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Jackfruit processing and utilization of its waste: A review

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Abstract

Jackfruit is a major fruit crop utilized widely for diverse food applications. Like many of the food materials, jack fruit too comprises of both edible and inedible waste composition. Processing enables the usability of jack fruit in various forms for longer durations. Post-harvest processing of jack fruit is the production of various value-added products which are commercially viable and exported to different places. There is an increasing demand for food and animal feed formulations by utilizing the various wastes from the processing industries. Lot of waste is generated from the jack fruit after the removal of edible portion (bulb). The objective of this review paper is to enlist the present utilization of jack for the manufacture of various products and the possible ways to utilize the waste effectively in food, feed, and other formulations. Many authors have conducted research to utilize the jack fruit wastes such as peel for the preparation of pectin, starch and protein fractions that are incorporated as nutrient enriched food and feed materials. It is also reported that the jack fruit seed powder can be used in various bakery products. This review article outlines the various types of waste generated from jack fruit and utilization of the wastes by using appropriate techniques. The present status of the jack fruit production and utilization of waste are also featured and discussed.

Keywords: Jackfruit, Pectin, Peel, Powder, Seed, Waste utilization

1. Introduction

Jackfruit (*Artocarpus heterophyllus*) belongs to the family Moraceae and is recognized as an indigenous crop in some areas of South and Southeast Asia. This crop is well suited for cultivation in the tropical lowlands and is widely cultivated in India, Bangladesh, Nepal, Sri Lanka, Cambodia, Vietnam, Thailand, Malaysia, Indonesia, Africa, Brazil and the Philippines [1]. In India, the jack fruit trees are widely distributed in the states of Kerala, Tamil Nadu, coastal Karnataka, Goa and Maharashtra and also grown to a lesser extent in other states such as Assam, Bihar, Tripura, Uttar Pradesh and foothills of Himalayas. The term "jackfruit" was originated from the Portuguese word *jaca* which was originally derived from *chakka,* the Malayalam term. The other vernacular names of jack fruit in different regions are *kathhal* (hindi and urdu), *pala* (tamil), *halasina hannu* (kannada) *panasa pandu* (telugu) and *phanos* (marathi and Konkani) [2].

Jack tree is a medium sized tree which bears around 20 to100 fruits per tree with an average weight of 10 to 30 kg per fruit. It is a large oval shaped fruit that can measure up to a size of 90 cm long and 50 cm in diameter and has thick rind with spines. In India, the average yield of the fruit per tree is about 150 numbers and some trees even bear about 250 to 500 fruits of small and medium size [2].

Jack tree grows well under the climatic conditions of warm humid (hill slopes) and hot humid of plains and produces good yield. It grows even at an elevation of 1200 m with an optimum temperature of 22 to 35°C. It can be grown in a variety of soil with a pH range of 6.0-6.5 and deep rich alluvial or open textured loamy soil or red laterite soils with adequate drainage condition.

1.1 Varieties of jack fruits

Owing to the variation in progenies of seed propagation, vegetative propagation of jack tree is generally recommended. The tree will bear fruit from seventh to eighth year onwards and the fruits will be available in the tree from the month of March to June. The harvest extends up to September in the jack trees that are cultivated in the higher elevation regions and in plains certain genotypes bear an off-season fruit during October to December also. Based on the firmness of the bulb, jack trees are divided in to two broad varieties *viz.,* firm flesh *(kappa) and* soft flesh *(rassal)*. Different organizations have released different varieties that suit the regional cultivation, and some important varieties of jack fruit are furnished in (Table 1).

Table 1 Jack fruit varieties developed in India.

