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ORIGINAL ARTICLE

Breadfruit (*Artocarpus altilis*): a source of high-quality protein for food security and novel food products

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Abstract Protein deficiency has been observed as a leading cause of malnutrition and child death in the tropics. The current study evaluated the protein quality of 49 important breadfruit cultivars (41 *Artocarpus altilis* and 8 hybrids of *A. altilis* × *A. mariannensis*). While significant differences were found between cultivars, all varieties contained a full spectrum of the essential amino acids and are especially rich in phenylalanine, leucine, isoleucine, and valine. The cultivar Ma'afala contained significantly higher total essential amino acid content than other varieties and higher-quality protein than staples such as corn, wheat, rice, soybean, potato, and pea.

Keywords Breadfruit · *Artocarpus altilis* · Protein quality · Essential amino acids

Introduction

The fundamental requirement for maintaining good health is access to sufficient food of adequate quality (WHO 2007), but adequate food is limited in many parts of the world and climate change seems likely to disrupt food supplies by 2050 (Porter and Xie 2014). Breadfruit (*Artocarpus altilis*, Moraceae) is a tropical staple crop used for more than 3,000 years by Pacific Islanders for food security (Ragone 1997). In 1769, Joseph Banks traveling with Captain James Cook to Tahiti recognized the potential of breadfruit and observed the following:

> "In the article of food these happy people may almost be said to be exempt from the curse of our forefather; scarcely can it be said that they earn their bread with the sweat of their brow when their cheifest sustenance Bread fruit is procurd with no more trouble than that of climbing a tree and pulling it down. Not that the trees grow here spontaneously but if a man should in the course of his life time plant 10 such trees, which if well done might take the labor of an hour or thereabouts, he would as compleatly fulfull his duty to his own as well as future generations as we natives of less temperate climates can do by toiling in the cold of winter to sew and in the heat of summer to reap the annual produce of our soil, which when once gatherd into the barn must be again resowd and re-reapd as often as the Colds of winter or the heats of Summer return to make such labor disagreable."
> (The Endeavour Journal of Joseph Banks, August 14th 1769)

A single breadfruit tree produces 250–400 kg of fresh fruit (Liu et al. 2014) that can be prepared in a variety of ways such as boiling, baking, dehydrating to make a flour, pickling, fermenting, and freezing (Jones et al. 2011a; Ragone 2011). Several hundred cultivars have been selected over the millennia by the indigenous peoples in the Pacific Islands (Jones et al. 2010, 2013a; Ragone 1997;

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Ragone and Raynor 2009) including cultivars high in protein, minerals, and vitamins (Jones et al. 2011b, 2013b). In comparison to other tropical crops, breadfruit contains an average of 3.9 % protein on a dry weight basis, which is 1.15 % higher than cassava, 1.1 % higher than banana, and 0.3 % higher than sweet potato (Jones et al. 2011b). One breadfruit cultivar, Ma'afala, has an average of 7.6 % protein, which is comparable to rice (Jones et al. 2011b). Previous work has shown that breadfruit contains all of the essential amino acids (Golden and Williams 2001; Morton 1987). Leucine (0.61 ± 0.01 g/100 g) and lysine (0.8 ± 0.22 g/100 g) made up to 30 % of the total amino acid content during the ripe developmental stage of breadfruit (Golden and Williams 2001). However, this research was based on only one (Golden and Williams 2001) or few (Morton 1987) cultivars and protein quality was not assessed. Protein quality is determined by the amino acid composition, specifically the essential amino acid content (Golden and Williams 2001). Essential amino acids are indispensable, but cannot be synthesised by the human body including lysine (lys), leucine (leu), threonine (thr), tryptophan (trp), histidine (his), isoleucine (ile), valine (val), phenylalanine (phe), tyrosine (tyr), methionine (met), and cysteine (cys) (WHO 2007). Since protein content varied widely depending on the cultivar (Jones et al. 2011b), an assessment of the variability of proteins between cultivars and of the protein quality of individual cultivars was warranted.

The current work was conducted to evaluate and describe the variation in the amino acid composition of a genetically diverse group of breadfruits growing in a single location and to elucidate how the essential amino acids vary between cultivars. Information obtained from this study will serve as a reference for breadfruit nutritional evaluation in comparison with grain staples and non-grain staples. Understanding the nutritional value of breadfruit is important to increasing acceptance and utilization of breadfruit for food security and novel food products.

