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Utilization of jackfruit by-products and application in food industry

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Abstract
There are portions of both edible and non-edible waste in every food source. In order to use the most amount of plant or animal resources, modern agriculture is concentrating on agro-processing to meet the growing demand for food and feed. The goal of this review study is to provide an overview of the current state of jackfruit (*Artocarpus heterophyllus* Lam, Moraceae) waste usage in the food, feed, and other industries. Other than the inedible parts like the peel and axis, edible byproducts like jackfruit seeds are largely underutilized. In addition to the luscious edible bulbs, this article has reviewed works that use other jackfruit waste parts. Numerous studies have suggested using the jackfruit's thick peel for biofuel production, nutrient-rich cattle feeds, nano-porous adsorbents for removing dye, etc. Pectin extraction from the fruit's peel and central axis has also been studied. Numerous studies have tried to employ jackfruit seeds in different baked goods.

Keywords: *Artocarpus heterophyllus*, Jackfruit rind, seed, antioxidant, Nutritional composition

Introduction

A projected 931 million tonnes of food, or 17% of all the food accessible to customers in 2019, was wasted by individuals, businesses, restaurants, and other food services. According to this, 17% of the food produced worldwide may be squandered (11 percent in households, 5 percent in food service, and 2 percent in retail) (Zhongming, 2021) [1]. Processing of by-products is a promising source of valuable substances such as phytochemicals (carotenoids, phenolics, and flavonoids), antioxidants, antimicrobials, vitamins, or dietary fats that possess favorable technological activities or nutritional properties (Kasapidou *et al*., 2015) [3]. According to the Food and Agriculture Organization (FAO), global jackfruit production was estimated at 3.7 million 86 tons in 2015-2017, with 2.96 million tons of potential bioenergy feedstock 87 produced in 2018, even though only 20% of the fruit (berries) is used as a food product (Alves *et al*., 2020) [2].

In India, the jack fruit (*Artocarpus heterophyllus*) is a popular fruit. The jackfruit tree is thought to have evolved in the Western Ghats rain forests in India's southwest, However, some researchers believe Malaysia could be the origin point (Ranasinghe *et al*., 2019) [10]. It is thought to be a poor man's cuisine. It is a widely produced tropical fruit in 75 countries, including India, Indonesia, Bangladesh, Thailand, Malaysia, and Brazil. The word Artocarpus is derived from the Greek words “artos” (bread) and “carpos” (fruit). The name "Jackfruit" comes from the Portuguese word "jaca," which is taken from the Malayalam word "chakka." In Bengali and Hindi, the fruit is referred to as “kathal” or “kata-hai” (Anonymous, 2012). The jackfruit is an underutilized fruit (Sundarraj *et al*., 2017) [4] Jackfruit flesh tends to be highly perishable accompanied by flavor loss, tissue softening, and cut surface browning. Tissue softening makes it more susceptible to bruising and mechanical injury. The rotting of ripe fruits is typically seen in limited pockets of the huge fruit (Li *et al*., 2019) [12]. Large numbers of ripe jackfruits deteriorate quickly after harvesting due to a lack of postharvest understanding, resulting in poor handling and insufficiency of hygienic practices and storage facilities in locations where they are processed and marketed.

Food processors and dealers typically discard jackfruit rind, peel, and seeds as waste. A large portion of the peel (which accounts for 59 percent of the mature fruit) gets discarded as waste due to its restricted usage. The yearly jackfruit production is predicted to be between 2714 and 11,800 kg per tree. Transforming these wastes into value-added commodities, and by-product recovery will achieve the dual goals of environmental protection and value creation (Noranizan *et al*., 2014) [5]. Pectin, a useful by-product of these fruit wastes, can be obtained (Begum *et al*., 2014) [6].