Name of the variety	Place of release or development
Konkan Prolific	Released from Dr BSKKV, Dapoli, Maharashtra.
Ceylon Jack	Sri Lankan variety introduced in Tamil Nadu
Hybrid jack	Developed at Fruit Research Station, Kallar, Tamil Nadu.
Burliar-1 (T Nagar selection)	Developed at Fruit Research Station, Burliar, Tamil Nadu
PLR-1(Palur-1)	Developed at Vegetable Research Station, Tamil Nadu Agricultural University.
PPI-1(Pechiparai-1)	Developed at Horticultural Research Station, Pechiparai of Tamil Nadu Agricultural University

1.2 Harvesting and grading of jack fruits

Jack fruits are harvested at different periodic intervals according to the intended purpose. The utility of the jack fruit based on the different stages of maturity is given in (Table 2). The tender ones are used as vegetables till the seeds turn hard. The physiological maturity of the fruit is attained after 90 to 110 days followed by the spike emergence. The following indicators are used for harvesting the jack fruit to utilize them as ripe fruits.

(i) Change in the appearance of the skin colour from green to yellow or light brown and last leaf of the stalk to yellow colour.
(ii) Flattening of spines and spacing out of spines.
(iii) Yielding of fruit to slight pressure application.
(iv) Hollow sound when tapered with hand.

Table 2 Maturity stages of jack fruit and intended use.

Stage of fruit	Preparations
Immature	Culinary preparations.
Half mature	Pickle, cutlets, pulao/briyani.
Fully matured	Papad, cutlet, chips, pakoda.
Well ripened	Pulp (base material), gulab jamun, halwa, mini aappam, sweet vada, leather, custard, jam, wine, squash, kheer, mocktail, cake.
Seeds	Culinary preparations, kheer, pakoda, starch flour.

1.3 Nutritional composition of jack fruit

Jack fruit is a good source of several nutrients and is capable of providing complete nutrients to the wellness of human beings. The nutritional profile of jack fruit includes carbohydrates, proteins, fiber, vitamins (B and C) and minerals such as calcium, iron, and potassium. The nutrients present in this fruit are equivalent to the nutrients available in grains, avocado and olive fruits. Jackfruit contains a chemical called “Jacalin” which is used as a medicine for the prevention of colon cancer and AIDS [3]. The proximate composition and nutritive value of jack fruit is provided in (Table 3).

In recent years, the processing and value addition of jack fruit has increased many folds due to the increase in area of cultivation and production as well. Studies on the dietary, medicinal, and miscellaneous uses of jackfruit have also been conducted by a few researchers. The consumption of fresh jackfruit and the processing of this fruit yield a high amount of non-edible wastes such as peel and central axis and edible by-products such as seeds and perianth.

Table 3 Proximate composition and Nutritive value of jackfruit.

Constituents	Average value (per 100 g)
Moisture (%)	76.20
Energy (Cal)	88.00
Protein (g)	1.90
Fat (g)	0.10
Fibre (g)	1.10
Carbohydrates (g)	19.80
Potassium (mg)	107.00
Calcium (mg)	20.00
Phosphorous (mg)	41.00
Iron (mg)	0.56
β Carotene (mg)	175.00
Thiamine (mg)	0.03
Riboflavin (mg)	0.13
Niacin (mg)	0.40
Vitamin C (mg)	7.00

1.4 Health benefits of jack fruit

Jack fruit possess the richest source of natural antioxidant vitamin C, which helps to protect our body against viral and bacterial infections like cough, cold and flu. Intake of one cup of jack fruit provides good sources of vitamin C, which boost up the immune system by supporting the white blood cells. Jack fruit is rich in flavanoids and phyto nutrients such as *lignants, lisoflavones* and *saopnin* which aid in eliminating cancer causing free radicals. Free radicals are formed due to oxidative stress and these free radicals damage DNA of the cell and converts the normal cell into a cancer cell. Antioxidants possess the capacity to neutralize these free radicals and act as a shield to protect DNA from free radicals. Jackfruit protects from colon, lung and oral cavity cancer and prevents aging.

The fruit contains a high amount of dietary fibre and prevents constipation and aids in smooth bowel movement. It protects the mucous membrane from the carcinogenic chemicals of the large intestine. It has anti-ulcer properties and helps to cure ulcers and digestive problems. Dietary fats in jackfruit help to clean toxins from the colon and reduce the effects of toxin in the colon and protect from colon cancer. Jack fruit is also a source of vitamin A, that helps in treating night blindness, muscular degeneration and maintains healthy skin and eyes.

