C [29]. The steps that were used to process the peel before it was used for an extended period are shown in the figure 1 below.

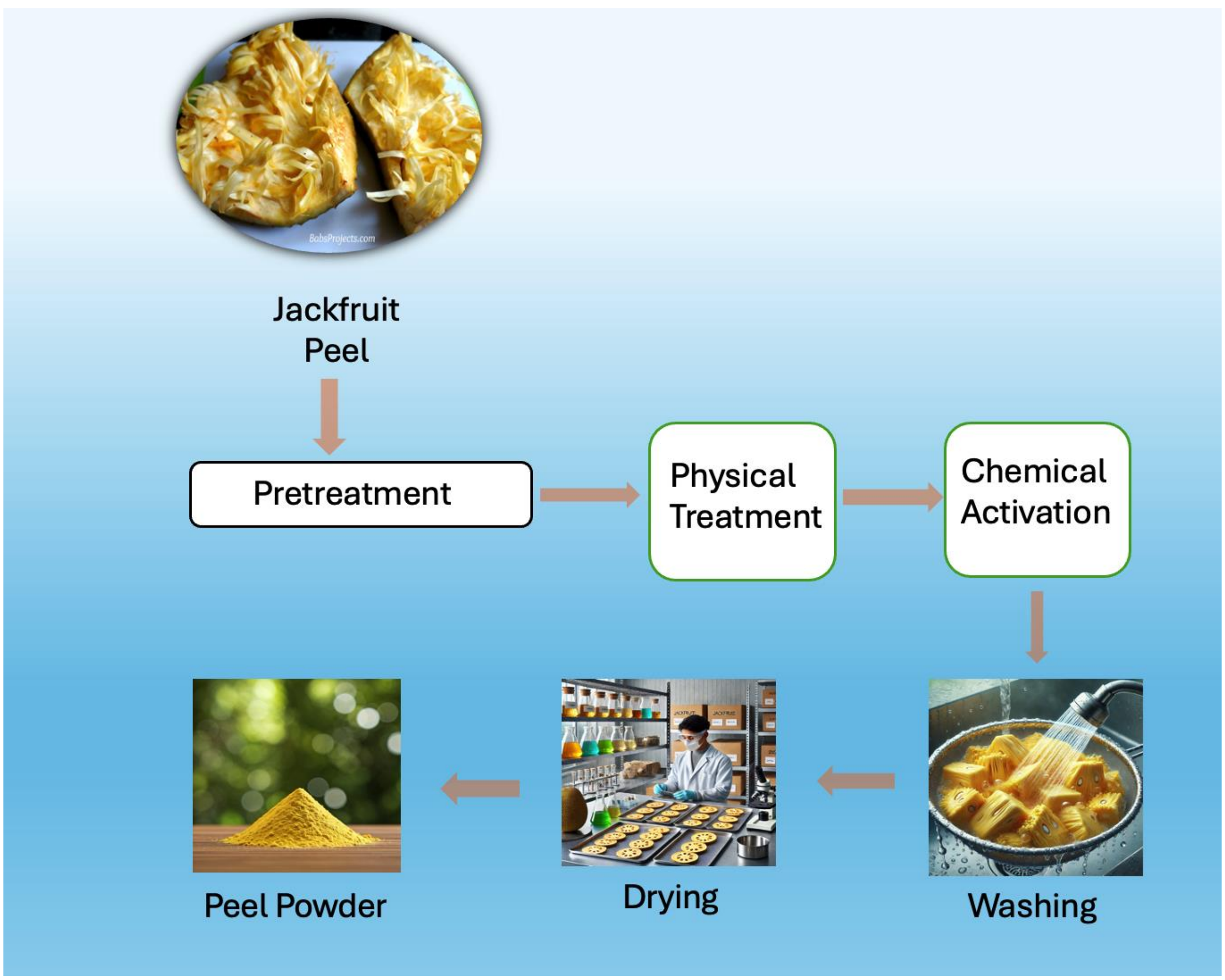


Fig 1: Schematic representation for pre-processing of jackfruit peel for further application

It is noteworthy that hydrothermal carbonization, torrefaction, vapothermal carbonization and autoclave are other thermal pre-treatment techniques used to modify the organic structural features of lignocellulosic biomass other than the physical pre-treatment such as washing and drying. Nevertheless, at the moment, there is no literature on the application of these methods for pre-processing jackfruit peels that has been published. Chemical activation on the other hand, has been explored sparingly with some of the research undertaken indicated in table 2. A diagrammatic representation of the various techniques used to recover valuable products from jackfruit peel can be seen in figure 2.

