Extension Publications

College of Tropical Agriculture and Human Resources
University of Hawai'i at Manoa

‘Ulu – Breadfruit

Postharvest Handling and Quality Maintenance Guidelines

At a Glance

Breadfruit (*Artocarpus altilis* (Parkins) Fosberg) is a starchy fruit produced on a long-lived perennial tree. It originated in the Borneo-New Guinea region and has been distributed throughout tropical climates. It is widely cultivated in household gardens, with limited commercial production. The Pacific and Caribbean islands are major production areas, with distributed plantings throughout the global tropics. It spoils rapidly, and this limits its commercial viability as a fresh product.

Figure 1. A young breadfruit orchard in Hawai‘i.

Scientific Name and Introduction

Breadfruit is in the family Moraceae that contains more than 1,100 species, including banyans, figs and mulberry; all have milky latex. Most Moraceae species are native to Asia, though only a few produce edible, starchy fruit that are frequently consumed as dietary staples, many of which are in the genus *Artocarpus*.

The most important *Artocarpus* species are the **breadfruit** (*A. altilis* (Parkins) Fosberg; syn *A. communis*, Foster; *A. incisus* L.; *Communis incisa*), its possible ancestor, the **breadnut** (*A. camansi* Blanco), the **jackfruit** (*A. heterophyllus* Lam.; syn *A. integer* (Thumb.) Merrill; *A. integrifolius*), its close relative, **chempedak** (*A. integrifolia* L.; syn. *A. polyphema* Persoon; *A. chempeden* (Lour.) Stokes), and **marang** (*A. odoratissimus* Blanco; syn. *A. carpus mutabilis* Becc.).

Breadfruit and breadnut originated in the Borneo-New Guinea region (Moluccas) and hundreds of varieties were spread by humans to the numerous islands of the Philippines, Melanesia, Micronesia, and Polynesia, where they became an important staple crop and component of Pacific agroforestry systems (Zerega et al., 2005; Ragone 2006, 2011; Williams et al., 2017) (Figure 1). Breadfruit's wild ancestor is thought to be the breadnut (*A. camansi* Blanco), which is indigenous to either the lowlands of New Guinea or possibly the Moluccas. Breadnut grows in flooded riverbanks, secondary and primary growth forest, freshwater swamps, and in cultivation. Dugdug (*A. mariannensis* Trécul), from western Micronesia, is another possible ancestor to breadnut and its hybrids.

From the 1600's onward, breadnut and breadfruit were distributed throughout the humid tropics, especially by the Portuguese, Spaniards, French, and English (Zerega et al., 2010; Williams et al., 2017). Today, breadfruit is principally grown as a subsistence crop in most areas of the world where it is cultivated. A history of its distribution and naming is given in this article.

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Botanical Description

Tropical breadfruit (*Artocarpus altilis* (Parkins) Fosb.) develops from the whole inflorescence, and the fruit size and shape vary, depending on cultivar. It is most often oblong and sometimes round, cylindrical, or irregular in shape (Figure 2). Diameter varies from 6 to 12 inches (15 to 30 cm) and weight from 1.1 to 6.6 pounds (0.5 to 3 kg), with fruit up to 12 pounds (5.4 kg) being recorded (Zerega et al., 2006; Ragone 1997; 2011). The fruit receptacle (core) is surrounded by a pale yellow-white edible pulp that is covered by a thin, yellow-green, reticulated skin.

Most varieties are seedless or nearly seedless, with a few cultivars containing numerous brown seeds of 0.4 to 0.8 inch (1 to 2 cm) in length (Ragone, 1997; Zerega et al., 2005). Examples of seeded breadfruit include the altilis/mariannensis hybrids in Hawai'i that contain numerous seeds, or the Ma'afala variety that often contains 1 to 4 seeds (Roberts-Nkrumah, 2014). Breadnut (*A. camansi*) is a seeded species closely related to *A. altilis* (Zerega et al., 2005, 2006; Aurore et al., 2014; Ferrer-Gallego and Boisset, 2018) and contains edible seeds about 1 inch (2.5 cm) long, with 10 to 150 in a fruit.