Methods and materials

Breadfruit (*Artocarpus* spp.) germplasm repository at the National Tropical Botanical Garden (NTBG)

The world's largest and most diverse collection of breadfruit (*Artocarpus altilis*, *Artocarpus camansi*, *A. mariannensis*, and *A. altilis* × *A. mariannensis* hybrids) is curated at the Breadfruit Institute of the National Tropical Botanical Garden in Hawaii. The breadfruit germplasm collection, comprising 285 well-documented trees, has been described in detail previously (Jones et al. 2011b, 2013a, b). Briefly, the trees were collected from 34 Pacific Islands, the Philippines, Indonesia, and the Seychelles between 1978 and 2004 and conserved in a single site (4.86 ha) at an elevation of about 15 m at Kahanu Garden in Maui (20°47′57.07″N, 156°02′18.42″W). Kahanu Garden has a mean maximum temperature of 27.1 °C, a mean minimum temperature of 19.7 °C and a mean rainfall of 2051 mm (Jones et al. 2011b, 2013b). The soil is classified as Hana very stone silt clay loam soil (http://websoilsurvey.nrcs.usda.gov), which generally drains well and is slightly acidic with 8 % organic matter in the surface layer. Soil analysis of the site has been reported in detail previously (Jones et al. 2011b, 2013b). The trees received minimal fertilizer and pruning prior to 2011. The fruit production from the mature trees is at regular intervals as shown in previous studies (Jones et al. 2010, 2013b).

Breadfruit sample collection and preparation

A detailed description of the sample collection and experimental design has been published previously (Jones et al. 2011b, 2013b). Three mature breadfruits were collected from 49 breadfruit cultivars including 41 *Artocarpus altilis* and 8 hybrids (*A. altilis* × *A. mariannensis*) (Table 1). Since different breadfruit cultivars produce fruit in different months, the collection process lasted several months during November 2008 to December 2010 (Jones et al. 2010, 2013b). After removing the stem, fruits were inverted for about 1 h to drain latex. The skin was removed with a good-quality household vegetable peeler, the fruit was cut into quarters, and the core was removed. The edible portion of the fruit was cut into 2 cm slices, frozen, and shipped to the University of British Columbia Okanagan. All the breadfruit samples were stored at −86 °C before analysis.

Reagents

AccQ-Fluor kits, comprising borate buffer (AccQ-Fluor 1), reagent powder (AccQ-Fluor 2A) and reagent diluent (AccQ-Fluor 2B), and AccQ Tag were purchased from Waters (Milford, USA). Both reagents were prepared and stored according to the Instruction Manual from Waters (Waters AccQ Tag Chemistry Package Instruction Manual, Revision 1). Acetonitrile (HPLC grade) and HCl (1 N) were purchased from Fisher Chemical (Fair Lawn, New Jersey). KOH and HCl (37 %) were obtained from Sigma–Aldrich (Louis, USA). Norleucine (Sigma Chemical Company, Louis, USA) stock solution (2.5 mM) was made in 0.1 N HCl. The mixed amino acid standard solution (each at 2.5 ± 0.1 μmol/mL, except cystine at 1.25 ± 0.1 μmol/mL) was Pierce™ Amino Acid Standard H (comprising 18 amino acids) from Thermo Scientific (Rockford, USA). Water used in this study was purified with Direct-Q® 3 Water purification System (EMD Millipore Corporation, Billerica, USA).

Table 1 Cultivars of breadfruit (*Artocarpus altilis* and *A. altilis* × *A. mariannensis*) analyzed for amino acid content and protein quality