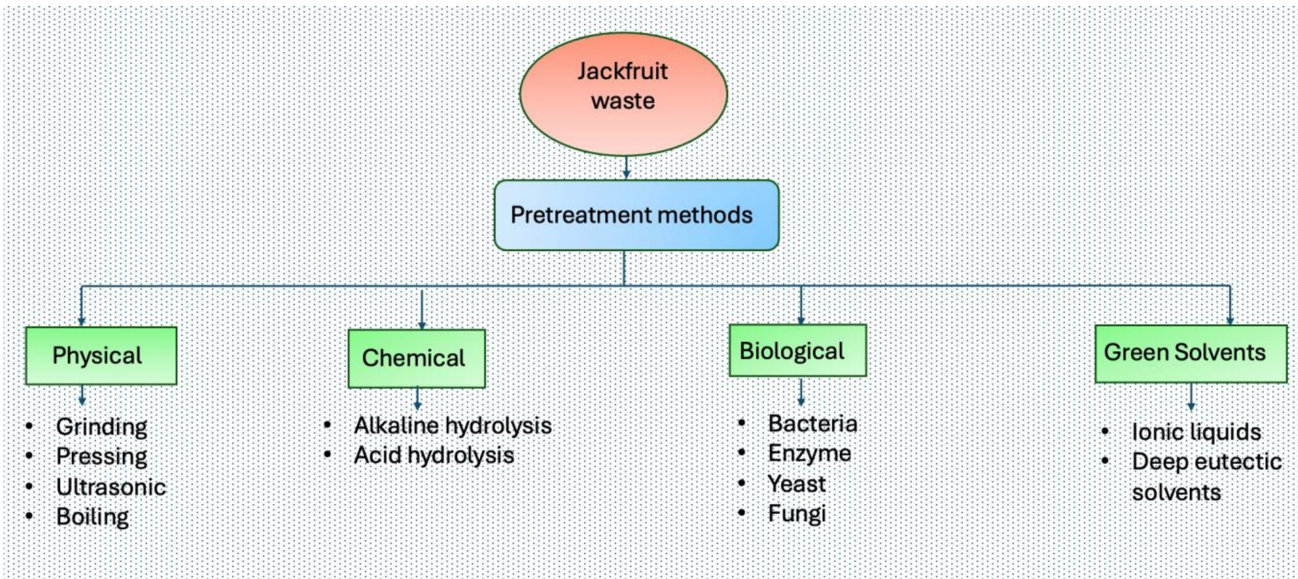


Fig 2: Flowchart for different methods of pretreatment for jackfruit waste.

Table 2. Chemical activation techniques employed for pre-processing of jackfruit peel.

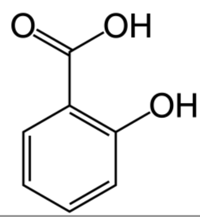
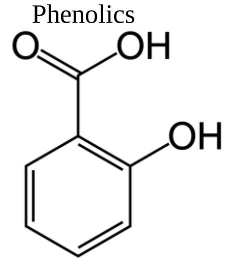
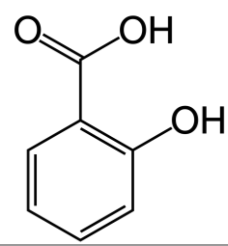
Treatment	References
A chemical activation process using phosphoric acid operated on the raw material. The mixture received 20 g of peel with 85% concentrated phosphoric acid and required intermittent stirring.	30
A microwave assisted chemical process was used to create activated carbons from jackfruit peel biochar. The activation process took place inside a glass container under the operation of four different microwave power levels from 200W to 800W during five distinct irradiation durations from 5 to 20 minutes.	31
A mixture contained one part jackfruit peel along with one part KOH according to weight. The reaction occurred under nitrogen flow at a heat of 800°C for a duration of one hour while using a ramp rate of 5°C/min.	32
The activation process of Jackfruit peel occurred at 900°C under potassium hydroxide (KOH) concentrations of 1:2 ratios.	33
Active jackfruit peel preparation used potassium hydroxide (KOH) at three heating temperatures of 600°C, 700°C, and 800°C.	34
A solution of 30% nitric acid (HNO3) with 1:1 ratio mixed with jackfruit peel underwent heating at 80°C for two hours followed by filtration and distilled water	35