Figure 2. Diversity of breadfruit form. Cylindrical and oblong fruit varieties (top) with seeded and seedless varieties (bottom).

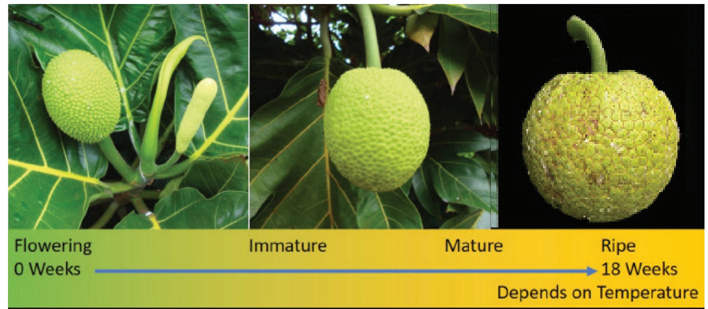

Figure 3. Change in color and form during growth and development. Mature and ripe fruit have similar color and shape. Transition from mature to ripe is indicated by softening of the flesh. *Photo courtesy of Hawai'i 'Ulu Producers' Cooperative (modified).*

Annual yields vary from as low as 50 to as many as 700 fruit per tree, with estimated yield of 7 to 22 U.S. tons per acre (16 to 50 metric tons per hectare), based on a density of 40 trees/acre (100 trees/ha). Canopy volume is a good measure of the potential yield.

Quality Characteristics and Criteria

The fruit reaches maturity 15 to 21 weeks after the female inflorescence is first detected in the terminal leaf sheath. During fruit development, the fruit undergoes two stages of growth. The first phase is the major period of diameter increase, and the second phase is associated with starch accumulation and weight gain (Figure 3).

Since breadfruit is used at various stages of maturity, quality criteria vary with its intended use. Baby fruit are harvested immature for use as a vegetable starch, while mature, unripe fruit are used as a starchy staple. As mature fruit ripen, they soften and become sweet and are used for various culinary purposes, including the preparation of desserts. The major market preference is for mature, unripe fruit with firm flesh having uniform shape; free from disease, decay, sunscald, cracks, bruises, and mechanical damage.

As the fruit approaches maturity, the flesh and skin will often exude a white viscous latex. The latex discolors to greenish or reddish-brown upon exposure to air. Dry, hardened drops of latex on the skin are an indication of fruit maturity in some varieties.

Harvest and Horticultural Maturity Indexes

Various maturity indexes are used. Indexes include the presence of small drops of latex on the rind, firm flesh, flattening texture on surface segments, and a change in skin color from bright green to dull yellow-green, with darkening fissures between segments (Figure 3) (Elevitch et al., 2014; Worrell, 1998).

Care should be taken during harvest to avoid mechanical injury and latex staining. Clippers and a pole harvester are useful for harvesting, and the stem should be clipped near

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History and Naming

Starting circa 3,200 years ago, Lapita seafarers began to migrate eastward from Papua New Guinea into the islands of Oceania, carrying with them staple crops, including breadfruit. Their migration extended throughout Oceania, including the Solomon Islands, Santa Cruz Islands, and Vanuatu, where the greatest diversity of seeded and few-seeded breadfruit cultivars is found, suggesting that extensive cultivation and selection occurred in these regions (Ragone, 1997).

Over millennia, Pacific Islanders have selected and named hundreds of traditional breadfruit cultivars, distinguished based on the fruiting season, fruit shape, color and texture of the flesh and skin, presence of seeds, flavor, cooking qualities, leaf shape (particularly the degree of dissection), tree form, and horticultural needs (Ragone, 1997). For example, there are 132 cultivars and 539 distinct names documented from Vanuatu alone. Other ethnographic research has documented 130 names and 78 cultivars from Pohnpei, 70 cultivars from Fiji, more than 30 cultivars from Tahiti, and more than 40 cultivars from Samoa (Ragone, 1997; Lincoln et al., 2018).