Fruits of jack tree provide instant energy when consumed due to the presence sucrose and fructose. Although it is rich in energy, it contains no saturated fatty oils or cholesterol. It is considered safer and more healthy food as it possesses potassium and helps in reducing blood pressure, the risk of heart attacks and strokes. The extract obtained from boiled jackfruit root is used to control asthma. Jackfruit is also rich in magnesium, which helps in the absorption of calcium and strengthens the bone by preventing bone related diseases like osteoporosis. Iron content of jack fruit helps in preventing anemia and helps in proper blood circulation. Copper is an important mineral, which plays a major role in thyroid metabolism, mainly hormone production and absorption. Since jack fruit is abundant in copper content, it maintains a healthy thyroid.

1.5 Aroma compounds in jackfruit

Jack fruit possess a distinct aroma due to the presence of volatile compounds [4]. analyzed the aroma compounds present in five different cultivars of Jack fruit using SPME for extraction of volatiles and GC-TOFMS for identification and quantification. It was found that there were 37 compounds identified and the main volatile compounds from these five cultivars were ethyl isovalerate, 3-methylbutyl acetate, 1-butanol, propyl isovalerate, isobutyl isovalerate, 2-methylbutanol and butyl isovalerate. It was suggested that alcohol and esters were present in all the five cultivars and were responsible for the sweetness and fruity aroma of the jack fruits. Owing to the natural sweetness and subtle flavour, it is used in making a variety of dishes.

The extraction of aroma volatiles from two varieties (hard and soft) of jack fruit cultivated in the Amazon region using the simultaneous distillation-extraction method and the samples were analyzed by Gas Chromatography – Mass Spectrometry (GC-MS). It was observed from the results that the most important aroma components present in the hard variety of jackfruit were 28.4% of isopentyl isovalerate and 25.6% of butyl isovalerate. Similarly, the soft variety contains 18.3% of isopentyl isovalerate, 16.5% butyl acetate, 14.4% ethyl isovalerate, 12.9% butyl isovalerate and 12% of 2- methylbutyl acetate as dominant aroma compounds [5].

2. Post-harvest processing and value addition of jackfruit

Fully ripened jack fruits are cut, opened, and used for edible purposes. Bulbs are removed by manual methods. This method involves much cost, time, and labour intensive. Mechanization for bulb removal has not yet been developed. Hence it is highly essential to develop machines for bulb removal.

2.1 Value added jack fruit products

Worldwide matured jackfruit bulb is consumed as dessert fruit or in processed form. Value added products such as jam, jelly, ready to serve beverage, squash, syrup, nectar, pickle and papad can be prepared from jackfruit bulb. Besides this, jackfruit pulp can also be used to flavour ice cream and beverages. Various value-added products prepared from jackfruit are shown in (Figure 1). and research carried out is provided in (Table 4). The major problem involved in processing jackfruit is the lack of machines to separate jackfruit bulb from the rind of the fruit [7].

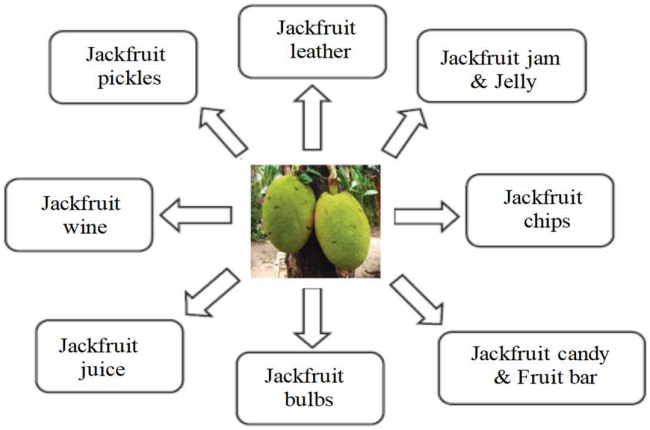

Figure 1 Value added products from jackfruit [6].