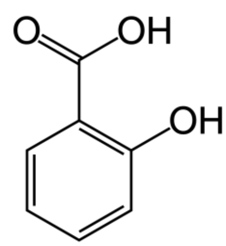
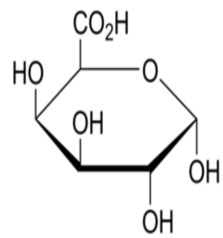
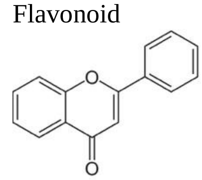
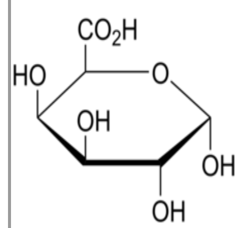
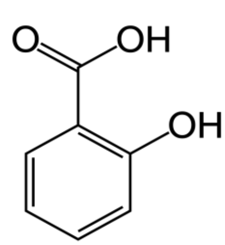
wash before drying at 105°C for 48 hours.	

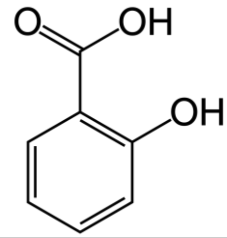
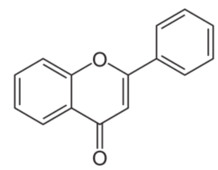
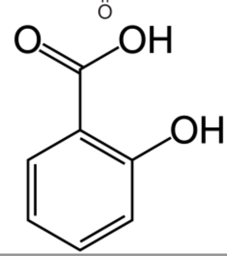
A. CONVENTIONAL EXTRACTION

Several functional components are obtained from samples through conventional methods such as solid-liquid or liquid-liquid extraction with high recovery rates. Due to the fact that these methods involve high temperature it leads to the thermal degradation of all heat sensitive compounds in the plant material. New solutions are possible to optimize the increased consumption of energy, instability loss, and reliability issues because the extraction process could be long. Adan et al., 2020 isolated and identified the bioactive chemicals found in jackfruit peel and were extracted for 48 hours and homogenized with methanol and distilled water [36]. They concluded that extraction with methanol had a better flavonoid extraction yield than when extraction was done using water. Boeing et al., 2014 conducted a study to find out this and found out that methanol has the ability to remove phenolic chemicals form berries [37]. More specifically, Alothman et al., 2009 found that the type of solvent used influences the procedure of eliminating phenolic compounds in plants [38]. Islam et al., 2021 worked to get extracts through the use of three extraction methods: The common methods of extracting solid fertilizers include enzyme-associated extraction, pressurized hot water extraction and organic solvent extraction systems [39]. Table 4 also provides a list of several ways that many functional components have been extracted by employing traditional extraction.

Table 3. Conventional extraction techniques employed to extract functional ingredients from jackfruit peel.