Grid	NTBG accession	Cultivar	Plant date	Species	Island of origin
55	770517001	Ma'afala	01/01/1975	*Artocarpus altilis*	Samoa
51	780338001	Tapehaa	03/01/1975	*Artocarpus altilis*	Society Islands
12	790488001	Toneno	11/09/1975	*Artocarpus altilis*	Society Islands
13	790491001	Tuutou	11/09/1975	*Artocarpus altilis*	Society Islands
32	780325001	Afara	13/09/1975	*Artocarpus altilis*	Society Islands
30	780333001	Ahani	15/09/1975	*Artocarpus altilis*	Society Islands
36	800269001	Mahani	15/09/1975	*Artocarpus altilis*	Society Islands
16	790485001	Puou	16/09/1975	*Artocarpus altilis*	Society Islands
9	790492001	Porohiti	17/09/1975	*Artocarpus altilis*	Society Islands
27	790487001	Huehue	17/09/1975	*Artocarpus altilis*	Society Islands
40	780330002	Fafai	17/09/1975	*Artocarpus altilis*	Society Islands
20	790486001	Roihaa	20/09/1975	*Artocarpus altilis*	Society Islands
43	810290001	White	05/01/1978	*Artocarpus altilis*	Seychelles
49	790497002	Meinuwe	05/01/1978	*Artocarpus altilis*	Micronesia
38	810289002	Yellow	06/01/1978	*Artocarpus altilis*	Seychelles
35	890258001	Ulu fiti	08/02/1985	*Artocarpus altilis*	Samoa
Y1	890154001	Hamoa (Maopo)	11/02/1985	*Artocarpus altilis*	Society Islands
V4	890159002	Meriaur	26/07/1985	*Artocarpus altilis*	Palau
V6	890470001	Furau	26/07/1985	*Artocarpus altilis*	Samoa
T6	890460001	Puaa	29/07/1985	*Artocarpus altilis*	Society Islands
V3	890463001	Patara	29/07/1985	*Artocarpus altilis*	Society Islands
W3	890471001	Uto dina	29/07/1985	*Artocarpus altilis*	Samoa
P7	890464001	Ouo	30/07/1985	*Artocarpus altilis*	Society Islands
R4	890477001	Uto samoa	01/08/1985	*Artocarpus altilis*	Samoa
S7	890152002	Puurea	01/08/1985	*Artocarpus altilis*	Society Islands
B8	900242001	Mei kopumoko	26/03/1986	*Artocarpus altilis*	Marquesas Islands
K7	900260001	Samoan	26/03/1986	*Artocarpus altilis*	Samoa
E5	900266002	Meiarephe	29/03/1986	*Artocarpus altilis*	Micronesia
F6	900241001	Mei aueka	29/03/1986	*Artocarpus altilis*	Marquesas Islands
I6	900247001	Tuutou ooa	29/03/1986	*Artocarpus altilis*	Society Islands
A8	900264001	Uto ni viti	30/03/1986	*Artocarpus altilis*	Fiji
B6	900237001	Mei puou	01/04/1986	*Artocarpus altilis*	Marquesas Islands
H7	900246001	Tuutou auena	01/04/1986	*Artocarpus altilis*	Society Islands
I8	900249002	Anahonaho	01/04/1986	*Artocarpus altilis*	Society Islands
M6	900262001	Manua	01/04/1986	*Artocarpus altilis*	Samoa
P8	880690001	Kea	01/04/1986	*Artocarpus altilis*	Tonga
A7	900232001	Atu	02/04/1986	*Artocarpus altilis*	Cook Islands
D9	910271001	Meiuhpw	12/07/1987	*Artocarpus altilis*	Micronesia
39	780327001	Otea	11/09/1975	*Artocarpus altilis*	Society Islands
47	780291001	Havana pataitai	17/09/1975	*Artocarpus altilis*	Society Islands
8	900233002	Pulupulu	28/03/1986	*Artocarpus altilis*	Samoa
1	790489001	Piipiia	13/09/1975	*Artocarpus altilis* × *A. mariannensis*	Society Islands
Z9	790494001	Meinpadahk	05/01/1978	*Artocarpus altilis* × *A. mariannensis*	Micronesia
L8	890183002	Midolab	08/02/1985	*Artocarpus altilis* × *A. mariannensis*	Palau
19	890161001	Yuley	10/02/1985	*Artocarpus altilis* × *A. mariannensis*	Micronesia
B5	900255001	Meinpwahr	29/03/1986	*Artocarpus altilis* × *A. mariannensis*	Micronesia
E6	910272002	Meinpohnsakar	09/07/1987	*Artocarpus altilis* × *A. mariannensis*	Micronesia
J9	910268001	Meion	09/07/1987	*Artocarpus altilis* × *A. mariannensis*	Micronesia
A9	910269001	Faine	15/07/1987	*Artocarpus altilis* × *A. mariannensis*	Micronesia

Preparation of amino acid samples

200 mg of each frozen sample (49 cultivars × 3 fruits × 3 replications) was weighed and transferred to a 1.5 mL MCT Graduated Natural tube (Fisherbrand, Mississauga, ON). The sample was placed in a CentriVap DNA Vacuum Concentrators (Labconco, Kansas City, USA) for an 18 h drying process, including 999 min centrifugation at 1725 RPM. The dried sample was weighed to determine dry matter, sliced, and transferred to a screw cap Pyrex vial (17 × 60 mm) (Fisherbrand). An aliquot of 20 µL of the 2.5 mM norleucine internal standard and 2000 µL 6.0 N HCl were added, the vial was flushed with nitrogen, and then quickly capped. The hydrolysis was performed at 110 °C for 19 h in a standard heating block (VWR, Radnor, USA). 500 µL hydrolyzed sample was filtered through an Ultrafree MC Centrifugation Unit (Fisherbrand). An aliquot of 1 µL of the hydrolyzed protein sample was diluted to a total volume of 40 µL with borate buffer (AccQ-Fluor Reagent 1).

Derivatization of amino acids

The derivatization was achieved by reacting 20 µL diluted sample or protein hydrolysis standard solution with 20 µL AccQ-Tag derivatizing reagent AQC (6-aminoquinolyl-*N*-hydroxysuccinimidyl carbamate) in 60 µL borate buffer (AccQ-Fluor 1). All the reagents were pipetted into a 250 µL glass conical insert bottom spring (6 × 29 mm) (Canadian Life Science, Peterborough, Canada), agitated moderately, and kept inside a screw cap injection vial. The vial was heated in the heat block at 55 °C for 10 min to complete the reaction. After regaining room temperature, 10 µL derivatized sample was injected into high-performance liquid chromatography (HPLC).

HPLC analysis

The analysis of breadfruit amino acid was performed on a Waters® 2659 HPLC Separations Module comprising of a multi-λ fluorescent detector (Waters 2475) and a photodiode array detector (Waters 2998), controlled by Empower 3 software (Waters, Milford, USA) and data system. The amino acids were separated on a 4 µm Nava-Pak C_{18}column (3.9 × 300 mm) (Waters, Milford, USA).Chromatographic analysis was performed at room temperature (32 ± 5 °C) using gradient elution shown in Table 2: eluent A was ACCQ Tag/water (10/90, v/v) and eluent B was acetonitrile/water (50/50, v/v). The peaks were detected by fluorescence over a period of 75 min with an excitation wavelength of 250 nm and an emission wavelength of 395 nm.

