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Carotenoid content of pandanus fruit cultivars and other foods of the Republic of Kiribati

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Abstract

Background: Kiribati, a remote atoll island country of the Pacific, has serious problems of vitamin A deficiency (VAD). Thus, it is important to identify locally grown acceptable foods that might be promoted to alleviate this problem. Pandanus fruit (*Pandanus tectorius*) is a well-liked indigenous Kiribati food with many cultivars that have orange/yellow flesh, indicative of carotenoid content. Few have been previously analysed.

Aim: This study was conducted to identify cultivars of pandanus and other foods that could be promoted to alleviate VAD in Kiribati.

Method: Ethnography was used to select foods and assess acceptability factors. Pandanus and other foods were analysed for β - and α -carotene, β -cryptoxanthin, lutein, zeaxanthin, lycopene and total carotenoids using high-performance liquid chromatography.

Results: Of the nine pandanus cultivars investigated there was a great range of provitamin A carotenoid levels (from 62 to 19086 μg β -carotene/100 g), generally with higher levels in those more deeply coloured. Seven pandanus cultivars, one giant swamp taro (*Cyrtosperma chamissonis*) cultivar and native fig (*Ficus tinctoria*) had significant provitamin A carotenoid content, meeting all or half of estimated daily vitamin A requirements within normal consumption patterns. Analyses in different laboratories confirmed high carotenoid levels in pandanus but showed that there are still questions as to how high the levels might be, owing to variation arising from different handling/preparation/analytical techniques.

Conclusions: These carotenoid-rich acceptable foods should be promoted for alleviating VAD in Kiribati and possibly other Pacific contexts where these foods are important. Further research in the Pacific is needed to identify additional indigenous foods with potential health benefits.

Keywords

Pandanus fruit
Vitamin A
Carotenoid
 β -Carotene
 α -Carotene
Kiribati atolls
Micronesia
High-performance liquid chromatography

Vitamin A deficiency (VAD) is a serious problem in developing countries that mainly affects children and women, causing increased susceptibility to infections and problems with vision and eye health¹. In communities with VAD and other nutritionally related diseases it is critical to identify and promote locally grown acceptable foods that may alleviate the problem and to understand the food beliefs and practices in the community². The identification and promotion of nutrient-rich indigenous

foods also has importance for cultural preservation, import substitution and income generation.

The Republic of Kiribati (population 84 494), a remote nation of 33 atolls* widely scattered along the Equator in the central Pacific Ocean³, has a serious problem of VAD that was first identified in the late 1980s^{4,5}, with continuing reports of VAD disorders from health surveys⁶ and unpublished health department reports. This problem

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*An atoll is a ring-shaped low-lying coral island or group of islands, often consisting of only a narrow strip of land with seawater on both sides, circling a lagoon.

followed the migration from outer atolls to the urban centre of Tarawa and an increasing trend towards consuming imported processed foods⁶, the major item being rice, which contains no provitamin A carotenoid. Non-communicable diseases, including diabetes, heart disease and cancer, have also recently emerged as major public health problems and are associated with dietary and lifestyle changes^{7–9}.

Kiribati faces a harsh environment with limited fresh water, making food production difficult. Furthermore, the islands are very low-lying with few places more than 2 m above sea level, making them vulnerable to sea-level rises, pollution and coastal erosion. Due to its high infant mortality rate (62/1000), low per capita income and low access to safe drinking water and sanitation (47% and 46%, respectively), Kiribati is classified as a Least Developed Country³.

Early studies indicated that the traditional diet was adequate and that there was no evidence of VAD¹⁰, but by the 1970s xerophthalmia (clinical signs of VAD including night blindness and Bitot's spots) was common^{11–13}. A nationwide routine vitamin A supplementation programme was established in 1992, and horticulture programmes were initiated for encouraging the production and consumption of green leafy and other types of vegetables¹³. However, vegetables are difficult to grow in an atoll environment. They also had not previously been part of the diet and were met with low acceptability¹³. People thought of green leafy vegetables as pig food¹⁴. Although there was some evidence of this vegetable promotion programme having an impact⁶, in general the attempts at introducing these foods into the dietary regime met with little success¹⁵.

Cultural and dietary roles of pandanus, giant swamp taro and breadfruit in Kiribati

Pandanus fruit, *te kaina* (*Pandanus tectorius*), which has the yellow, orange and red coloration indicative of carotenoid content, has been a very acceptable food for many years^{16,17}. Pandanus is known as the second 'tree of life' after coconut¹⁸, due to the importance of the edible varieties for food and other varieties for weaving, handicrafts, building and medicine. Pandanus is also known as the ancestress-tree¹⁶ and Kiribati people were referred to by one writer as the 'pandanus people'¹⁶. Preserved pandanus was formerly used to survive long sea voyages¹⁷.