Technique	Extraction conditions	Functional ingredients	References
Solvent	Two grams (2g) of peel powder underwent methanol extraction by a ratio of 1:30 (g/ml) in 60ml of 90% methanol solution with stirring at 100 rpm for six hours.	Phenolics 	25
Solvent	Methanol functioned as the solution for 48-hour incubation at an incubation temperature of 24°c.	Phenolics 	36
Pressurized hot water	The process combined 10 g of peel powder with 200 ml of distilled water in a 1000 mL pressure cooker at 138°C for 9.15 minutes through a solid/liquid ratio of 1:20 (g/ml).	Phenolics 	39

Enzymes	The mixture included 2.5 grams of peel powder dispersed in 50ml of phosphate buffer solution at a ratio of 1:20 (g/ml) with enzyme-containing aqueous solution.	Phenolics 	39
Chemical	Oxalic acid served as the extraction solution for 60 minutes under 90°C temperature conditions	Pectin 	19
Solvent	70% of ethanol extract from jackfruit peel	Flavonoid 	40
Chemical	The extraction of jackfruit peel pectin required Sodium Hexametaphosphate solution.	Pectin 	41
Chemical	A GC-MS investigation indicated the discovery of furanone along with furfural and phenolic compounds after extracting 10 g of jackfruit peel powder using 200ml of acetone.	Phenolics 	42

Solvent	A mixture consisting of 30 grams of peel with 1:10 (g/ml) ethyl ether was treated with ultrasonic waves for thirty minutes at 360W to accelerate extraction duration.	Phenolics 	43
Solvent	20g of methanol extract from jackfruit peels underwent fractionation by using both n-hexane and water separation methods. The analysis focused on the ethyl acetate fraction obtained following fractionation of the water portion.	Phenolic and flavonoid  	44

B. NON-CONVENTIONAL EXTRACTION

Tramontin et al., 2019 used experimental parameters, and studies performed supercritical extraction of the jackfruit components such as seeds, temperature 50°C, pressure 12MPa, flow rate of carbon dioxide was 4.0 ml/min for the extraction of functional compounds for about 150 minutes [45]. To determine the components of jackfruit leaves, Veggi et al., 2009 used high pressure at 49.85°C for 2 hours at 15-30 MPa but the yield obtained was lower than that of extraction yields of low-pressure solvent extractions [46].

C. EMERGING TECHNOLOGIES

In the recent past, a number of technologies in the frontier area of a have been made with a view to extracting pectin from outer skin of jackfruit. Green technology that includes the latest ideas of separating healthy chemicals into foods is pricey. These methods include pulsed electric field microwave assisted extraction, ultrasound assisted extraction, ultrasonic microwave assisted extraction and radio frequency extraction. Another new strategy that increases the rate of obtaining useful and minimizing the creation of unutilized waste components is the use of a green technology approach [47].

The extraction of functional components of jackfruit peels have been researched through the use of Ultrasounds, microwaves, radio frequency and pulsed electric fields. Since an optimal yield of 29.40% pectin is expected the response value of item B level three the radiofrequency time should be 61.50 min, and the pH level 2.61. Xu et al.,2018 performed the studies to learn how and with the help of microwave and ultrasonic extraction one may obtain 21.50% pectin from jackfruit peels [48]. In another study, Moorthy et al.,2017 conducted that if the JP extract is exposed to ultrasound, pH 1.60, 60°C and sonication time of 24 minutes, resulted only 14.5% pectin [49]. Table 4 also presents the different methods that different technologies at the development stage have been utilized to extract the functional components as presented below;

