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(Review Article)

The nutritional aspects and food applications of *Artocarpus altilis* starch: A review

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Abstract

Artocarpus altilis is commonly referred to as breadfruit as it is similar to freshly baked bread. It is native to Malaysia, Southern Pacific, and the Caribbean and a mature breadfruit tree can yield between 400 and 2400 kg of breadfruit annually.The amount of different minerals found in breadfruit varies greatly depending on the cultivar and growth area. These minerals include copper, magnesium, phosphorus, potassium, calcium, cobalt, iron, and manganese. It is abundant in calcium, vital minerals, and carbohydrates. It offers infection protection and is beneficial to heart health. It contains fatty acids that are omega 3 and 6. It is increasingly used as a food additive, regulating stability, texture, and sweetness. It is gluten-free, used in bakery products, and has anti-inflammatory, anti-malarial, and atherosclerotic properties. It is also used in value-added products like Murukku, noodles, and alcohol and is also used as bioplastics and coating materials. Therefore, drying and milling breadfruit into starch is one possible solution. In modern studies, some researcher uses many different methods to preserve or alter the properties of starch and flour via modification methods such as gamma-irradiation. This method is also called the cold-sterilization method and is non-toxic by nature that's why most of the researchers prefer that method to increase the shelf-life of the flour/starch.

Keywords: Starch; Additives; Gluten-free; Fatty acids; Bakery products

1. Introduction

Breadfruit (*Artocarpus altilis*) is a seedless, starchy tropical fruit native to the Pacific Islands (Worrell *et al.*, 2002). It is a *Moraceae* family evergreen tree that yields enormous starchy fruits. It is a highly productive and long-lived tree crop with significant potential to improve human and environmental health and well-being. Food products containing starch (amylum) are rich energy sources and are consumed in the form of a staple diet by all sections of society because of their accessibility and comparatively low cost. Starch, a tasteless, odorless white polysaccharide, may be present in the roots, tubers, and seeds of the plant kingdom (Takeda *et al.*, 1989; Han and Bemiller 2007; Chung and Liu 2009). The starch can be divided into three main groups which include: native starch (includes starch which after its extraction from its source is not subjected to any treatment, is white odorless, and colorless either powder or liquid), modified starch (includes that starch in which if any one or more of the original characteristics of the native starch has been altered or modified with any of the treatments like physical, chemical or enzymatic or combination of these as per the Good Manufacturing Practices), hydrolyzed starch (includes that starch in which the polymeric chains are broken into simple sugars like maltose) (Chung and Liu 2009; Chung *et al.,* 2010). Worldwide, the main sources of starch include maize (73 %), tapioca (11 %) wheat (9 %), potatoes (6 %), and others (2-3 %). Breadfruit is also a valuable food resource due to its high caloric content with a moderate glycemic index and a significant number of vitamins and minerals. It is consumed unripe and cooked as a starchy staple that rivals or outperforms other tropical crops such as sweet potato and cassava in terms of protein and carbohydrate content. The high carbohydrate content of the fruit makes it a potential staple that could be used to combat hunger and provide food security (Appiah *et al*., 2011). As an agroforestry component, the crop is recognized to aid in soil retention and carbon sequestration, and it is high in carbs (starch, resistant starch, and fiber), particularly amino acids, and some vitamins and minerals. As breadfruit grows in

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popularity among local communities throughout the world due to its numerous nutritional and environmental benefits, it is critical to comprehend key aspects of the fruit and its growing settings. It is a fast-growing deciduous tree, able to grow up to 20 meters in height and slightly over one meter in diameter (Sikarawr *et al*., 2014). It is known that breadfruit quickly ripens in just 1-3 days after harvesting and can hardly be stored for five days even at that it has to be stored in a cool place or under water to delay ripening (Ragone, 2006).