Table 2 Elution gradient for breadfruit amino acid quantification

Time (min)	Flow	% *A*	% *B*	Curve
	1	100	0	
2	1	93	7	6
4	1	90	10	6
28	1	80	20	3
32	1	75	25	8
38	1	61	33	4
50	1	35	65	6
52	1	0	100	6
55	1	100	0	6
60	1	100	0	2

Eluent A was ACCQ Tag/water (10/90, v/v) and eluent B was acetonitrile/water (50/50, v/v)

Data analysis

Genesis 1.7.5 (Institute for Genomics and Bioinformatics; Graz, Austria) was used to build the essential amino acid profile. All statistical analyses were conducted using RStudio Version 0.98.1062 (RStudio Inc. USA) with a type 1 error rate of 0.05. Essential amino acid data for other staples listed in this article are reported by the Food and Agriculture Organization of the United Nations (FAO 1981).

Results and discussion

Children and infants usually have a higher demand for essential amino acids (WHO 2007). Children who do not have access to adequate protein sources or essential amino acids in their diets are underweight leading to serious health consequences (WHO 2009). In 2004, about 20 % (112 million) of preschool children were underweight, resulting in 2.2 million child deaths and many other long-term developmental problems. Developing countries experienced most of the underweight cases with almost half of the deaths from this cause occurring in Africa and over 800,000 deaths in Southeast Asia (WHO 2009).

In the daily diet, staples are consumed in such quantities that they constitute a dominant proportion of nutrient intake, including protein intake. Corn, wheat, and rice are the most common staples and comprise two-thirds of the world's energy intake (FAO et al. 2012). However, most cereals have poor protein quality and are low in tryptophan (especially maize) and/or lysine (especially wheat) (WHO 2007). People usually consume meat, fruit, vegetables, and other dairy products as a supplementary intake for essential amino acids, but these options are not always affordable especially for undernourished populations (WHO 2007, 2009). In addition, 349 million undernourished people (nearly 50 % of the world's starving population) are found near the equator (FAO et al. 2012). Production of typical staple crops, such as wheat and corn, may be limited by the warm, wet climate and absence of winter freeze that can allow proliferation of pathogenic microbes. Therefore, a suitable affordable and nutritious alternative staple is critical for improving food security in the tropical regions.

Quantification of essential amino acids

All essential amino acids were found in breadfruit (*Artocarpus altilis)* and hybrids *(A. altilis* × *A. mariannensis*), which is consistent with the previous study (Golden and Williams 2001). Significant differences were observed in the essential amino acid content of the protein among breadfruit cultivars and hybrids (Fig. 1). Quantification of met and trp may have been underestimated due to destruction of the structure during the hydrolysis process (Pickering and Newton 1990). Cysteine was not quantified in this study because of limitations of the analytical technique. When comparing individual essential amino acids, Ma'afala (Samoa), Afara, and Hamoa (Maopo) (Society Islands) had the highest levels of all of the essential amino acids, while Ahani and Mahani (Society Islands) and Uto ni viti (Fiji) had significantly lower protein quality. When the data are expressed as a percentage of total protein, hybrids had a significantly higher content of tyr than the *A. altilis* cultivars evaluated (Fig. 2a). When the data were expressed on a dry weight basis, met and tyr were significantly higher in the hybrids than *A. altilis* cultivars. The hybrids also tended to contain more of other amino acids, but these differences were not statistically significant in our sample size (Fig. 2b).

Nutrition and food security

Grain crops, such as maize, rice and wheat, are the most common staples in the world (Lancaster and Coursey 1984). However, in tropical countries, non-grain staples such as cassava, potato, sweet potato, banana, taro, yam, and breadfruit provide the dietary base for 500-700 million people (Lancaster and Coursey 1984). The overall goal of our research was to determine whether a diet rich in breadfruit could provide adequate protein quality for food security in these regions. A typical breadfruit-based main dish usually uses one mature fruit of an average weight of 1.2 kg (HHFN and NTBG 2012). Previous research has shown that 60 % breadfruit with 40 % soy flour in a weaning diet for children from 1 to 3 years old can supply the recommended overall dietary nutritional allowances within the tolerably low antinutrient levels (Ijarotimi and Aroge 2005), but protein quality was not assessed.