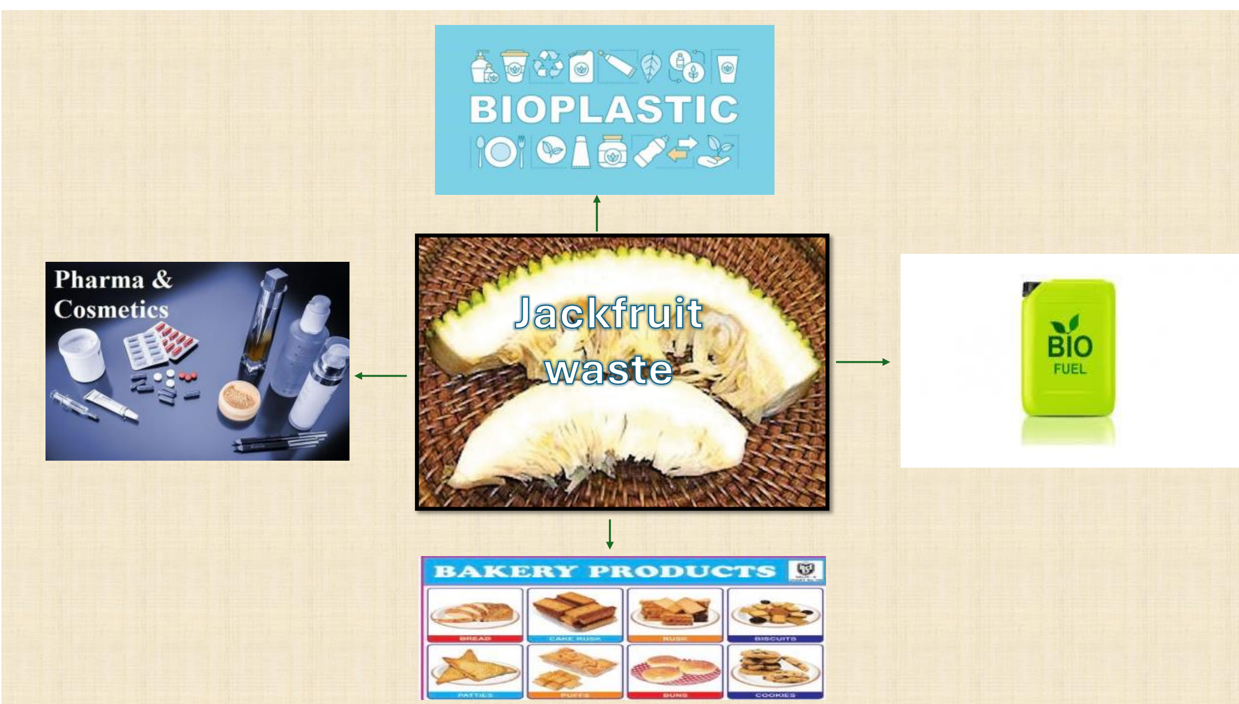
Techniques	Extraction conditions	References
Ultrasonic microwave coupled with macroporous resin chromatography	63% of the mixture is ethanol, with a solvent-to-solid ratio of 34 ml/g, a microwave power of 160 W, and a 20 minute exposure time	50

Radio frequency	Jackfruit peel was exposed to radio frequency for 61.50 mins	47
Ultrasonic microwave	Microwave time: 10 minutes, 29 minutes for ultrasound, 50W of power at a 1:48 g/ml ratio	48
Ultrasound	Sonication time: 24 min, Temperature of 60°C, Liquid-solid ratio of 15:1ml/g	48
Microwave	Power: 450W	51
Microwave alkaline hydrolysis	Sodium Hydroxide was used for microwave alkaline hydrolysis of defatted soybean meal and jackfruit peel for 2-11 mins at 300W microwave power level to obtain protein	52

5. APPLICATION OF JACKFRUIT BIOPRODUCTS

Seeds and perianth are other eatable parts and peel and central axis are inedible parts from consuming or processing fresh jackfruits. The bio-based idea has become the most significant working hypothesis at the moment as it seems to be the only viable concept that may lead to the radical improvement of productivity, cost effectiveness, yield, and managing the impacts on the environment. Some examples of the bioproducts from waste biomass of jackfruit tare biofuels, bioplastics, bakery products, pharmaceuticals and cosmetics. (figure 3). Biotransformation was expected to afford the conversion of fruit waste into useful products.