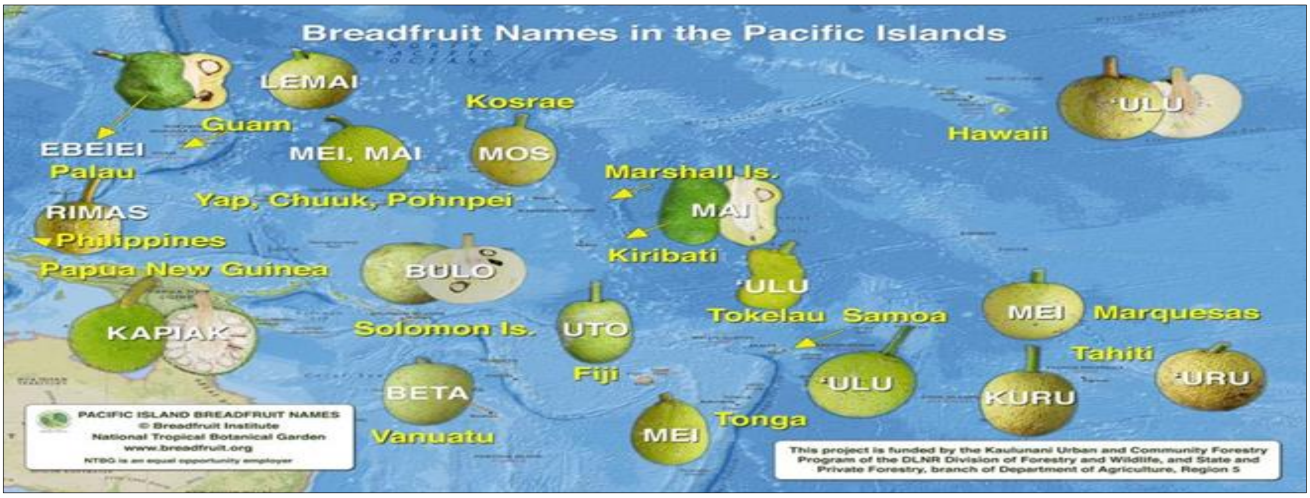

Figure 1 Local names for breadfruit in Pacific islands (*Source: agro.biodiver.se*)

Yield is known to vary vastly between the Caribbean, South Pacific, and other regions; one breadfruit tree is capable of producing anywhere from 200-400 kilograms of fruit annually yet sometimes as little as 50 kilograms (Lincoln *et al*., 2018; Ragone, 1997). Though productivity may vary this way, the tree is known to be long-lived, giving fruit for several years. Over the last three thousand years the fruit tree has traveled across the Pacific, becoming the staple food for many island nations and cultivated in tropical and subtropical regions (Ragone, 1997). As a result, attempts should be made to use it in the manufacturing of breadfruit starch and flour to create more varied goods with a longer shelf life. A valuable source of starch, breadfruit has a high carbohydrate content. Since ancient times, native starches have been utilized as raw materials to create a variety of goods. They are used in food because of their excellent gelling and thickening qualities. The three main species of breadfruit which is popular all over the country as shown in figure 2.

- *Atrocarpus altilis*: The growing region is the Pacific Island. It is a round, oval, oblong shape with yellow to green in color.
- *Artocarpus camansi*: The growing region is New Guinea. It is oblong and spiky with green to green-brown.
- *Artocarpus mariannenis*: The growing region is Palau and the Mariana Islands. It is small in size with a pebbly texture over the surface having a dark green color.