Table 4 Value added products from Jackfruit.

Product name	Source	Additives/ materials used	Shelf life	References
Jam	Pulp and juice			[8]
Ready to serve beverages	Pulp	10% pulp content, 12% TSS and 0.3% acidity		[9]
Squash	Ripened fruit pulp	vitamin C	60 days	[10]
Preserved jack fruit bulb	fruit bulb	Potassium meta bisulphite (1.5%) and sodium benzoate (0.5%)	15 days	[11]
Jackfruit nectar	Fruit Pulp	Sugar and citric acid		[12]
Canned jackfruit	raw and ripe jack fruit bulbs	0.5-0.75% citric acid		[13]
Dehydrated jackfruit bulbs	Fruit Pulp	45° Brix sugar solution	8 months	[14]
Jackfruit chips	Raw jackfruit	0.1% KMS	2 months	[15]
Dehydrated jackfruit chips	Mature jackfruit	ascorbic acid	2 months	[16]
Jack fruit Papad	Jackfruit rind flour	Rice flour and black gram flour	3 months	[17]
Jackfruit Candy	Fruit Pulp	sugar syrup, 20% glycerol		[18]
Wine	jackfruit juice			[19]
Vinegar	jackfruit juice		1 year	[20]
Brined jackfruit	Raw jackfruit	Salt		[21]

3. Waste utilization from jackfruit

Fruit process industries pose a lot of problems in disposing of the waste generated. Fruit waste includes peel, seeds, etc. These wastes, if not disposed of properly will cause serious environmental problems such as water pollution, unpleasant odours, explosions and combustion and greenhouse gas emissions. Many reports have stated

that the integral exploitation of bioactive compounds from the wastes and their potential applications as antioxidant, antimicrobial, flavouring, colorant and texturizing agents. Proper utilization of the jack fruit waste could be effectively performed in the similar way as mentioned [22]. for improved degradation of organophosphorus-based chemical warfare agents on metal oxide surfaces. however, proper utilization of the by-products not only increases the economic value but also reduces the cost of disposal.

The environmental problems caused by waste could also be overcome by adopting computational approaches which provide solutions for the processing of waste products and provide additional benefits in conserving the environment [23]. studied the disposal and decomposition of nuclear waste by using computational techniques for analyzing the data for waste disposal effectively. This method is reported to be effective in increasing the efficiency for novel waste form of discovery that could impound specific species within the diverse waste streams. The database on density-functional theory, such as, the materials project and the open quantum materials aid in finding new materials with targeted properties from the wastes have also been explored [23]. The thick peel of jackfruit can also be used in cattle feeds, bio-fuel extraction, nano-porous adsorbent materials for removing dye etc. Solid wastes, particularly from processes such as peeling and coring, which have high nutritional value are used as animal feed. The value of addition of products from fruit wastes economizes the fruit processing units [24].

Jackfruit (*Artocarpusheterophyllus* lam) generates huge quantity of solid wastes, as its seeds and peel are not utilized efficiently. It was reported that jackfruit peel has been used for anaerobic bio hydrogen production and the nano sized seed powder has been studied for its antimicrobial potential [25].

3.1 Jack fruit seed

In recent years, research and development have focused on exploitation of underutilized fruits. Waste valorization has become an important task for modern food industries**.** Jack fruit seed is considered as a source of natural food additives and ingredients. More emphasize was given to the utilization of seeds. Seeds are rich in minerals with moderate amounts of phytochemicals and possess strong antioxidant properties [26]. explained the possible ways of using the seeds as natural antioxidants. For the extraction of antioxidants, factors like time, temperature, pressure, solvent concentration, solid to liquid ratio and pH should be optimized. Jacalin, a major protein that possesses immunological properties that has been isolated from jackfruit seeds can be used as a good substitute where the food requirements are not being fulfilled by seasonal vegetables. The proximate composition of jack fruit seed is furnished in (Table 5). and it is observed that the seed contains more quantity of carbohydrate followed by crude fat.