Fig 3: Application of Jackfruit in different industries



5.1 BIOPLASTICS

Some of the manufacture of bioplastic has been done using the *Bacillus megaterium* strain JHA and this had a high potential in microbial manufacture. This microbe was isolated from oil-contaminated soils and after that tested in laboratory condition for its capacity to assimilate glucose substrate resulting in accumulation of intracellular plastic like material polyhydroxyalkanoates (PHA) [53]. *B. megaterium* biosynthesized this plastic using jackfruit waste-like seeds and few inorganic or organic material/chemicals. Then it was found that this waste material was suitable for a high accumulation of PHA within microbial cells. Still other efforts were made in order to describe the bioplastic layer that the PHAs forced inside the cell to produce [54]. There are quite a few uses of PHAs in pharmaceutical, cosmetic, and medical science applications that have been observed. Adequate investigations and process parameter enhancement are essential for the best production of PHA, which could lead to the producing a high yield of PHAs from cheap sources such as jackfruit wastes. This waste material is an effective source of supply of nitrogen and carbon for conducting these experiments in order to develop a technique which is commercially viable [54,55]. Another PHA product that has come out as a long-lasting and efficient process is biodegradable plastic [56]. The use of biological pretreatment is effective and environmentally friendly for the conversion of jackfruit waste into fermentable sugar aimed at the attempted hydrolysis of the waste.

5.2 BIO-OILS/FUELS

Soetardji et al., 2014 [57] studied the conversion of jackfruit peel waste to bio-oil in a fixed bioreactor applying a pyrolysis process. As a result of pyrolysis at high temperatures of 400-700°C, it possible to reveal a large list of volatile chemicals in the peel of the biomass which suggest that it may be used to produce bio-oil. The bio-oil containing nitrogen at a trace level of 0.61% and sulfur at a 0.03% is likely to be environmentally friendly. The biofuel quality was optimum at 550 °C with 85.2% of organic carbon content and 14.8% of water content. Bio-oil can be generated from the unused jackfruit peels by a low temperature pyrolysis process using the adsorption technique and cheap adsorbents [58]. Adsorption-based purification offers an easy to use, highly selective, and often low cost solution to other forms of purification. The use of the transesterification technique has found jackfruit peel oil to be suitable. After that, when the bio-oil was filtered using zeolite and silica gel in turn, it was possible to reduce its water content. For fermentation, Yuvarani and Dhas 2017 used *Saccharomyces cerevisiae* [59] to convert the cellulosic jackfruit responsibility into bioethanol. To identify the highest yields and the best conditions to cultivate the product, researchers are studying several factors crucial to jackfruit peel fermentative process, such as temperature and the time required for fermentation, the constitute of jackfruit peel and the availability of nutrients. These factors may somehow affect the production of biofuel from jackfruit peel. In another article, Ranasinghe and Marapana, 2019 [60] said that biogas was produced from jackfruit which incorporated carbohydrates as a substrate utilizing the microbial fermentation method. Hydrolysis, acidogenesis, acetogensis and methanogenesis of the substrate is a critical step to achieving biogas out of the substrate [61]. Some of the parameters including, pH, temperature and C-N ratio perhaps affect the anaerobic digestion process which microorganisms perform in order to produce biogas from a feedstock material derived from cow manure and jackfruit waste [62].

5.3 BAKERY PRODUCTS

Several researchers have reported that they prepared flour from jackfruit seeds. From the drying procedure, Akter 2018 [63] crushed the dried seeds to make the jackfruit seed flour and it was stored in hermetically sealed canisters. In another research, the authors cooked pasta employing blends of wheat flour and jackfruit seed flour [64]. It was identified from the analysis that they were able to add nutritive value to the pasta by using a composite flour. In another study, Khan et al., 2016 quantified the qualitative characteristics of a mixed cake produced from jackfruit seed flour and wheat flour [65]. In other studies, Butool and Butool, 2015 explained how to prepare bread and cookies from the seeds' flour of jackfruits [66]. They also found out that the color and texture of the bread and biscuit recipes incorporating 10% and 20% jackfruit seed flour were better [66]. Compared to biscuit control, biscuits produced from jackfruit seed flour provided less carbohydrate and more ash and crude fiber values. Aziz, 2006 [67] found that if he used wheat flour blended with jackfruit seed flour for preparing bread, the fiber content in the bread increased a bit while the protein content slightly decreased. However, Hasidah and Noor Aziah 2003 [68] carried out similar study and it was found that a sensory panel preferred bread containing up to 25% jiffy seed flour. After much debate they ended up advice that in some cases jackfruit seed flour can be used in place of wheat flour.