Atrocarpus altilis ***Artocarpus camansi*** ***Artocarpus mariannenis***

Figure 2 The different species of breadfruit

1.1. Production

Breadfruit trees are extremely productive, which is why they are considered a staple crop in the Pacific Islands. Breadfruit (*Artocarpuscommunis*, Frost, family *Moraceae*) is native to Malaysia, the Southern Pacific, and the Caribbean (P.J. *et al*., 1981). Yields differ by cultivar, age, tree health, and growth conditions. A typical-sized tree can produce approximately 100 fruits per year. Larger trees can produce 400 to 600 fruits per year, with claims of 700 to 900. Fruit weighs between 1 and 4 kg on average, but has been known to weigh up to 6 kg. Therefore, one mature breadfruit tree can produce from 400 to 2400 kg of breadfruit in a year. A fruit growing on the breadfruit tree (*Artocarpus altilis*) is the islands such as cassava and yam because of its verticality of production. The edible portion for seedless cultivars is approximately 70% of the fruit with skin, stem, and core removed Ragone, (1997). Breadfruit can be produced year-round due to cultivar diversity with different fruiting seasons. A tree of *Altilis* is enormous, evergreen, and stands to be around eighteen meters tall. The dorsal side of the thick, leathery leaves has a dark green hue that frequently gives the impression of being glossy. It produces a large number of monoecious flowers. There are two varieties of breadfruit: the seeded variety, which is typical in the western Pacific, and the seedless variety, which is ubiquitous worldwide. The dark, shiny, ovoid-shaped, irregularly compressed seeds have little to no endosperm, no dormant period, and can germinate right away; as a result, they cannot be dried or saved for planting. It could be cultivated from the hot humid and tropical lowland areas although rain plays an important role in the rate of growth of the fruit hence requires a rainfall of fairly equal distribution. The plant grows best in equatorial lowlands and is occasionally found in the highlands but the production and quality of the fruits decreases in cooler conditions. The soil conditions required for the proper growth of the plant are sandy or loamy soil with essentially good drainage. The plant grows best in hot temperatures of 21-32 ∘ C and requires a soil that is neutral to alkaline and with a pH of 6.1 to 7.4 (Zerega *et al*., 2005). The plant species known as breadfruit (*Artocarpus altilis*), which is widespread throughout Polynesia, the Pacific, and Southeast Asia, is found in Indonesia. Typically, breadfruit is harvested twice a year in August and January–February. Since ripe breadfruit decomposes quickly, it cannot be kept for extended periods.

1.2. Nutritional Value

Breadfruit is a good carbohydrate source supplying about as much energy as most staple crops (USDA 2016). A recent study showed the starches of ‘Local Yellow’, ‘Hope Marble’, ‘Creole Doyle’, ‘Common’, and ‘Ma‘afala’ cultivars were classified as very low amylose (2 to 9%) while ‘Local White’, ‘Kashee Bread’, ‘Jackson Macca’, ‘Timor/ St. Kitts’, ‘Cassava Murray’, and ‘Pii Piia’ were classified as low amylose (10 to 20%) (Broomes*et al*., 2015). Minerals found in breadfruit include: copper, magnesium, phosphorous, potassium, calcium, cobalt, iron, and manganese, but amounts are highly variable and associated with growth location and cultivar (Huang *et al*., 2000; Jones *et al*., 2013; Jones *et al*., 2010; Morton 1987; Ragone 1997, 2011; Ragone and Cavaletto 2006). Moreover, it can be substituted entirely or partially for wheat in a variety of products because it is gluten-free. Not to mention that depending on the maturity stage, the nutritional composition- that is, the levels of fat, protein, carbs, vitamins, and minerals. Researchers have looked into using carotenoids to treat vitamin A deficiency in undernourished areas of the world. Certain breadfruit varieties have been found to contain significant levels of carotenoids. Every necessary amino acid is present in breadfruit. Throughout history, breadfruit was considered a “poor man’s food” since it was associated with slavery, food shortages, and poverty Roberts-Nkrumah,(2007). Although it has a higher protein and mineral content than other cultivars and contains "a full spectrum of essential amino acids rich in valine, phenylalanine, isoleucine, and leucine," it is the most popular and advantageous.