While breadfruit has been a staple crop of Pacific Islanders for many years, the species was first described to the Western world by the Portuguese navigator Pedro Fernandes de Quiros (1563-1614). Quiros described breadfruit while in service of Spain, following his visit to the Marquesas Islands in 1595, while accompanying the Spanish explorer Álvaro de Mendaña y Neira. This was Mendaña's (1542-1595) second voyage from Peru across the Pacific, during which he died and Quiros took command and is credited with saving the only remaining ship.

The term *breadfruit* appears to have been coined by William Dampier, an English explorer, pirate and navigator (1651-1715), who first saw it on Guam in 1686. He wrote that "the breadfruit (as we call it) grows on a large tree, as big as our largest apple trees ... there is neither seed nor stone in the inside but all is of a pure substance like bread." Dampier was particularly enthusiastic about breadfruit's use and potential, crediting it for saving the lives of his starving, scurvy-ridden crew.

In the second half of the 18th century, interest in breadfruit grew among European powers as a potential food for slaves in their Caribbean colonies. During this period, a debate arose regarding breadfruit's Latin name, and a memorable mutiny occurred which led 19 seamen to making an open sea voyage to Timor (Dutch East Indies) on a 23-ft longboat.

During Captain James Cook's first voyage (1768-1771, "HMS *Endeavor*") to the Pacific, the naturalist Joseph Banks described breadfruit growing notably in Tahiti (Society Islands). Bank's Swedish botanist Daniel Solander named it *Sitodium altile*, and a specimen was drawn by botanical artist Sydney Parkinson. After Parkinson's death on the return journey (1771), Parkinson's brother published the drawing with Solander's Latin name for breadfruit (1773).

However, Solander died in 1782 and had not published his work with Banks from the huge collection of specimens made on the voyage.

On the advice of the Royal Society, the British Admiralty sent Cook on a second voyage (1772-1775; HMS *Resolution*) to find the purported "Southern Continent" (Terra Australis). Banks, at the last moment, withdrew from this voyage and was replaced by Johann Forster and his son Georg as the naturalists. The two kept detailed records and published their findings in 1777 and 1778, naming breadfruit as Artocarpus; coming from the Greek words *artos* (bread) and *karpos* (fruit). This naming led to a complicated and drawn-out taxonomic history (Zerega et al., 2005).

Some of the more common but no longer accepted names include *A. communis* and *A. incises,* still seen in the literature. The previous genus name *Sitodium altile* was not regarded by all taxonomists as validly published, so *Artocarpus* is the currently accepted genus name (Ferrer-Gallego & Boisset, 2017). Over the past century, the trend has greatly favored *A. altilis* (Lincoln et al., 2018). The proper name for breadfruit is *Artocarpus altilis* (Parkinson) Fosberg.

Apart from the naming debate, breadfruit is known as a part of the famous, 18th-century mutiny on the ship *Bounty*. Captain Cook, in his journal from his first voyage, and Joseph Banks indicated that breadfruit might be a useful food in the West Indies plantations. On Banks' suggestion, the Admiralty sent Commanding Lieutenant William Bligh on a voyage to Tahiti in 1787-1789 on the "HM Armed Vessel *Bounty*." Bligh, as Chief Navigator, had sailed with Cook on his third and final voyage when Cook was killed in Hawai'i.

The *Bounty*, a modified commercial vessel, was only a cutter (~200 tons) with no officers, other than Bligh, and a crew of 46 men — two of whom died before arriving in Tahiti. There were no Royal Marines on board, whose customary role was to protect the officers and maintain discipline in the crew. Bligh's orders from the Admiralty were to collect breadfruit seedlings and transport them to the West Indies. The intent was to introduce the crop to the West Indies as potential food for the slaves on sugar plantations (Spary & White, 2004). Bligh and his men spent five months in Tahiti collecting more than 1,000 seedlings.