Pectin is a heteropolysaccharide with 1,4-linked -D-galacturonic acid residues, some of which are esterified by methanol. It's often present in higher plants' cell walls and middle lamellae. Pectin is used as gelling, stabilizing, emulsifying, and binding agent in food, pharmaceutical, and cosmetics. This polysaccharide lowers cholesterol, blood sugar, ulcers, and cancer, and boosts the immune system. Consumption of these polysaccharides has substantial health benefits, including lowering blood cholesterol and blood glucose levels and boosting the immunological response. (Begum *et al*., 2017) [29]

Jackfruit

Jackfruit (*Artocarpus*) is a genus of roughly 60 trees and shrubs native to Southeast Asia and the Pacific that are members of the Moraceae (mulberry) family. All *Artocarpus* species are lactiferous trees, which means they have milky sap-producing leaves and stems. The zoological type is monoecious, producing unisexual flowers, and both sexes can be found on the same plant. Small, greenish female flowers develop on delicate, fleshy spikes produced by the bushes. After fertilization, the blooms develop into asyncarpous fruit that can grow to enormous proportions. The leaves specified range in size from little and whole (Artocarpus integer) to enormous. (Sundarraj *et al*., 2017) [4]

The external rind of the jackfruit is made up of hexagonal, bluntly conical carpel apices that cover a thick, rubbery, and pale to yellowish wall (Ranasinghe *et al*., 2018). It's a multiple aggregation fruit that forms when numerous blooms in an inflorescence fuse together (Mushumbus *et al*., 2015). The flesh makes up about 30% of the weight of the fruit. The fruit contains a large number of bulbs with a high nutritional value. The fruit is divided into three sections, the fruit axis, the persisting perianth, and the true fruit (Ranasinghe *et al*., 2018). The axis and core of the fruit are inedible due to the presence of lactiferous cells that produce latex, which helps to hold the fruits together. The perianth is made up of three regions such as the bulb (the lower fleshy edible region), the middle-fused region that forms the rind of the syncarp, horny non-edible region commonly known as the spikes (Prakash *et al*., 2009). Jackfruit seeds are light brown and spherical, measuring 2-3 cm long and 1-1.5 cm wide. They are encased in a white aril that is enclosed by a thin brown spermoderm that covers the fleshy white cotyledon. These have been found to be high in carbohydrates and proteins (Mushumbusi *et al*., 2015) [64]. According to a study, ripe jackfruit contains more nutrients and vitamins than apples, apricots, avocados, and bananas (Tiwari *et al*., 2015) [16].

Common Wastes and By-Products of Jackfruit and Its Utilization

Fresh jackfruit consumption, as well as its processing, generates a large amount of non-edible waste, such as peel and central axis, as well as edible by-products, such as seeds and perianth.

Jackfruit Peel

The exterior protective coat of jackfruit is known as the peel, rind, or skin. The outer peel corresponds to around half of the ripe jackfruit (Moorthy *et al*., 2017) [9, 11]. The improper disposal of peel has a significant negative impact on the environment. The proper exploitation of by-products, on the other hand, not only increases the economic value but also lowers the disposal cost. Calcium is abundant in the peel. It also contains 7.32 to 15.14 percent pectin in dry matter (DM), making it a valuable source of this polysaccharide (Li *et al*., 2019) [12]. Pectin is a type of heteropolysaccharide found in the cell walls and middle lamellae of soil-grown plants (Adetunji *et al*., 2017) [13]. It's made up of L-rhamnose, L-arabinose, and D-galactose, as well as 1,4-linked D-galacturonic acid partially esterified with methyl groups (Amadi *et al*., 2018) [14].

Central core or axis of jackfruit

The modified mature inflorescence axis has a dome-shaped, stiff, and slightly fleshy fruit axis. The non-edible core creates a longitudinal axis with the rags, which are then attached to the syncarp's rind. The modified mature inflorescence axis has a dome-shaped, stiff, and slightly fleshy fruit axis (Cruz-Casillas *et al*., 2021) [15].

Seeds

Around 10% to 15% of a jackfruit's weight is made up of seeds. Seeds are usually thrown away or boiled and eaten as a snack or in specific regional recipes. Fresh seeds cannot be stored for long periods of time. The seeds of the jackfruit are light brown and spherical, measuring 2-3 cm in length by 1-1.5 cm diameter. They are encased in a white aril that surrounds a thin brown spermoderm that covers the fleshy white cotyledon and is encircled by the flesh. These are high in carbs and proteins, according to research (Ranasinghe *et al*., 2018). Thiamine and riboflavin are two B vitamins found in abundance in these seeds. Both aids in the production of energy and perform other vital activities in the body. Additionally, jackfruit seeds include fiber and resistant starch, which pass through the body undigested and provide nourishment for our healthy gut bacteria (Cheri Bantilan., 2019).