Owing to harsh atoll island climates, particularly in the southern islands of Kiribati, pandanus is among the few crops that can grow¹⁹. To obtain edible fruits, vegetative propagation is necessary, by taking a cutting from a pandanus tree that bears edible fruits. The current collection of pandanus varieties has resulted from careful propagation by Kiribati people over past generations. Pandanus is a well-liked staple food, consumed raw or cooked in various recipes with different ingredients,

including coconut cream. None the less, due to lifestyle changes and the increasing reliance on imported foods, there has been a great neglect of pandanus. This led to the Kiribati Pandanus Project²⁰, initiated in 2001 for documenting, conserving and promoting Kiribati pandanus cultivars*. It was the basis for initiating this study.

Pandanus fruit is a composite fruit, called a bunch (or syncarp), which has many sections called keys (or phalanges) (Fig. 1) attached to an inner core. Pandanus bunches generally weigh from 9 to 14 kg²¹ and occasionally up to 30 kg²². A 14-kg bunch may have approximately 50 keys, with the core and stem weighing approximately 1 kg²¹. The inner part of the key is chewed and sucked for its sweet pulp (Fig. 2), or the pulp may be extracted with a scraper (formerly shell, now metal). The nutrient-rich pulp is embedded in a highly fibrous mass, similar to some types of mangoes, and is hard work to consume. Boiling the keys makes the pulp more available and assists in the release of carotenoids from the cellular matrix, which may provide a greater amount of carotenoids compared with raw keys¹. The outer part of the key is inedible. There is a great diversity of Kiribati pandanus, most reports suggesting that there are approximately 170 varieties^{16,19,22}. Other reports list 200²³ and 259 varieties²⁴, some of which are thought to be different names given for the same variety. Names are given according to taste, speed of ripening, seasonality and other local discretionary factors.

The only known nutrition studies of Kiribati pandanus fruit cultivars are one study using an older methodology and where cultivar names were not provided²⁵ and a more recent analysis of preserved pandanus powder²⁶. These studies did not include fresh, named cultivars, and thus provide little information relevant to the issues associated with the promotion of local pandanus cultivars to address VAD.

Giant swamp taro, *te babai* (*Cyrtosperma chamissonis*), is important in the diet as well as culturally in Kiribati food-giving ceremonies. Along with coconut and pandanus, *babai* has been named among the three most important Kiribati indigenous foods²². There are around 20 cultivars¹⁹. These vary by characteristics that include the colour of the edible corm (white to yellow). Unseeded and seeded breadfruit, *te mai* (*Artocarpus altilis* and *Artocarpus mariannensis*) and native fig, *te bero* (*Ficus tinctora*), have edible flesh with varying shades of yellow to orange coloration when ripe and are among the important indigenous Kiribati foods²⁷. Apparently there are no previous studies assessing the carotenoid content of these foods from Kiribati.

Studies assessing the nutrient content of other Micronesian pandanus, giant swamp taro and breadfruit

*A cultivar refers to a variety produced by cultivation. In this paper, all pandanus cultivar names are capitalised for consistency with standard practices.



Fig. 1 A ripe pandanus bunch, *Tearabaikiaro* cultivar, and one key, showing the outer green inedible portion and the orange-yellow coloration of the edible portion

cultivars^{28–30} show that the carotenoid content varies greatly among cultivars, with the greater carotenoid content found in those cultivars with the deepest coloration. The provitamin A carotenoids include β -carotene (the carotenoid making the greatest contribution to vitamin A activity), α -carotene and β -cryptoxanthin¹. Epidemiological studies show that the consumption of foods rich in other carotenoids, such as lutein, zeaxanthin and lycopene, protects against certain chronic diseases such as heart disease, certain cancers, diabetes and age-related macular degeneration^{31–34}, indicating that consuming these carotenoid-rich foods may have multiple health benefits.

Thus, the purposes of the present study were to: (1) identify carotenoid-rich Kiribati pandanus cultivars and other locally grown foods by analysing for β - and α -carotene, β -cryptoxanthin, lutein, zeaxanthin, lycopene, total carotenoids and water; (2) explore factors relating to the production, consumption and acceptability of these foods; and (3) assess their potential for alleviating VAD.

Methods

Ethnographic methods^{2,30,35,36}, including key informant interviews (face-to-face), informal focus group discussions, observations, photography, literature review and



Fig. 2 Young child chewing and sucking on a pandanus key for its sweet pulp

structured collection of pandanus samples, were used to more fully characterise the cultivars and samples collected.

The sample data collection kit included: a formatted documentation list and interview guide; labelling tape; sample labels; zip-lock sample bags; a labelling marker; the DSM Yolk Colour Fan; a digital camera; Soehnle electronic kitchen scales (accurate to 2 g); a measuring tape; and a vacuum-pack sealing machine (FoodSaver Vac 750/Ultra).