Table 5 Proximate composition of jackfruit seed.

Contents	Net wt. (g)
Ash	0.15
Moisture	61.8
Crude fat	11.85
Total carbohydrate	26.20

Source: Gupta et al. [27].

Jackfruit seeds are edible and must be utilized in a proper way. Flour obtained from jack fruit can be an alternative product to seeds as they have a very short shelf life. Seed flour can be stored, utilized, and offers opportunity to develop value added products from them.

Priyadarshini et al. [28] carried out a study to utilize jackfruit seed flour along with de-fatted soy flour as a protein rich material in formulation of four sets of extruded breakfast cereals *viz.,* Extruded breakfast cereal A-EBCA which contains jackfruit seed flour (150 g), soy flour (50 g), milk powder (20 g), sugar powder (30 g), moisture (5-6%), Extruded breakfast cereal B- EBCB includes jackfruit seed flour (140 g), soy flour (60 g), sugar powder (40 g), cocoa powder (10 g), moisture (5-6%), extruded breakfast cereal C-EBCC consists of Jackfruit seed flour (140 g), Soy flour (60 g), Milk powder (20 g), Sugar powder (20 g), Cocoa powder (10 g), Moisture (5-6%) and Extruded Breakfast Cereal D- EBCD is a combination of Jackfruit seed flour (150 g), Soy flour (50 g), Milk powder (20 g), Sugar powder (20 g), Cocoa powder (10 g), Moisture (5-6%). It is evident from the findings that Extruded Breakfast Cereal C (EBCC) among the four sets of formulated products has the highest amount of Protein, Fiber and fair amount of some important minerals have been rated the best in terms of sensory evaluation. Hence, it was decided that extruded breakfast Cereal C is the best and has the highest nutritive value as compared to the other breakfast cereals and the Control Extruded Breakfast Cereal. Jackfruit seed is used to prepare a wide range of value-added products like, kheer, burfi, pakodas, etc.

Jackfruit seeds contain antinutritional factors like tannins, saponin, trypsin inhibitors etc., Seeds can be converted into flour after inactivating those factors by drying. Jackfruit seed flour is used in the preparation of chapathis by using an optimal blending of wheat flour and seed flour in the ratio of 25:73. The flour from jack

fruit seed is considered as a good thickening and binding agent in food product development. Jackfruit seed contains a good amount of protein, has low water and fat absorption capacity, and hence can be used in deep fried food products [29].

Jackfruit seed flour is utilized for preparing oil fried snack foods by replacing (50%) cereal/pulse-based flour. The overall acceptance of the product was found to be good. The process for the production of good quality jack fruit seed flour was optimized by Ukkuru and Pandey [11]. It was suggested that the flour could be used in the manufacture of confectionery and bakery products and got wide acceptance from the consumer.

Prebiotics are the nondigestible food ingredient(s) that beneficially affects host health by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon. Bhornsmithikun et al. [30] extracted prebiotics from the seeds of jackfruit by designing and constructing a continuous extractor and studied the optimum conditions of prebiotics extraction from jackfruit seed. The optimum condition for extraction was temperature 60°C, extraction time 15 min, and L/S ratio at 10:1(v/w) using 50% ethanol as a solvent. These conditions were applied for pilot scale continuous extraction at three stages. The extract (third stage) gave an average extraction yield of 20.25% and the average non-reducing sugar of 400 mg/g extract.

Fernanda et al. [31] compared roasted jackfruit seed flour aroma with cocoa and chocolate powder. Particle size, solubility, water uptake, sensory preference, wettability, apparent density, viscosity, and intensity of chocolate aroma were measured. It was found that jackfruit seed flour had a higher solubility and less viscosity which was the desirable characteristics of cocoa powder. It was suggested that jackfruit seed flour can be an ingredient for cocoa replacer.