The return voyage ended with bloodless mutiny about three weeks after leaving Tahiti when they had arrived at Tonga. The mutiny was led by Master's Mate Fletcher Christian, who had been known to Bligh before this voyage and was appointed by Bligh as Master's Mate. Bligh was set adrift in a 23-foot longboat with 18 loyal seamen, a sextant, a compass, a pocket watch, four cutlasses, and food and water for about a week, but no charts. They sailed more than 3,600 miles to Timor (Dutch East Indies) in 47 days. Twenty-five seamen remained onboard the *Bounty*, 18 who sided with Fletcher and seven loyal to Bligh but could not fit on the 23-ft. longboat.

Fourteen of the mutineers were arrested in 1791 in Tahiti, with Christian's group having sailed and settled on Pitcairn Island. This group was found in 1808 with only one mutineer still alive; the others being killed by each other or their Tahitian companions.

Contrary to popular belief, Bligh was relatively lenient compared to other British Officers and not as portrayed in some movies.

Before Bligh's second voyage of 1793, when breadfruit was taken to St. Vincent and Jamaica, the Spaniards had introduced breadfruit to Mexico and Central America (Parrota, 1994). The French had introduced breadnut from the Philippines and breadfruit to their Caribbean colonies in Martinique, Guadeloupe, and Cayenne from 1780 onward (Zerega et al., 2006).

In all cases, the slaves apparently did not eat the fruit but fed it to their animals.

the fruit. Harvested fruit produces copious latex, especially from the cut peduncle and injuries on the fruit. To avoid latex stain, latex should be allowed to drain from the fruit, with the cut stem facing down and the fruit washed with water. Harvested fruit should be kept out of the sun, and if not field packed, should be transported to the packing area in shallow bins to avoid compression injury.

Grades, Sizes and Packaging

There are no U.S. or international grade standards. Fruit are graded according to weight or diameter, often based on count per cardboard carton weighing 11 to 40 lbs (6 to 18 kg), with 6 kg cartons being used in Australia (Goebel, 2007). The Hawai'i 'Ulu Producers' Cooperative grades on diameter, with Grade A being greater than 5 inches (12.7 cm) and Grade B being less than 5 inches. Graded fruit must be delivered to the co-op within 24 hours of harvest.

Fruit are sold on a weight basis, and packed in telescoping two-piece cardboard cartons or one-piece cartons, with dividers to minimize fruit movement and rubbing that leads to abrasion injury. Misshaped, diseased, and mechanically injured fruit are culled and not packed, though they can be used for processed products (Figure 4).