Material

Data collection focused on South Tarawa of Tarawa Atoll, due to geographic dispersion of the atolls, irregular flights and boats, and limited resources to collect data and samples from outer atolls. This is an urbanised area compared with the rest of Kiribati and more dependent on imported food due to lack of land, thereby affecting the data and information collected. As Kiribati is a highly dispersed set of atolls on both a north/south as well as an east/west axis, seasonality greatly varies from atoll to atoll, which also affects the types and varieties of foods grown.

Selection, documentation and preparation of samples

The lead author, assisted by local government officers, carried out the data collection during two visits to Tarawa, Kiribati, in September 2003 and May 2004. The criteria for selecting the samples were that the foods were indigenous and had a yellow, orange or orange-red coloration

indicative of carotenoid content. Some cultivars with lighter coloration were collected for comparison purposes. Most samples were collected from two local produce markets, Bikinibeu and Bairike Markets, with two samples collected directly from growers.

The sampling plan included collecting at least six good-quality pandanus keys or three or more fruits or corms or berries of the other foods per composite sample to provide a representative sample. Due to the large size of the inedible portion of the pandanus key, limited space and weight for transporting the frozen samples, and the need to avoid confusion among laboratory analysts who may not be familiar with what part of the pandanus key is edible, only edible portions were included in the composite sample. For pandanus, the edible portion of each key was cut off, then cut again in order to provide equal portions from each key and to prepare two replicate sets of composite samples, one set each for two study laboratories. For the taro, breadfruit and pumpkin, equal portions from each corm or fruit were selected to make the composite sample. For the composite sample of berries, sufficient berries were selected to make 1 cup.

The cooking procedures were standardised, using the type of cooking normally used for the particular food and carried out by the primary author in most cases. All raw pandanus samples were boiled for about 30 min, whereas the preserved pandanus samples were cooked and prepared on outer atolls with the reported cooking time being about an hour. The fresh pandanus samples were frozen immediately after bagging.

The pandanus cultivar names were obtained from the local market sellers or growers from whom the samples were collected. Local food experts were contacted to confirm the identification. Measurements were taken of the length of the whole pandanus key (from the top of the inedible portion to the bottom of the edible portion), its girth (widest point around the key) and weight of the whole key (including the inedible and edible portion).

Digital photographs of the pandanus plants, bunches and keys and other foods were taken in order to assist in identifying and documenting the cultivars. Marshall Islands pandanus photographs were used to assist in identifying Kiribati cultivars that are also growing in the Marshall Islands, but are known by different names.

The coloration of the edible portion of the pandanus key and other food samples was assessed visually as yellow, orange or orange-red coloration, and then estimated by the DSM (formerly Roche) Yolk Colour Fan in order to standardise the description of coloration. This fan, developed for objectively judging egg yolk colour³⁷, is composed of 15 segments of increasing intensities of yellow, orange and orange-red numbered from 1 to 15.

To prepare pandanus samples, the inedible key portion was cut off and discarded; the soft edible portions were packed in zip-lock plastic bags, identifying by cultivar name, number of keys (or fruits, corms or berries), sample

collection date, maturity and processing (if raw or cooked, how cooked and how long). The other food samples were prepared in a similar way, preparing samples cooked or raw, as normally consumed.

Sample allotments, storage and transport to the laboratory

As there are no facilities for nutrient analysis in Kiribati, the samples were frozen and transported (continuous cold-chain using frozen gel-ice packs) to overseas laboratories. The Institute of Applied Sciences/University of the South Pacific (IAS/USP), Fiji, and the DSM Nutritional Products laboratory, Switzerland, provided the comprehensive set of results and are the basis for the major interpretation. Some samples were analysed at the University of Adelaide laboratory in Australia to assess how sensitive the results would be to differences in preparation/handling/analytical techniques.

For pandanus samples collected in 2004, the edible portion of each key was cut in half and replicate samples were prepared for the IAS/USP and Australian laboratories. Storage and transport of the sample sets were similar: preparing the samples and hand-carrying (continuous cold-chain) to the laboratories. However, the samples sent to IAS/USP were frozen in zip-lock bags with air removed manually; the samples sent to the Australia laboratory were prepared and transported first to Pohnpei, Micronesia, re-packed using vacuum sealing, frozen/stored and then transported to the laboratory. Quarantine requirements for sample transport were fully met.