2. Breadfruit Starch

Breadfruit is an excellent source of starch due to its high carbohydrate content. Since ancient times, native starches have been utilized as raw materials to make a variety of goods. They are used in food because of their good gelling and thickening qualities. They work well in food systems as regulators and texture stabilizers as well. Nonetheless, they only show a few industrial uses in their native state. They have high syneresis and retrogradation, but moderate resistance to thermal degradation and shear stress. Modifying starch can help alleviate these drawbacks. In the literature, chemical, physical, and enzymatic methods have been employed for the modification of starches (Betancur *et al*., 1997; Adebowale *et al*., 2002). The starch modification techniques are usually physical (e.g. gelatinization), chemical (e.g. etherification, esterification, crosslinking, and oxidation), and enzymatic (enzymatic hydrolysis). The physical modification processes of treatment and annealing, together known as hydrothermal treatment, involve adjusting the temperature and moisture content of starch throughout the processing process. By altering starch slurries in excess water at temperatures below gelatinization, annealing is accomplished. Chemical modifications, which include oxidation and acetylation, have also been employed as means of chemical modifications. Oxidizing agents such as sodium hypochlorite and hydrogen peroxide have been used extensively for starch oxidation (Forssell *et al*., 1999; Schmorak *et al*., 1962; Sathe and Salunke, 1981; Hebeish *et al*., 1989; Konoo *et al*., 1996). This chemical process also results in a reduction in the chain length of starch molecules as a result of oxidative degradation of linking glycosidic bonds (Kuakpetoon and

Wang, 2001). Oxidized starches have been established to be whiter in color and have restricted retrogradation or setting up on standing (Kuakpetoon and Wang, 2001). Acetylation is a form of starch esterification. As in all chemical reactions, acetylation depends upon factors such as reactant concentration, reaction time, pH, and the presence of a catalyst (Whistler and Daniel, 1990). In previous works, it has been established that acetylation retards starch retrogradation or recrystallization (Adebowale*et al*., 2002). Increases in paste clarity, gel clarity, solubility, and swelling power following acetylation have also been reported (Betancur *et al*., 1997).

Table 1 Proximate composition of breadfruit starch (*Source:* Mehta *et al*., 2023)

S.No.	Proximate	Breadfruit Starch
1.	Ash %	0.41
2.	Moisture %	11.43
3.	Total Carbohydrate (g)	82.83
4.	Fats (g)	0.60
5.	Protein (g)	1.71
6.	Amylose content	22.52
7.	Amylopectin	77.48

The starchy flesh of the breadfruit fruit is the most often consumed plant part, and it is prepared mostly by steaming, baking, frying, and boiling. It has soft tissue and high starch content, thus facilitating the starch extraction process (Adebayo *et al*., 2008). Several studies have reported that breadfruit contains 15 % to 20 % starch content. Because of its high carbohydrate content, it is an excellent source of starch. The soft tissues make it simple to extract starch and the lengthy history of local usage across many groups points to a strong safety profile and significant potential for acceptance by regulations in several nations. It has high syneresis and retrogradation, but moderate resistance to thermal degradation and shear stress. Modifying starch can help alleviate these drawbacks. However, the current usage, particularly in developing countries, is limited by the poor storage properties of fresh fruit. The amylopectin and amylose content of breadfruit starch is approximately 22.52 and 77.48 %, respectively, and has a moderately high breadfruit starch yield of 14.26 % (Akanbi *et al*., 2009). Because native breadfruit starch has low paste clarity and is easily retrograded, its use as a food addition or functional ingredient is restricted. It has been observed to have superior functionality over wheat, rice, and cassava flour in terms of viscosity, oil, and water binding capacity, and swelling power (Liu *et al*., 2015; Huang *et al*., 2019; Andrade *et al*., 2020). It is small, irregularly shaped (polyhedral, spherical, and elliptical) and ranges in size from 3.0 to 7.9 µm (Marta *et al*., 2019).