While experimenting for the preparation of bread, Hossain et al., 2014 [69] changed the code ratio of jackfruit seed flour. According to the findings made by the authors, all the bread that is produced with the jackfruit seed flour was the best.

5.4 PHARMACEUTICALS AND BEAUTY AIDS

Pharmaceuticals may make use of the protein and carbs included in jackfruit seeds. Jackfruit seed starch is a powerful disintegrant that turns fast action pills that dissolve or disintegrate without requiring any further water [70]. According to Jitendra et al., 2014 [71] research, jackfruit latex contains high resin content, making it a potential help for treatment of different forms of dental problems. Jack fruits, leaves and bark are rich in anti-inflammatory, antifungal, anticarcinogenic, wound healing, and hypoglycemic properties, which have made them popular in traditional medicine. The use of jackfruit peel pectin has been shown to make superior antibacterial bio-nanocomposite materials when used to heal bones. The bionanocomposite containing 0.10% jackfruit pectin exhibits good biological and physiochemical properties, making it appropriate for orthopedic and orthodontic applications [72]. It could also be used in skin and bone transplants, according to Hutmacher. Biopolymeric materials were examined in the therapeutic use by Pathak et al., 2022 [72]. Therefore, Mandhare et al., 2020 [73] studied the efficacy of derivatives of components, including jackfruit extract and phytochemical extracts, for health benefits to get insights into the biochemical point of effect and overall nutritional value.

6. FUTURE PERSPECTIVES AND CHALLENGES

Concentrating on jackfruit waste valorization techniques to generate useful bioproducts in an eco-friendly way is possible. To make 'interdisciplinarity' work, industries such as baking, pharmaceuticals, producing biofuels and biomaterials, and the like, will have to come together. Fundamentally, the key strategies should be to utilize ecofriendly pretreatment and integrated valorization technology to fulfill present demand for biofuels, bioproducts from renewable natural resources, and to protect environment. In recent years, degradation through physical or chemical means of the polymer followed by conversion by microorganisms are two of the most promising approaches of pretreatment. In the realm of jackfruit agriculture, the unique properties of jackfruit have spurred interest in a variety of novel biotechnological approaches, such as molecular markers, omics technologies, and functional genomics, which in turn have enabled the characterization of the interpenetrating molecular spaces in the three hard structures, i.e., seed, rachis, and calyx. Considering a possible alternative to traditional jackfruit cultivation, a multitude of new biotechnology techniques for the production of genetically modified versions of jackfruit that have higher agricultural productivity have become available. Methods in modern times can reduce a lot of the jackfruit waste. This curiosity began with the fact that you could use jackfruit in so many different ways. There have been numerous uses shown for jackfruits. Jackfruit waste which contains enormous amounts of different types of carbohydrates, protein and minerals can be used to produce and culture a variety of other microbial groups which can produce essential metabolites at commercial level such as enzymes, polysaccharides, organic acids and medicines.

7. CONCLUSION

With newfound hope of health and sustainability, jackfruit waste, especially its seeds, peels, and other byproducts, has come to stand as a notable study in its medicinal potential. Abundant in bioactive components comprising flavonoids, phenolics, and proteins with various health benefit properties like anticancer and antioxidant activities, jackfruit waste is rich in bioactive components. jacalin, a carbohydrate binding protein show anticancer property against several cancer types, which suggests the possibility of its use as targeted treatment and dietary strategy for cancer prevention, and further research in this area seems promising. Additionally, the valorization of jackfruit waste effectively addresses environmental concerns related to food waste, and also encourages the development of sustainable bioproducts. Jackfruit leftovers can be transformed into value added commodities such as biodegradable polymers and biofuel, highlighting the fruit's flexibility and their combination with waste management and resource recovery. Currently, ongoing study shows that jackfruit waste, as an underutilized resource, could greatly benefit public health and environmental sustainability. Novel uses of bioactive chemicals within the food, feed, and the bioproduct sectors constitute the second focus of subsequent research; and extraction techniques should be further refined to better extract bioactive chemicals. This holistic approach will help amplify the therapeutic potential of jackfruit waste as well as reinforcement of wider ambitions towards circular economy.

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