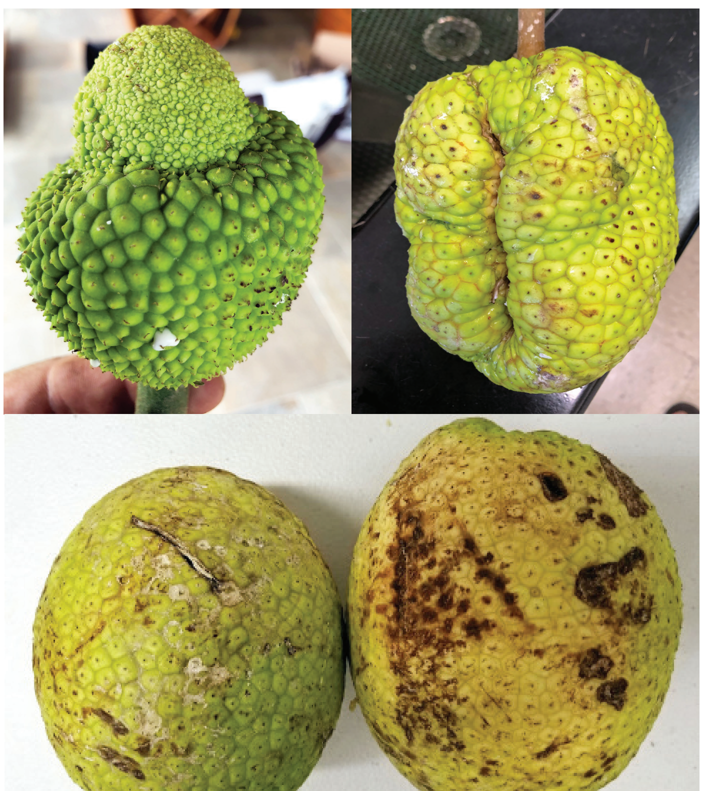

Figure 4: Misshaped fruit (top) and fruit with impact and puncture damage (bottom). *Photo courtesy of Hawai'i 'Ulu Producers' Cooperative (bottom photo)*

Pre-cooling Conditions

Breadfruit should be cooled and transported as soon as possible after harvest. The fruit are cooled commonly by using cool air or hydrocooling to a temperature of 55 to 63 °F (13 to 17 °C). The Breadfruit Institute and the Hawai'i 'Ulu Producers' Cooperative suggest hydrocooling by soaking in water at room temperature or an ice bath for 10 to 15 minutes soon after harvest (Elevitch et al., 2014; Hawai'i 'Ulu Producers' Cooperative, 2020).

Monitoring of fruit core temperatures demonstrates a reduction in core temperature from 77 °F (25 °C) to 64 °F (17.5 °C) after a one-hour ice bath at 33 °F (0.5 °C). It takes about 3 hours to reduce the core temperature to 41 °F (5 °C) and 5 hours to reduce the core temperature to 33 °F (1 °C). Under non-circulating refrigeration 50 °F (10 °C), core fuit temperature dropped from 77 °F (25 ° C) to 68 °F (20°C) after 1 hour (30% reduction), to 59 °F (15°C) after two hours (60% reduction), and 56 °F (13°C) after three hours (80% reduction).

Chilling Sensitivity and Optimum Storage Conditions

Sensitivity to chilling injury may vary with variety. Symptoms are a brown scald-like discoloration of the skin, failure to fully soften, poor flavor development, and increased decay. Mild chilling injury occurs after about 10 days at temperatures as high as 63 °F (17 °C), while severe chilling injury develops within a few days at temperatures lower than 54 °F (12 °C) (Maharaj & Sankat, 1990; Molimau-Samasoni et al., 2020; Thompson et al., 1974; Worrell et al., 2002). Fruit should be stored at 54 to 64 °F (12 to 18 °C) and at 90 to 95% RH for a maximum postharvest life of about 10 days.

Modified & Controlled Atmospheres (CA) Considerations

Film wrapping delays the softening and skin discoloration of breadfruit stored at 55 to 61 °F (13 to 16 °C) (Samsoondar et al., 2000; Thompson et al., 1974). In film-wrapped fruit, the oxygen levels inside the wrapped fruit quickly drop to less than 5%, while carbon dioxide rises to 10 to 30%. Such a modified atmosphere delays fruit softening, but can also lead to fermentation and uneven ripening (Thompson et al., 1974; Worrell et al., 2002; Worrell & Carrington, 1997). Controlled atmosphere studies indicate that at 54 °F (12 °C), the best storage atmosphere is 2 to 5% oxygen and 5% carbon dioxide for up to 3 weeks (Ramlochan, 1991, and as cited in Worrell & Carrington, 1997).

Retail Outlet Display Considerations

Breadfruit should be displayed at 61 to 64 °F (16 to 18 °C). Misting displayed fruit is not recommended.