Jackfruit Perianth

The most significant part of the fruit is the perianth, which makes up the majority of it. The lower fleshy edible part (often referred to as the bulb), the middle-fused region (which forms the syncarp's rind), and the upper free and horny non-edible region are the three regions. The actual fruit is made up of the carpel (ovary) and the fleshy perianth (Ong *et al*., 2006). This waste part accounts for around a quarter of the overall fruit weight (Dam *et al*., 2013).

Table 1: Nutrient composition of jackfruit

Nutrient	Young fruit	Ripe fruit	Reference
Calcium(mg)	30.0-73.2	20.0-37.0	Baliga *et al*., 2011 [37]; Chandra *et al*., 2020 [38]; Swami *et al*., 2018 [39]; Sundarraj *et al*., 2018; Ranasinghe *et al*., 2019 [10]
Magnesium	-	27.0	
Phosphorous	20.0-57.2	38.0-41.0	
Potassium	287-323	191-407	
Sodium	3.0-35.0	2.0-41.0	
Iron	0.4-1.9	0.5-1.1	
Vitamin A	30	175-540	
Thiamine	0.05-0.015	0.03-0.09	
Riboflavin	0.05-0.2	0.05-0.04	
Vitamin C	12.0-14.0	7.0-10.0	

Health benefits

Vitamins, minerals, and fiber are abundant in seed. Fiber makes weight reduction simpler, and it may reduce risk of heart disease (high cholesterol, high blood pressure), as well as constipation. Jackfruit seeds also include resistant starch, which aids in blood sugar regulation and the maintenance of a healthy gut. Being high in thiamine and riboflavin, two B vitamins, aids in the conversion of food into energy and the maintenance of healthy skin, eyes, and hair. Riboflavin is also an antioxidant, which helps to protect cells from free radical damage.

Minerals such as zinc, iron, calcium, copper, potassium, and magnesium are vital for immunological function, the formation of red blood cells, and the formation of strong bones, respectively. The human body need potassium to keep (blood pressure in check and magnesium to keep blood sugar levels in check. Consumption of jackfruit seeds provides a variety of phytochemicals or plant chemicals, some of which may have antioxidant activity, such as polyphenols, and other phytochemicals found in jackfruit seeds include saponins, which may have some anticancer activity, and flavonoids, which may help reduce the risk of blood clots (Maurya, 2016) [24].

Bhuiyan, (2016) [25] found that functional molecules isolated from seeds and peel of *Artocarpus heterophyllus* showed antibacterial, antidiabetic and antioxidant activities. *Artocarpus heterophyllus* stem and root, barks, stem and root heart-wood, leaves, fruits, and seeds, showed a broad spectrum of antibacterial activity. Antioxidant activity is linked to the total phenolic and flavonoid content of jackfruit flesh extracts. Fresh seed and meat show considerable ascorbic acid equivalent antioxidant effects gallic acid equivalent phenolic contents which are thought to account for around 70% of the overall antioxidant activity. Vitamin C, which may be found in jackfruit, protects the skin from damage caused by the natural ageing process as well as prolonged sun exposure. Vitamin C is also required for the production of collagen, which provides the skin its rigidity and strength, as well as dentalhealth. Anti-inflammatory effects have been discovered in isolated bioactive components from the fruits of *Artocarpus heterophyllus*. Flavonoids in jackfruit aid to prevent mast cells, neutrophils, and macrophages from releasing inflammatory mediators (Sajad and Singh, 2022).

Zhang, (2017) [32] found that the highest total phenolic and total flavonoid content was found in peel extract, with phenolics greater than pulp, flake, and seed extracts. The findings suggested that jackfruit peel has potential as a new source of natural antioxidants and hypoglycaemic agents. When jackfruit seed flour is added to deep-fried foods, fat absorption is reduced to a certain extent. Because of their high fiber content, the seeds can lessen the risk of heart disease, prevent constipation, and encourage weight loss. Resistant starch, found in jackfruit seeds, helps to regulate blood sugar and maintain the gut healthy. Jackfruit seeds have antimicrobial action, which helps to avoid foodborne illnesses, and they contain an essential lectin called jacalin, which is used to assess an HIV patient's immune system. In China, the seeds are known to help people overcome alcohol poisoning, while in India, the seeds are a key component of an antidote for heavy drinkers (Waghmare *et al*., 2019) [33].