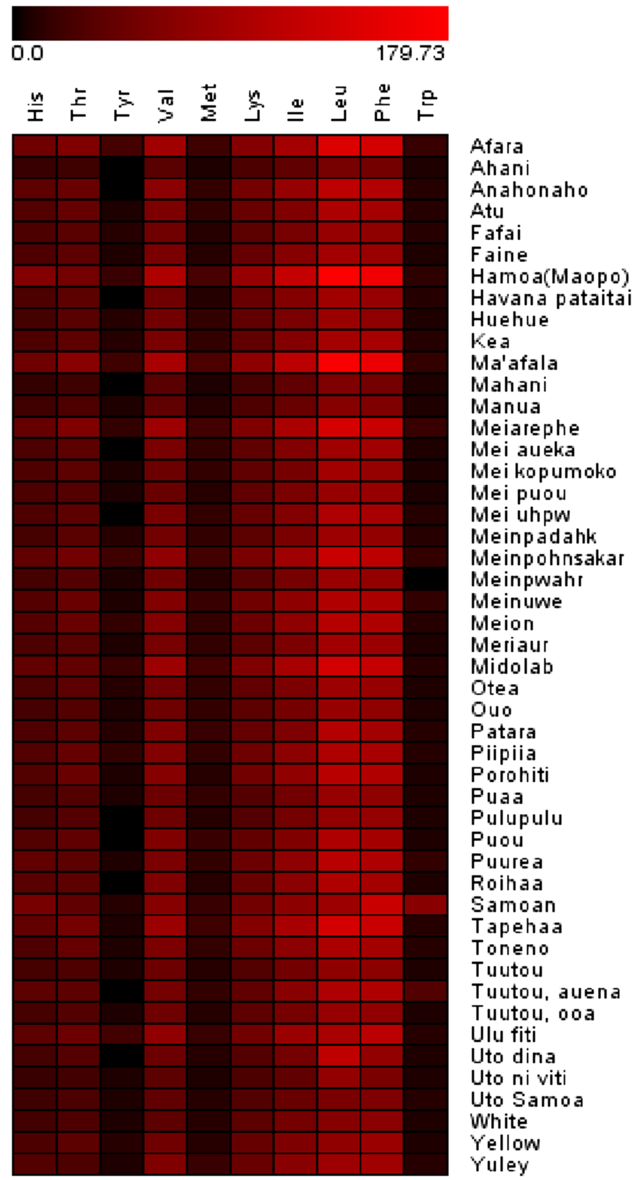

Fig. 1 Essential amino acid content (mg/g protein) of breadfruit (*Artocarpus altilis*) and hybrids (*A. altilis* × *A. mariannensis*). $n = 9$ for each cultivar. Lysine (lys), leucine (leu), threonine (thr), tryptophan (trp), histidine (his), isoleucine (ile), valine (val), phenylalanine (phe), tyrosine (tyr), and methionine (met)

The cultivar Ma'afala had the highest essential amino acid content based on both dry weight and protein weight (Table 3) and was the highest protein variety found in the earlier study (Jones et al. 2011b). When compared to other staples, Ma'afala had the highest total essential amino acid content as a proportion of the total protein (>568 mg/g protein; Fig. 3). The value represents a higher percentage of the essential amino acids than normally found in soybean (Fig. 3), indicating that breadfruit cultivars can have better protein quality than soy. Ma'afala was especially rich in ile (79.3 mg/g protein) and phe+tyr (149.9 mg/g protein),