Ethylene Production and Sensitivity

Breadfruit is a so-called climacteric fruit that shows rapid changes during ripening such as that occurring in banana. Naturally produced ethylene is involved in this ripening, and in breadfruit, ethylene production rate peaks at 1.0 to 1.5 μl·kg^{-1}·hr^{-1} for early mature fruit and 0.7 to 1.2 μl·kg^{-1} ·hr^{-1} for late mature fruit (Worrell et al., 1998; Worrell & Carrington, 1997). Exposure to external ethylene sources induces rapid ripening. Mechanical injury will also trigger increased ethylene production (wound ethylene) that causes injured fruit to ripen more quickly and can also cause ripening of adjacent fruit.

Respiration Rates

As a climacteric fruit, the respiration rate also increases during ripening, and this respiration generates heat that should be removed by cooling. The heat production can be calculated from the respiration rate by multiplying the ml CO_2 kg^{-1}·hr^{-1} by 440 to get Btu/ton/day, or by 122 to get kcal/metric ton/day. The pre-climacteric mature green respiration rate is 34 ml CO_2 kg^{-1}·hr^{-1} (Biale & Barcus, 1970). At 77 °F (25 °C), the climacteric peak rate of respiration is 300 to 350 ml CO_2 kg^{-1}·hr^{-1} (slightly immature) and 150 to 200 ml CO_2 kg^{-1}·hr^{-1} (mature) (Worrell et al., 1998). At 55 °F (13 °C), the climacteric is decreased, peaking at 275 to 300 ml CO_2 kg^{-1}·hr^{-1} (slightly immature) and 45 to 60 ml CO_2 kg^{-1}·hr^{-1} (mature) (Worrell & Carrington, 1997).

Physiological Disorders

Mechanical injury is a major cause of postharvest losses, as it leads to rapid deterioration, possibly due to wound-induced ethylene production, causing premature and more rapid ripening. No other major disorders have been reported (Worrell & Carrington, 1997).

Postharvest Pathology

Fruit rot due to *Phytophthora palmivora* and pink disease (*Erythricium salmonicolor*) have been reported. *Rhizopus* spp. may cause soft rot after harvest, especially if moisture condenses on fruit after removal from cold storage (Sangchote & Wright, 2003; Trujillo, 1971). Additionally, *Dothiorella sp.* causes a soft rot (Wall, 1989). Anthracnose caused by *Glomerella cingulate* and *G. acutata* (asexual form *Colletotrichum gloeosporioides*) can lead to fruit drop and postharvest losses (Sangchote & Wright, 2003). Blemishes from *Colletotrichum* spp. are unsightly, as well as problematic for processing using industrial peelers (Figure 5).

Quarantine Issues

Breadfruit is regarded as a fruit fly host and has been successfully treated by vapor heat treatment and irradiation. U.S. importation and interstate shipment regulations require an irradiation treatment and inspection for pests. The recommended irradiation minimum dose for fruit flies is 150 Gy (Follett & Weinert, 2012).

Figure 5: Various postharvest pathological damages to breadfruit. Left, various stages of fruit rot caused by fungal pathogens. Top right, fruit rot associated with Phytophthora. Bottom right, unsightly but superficial damage likely caused by the fungal pathogen Glomerella.

Suitability as Fresh-cut Product

Minimally processed fruit is marketed frozen (Beyer, 2007; Passam et al., 1981; Roberts-Nkrumah, 2007). Refrigerated storage of minimally processed fruit in polyethylene pouches has been suggested (Roopa et al., 2015). As a low-acid fruit, care is needed to avoid bacterial growth in these products. In particular, processed fruit should not be stored in an oxygen-free environment (e.g., should not be vacuum sealed) to lower the risk of botulism, as well as potential unpleasant odors and flavours.