Chemical analysis

The primary laboratory (IAS/USP, Fiji) used standard carotenoid analysis procedures³⁸, including high-performance liquid chromatography (HPLC). The extraction, separation, identification and quantification methodologies of the Fijian and Swiss laboratories are described previously^{28,39}. As for the primary laboratory, the food sample was exhaustively extracted with acetone and filtered. The organic layer was evaporated at low temperature and pressure, using nitrogen gas to remove all traces of solvent. After filtering through a 0.45 µm HPLC filter paper into a volumetric flask, the extract was made to an appropriate volume (depending on expected concentration) with methanol. An appropriate sample volume (usually 25 µl) was injected onto a Novapak C18 (3.9 mm internal diameter × 300 mm length) stainless-steel column with C18 guard column. The mobile phase was methanol–tetrahydrofuran (90:10) flowing at 0.5 cm³ min⁻¹ using a Waters model 510 pump. The ultraviolet detector (a Waters 461 spectrophotometer) was set at 450 nm, with α- and β-carotene eluting at about 30 and 32 min, respectively. The concentration of standards was determined by measuring the absorbance of the β-carotene at 463 nm and using Beer's law with a molar absorptivity of 125 893. All analyses were carried out in duplicate with the mean

reported (results must vary by less than 10%). Blanks and recovery samples were run as quality assurance methods. A set of analyses was accepted if recoveries were in the range 80–120%. The sum of total carotenoids was estimated by comparing the sum of their peak areas with that of β -carotene.

The extraction methodology of the Australian laboratory used saponification, converting carotenoid esters to their parent hydroxycarotenoids⁴⁰. The carotenoid analyses were performed on an Agilent Technology model 1050 HPLC system equipped with a quaternary solvent delivery system, a 1050 autosampler, a thermostatted column compartment and a 1050 diode array detector. Separations were carried out on a silica-based nitrile-bonded (25 cm length \times 4.6 mm internal diameter; 5 μ m spherical particle) column (Regis Chemical, Morton Grove, IL, USA) protected with a Brownlee nitrile-bonded guard cartridge (3 cm length \times 4.6 mm internal diameter; 5 μ m particle size). The separation, identification and quantification of the major carotenoid constituents were determined by normal-phase HPLC and are described by Khachik *et al.*⁴¹. β -Apo-8'-carotenal was used as the internal standard with 99% recovery. The results are a mean of three replicates. The Australian laboratory participated in the HarvestPlus carotenoid proficiency test early in 2005, all groups analysing three samples in triplicate for β - and α -carotene, lutein and zeaxanthin. All results of the Australian laboratory were within the average ranges of the other groups.

From the time of sample collection until the time of sample analysis by the laboratory, there were less than two months of frozen storage for the samples sent to Fiji, about six months for those sent to Switzerland, and four months for those sent to Australia.

Assessment of carotenoid content and impact on vitamin A requirements

In order to assess all pandanus cultivars and avoid inter-laboratory data differences (see below), this assessment used the Fiji laboratory results. The number of keys needed to meet estimated vitamin A requirements⁴² was calculated using the mean weight of the edible portion per key and the β -carotene equivalents/100 g per cultivar. The calculations were made for non-pregnant, non-lactating women and children aged 1–10 years. Pregnant and lactating women and young children are particularly vulnerable to VAD and the VAD disorder of night blindness, which can be combated by provision of vitamin A¹.

The β -carotene equivalent value was calculated from the HPLC analyses by adding the β -carotene content and half of the sum of the α -carotene and β -cryptoxanthin content. Retinol equivalents (RE) were calculated as one-sixth of β -carotene equivalents, according to the conversion factor 6 μ g β -carotene to 1 μ g retinol⁴². Retinol activity equivalents (RAE) were also calculated, using the

newly advised conversion factor of 12:1 for β -carotene equivalents⁴³.

Results and discussion

Samples of nine pandanus cultivars were obtained, varying by size, appearance, coloration, taste and carotenoid level. Cultivar seasonality also varied, as seen by the market surveys, with mostly different cultivars present in the two different collection periods (September 2003 and May 2004). Also, samples were collected of two types of preserved pandanus, two giant swamp taro cultivars, native fig, three breadfruit cultivars and one pumpkin cultivar.

Reconciliation for spellings

The spellings of pandanus cultivars and other foods were reconciled with those in the literature^{20,22,24,44}. Pandanus names often begin with '*te ara*', which literally means 'the name'. Another common prefix to pandanus names is '*te iri*', which refers to the pandanus itself as a particular type. Luomala²² points out that the prefix '*ani*' is common, but that there is no apparent pattern of naming pandanus: they can be named for mythical lands, deities, colours, places and qualities. Informants pointed out that some pandanus cultivars may be known by two names, one with the prefix and one without, but that it is always correct to use the prefix.

Assessment of carotenoid content of pandanus fruit cultivars

For the nine pandanus cultivars the carotenoid levels ranged from 62 to 896 μ g β -carotene/100 g (Fiji laboratory) (Table 1). There was excellent agreement between the Fijian and Swiss laboratories on β -carotene content of the preserved pandanus paste and powder (Fig. 3), with differences less than 60 μ g (Table 1). The carotenoid levels (including lutein and zeaxanthin) in the preserved pandanus paste, *te tuae*, were relatively high despite the fact that this product was sun-dried, a processing known to destroy carotenoid content⁴⁵. On the other hand, the preserved pandanus powder, *te kabubu*, contained low carotenoid levels; very likely due to the greater severity of the processing treatment. Kumar *et al.*²⁶ also found low carotenoid levels in their analysis of Kiribati preserved pandanus powder (22 μ g β -carotene equivalents/100 g). Consistent with other studies showing that riper fruits have higher carotenoid levels⁴⁵, the ripe *Tearaonimaai* contained significantly higher levels than the half-ripe *Tearaonimaai* pandanus and the ripe native fig (*te bero*) also had higher levels than the half-ripe sample (Tables 1 and 2). There were too few sample sets of raw cultivar versus cooked cultivar to determine the effect of cooking on carotenoid content for these samples.