Table 2 Several studies on modified breadfruit starch

S.No.	Modification method	Objective	References
1.	Heat-moisture treatment (HMT), Microwave heating treatment (MHT), Annealing	Determine the physical characteristics of edible film.	Arifin, H.R., *et al*., (2020)
2.	Chemical: citrification, acetylation, phosphorylation, and Microwave-assisted chemical	To determine the degree of substitution, physicochemical properties, and in-vitro starch hydrolysis of the samples. the improvement of functional properties and the glycemic index of breadfruit starch.	Otemuyiwa, I.O., and Aina, A.F., (2020)
3.	Chemical: octenyl succinic anhydride (OSA)	To stabilize high-oil-load emulsions using high-pressure homogenization and low-frequency ultrasonication.	Anwar, S.H., *et al*., (2020)
4.	Heat-moisture treatment (HMT), Microwave heating treatment (MHT), Heat pressure treatment	Comparing the effect of four different thermal modifications on physicochemical and pasting properties of breadfruit (Artocarpus altilis) starch.	Marta, H., *et al*., (2019)

	(HPT), and Osmotic pressure treatment (OPT)		
5.	Enzyme- pullulanase, Microwave heating	Effect of debranching enzyme hydrolysis and microwave treatments on the resistant starch enrichment of breadfruit	Thanh Thi Le *et al.*, (2024)
6.	Acetylated, Oxidized, OX, and Acid-thin	To improve the functional properties of modified starch and maximize its potential for industrial applications.	Adewale, O. A., *et al.*, (2020)
7.	Oxidation, Acetylation, Heatmoisture treatment, and Annealing.	To improve functional properties for searching the novel starch sources which will be useful for both food and non-food industrial applications.	Adebowale, K.O., *et al.*, (2005)
8.	Hydrothermal treatment such as heat-moisture treatment	Showed increased thermal stability, higher pasting temperatures, and lower viscosities. Moreover, the treated samples had enhanced enzyme resistance (i.e., the increased SDS and RS contents),	Tan, X., *et al.*, (2017)

3. Utilization in Food Industry

In addition to being a component of our regular diet, starch is utilized widely in the paper, food, and pharmaceutical industries. Asia and Europe are the next largest producers of starch after the United States. There are various ways to consume breadfruit as shown in figure 3. Currently, the food industries (candy, beverages, and other processed foods) utilize 52% of starch, while the non-food industries (pharmaceuticals, paper, feed, and other uses) use 48% of starch (Saunders 2010; Al-Assaf *et al*., 2007). *A. altilis* will sometimes have large seeds within the flesh and, like that of the breadnut, a relative that has many seeds compared to the few of breadfruit, they can be roasted or boiled and eaten as well (Zerega *et al*., 2005). The fruit is eaten at all levels of maturity; juveniles may be pickled, slightly under-ripe fruit is preferable for the aforementioned preparation methods, and overripe fruit is compared to pudding in consistency and sweetness (Ragone, 2014; Sikarawr *et al*., 2014; Zerega *et al*., 2005). Other plant parts are functional as well. In Hawaiian culture and crafts, the wood of the tree could be used for carving small canoes and surfboards, and the sticky latex sap excreted by a wound was used in bird-catching techniques (McCoy *et al*., 2010). The dried male flower of the breadfruit can be used as an insect repellent when burned and is reported to be more effective than DEET (diethyltoluamide) (Avant, 2013). Some cultures use the leaves as a food wrapping for underground ovens or other cooking methods. The leaves have also been found to hold anti-inflammatory, anti-malarial, and atherosclerotic properties, as well as cytotoxicity, and improvement in renal function (Baba *et al*., 2016). Furthermore, the bark was found to be antimicrobial and anti-oxidative. Its heartwood and root cortex are even reported to be anti-cancer and offer aspects of UV protection (Baba *et al*., 2016).