Utilization

Fruit can be cooked, dried, processed for storage, or transformed into a value-added product. To cook, the breadfruit is roasted, steamed, boiled, fried, or used in bread making. Traditionally, breadfruit is stored fermented (Barrau, 1957; Whitney, 1988). Slices can be dried or stored in brine. Fried chips are sold commercially (Bates et al., 1991; Ragone, 2011; Roberts-Nkrumah, 2007). Flour made from dried breadfruit can be used as a substitute

Figure 6: Prepared breadfruit dishes. Clockwise from top left: baby breadfruit pickles, breadfruit-based chocolate mousse, breadfruit poke, cinnamon rolls made with ripe breadfruit, and breadfruit parfaits.
Photos courtesy of Hawai'i 'Ulu Producers' Cooperative.

for wheat flour (Arinola & Akingbala, 2018; Olaoye, 2007; Roberts-Nkrumah, 2007). The sweet, ripe fruit is prepared as a dessert and used to make pies, cakes, and other sweets (Figure 6).

Leaves and fallen fruit are fed to animals. The collected latex is used medicinally and as a caulk, glue, and chewing gum.

Dietary Nutritional Value

The nutritional composition of breadfruit varies based on cultivar, environment, maturity, storage and preparation. Fruit size can vary widely depending upon cultivar and growing conditions. The edible flesh portion is approximately 79 to 87% of the fruit weight, and the flesh is 59 to 84% water (Table 1).

Based on the Nutrition Labeling and Education Act (NLEA) guidelines, breadfruit is carbohydrate-rich gluten-free energy source that is low in fat, saturated fat, and sodium. As with all fruits and vegetables, breadfruit is cholesterol free. Breadfruit is a good source of vitamin C, thiamin (vitamin B1), and copper. A "good source" is defined by the FDA as a portion of food containing at least 10% of the Daily Value for a standardized reference amount consumed. For breadfruit that standardized amount is about 4 ounces (110 grams) as for other starchy foods such as potatoes. Baking or steaming results in about 30 percent reduction of Vitamin C and a 15% reduction of thiamin. Vitamin C is also lost during storage.

The glycemic index is often used to quantify how foods affect blood glucose. The published glycemic index for breadfruit varies widely from low of 47 to high of 72. The reason for this wide range is unclear and further research is needed. Although breadfruit flour contains relatively low protein, it can be used in bread products when mixed with higher protein gluten-free starches or nut flours.

Table 1. Nutritional analysis of mature raw uncooked Hawaiian 'Ulu Breadfruit per 100 gram fresh weight of the edible portion. Values are compiled from studies (1917 to 2000) analyzing Hawaiian breadfruit. Individual study data presented in Meilleur et al (in press).

Nutrient (unit)	Average	Range	10% Daily Value*
Water (g)	68.6	58.2 - 79.4	-
Protein (g)	1.21	0.8 - 1.58	5
Total fat (g)	0.25	0.12 - 0.31	-
Total CHO (g)	29.02	18.3 - 39.1	-
Dietary fiber (g)	1.27	0.8 - 1.9	2.8
Energy (kcal)	112	68 - 148	-
Energy (kjoule)	469	285 - 619	-
Minerals			
Ash (g)	1.01	0.72 - 1.23	-
Ca (mg)	23	17 - 36	130
P (mg)	42	26 - 63	125
Mg (mg)	33	25 - 45	42
Na (mg)	7	2-13	-
K (mg)	399	224 - 551	470
Cu (mg)*	0.08	0.06 - 0.1	0.09
Fe (mg)	0.41	0.26 - 0.54	1.8
Vitamins			
Vit A RE (ug)	4	4	90
A-IU	41	40 - 41	
B carotene (ug)	0	0 - 0	
Vit C (mg)*	**19.8**	**13.2 - 29**	**9**
Thiamine B1 (mg)*	**0.18**	**0.1 - 0.31**	**0.12**
Riboflavin B2 (mg)	0.07	0.03 - 0.11	0.13
Niacin B3 (mg)	1.32	0.84 - 1.80	1.6
B6 (mg)	0.1	0.1 - 0.1	0.17

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