The carotenoid levels of the five pandanus cultivars analysed by the Australian laboratory ranged from 548 to

Table 1 Carotenoid content of selected Kiribati pandanus cultivars of *te tou* (*Pandanus tectorius*) and preserved products ($\mu\text{g}/100\text{ g}$ edible portion, means of duplicate analyses)

Pandanus cultivar or preserved product	Raw or cooked*	Maturity ††	Colour of edible flesh†	β -Carotene	α -Carotene	β -Cryptoxanthin	β -Carotene equivalents§	RE¶	RAE	Lutein	Zeaxanthin	Lycopene	Total carotenoids**	Water (%)	Lab††
<i>Teaarakitaba</i>	Raw	Ripe	9 Orange-red: 12	896	90	NA	941	157	78	NA	NA	NA	3602	78	A
<i>Tekaureiko</i>	Raw	Ripe	6 Orange: 7	410	29	243	546	91	46	151§§	§§	NA	833	77	A
<i>Tekaureiko</i>	Boiled	Ripe	7 Orange: 7	163	49	57	216	36	18	65§§	§§	NA	334	77	A
<i>Te tuae paste††</i>	Boiled	Ripe	– Brown	444	60	117	533	89	44	98§§	§§	NA	734	15	A
<i>Te tuae paste††</i>	Boiled	Ripe	– Brown	390	<10	40	415	69	35	310	190	¶¶	200	14	B
<i>Teaoninaai</i>	Raw	Ripe	6 Orange: 7	287	51	206	416	69	35	67§§	§§	NA	611	82	A
<i>Teaoninaai</i>	Raw	Half-ripe	8 Yellow: 4	58	3	44	82	14	7	7§§	§§	NA	112	77	A
<i>Teaabaikaro</i>	Raw	Ripe	6 Yellow: 4	233	66	NA	266	44	22	NA	NA	NA	1018	82	A
<i>Teaabaikaro</i>	Boiled	Ripe	6 Yellow: 4	105	12	NA	111	18	9	NA	NA	NA	175	77	A
<i>Teaarakitaba</i>	Raw	Ripe	5 Orange: 6	181	47	NA	205	34	17	NA	NA	NA	703	82	A
<i>Teatinakawae #2</i>	Raw	Ripe	6 Yellow: 5	150	33	NA	167	28	14	NA	NA	NA	271	80	A
<i>Teatinakawae #1</i>	Raw	Ripe	7 Yellow: 5	94	23	111	161	27	13	34§§	§§	NA	262	80	A
<i>Teirubura</i>	Raw	Ripe	8 Orange: 8	129	34	60	176	29	15	129§§	§§	NA	352	81	A
<i>Teauramaere</i>	Raw	Ripe	6 Yellow: 4–8	103	9	NA	108	18	9	NA	NA	NA	188	81	A
<i>Te kabubu powder††</i>	Baked	Ripe	– Pale yellow: <1	90	<10	<10	100	17	8	50	70	¶¶	300	13	B
<i>Te kabubu powder††</i>	Baked	Ripe	– Pale yellow: <1	88	9	14	100	17	8	63§§	§§	NA	185	11	A
<i>Teannaewati</i>	Raw	Ripe	8 Yellow: 4	62	40	40	102	17	9	12§§	§§	NA	154	81	A

NA – not analysed.

Samples were collected from Tarawa Atoll in two allotments in September 2003 and May 2004, and analysed by high-performance liquid chromatography in two laboratories.

* If boiled, the samples were boiled for about 30 min. For the preserved product that was baked, the cooking time was reported to be approximately 1 h or longer.

† Number of pandanus keys in the composite sample.

‡ Colour was described visually and also estimated on raw or cooked keys using the DSM Yolk Colour Fan, with numbers ranging from 1 to 15 for increasing colorations of yellow, orange and orange-red. The DSM colour estimate presented here represents the colour covering the greatest area of the pandanus key surface. See Table 3 for further estimates of colour variation.

§ Content of β -carotene plus half the content of α -carotene and β -cryptoxanthin.¶ Retinol equivalents (conversion factor 6:1 from β -carotene equivalents to RE).|| Retinol activity equivalents (conversion factor 12:1 from β -carotene equivalents to RAE).** Estimated by calculating total peak areas recorded in the chromatograms (using the response factor of β -carotene); it includes xanthophyll- and cryptoxanthin-like compounds.