Utilization of By-Products

The jackfruit is a multi-purpose plant that provides food, lumber, fuel, fodder, medicinal and industrial products (Zhang *et al*., 2021). Jackfruits are made up of yellow berries with brown seeds wrapped in a hard shell. The berries can be eaten straight from the plant or processed into jams, compotes, frozen fruit pulps, juices, and soft beverages. The agroindustry produces two by-products: jackfruit peels (JP) and jackfruit seeds (JS) (Alves *et al*., 2020) [2]. The fruit is the main commercial product of jackfruit, which is used in both mature and immature forms. Jackfruit has a texture that is strikingly similar to chicken, making it an ideal vegetarian meat replacer. In fact, "Vegetable Meat" is sometimes used to describe canned jackfruit (in brine) (Hamid *et al*., 2020) [23]. Jackfruit has a variety of value-added products that include chips, papads, pickles, ice cream, jelly, sweets, beverages like squash, nectar, wine and preserved flakes, etc. In addition, traditional medicines used to use jackfruit leaves, bark, flowers, seeds, and latex. Wood from the tree is also utilized for various purposes (Mandhare *et al*., 2020) [35]

The byproducts of jackfruit offer a lot of potential for application in the food business. Their use improves the nutritional value of products, they are being used in products such as bread, biscuits, cakes, cookies, ice creams. The by-products are also used to extract favorable compounds from them. Babu, (2017) found that the oil from jackfruit seeds was high in essential fatty acids such as linoleic and alpha-linolenic acids. Recent research on the nutritional properties jackfruit seed flour revealed that they contain high levels of protein (Abedin *et al*., 2012). Jackfruit seed starch has a greater amylose concentration and might be utilized as an alternative for modified starch. Jackfruit seeds found to contain high amount of saponins and phytochemicals (Gupta *et al*., 2011). Jack fruit seeds contain high flavonoid concentration as well as reducing potential and can be used as a functional medicine and pharmaceutical plant-based product (Shanmugapriya *et al*., 2011). Cagasan, (2020) showed that dinner wine produced from jackfruit byproducts such as seed coat, pith, rags, peel, and over ripen pulp was accepted by the sensory panel. After only two weeks of fermentation and have a good potential to become materials that could be used for wine preparation. Low glycaemic foods have therapeutic benefits for diabetic patients and generally recommended to the overall population. Ravindran, (2020) [18] made a diet chocolate with cocoa powder replaced by jackfruit seed and showed promising results as the end product formed had a low glycaemic index. Hamid, (2020) [23] made healthy meat analogue utilizing jackfruit by-products. Rinds, rags and seed powder was utilized. The nutritional composition of the developed meat analogue showed higher protein and dietary fiber content. Study of textural properties of meat analogues showed that with decreasing wheat gluten content, there was a significant reduction in hardness and chewiness.

Application in Other Industries

Textile industries' dye waste mismanagement plays a key role in water pollution affecting both flora and fauna, so a feasible and environment friendly solution is required to curb this problem. Kooh, (2018) [19] made use of jackfruit seeds as an adsorbent against malachite green, which is a dye broadly used in the textile industry due to its various applications. Their study concluded that seeds were able to adsorb the dye without any pH alteration, and it wasn't affected by salt or temperature variations. This method also proved to be a feasible low-cost solution as seeds could be reused again using water and base. Nsubuga, (2021) [20] characterised jackfruit peels and seed jackfruit varieties as feedstocks for anaerobic digestion and slow pyrolysis. They found out that the jackfruit seeds and peels can be classified as potential slow pyrolysis feedstocks. Peels and seeds under slow pyrolysis regime. Thus, they concluded that jackfruit peels and seeds have potential for production of biochar. Ibrahim, (2019) [22] found that activated Jackfruit peel biochar was highly effective in adsorbing heavy metals from aqueous solutions. This study confirmed that using jackfruit peel was a viable and cost-effective adsorbent of heavy metals such as Cd, Pb, Cu, Fe, and Mn from aqueous solutions. The biochar had functional groups that supported metal ion binding. Abid, (2019) [22] utilized peel and seeds to synthesize biochar for the removal of copper metal ions from water. The biochar obtained from peel recorded excellent adsorption capacity. Patowary, (2022) found that jackfruit waste can be used as the sole media for noncytotoxic rhamnolipids production. The tests revealed that the final compound has significant antifungal action against *Alternaria solani*. Rhamnolipids derived were nontoxic indicating that they could be used in cosmetics and pharmaceuticals. Choy, (2016) isolated, characterized, and found great potential for starch from jackfruit waste to act as a coagulant aid for the treatment of turbid water. Jackfruit seed contained more than 50 % of total starch. Ginting, 2020 [70] found that Jackfruit seeds have the potential to be a raw material for bioethanol production. Santana, 2018 found that starch-based bioplastics can be made from jackfruit seed. Nayak, 2015 [72] isolated polysaccharides from Jackfruit seeds and found out that it can be used as pharmaceutical excipients in various pharmaceutical formulations. Prasad, (2020) [73] found that bio adsorbent made from jackfruit seed can be used for Cadmium adsorbtion from aqueous solution thus helping in pollution control. Kumar, 2021 [74] found jackfruit seed slimy sheath to be a novel source of antioxidant-rich pectin for use in functional foods and the medicine. Zhu, (2018) [75] found that the starch from jackfruit seeds has great potential as a microcapsule shell material and for application in the food industry. Giri, 2021 [76] found that Jackfruit seed kernel bio-sorbents are effective at removing chromium from aqueous solutions. Chakraborty, (2022) [80] made Fungal biomass protein from Jackfruit seed waste. Choy, 2018 isolated and found the potential use of starch from jackfruit seed wastes as a coagulant aid for treatment of turbid water.