3.2 Jack fruit peel

After consumption of the bulbs, peel is discarded as waste which accounts for about 59%. It was estimated that the amount of peel generated annually was about 2714 - 11800 kg/tree [32]. Utilization of waste to produce value added products will serve to protect the environment and at the same time provide economic benefits. Before converting the peel into value added products the composition of the peel must be known. Sundarraj and Ranganathan [33] analyzed the proximate composition of dried jack fruit peel and found that the cellulose content is about 27.75%, which was more than that of the pomelo, albedo peel, orange rind and lemon peel and orange peel [34].

3.2.1 Extraction of Pectin from jack fruit peel

Pectin is a unique heteropolysaccharide mainly present in the cell wall and middle lamellae of terrestrial plants [35]. Pectin finds vast applications in food, pharmaceutical and cosmetic industries mainly as thickening, gelling, binding, and emulsifying agents [36]. Pectin is produced from apple pomace and citrus waste at the commercial level. For more pectin production other food industry waste should be explored. Waste obtained from jack fruit was accounted as 60% and the pectin content of the peel is more than the edible fruit that can be considered as a budding source for the extraction of pectin [37].

Begum et al. [38] studied various methods used for extracting jack fruit pectin and analyzed its suitability for use in industries. Alcohol Insoluble Residue (AIR) of jack fruit peel was prepared and dried at 50°C. Pectin was extracted from AIR by using three conditions viz., 0.25% ammonium oxalate/oxalic acid at pH 4.6 and temperature 85°C; 0.1 N H_2SO_4 at pH 2.5 and temperature 80°C; and 0.3% sodium hexametaphosphate/ HCl at pH 2.2 and temperature 80°C for 1h with continuous stirring. Among the extracting conditions, ammonium oxalate yielded pectin with lower moisture content than the rest of the two in terms of chemical and functional properties. The pectin obtained showed high amount of Anhydrouronic acid (AUA), high degree of esterification (DE) and viscosity but the color of the pectin is slightly darker than the commercially available pectin.

Begum et al. [39] analyzed the quality of pectin extracted from jack fruit waste, dried under freeze, spray, vacuum oven and oven drying techniques. The quality of the pectin was determined in terms of structure and composition, appearance, flow behavior, flowability and viscosity. It was observed that the freeze-dried samples showed higher solubility, viscosity and brighter colour than the pectin obtained by other drying techniques. On the other hand, smaller particle size, more surface area, lesser flowability were shown by spray dried pectin and the quality of oven and vacuum dried pectin were similar. It was concluded that the effect of drying techniques has no significant changes in the quality parameters. Depending upon the food purpose and the quality of the final product, appropriate drying method may be selected.

3.2.2 Production of ethanol

Agricultural waste materials could be a good source of carbohydrate for ethanolic fermentation process. Chamutpong et al. [40] investigated waste materials (Durian peels and the rind and pulp wastes from Jackfruit) containing high contents of starch were comparatively tested for their cellulosic digestion. Natural habituating

microorganisms on the waste and/or the isolated active strains were successfully achieved in 25-30 days for the digestion (8-10% Brix). To activate the digestion, about 10^9-10^{12} cells/mL of the culture (inoculums) were added first. It was noted that there was no significant difference between these two materials in terms of digestion speed and the ability to digest cellulose and starch to sugar. During digestion (25-30 days) from durian peels, many varieties of microbial species were observed, especially fungi types white and black *Aspergillus* spp. as well as bacilli.

On the contrary, the rind and pulp wastes of jack fruit, revealed most bacteria types cocci and small rods as well as *Aspergillus* spp. In the second step of alcohol production, in durian waste sample, the starch and sugar portions could possibly be better retrieved for alcohol production than those of jack fruit (60 and 55% w/w of wastes). It showed saturated 10-15% v/v of ethanol contents in about 15 days and 22 days in durian and jack fruit wastes, respectively. It was concluded that jackfruit wastes could comparably be a good source for ethanol production like durian peels provided all optimizing conditions at each step were considerably done. Antony et al. [41] optimized extraction conditions of pectin from jackfruit waste. Using oxalic acid at the temperature of 90°C for 60 min gave the best result with 38.42% pectin yield. Begum *et.al.* [36] treated jackfruit waste separately with dilute sulphuric acid, ammonium oxalate and sodium hexametaphosphate to extract pectin. Highest yield was found with the extraction of sodium hexametaphosphate whereas it had high ash content and slowest solubility.