†† Laboratory where samples were analysed. A – Institute of Applied Science/University of the South Pacific (IAS/USP), Suva, Fiji; B – DSM Nutritional Products, Basel, Switzerland.

‡‡ *Te tuae* and *te kabubu* are preserved pandanus products. *Te tuae* is preserved by sun-drying the pulp of many boiled keys. *Te kabubu* is preserved by finely slicing the edible portion of the keys, then baking, grinding and sun-drying them. These samples were from a mixture comprising an unspecified number of keys and bunches and were prepared from one or more unspecified cultivars.

§§ The method of carotenoid analysis presents a sum of both lutein and zeaxanthin.

¶¶ Below the detection limit.

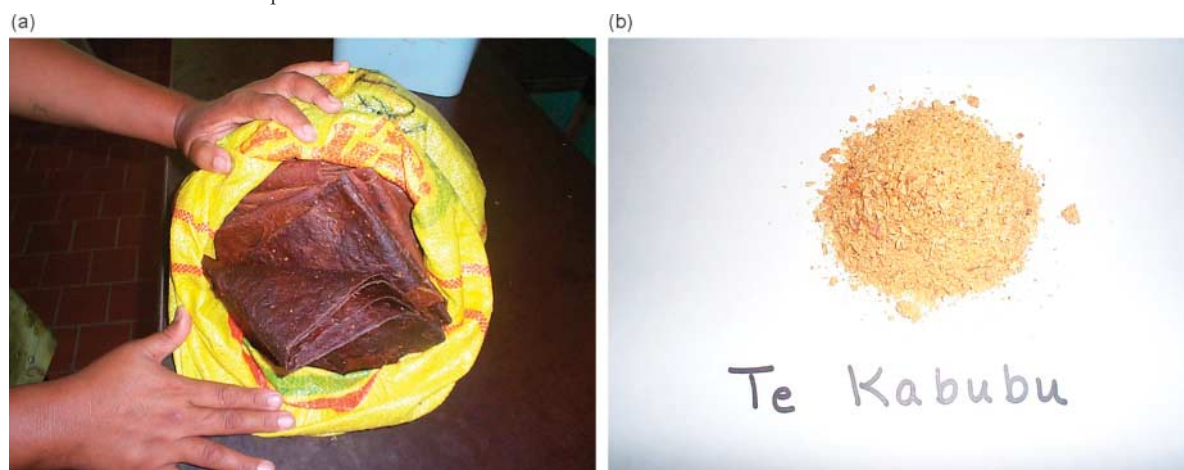


Fig. 3 The deep brown-coloured preserved pandanus paste, *te tuae*, folded in sheets ready for sale (a) and the pale yellow-coloured preserved pandanus powder, *te kabubu*, ready for mixing in water for a drink (b)

19086 μg β -carotene/100 g (Table 3), considerably higher than those of the other laboratories. This shows how sensitive laboratory results can be in terms of handling, preparation and analytical techniques. Despite the differences, the carotenoid levels are still high, the unresolved question being exactly how high.

Of those other foods analysed in addition to pandanus, the native fig, *Te Katutu* giant swamp taro cultivar and pumpkin had carotenoid levels similar to and exceeding those of some of the pandanus cultivars, including lutein and zeaxanthin. In contrast to all other samples, the ripe native fig contained lycopene; the level was relatively high. The *Te Mai Kora* seeded

breadfruit cultivar did not contain high provitamin A carotenoid levels compared with the pandanus, but it contained higher levels than the other breadfruit cultivars and its level of lutein/zeaxanthin was higher than that of the pandanus cultivars. The seeded breadfruit sample was ripe, as it is consumed ripe, whereas the other two breadfruit cultivar samples were at the mature stage (ready to eat, but not ripe) as they are generally eaten at that stage. Possibly the other two breadfruit cultivars would also contain higher carotenoid levels if analysed at the ripe stage.

In general the deeper coloured pandanus cultivars and other foods with deeper coloured edible portions had



Fig. 4 Comparison of four pandanus cultivars with the DSM Yolk Colour Fan, with the *Tearabukitaba* cultivar showing with the greatest coloration

Table 2 Carotenoid content of other selected Kiribati atoll foods ($\mu\text{g}/100\text{g}$ edible portion, means of duplicate analyses)