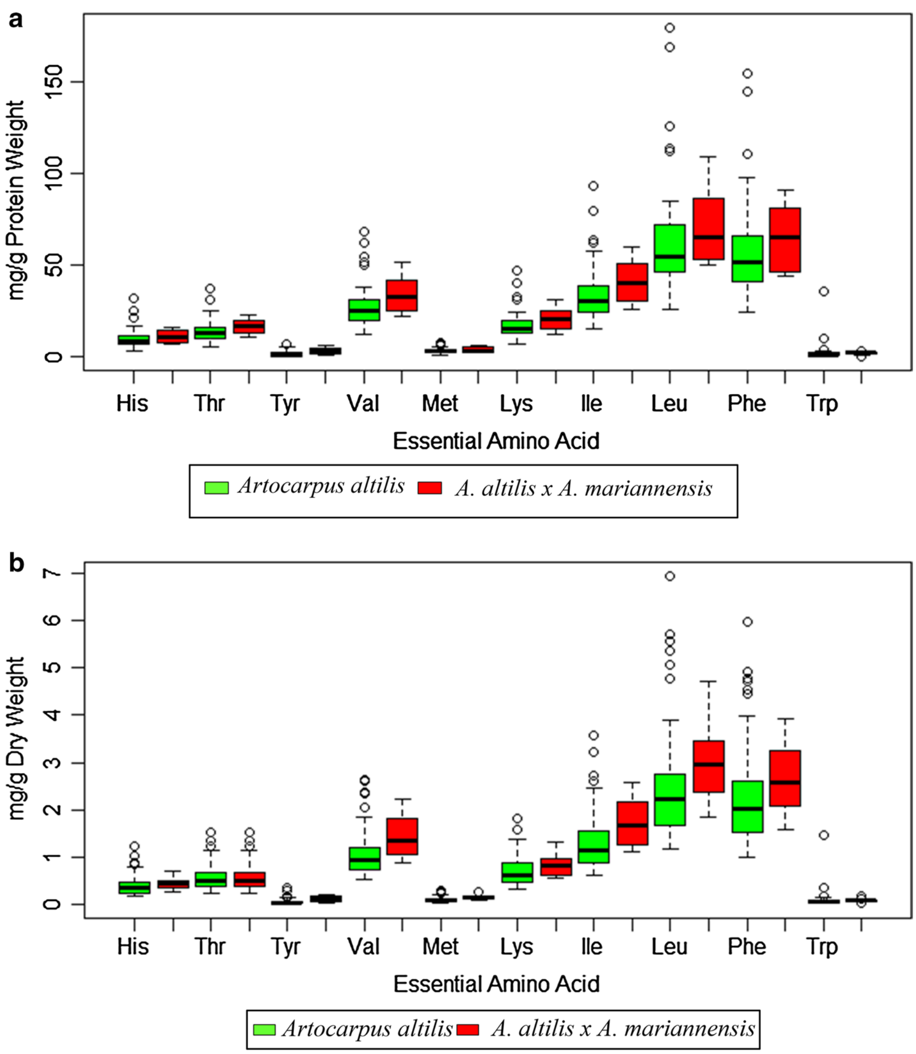

Fig. 2 Comparisons of essential amino acid content between breadfruit (*Artocarpus altilis*) and hybrids (*A. altilis* × *A. mariannensis*) based on protein weight (**a**) ($n = 39 \times 9$ for breadfruit, $n = 8 \times 9$ for hybrids) and dry tissue weight (**b**) ($n = 41 \times 9$ for breadfruit, $n = 8 \times 9$ for hybrids). Comparisons significant at the 0.05 level are indicated by *asterisks*. *Bars* represent the standard error of the mean over individual species. Lysine (lys), leucine (leu), threonine (thr), tryptophan (trp), histidine (his), isoleucine (ile), valine (val), phenylalanine (phe), tyrosine (tyr), and methionine (met)

which were both ~2 to ~4 times higher than other staple crops, and leu (168.6 mg/g protein), which was 1/3–4 times higher than other staples. Ulu fiti had a total essential amino acid (325.1 mg/g protein) that was most similar to potato and higher than cassava and sweet potato. Based on fresh weight, the total essential amino acid contents in Ma'afala (1,071.5 mg/100 g fresh tissue) and Piipiia (889.2 mg/g fresh tissue) were higher than in non-grain tropical staples, such as potato, sweet potato, cassava, banana, taro, and yam (Fig. 4). Ma'afala (1,071.5 mg/100 g fresh tissue) contained total essential amino acid that was 1.6 times higher than that of potatoes and ~2.6 times higher than that of sweet potatoes, cassava, or banana. Yellow (538.5 mg/100 g fresh tissue) and Ulu fiti (489.4 mg/100 g fresh tissue) had higher total essential amino acid contents than cassava, sweet potato, and banana. We estimate that a 500 g Ma'afala or Ulu Fiti could provide a significant contribution toward the essential amino acid requirement of a preschool child weighing 20 kg (Table 4). Similarly, these cultivars contribute significantly toward meeting the nutritional requirements of a 60 kg adult (Table 4).

Efforts to bring breadfruit into larger-scale production and distribution were limited by difficulties in propagation, transport, and acclimatization of the trees. Traditional propagation of breadfruit cultivars primarily used root shoots, but only small numbers of trees were recovered in this way. Following his infamous voyage of 1,789, Captain Bligh transported more than 2,000 individual breadfruit trees from

Table 3 Summary of amino acid content in commercially available breadfruit cultivars (*Artocarpus altilis* and *A. altilis* × *A. mariannensis*): Ma'afala, Yellow, White, Piipiia, Puaa, and Ulu fiti

Amino acid	mg/g	Ma'afala	Yellow	White	Piipiia	Puaa	Ulu fiti
Ala	Average						
	Dry weight	1.20a, b	0.90b, c	0.33d	0.89b, c	0.65c, d	1.42a
	Protein weight	36a	17b, c	8c	22b	17b, c	25b
	SE	0.18	0.29	0.11	0.15	0.10	0.10
Arg	Average						
	Dry weight	1.22a	0.70b	0.43b	0.72b	0.42b	1.29a
	Protein weight	37a	13c	11c	18b, c	11c	23b
	SE	0.18	0.16	0.08	0.10	0.05	0.10
Asn	Average						
	Dry weight	3.05b	2.54b	1.25c	1.99b, c	1.12c	5.00a
	Protein weight	92a	48b	31b	50b	29b	89a
	SE	0.41	0.64	0.26	0.23	0.20	0.54
Asp	Average						
	Dry weight	2.49b	2.09b, c	1.06d	1.46c, d	0.67d	4.05a
	Protein weight	76a	39b	26b, c	36b, c	18c	72a
	SE	0.38	0.40	0.22	0.18	0.07	0.46
Glu	Average						
	Dry weight	2.34a	1.35b, c	0.76	2.02a, b	0.97c	1.89a, b
	Protein weight	71a	25c	19c	50a, b	26c	34b, c
	SE	0.54	0.30	0.14	0.37	0.13	0.14
Gly	Average						
	Dry weight	1.03a	0.49b	0.35b	0.53b	0.41b	0.99a
	Protein weight	31a	9c	9c	13b, c	11c	18b
	SE	0.13	0.12	0.06	0.10	0.06	0.11
His	Average						
	Dry weight	0.70a	0.42b	0.25b	0.41b	0.25b	0.80a
	Protein weight	21a	8c	6c	10b, c	7c	14b
	SE	0.09	0.10	0.05	0.06	0.03	0.06
Ile	Average						
	Dry weight	2.62a	1.58b	0.98b	1.56b	0.88b	2.72a
	Protein weight	79a	30b, c	24c	39b, c	23c	49b
	SE	0.40	0.38	0.17	0.23	0.10	0.28
Leu	Average						
	Dry weight	5.56a	2.68b	1.72b	2.74b	1.73b	4.78a
	Protein weight	169a	51c	42c	69b, c	46c	85b
	SE	0.68	0.65	0.29	0.38	0.20	0.43
Lys	Average						
	Dry weight	1.30a	0.92a, b	0.53b, c	0.83b, c	0.42c	1.28a
	Protein weight	39a	17b, c	13b, c	21b, c	11c	23b
	SE	0.24	0.22	0.10	0.12	0.05	0.13
Met	Average						
	Dry weight	0.25a	0.11c	0.07c	0.13b, c	0.10c	0.20a, b
	Protein weight	8a	2b	2b	3b	3b	4b
	SE	0.04	0.04	0.02	0.02	0.01	0.02
Phe	Average						
	Dry weight	4.77a	2.60b	1.57b	2.49b	1.56b	4.46a
	Protein weight	145a	49c	38c	62b, c	41c	80b
	SE	0.60	0.64	0.27	0.34	0.20	0.40