Table 2: Utilization of jack fruit and by-products in different foods

Part	Product	References
Rind	Cookie	Ramta *et al*., 2020
	Biscuit	Jayasinghe *et al*., 2018 [79]
	Bread	Feili *et al*., 2018
	Meat analogue	Hamid *et al*., 2020 [23]
	Jelly	Gani *et al*., 2015; Mondal *et al* 2016 [50, 66]; Sultana, 2021 [51]
Seed	Biscuit	Islam *et al*., 2015 [77]; Barge *et al*., 2018 [78]
	Pasta	Lakmali *et al*., 2021 [82]; Swathi *et al*., 2019 [83]
	Noodles	Divakar, 2017 [84]; Binti *et al*., 2013; Pakhare *et al*., 2018 [89]
	Spaghetti	Prajakta *et al*., 2018 [86]
	Chips	Latifa *et al*., 2020 [87]
	Extruded Product	KS *et al*., 2021
	Cake made with seed flour	Khan *et al*., 2016 [50, 66]; Faridah *et al*., 2012 [48]; Akter *et al*., 2020 [52]
	Bread made with seed flour	Hossain *et al*., 2014; Nwamarah *et al*., 2013 [49]
	Cookies made with seed flour	Maskey *et al*., 2020; Hidayati *et al*., 2019 [40]; Ibrahim, 2021 [41]; Varghese *et al*., 2022 [42]
	Oil	Babu *et al*., 2017; Nagala *et al*. 2013 [43]
	Diet chocolate	Ravindran *et al*., 2020 [18]; Molu *et al*.,2021 [44]; Banuelos 2019 [45]
	Bread spread	Supit *et al*., 2018; Nur 2020 [46]; Molu *et al*.,2021 [44]
	Ice cream	Lumbantobing *et al*., 2020 [53]
	Tortilla	Nurhayati, 2020
	Bun	Ngwere *et al*., 2021 [62]
	Cocoa substitute	Delfino *et al*., 2021 [63]; Papa Spada *et al*., 2018 [91]
Pulp	cake	Haque *et al*., 2015 [63]; Hossain *et al*., 2007;
	Ice cream	Gaikwad *et al*., 2020 [56]
	Yogurt	Rajarathna *et al*., 2021; Dissanayaka *et al*., 2019 [59]; Benalcázar *et al*., 2021 [60]; Sampurno *et al*., 2020 [69]
	Idli	Shirsat *et al*.,2019
	Jam	Mushumbusi *et al*.,2015 [64]; Tiwari *et al*., 2016 [65]; Mondal *et al* 2016 [50, 66]; Kanishka *et al*., 2018 [67]; Remya *et al*., 2019 [68]

Conclusion

With the demand for existing resources increasing, there has been a deliberate attempt to convert more agricultural waste and by-products into value-added products. Due to the recognized uses of jackfruit, research on its consumption and use is gradually growing. The nutrient and biochemical profile of jackfruit make it a highly desirable fruit tree with the potential to reduce food insecurity, particularly in developing nations, especially given the tree is highly robust and requires little care. Customers can profit from the wide range of products offered by this fruit tree.

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