Sreena et al. [42] investigated five different agro waste namely tamarind husk, arecanut husk, pepper waste, banana peduncle and jack fruit outer rind as a substrate for saccharification. Among the different agro waste jackfruit outer rind showed the highest saccharification of 33.4%. The concluded the economic utilization of agro waste for sugar production.

3.2.3 Production of Activated carbon from jack fruit peel

Jackfruit peel waste as such has no economic value and has been utilized to produce activated carbon. It was produced using a chemical activation method with phosphoric acid as activating agent. The impregnation ratio was 4:1 (g H_3 PO_4/g raw material) and semi carbonization process was conducted at 200°C and followed with carbonization at 550°C. This was used as an adsorbent for organic pollutant removal purposes then evaluated using Methylene Blue adsorption in aqueous solution.

Nagalakshmi et al. [43] prepared activated carbon from jackfruit waste and named as JC_{600}. The absorption capacity of the activated carbon was tested by removal of Disperse Blue 14 (DB14). It was reported that dynamics of sorption can be better explained by pseudo-second-order model. Priyatharishini and Mokhtar [44] developed a plant-based coagulant using jackfruit peel. It was observed that the jackfruit peel extract showed the best result at pH value 2. It was suggested that jackfruit peel coagulant can be used in the primary treatment of wastewater.

Jennifer et al. [45] conducted experiments to produce bio-oil from jack fruit peel waste. It was reported that the most important parameter in the production of bio-oil is the temperature of pyrolysis process. About 52.6% of bio-oil was obtained at 550°C with heating rate of 50°C/min and nitrogen flow rate of 4 L/min.

3.2.4 Antimicrobial activity of jack fruit peel

Soma et al. [46] investigated the antimicrobial potential of five fruits peel waste (pineapple, custard apple, jackfruit, pomegranate, and papaya) extracted in four solvents (chloroform, petroleum ether, acetone, benzene) against clinical isolates of gram positive and gram-positive pathogenic bacteria. The fruit peels were collected based on their high amount of waste (unused disposed portion) of peels. The compounds responsible for the antimicrobial activity were found using GC-MS Analysis. The antibacterial potential was assessed by measuring the diameter of the zones of growth inhibition, minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) values. Amongst the solvents used, acetone extract exhibited the best antimicrobial activity. Maximum activity was seen for the acetone extracts, in the order of pomegranate peels > jackfruit peels > custard apple peels. GC-MS analysis of acetone extracts showed antimicrobial activity revealed prominent peaks of furanone, furfural (along with imidazole) and phenolic compounds (mainly benezenetriol). This work is the first of its kind to analyze the reusability potential of acetone extracts of fruit peel wastes for developing natural antimicrobials.

3.2.5 Other uses of jack fruit peel

Aditya et al. [47] extracted a natural photo active dye from jackfruit rags which exhibited a dominant photo-absorption in the spectral range of 350 nm to 800 nm. Therefore, it was suggested to use as photo-sensitizer on titanium dioxide in dye sensitized solar cells (DSSCs). It was concluded that the jackfruit derived natural dye can be used to establish a cost effective excitonic photovoltaic technology. Jose et al. [48] reported that jackfruit waste can be utilized as feedstock for combustion. Emission and combustion characteristics were studied for mainly jackfruit peel and seeds. It had a heating value which ranged from 16.3-17.2 MJ k/g, carbon content ranged from

40.8-41.8 wt.% and volatile solids ranged from 75.1-81.3 wt.%. It was concluded that jackfruit waste can be utilized as an efficient renewable source of bioenergy as it had high heating value and low CO emission.

Mahesh et al. [49] analysed jackfruit peel oil with diesel at different combinations 20:80, 40:60 and 60:40 to prepare biodiesel. The experiment was done with a single cylinder, water cooling system using single hole nozzle with varying loads. It was found that emission characteristics such carbon monoxide and hydrocarbon are less.