Table 3 continued

Amino acid	mg/g	Ma'afala	Yellow	White	Piipiia	Puaa	Ulu fiti
Pro	Average						
	Dry weight	0.41a	0.26b	0.13b	0.26b	0.12b	0.47a
	Protein weight	13a	5b, c	3c	7b, c	3c	8b
	SE	0.10	0.07	0.02	0.03	0.02	0.03
Ser	Average						
	Dry weight	1.12a	0.69b	0.29c	0.62b, c	0.43b, c	1.13a
	Protein weight	34a	13b, c	7c	15b, c	11c	20b
	SE	0.17	0.16	0.07	0.12	0.05	0.08
Thr	Average						
	Dry weight	1.22a	0.70b	0.35b	0.68b	0.39b	1.14a
	Protein weight	37a	13b, c	9c	17b, c	10c	20b
	SE	0.20	0.16	0.08	0.10	0.04	0.08
Trp	Average						
	Dry weight	0.11a, b	0.07b, c	0.06c	0.08a, b, c	0.04c	0.12a
	Protein weight	3a	1b	1b	2b	1b	2a, b
	SE	0.03	0.02	0.01	0.02	0.01	0.01
Tyr	Average						
	Dry weight	0.17b	0.13b, c	0.04c	0.13b, c	0.04c	0.34a
	Protein weight	5a, b	2c	1c	3b, c	1c	6a
	SE	0.05	0.04	0.01	0.02	0.01	0.06
Val	Average						
	Dry weight	2.04a	1.19b, c	0.59c	1.29b	0.76b, c	2.35a
	Protein weight	62a	22c, d	14d	32b, c	20c, d	42b
	SE	0.30	0.32	0.16	0.19	0.09	0.20

Means with the same letter are not significantly different. $n = 9$. SE represents the standard error of the mean over individual cultivar. Alanine (ala), arginine (arg), asparagine (asn), aspartic acid (asp), glutamic acid (glu), glycine (gly), proline (pro), serine (ser), lysine (lys), leucine (leu), threonine (thr), tryptophan (trp), histidine (his), isoleucine (ile), valine (val), phenylalanine (phe), tyrosine (tyr), and methionine (met)