English, local, and scientific names*	Raw or cooked†	Maturity	n‡	Colour of edible flesh§	β -Carotene	α -Carotene	β -Cryptoxanthin	β -Carotene equivalents¶	RE	RAE**	Lutein	Zeaxanthin	Lycopene	Total carotenoids††	Water (%)	Lab‡‡
Native fig, <i>te bero</i>	Boiled	Ripe	80	Orange: 6	160	10	20	175	29	15	590	1420	320	2830	86	B
Native fig, <i>te bero</i>	Boiled	Half-ripe + ripe	133	Green and orange: 6	7	1	16	16	3	1	154		¶¶	178	86	A
Giant swamp taro, <i>Te Katutu</i> cultivar	Boiled	§§	4	Creamy: <1	133	96	NA	181	30	15	NA	NA	¶¶	294	61	A
Giant swamp taro, <i>Te Katutu</i> cultivar	Boiled	§§	4	Creamy: <1	¶¶	¶¶	NA	¶¶	¶¶	¶¶	226	NA	NA	226	0.6	C
Giant swamp taro, <i>Te Ikaraoi</i> cultivar	Boiled	§§	1	White: <1	4	1	0	5	1	0.4	4		¶¶	9	61	A
Pumpkin, <i>te baukin</i>	Boiled	Ripe	1	Orange: 11	81	73	9	122	20	10	16		¶¶	179	90	A
non-specified cultivar	Boiled	Ripe	3	Yellow: 4	48	14	1	56	9	5	204		NA	267	72	A
Breadfruit, <i>Te Mai Kora</i> cultivar	Raw	Ripe	1	Yellow: 3	1	0	0	0	0	0	35		NA	36	65	A
Breadfruit, <i>Te Bokeke</i> cultivar	Boiled	Mature	1	Creamy: <1	0	0	0	0	0	0	0		NA	0	67	A
Breadfruit, <i>Te Bukiraro</i> cultivar	Boiled	Mature	1	Creamy: <1	0	0	0	0	0	0	0		NA	0	67	A

NA – not analysed.

Samples were collected in two allotments in 2003 and 2004 (the half-ripe native fig, taro and pumpkin samples were collected in Kiribati; the ripe native fig sample was collected in the Marshall Islands), and analysed by high-performance liquid chromatography.

* Name of food and cultivar if available. Scientific names are: native fig – *Ficus tinctora*; giant swamp taro – *Cyrtosperma chamissonis*; pumpkin – *Curcubita pepa*.

† The giant swamp taro samples were boiled for about an hour. The native fig and pumpkin were boiled for about 30 min.

‡ Number of berries (native fig), corms (giant swamp taro) or fruits (pumpkin) in the composite sample. The two native fig samples were collected from two separate trees.

§ Colour was described visually and also estimated on raw or cooked foods using the DSM Yolk Colour Fan, with numbers ranging from 1 to 15 for increasing colorations of yellow, orange and orange-red. The number here is that of the colour covering the greatest area of the edible portion.

¶ Content of β -carotene plus half the content of α -carotene and β -cryptoxanthin.|| Retinol equivalents (conversion factor 6:1 from β -carotene equivalents to RE).** Retinol activity equivalents (conversion factor 12:1 from β -carotene equivalents to RAE).†† Estimated by calculating total peak areas recorded in the chromatograms (using the response factor of β -carotene); it includes xanthophyll- and cryptoxanthin-like compounds.

‡‡ Laboratory where samples were analysed: A – Institute of Applied Science/University of the South Pacific (IAS/USP), Suva, Fiji; B – DSM Nutritional Products, Basel, Switzerland; C – University of Adelaide, Glen Osmond, Adelaide, Australia.

§§ Giant swamp taro corms are harvested only at maturity.

¶¶ Below the detection limit.

||| The method of carotenoid analysis presents a sum of both lutein and zeaxanthin.

Table 3 Carotenoid content of selected Kiribati pandanus cultivars of *te tou* (*Pandanus tectorius*) ($\mu\text{g}/100\text{ g}$ edible portion, means of triplicate analyses)

Pandanus cultivar or preserved product	Raw or cooked*	Maturity	rt†	Colour of edible flesh‡	β -Carotene	α -Carotene	β -Carotene equivalents§	RE¶	RAE	Lutein	Zeaxanthin	Water (%)
<i>Teantinakarewe</i>	Raw	Ripe	6	Yellow: 2 (20%), 3 (30%), 5 (40%), 9 (10%)	19 086	**	19 086	3181	1591	1349	**	80
<i>Tearauriamaere</i>	Raw	Ripe	6	Yellow: 4 (40%), 8 (40%), 10 (20%)	10 522	**	10 522	1754	877	5037	**	79
<i>Tearabukitaba</i>	Raw	Ripe	9	Orange-red: 6 (30%), 12 (50%), 14 (20%)	6118	**	6118	1020	510	5721	10	79
<i>Tearabaikiaro</i>	Boiled	Ripe	6	Yellow: 4 (70%), 6 (25%), 15 (5%)	1913	**	1913	319	159	276	**	75
<i>Tearabaikiaro</i>	Raw	Ripe	6	Yellow: 4 (70%), 6 (25%), 15 (5%)	**	**	**	**	**	8043	**	81
<i>Tearaikitoo</i>	Raw	Ripe	5	Orange: 3 (35%), 6 (60%), 15 (5%)	548	65	581	97	48	28	20	79

Samples were collected from Tarawa Atoll in 2004, and analysed by high-performance liquid chromatography at the University of Adelaide, Glen Osmond, Adelaide, Australia.