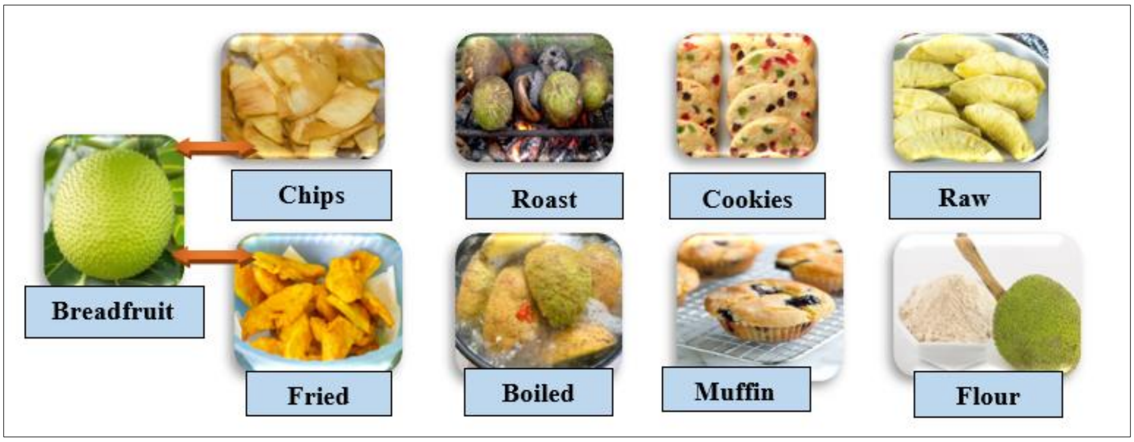

Figure 3 The various ways to use breadfruit

It has captured the attention of local people all over the world for its multifaceted utility as well as other reasons relating to human and environmental health and agricultural output. It is critical to comprehend how it can be used in food and how it can enhance consumer's health. Furthermore, goods enriched with breadfruit may assist in managing blood sugar levels due to the high amylose content of the starch and its ability to withstand digestion. Since ancient times, native starches have been utilized as raw materials to make a variety of goods. It is used in food because of its good gelling and thickening qualities. It works well in food systems as a regulator and texture stabilizer as well. Breadfruit is becoming more and more popular around the world as a very nutritious and productive crop, it could also be a viable substitute for other bioproducts like sorbitol and glycerol coatings. Nonetheless, they only show a few industrial uses in their native state. Starch isolation from amylaceous breadfruit as a food additive to control the stability, uniformity, and texture of various food applications and as a sweetener is becoming popular (waterschoot *et al*., 2015). As economic conditions improved and lifestyles changed, staple foods and diets changed as well. Importation of the more preferred wheat, rice, and other cereal and non-cereal grains to island nations replaced the original intent of breadfruit to combat mass starvation (Balick 2009; Roberts-Nkrumah 2007; Thorburn *et al*., 1987). Food Data Central has discussed the advantages of breadfruit. The appropriate ratios of Omega-3 and Omega-6 fatty acids are present in the body. These vital fatty acids support healthy brain and body development. In addition, fatty acids support bone health, reproduction, metabolism regulation, and the growth of skin and hair. Breadfruit also contains vitamin C, thiamin, riboflavin, niacin, iron, and phosphorus in addition to these health benefits. Another benefit of breadfruit flour over other starches is its reputation as a healthier substitute. It is a very adaptable product with the ability to support sustainability and climate resilience, particularly in low-latitude agricultural systems. For the food industries to develop and use breadfruit in food applications there is a need for greater awareness of this underutilized superfood.

Table 3 The different applications of breadfruit in the food industry**.** (*Source:* Mehta *et al*., 2023)