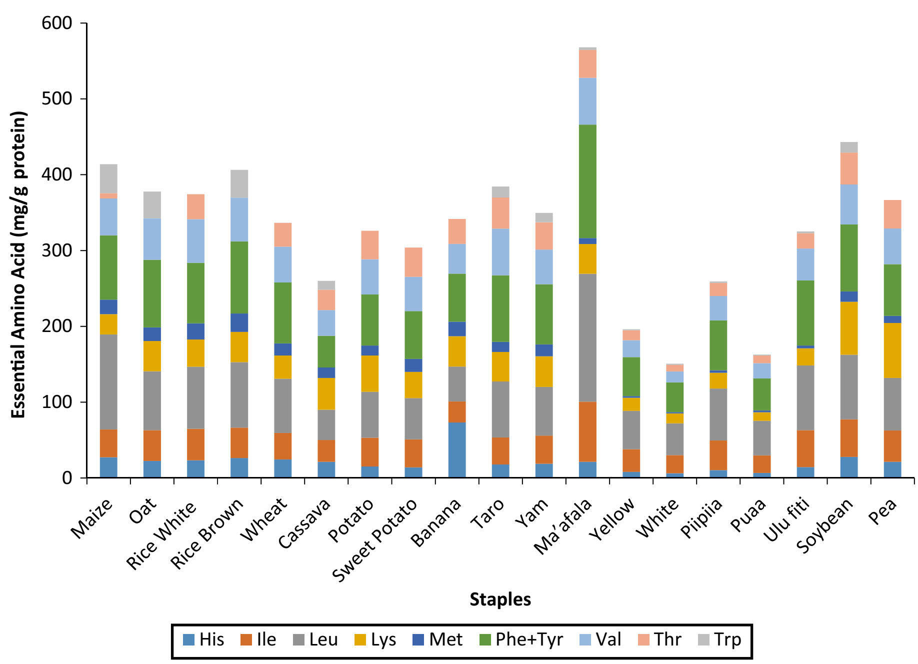

Fig. 3 Comparison of essential amino acid content between commercially available breadfruit cultivars (*Artocarpus altilis* and *A. altilis* × *A. mariannensis*): Ma'afala, Yellow, White, Piipiia, Puaa, and Ulu fiti and other staples based on protein weight. Essential amino acid data for other staples listed is from the Food and Agriculture Organization of the United Nations (FAO 1981). Lysine (lys), leucine (leu), threonine (thr), tryptophan (trp), histidine (his), isoleucine (ile), valine (val), phenylalanine (phe) tyrosine (tyr), and methionine (met) (color figure online)

Tahiti to the Caribbean, but only 678 survived the voyage (Alexander 2009; Powell 1977). In 2008, we reported the development of in vitro propagation methods which made larger numbers of breadfruit cultivars and trees available for the first time (Murch et al. 2008; Shi et al.2007). To date, more than 50,000 trees have been planted in 31 countries through this project and the potential of the project for food security has been recognized (Zielinski 2013).

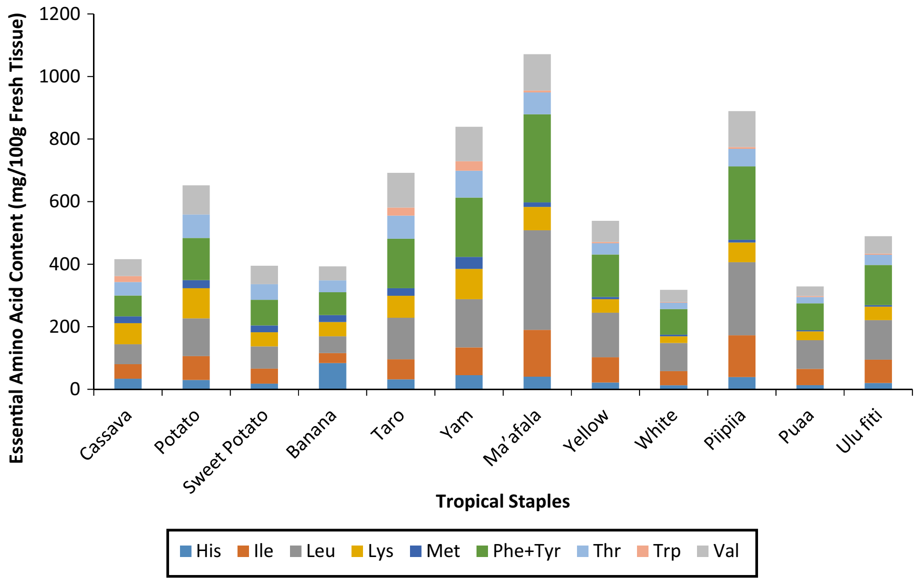

Fig. 4 Comparison of essential amino acid content between commercially available breadfruit cultivars (*Artocarpus altilis* and *A. altilis* × *A. mariannensis*): Ma'afala, Yellow, White, Piipiia, Puaa, and Ulu fiti and other tropical staples based on fresh tissue weight. Essential amino acid data for other staples listed is from the Food and Agriculture Organization of the United Nations (FAO 1981). lysine (lys), leucine (leu), threonine (thr), tryptophan (trp), histidine (his), isoleucine (ile) and valine (val), phenylalanine (phe) and tyrosine (tyr), and methionine (met) (color figure online)

Table 4 Nutritional value of commercially available breadfruit cultivars (*Artocarpus altilis* and *A. altilis* × *A. mariannensis*): Ma'afala, Yellow, White, Piipiia, Puaa, and Ulu fiti

	mg/500 g fresh breadfruit						Requirement per day			
	Ma'afala	Yellow	White	Piipiia	Puaa	Ulu fiti	mg/kg per preschool kid	mg/20 kg per preschool kid	mg/kg per adult	mg/60 kg per adult
His	200	108	64	195	67	100	–	–	10	600
Ile	749	404	226	668	259	373	27	540	20	1,200
Leu	1,593	714	450	1,167	459	631	54	1,080	39	2,340
Lys	372	215	109	313	141	217	45	900	30	1800
Met	71	35	25	46	18	24	22	440	10	600
Phe+Tyr	1,410	681	409	1,173	428	641	40	800	25	1,500
Thr	349	178	101	279	100	166	23	460	15	900
Trp	32	20	10	30	15	16	6	128	4	240
Val	581	338	196	575	157	279	36	720	26	1,560

Daily requirements listed are from the World Health Organization (WHO 2007). Lysine (lys), leucine (leu), threonine (thr), tryptophan (trp), histidine (his), isoleucine (ile), valine (val), phenylalanine (phe), tyrosine (tyr), and methionine (met)

Conflict of interest The authors declare that they have no conflict of interest.

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