A study was carried out to isolate nanomaterials, cellulose and spherical cellulose nanocrytals from jack fruit peel. The isolation was carried out using three different methods. Among the treatments sodium chlorite treated jack fruit peel resulted in high yield of cellulose. It was also observed that the cellulose obtained was free from hemicelluloses and lignin content [50]. Antony et al. [41] have also extracted cellulose, alpha cellulose and microcrystalline cellulose from the jack fruit peel. It was concluded that these materials can be successfully used in food and pharmaceutical industries because of their thickening, binding, emulsifying and stabilizing properties.

4. Marketing potential for jack fruit

In general, jackfruit is not cultivated as a monocrop but, it is grown as an intercrop. Even though the entire tree is a heavy producer, it is regarded as a minor crop in many countries. Hence, data on the exact area and production is not available. Similarly, there is scarce information on consumption, wastage, export, processing, and value addition etc. It was estimated that 75% of the jack fruit is discarded as waste in India and in Kerala the waste accounts for about 35 Crores every year. Due to insufficient data availability, the correct quantity of waste generated could not be estimated.

4.1 Domestic market

Jackfruit is sold at villages itself or collectors from outside the villages or villagers themselves sell it to external markets like village fairs, roadsides sheds as there is no stable market chain. As the price is decided by the middlemen, the producers are exploited more. In addition, the consumption percentage is also very low (30-35%) and nearly 70% of the fruit goes as waste during post-harvest stages. Jackfruit marketing includes personnel involved in production and trading (wholesalers and retailers). There is no defined market system for jack fruit marketing. Future production of jackfruit will depend upon the developing suitable cultivars for consumption, production, processing, and utilization.

4.2 Foreign market

The production and demand for jack fruit depends upon the availability of processed products in the international market. Fresh fruits are more accepted in countries like Japan, Malaysia, The United Kingdom, Singapore, Hong Kong and some Middle Eastern countries. There is a greater scope for jackfruit in the regional and international markets because it is available both in fresh fruit as well as a processed form.

5. Conclusion

The is an increasing pressure prevailing on the existing resources which are to be utilized optimally and substantial effort is being taken for the conversion of agricultural wastes and other by products into value added products. Jack fruit is one of the promising fruit crops which is processed into various products by means of value addition. Proper post-harvest processing is essential to convert the fruit into edible form and to increase the shelf life by preventing wastages. The main product(bulb) is converted into other products and is also incorporated into various food products. The by-products(wastes) obtained from jack fruit processing also have good potential and augmented to be explored as food and feed constituents due to their high nutrient value contents. However, conversion of jack fruit wastes is challenging mainly because of the perishability and unavailability of suitable technologies. There is a need to develop proper technologies to strengthen the value chain in the production areas. The present review encapsulates the important research attempts and findings on the utilization of jackfruit waste and by products to have the information readily available for further research. It is also perceived from the compiled information that the development of feasible technologies and facilities to process the perishable wastes will provide economic benefits to the producers and processors and health benefits to the consumers. Production of animal feed on commercial level using jackfruit peel and central core can also be promoted in the regions where enormous quantity of these wastes are produced every year. The jack fruit seed powder can also be augmented with other ingredients in the bakery food formulation, extruded products, and confectionary.

Increasing population and limiting resources need to focus on steady supply of good quality foods. The widespread malnutrition and undernutrition status in developing countries is challenging and providing quality food has become a main issue. Even though cereals, pulses and oilseeds provide carbohydrates, proteins and fat, there are remarkable deficiencies in vitamins and minerals. This could be overcome by consuming nutrients that

are abundantly available in underutilized fruits such as jack fruit. Due to limited product development, it remains a minor product in the local market. Scientific interventions for product development and waste utilization need to be addressed to promote and commercialize jackfruit products. The adoption of appropriate strategies for effective utilization of this underutilized fruit will increase the farm income, provide nutrition to the people, and improve the nation's economy.

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