S.No.	Applications	Findings
1.	Carbohydrate staples	Pasta made using breadfruit flour, tapioca starch, salt, psyllium powder, xanthan gum, and coconut oil showed similar acceptability to the normal wheat pasta. Noodles substituted with 30 % breadfruit flour showed no significant differences in organoleptic quality. However, noodles made with 20 % breadfruit starch and 80 % wheat flour showed better proximate, functionality, and organoleptic attributes compared to 100 % wheat flour noodles. Full substitution of breadfruit flour negatively impacted the perception of slipperiness and glossiness.
2.	Meat analogs	Soy protein gels incorporated with 4 % extruded breadfruit flour did not affect processing yields and helped improve the color and texture of protein/starch food systems. Beef meat emulsions combined with 3% extruded breadfruit flour did not affect the redness value of cooked meat emulsions.
3.	Baked goods	Baked bread substituted with 10–15 % of breadfruit flour has acceptable sensory properties i.e., no significant differences in terms of crust, aroma, shape, chewiness, hardness, and springiness compared to the normal wheat flour bread. However, it is slightly lower in moisture and volume. Biscuit when substituted with 15 % breadfruit flour displayed a significant difference in sensory attributes compared to the whole-wheat flour biscuits. However, the biscuits were acceptable with 5 % soy protein and 10 % breadfruit flour. Cookies made with pure breadfruit flour had similar sensory properties to pure wheat flour cookies. Pressed cookies and pie crust (without filling) with pure breadfruit flour reported higher sensory acceptance ratings with better crunchiness. Cakes substituted with 10–30 % showed no significant effect on sensory attributes. However, full substitution of breadfruit flour had undesirable effects on texture. Muffins made with 15 % breadfruit flour and 5 % breadfruit starch displayed similar organoleptic properties.
4.	Beverages and dairy products	Probiotic beverages made with 7% breadfruit flour, 1 % inoculum, and 15 % sugar after fermentation at 30 ∘ C for 48 h produced the best-tasting beverage. Breadfruit milk alternatives and probiotic yogurt with soy milk and 4 % breadfruit flour with *Bifidobacterium bifidum* (ATCC 11883) and *Lactobacillus acidophilus* showed promising results

4. Health Benefits

To reduce joint and muscle pain due to the presence of prenylated phenolic compounds (like flavonoids, coumarins, xanthones, and stibenoids in breadfruit. Several studies showed that these compounds may be helpful in the treatment of rheumatic and muscular pain. Due to the inflammatory action of phenolic compounds, it helps to boost human health and is also beneficial to anti-diabetic activity, obesity prevention neuroprotection, etc. (Chang *et al*., 2021). Breadfruit is gluten-free which is more digestible than wheat flour therefore it is more beneficial to a person who is suffering from celiac disease or non-celiac gluten sensitivity. Some studies show that breadfruit flour and starch have advantages over wheat flour in water and oil binding capacity, swelling power, viscosity, and having a low glycemic index (Liu *et al*., 2015). Breadfruit also contains ethyl acetate and methanol which have antibacterial effects specifically on bacteria such as *Streptococcus mutans* found in the mouth and contribute to cavities and *Pseudomonas aeruginosa* can lead to lung infection so it can prevent bacterial infections (Ramalingum and Mahomoodally, 2014). It also helps to maintain healthy eyesight due to the presence of carotenoids. It does so by regulating muscular contraction in the heart and also controlling blood pressure and lowering levels of bad cholesterol because breadfruit contains dietary fibre which helps to bind the cholesterol and carry it out of the body. Due to the presence of omega-3 fatty acids, it can improve both male and female fertility. According to some researchers, they were found that omega-3 fatty acids improve PCOD in women and also enhance insulin resistance and prevent prostate and ovarian cancers.

5. Conclusion

Starch is one of the functional components gaining interest due to its unique functional features and potential physiological benefits. Diverse food digestibility rates after consumption are typically linked to diverse physiological functions. As a result, they have different effects on health, including decreasing the response of the body to glucose and insulin, acting as a hypo cholesterolemia inhibitor, and providing protection against colon cancer. Customers are starting to favor food products fortified with starch, and many are even willing to pay extra for products enhanced with starch to boost their intake of dietary fiber. According to the study's findings, breadfruit starch offers a variety of pasting, proximate, and functional qualities that make it useful in a wide range of situations where the qualities of other starches are acceptable. This evaluation encourages future exploration and improvement of breadfruit use globally. It has brought together the existing techniques for breadfruit harvesting, post-processing, and industrial food applications. It has been demonstrated that the physicochemical, functional, nutritional, and technological characteristics of breadfruit positively impact the manufacture of healthier food products employing breadfruit starch and flour. Future studies can concentrate on the breadfruit's flour and post-processing functionality, as well as more focused food uses.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding the publication of this paper.

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