* If boiled, the samples were boiled for about 30 min.

† Number of pandanus keys in the composite sample.

‡ Colour was described visually and also estimated on raw or cooked keys using the DSM Yolk Colour Fan, with numbers ranging from 1 to 15 for increasing colorations of yellow, orange and orange-red. An estimated percentage is given for the area of the different colorations of the outer surface of the key.

§ Content of β -carotene plus half the content of α -carotene and β -cryptoxanthin.

¶ Retinol equivalents (conversion factor 6:1 from β -carotene equivalents to RE).

|| Retinol activity equivalents (conversion factor 12:1 from β -carotene equivalents to RAE).

** Below the detection limit.

higher carotenoid levels, as assessed visually and estimated using the DSM Yolk Colour Fan (Fig. 4), although sometimes colour estimates were difficult due to the subtle shades of coloration. The fan's small size facilitated its use in the field and the fan colours matched well to the pandanus fruit and other foods analysed.

Assessment of impact of pandanus cultivars and other foods on vitamin A requirements

Of the nine pandanus cultivars analysed, eight were assessed for their impact on meeting vitamin A requirements (Table 4), comparing the carotenoid levels and key size to determine the number of keys needed for meeting vitamin A requirements (one cultivar was not assessed for this as measurements of its keys were not taken).

A previous study²¹ showed that consuming up to 50 pandanus keys was within the normal pattern of adult consumption and that 2- to 3-year-old children commonly consumed up to 10 keys per day, thus providing a standard for the limits of normal pandanus consumption.

Of the eight pandanus cultivars assessed, seven were found to contain carotenoid levels that could meet the total estimated vitamin A requirement for non-pregnant, non-lactating women, within the normal patterns of consumption. Three cultivars contained levels sufficient to meet the total child (2–5 years old) estimated vitamin A requirement within normal patterns of consumption.

In assessing the potential impact of consumption of the native fig (*te bero*) and *Te Katutu* giant swamp taro cultivar on meeting estimated daily vitamin A requirements, a comparison can be made to the amount of local starch foods eaten traditionally by Pacific Islanders. This is estimated at 750–1000 g daily⁴⁶. If a non-pregnant, non-lactating woman ate 1000 g of either *te bero* or *Te Katutu*, she could obtain over half her estimated vitamin A requirements. A similar comparison for 2–5-year-old children, who may eat 250 g per day, shows that these two foods might contribute to slightly less than a quarter of estimated vitamin A requirements, a smaller but important contribution. Women and children do not normally eat pumpkin and raw seeded breadfruit in such large quantities and so the impact of consumption of these foods on vitamin A status would be less, although still adding to overall intake. Bioavailability studies have not yet been carried out on these foods; these are still needed in order to confirm the contribution of the foods to meeting vitamin A requirements.

Assessment of availability and acceptability

All nine pandanus cultivars were highly acceptable, as confirmed by key informants providing information on the different cultivars (Table 5). Informants noted that although some cultivars produce a slight itchy sensation in the throat after consumption, this may be avoided by first cooking the pandanus. Some cultivars (such as *Teantinakarewe*) were more popular and well-known.

Table 4 Comparison of ripe raw Kiribati pandanus cultivars for key size and impact on vitamin A intake in terms of Recommended Safe Intake (RSI), using composition estimates from Table 1

Local name of cultivar*	Reported normal key size†	Mean sample key length (cm)‡	Mean sample key girth (cm)§	Mean sample key weight (g)¶	Mean sample key weight of edible portion (g)	β-Carotene equivalents per 100 g** (µg)	β-Carotene equivalents per key†† (µg)	RE per key‡‡ (µg)	No. of keys to meet RSI (µg RE day ⁻¹) for non-pregnant, non-lactating women§§,¶¶	No. of keys to meet RSI (µg RE day ⁻¹) for pre-school children¶¶,
<i>Tearabukitaba</i>	Medium	9 ± 1	14 ± 1	72 ± 11	36 ± 5	941	339	57	9	7
<i>Tekaureiko</i>	Medium	12 ± 1	19 ± 1	149 ± 14	89 ± 12	546	486	81	6	5
<i>Tearaonimaai</i>	Big	9 ± 0	18 ± 2	127 ± 22	59 ± 7	416	245	41	12	10
<i>Tearabaikiaro</i>	Big	10 ± 1	19 ± 2	160 ± 24	80 ± 8	266	213	36	14	11
<i>Teiribura</i>	Big	10 ± 0	23 ± 1	202 ± 24	91 ± 12	176	160	27	19	15
<i>Teatinakawae</i>	Small	7 ± 0	16 ± 2	109 ± 16	46 ± 4	164***	75	13	38	31
<i>Tearauriamaere</i>	Big	10 ± 2	20 ± 1	190 ± 21	95 ± 11	108	103	17	29	24
<i>Teanaewati</i>	Medium	8 ± 1	14 ± 1	58 ± 15	25 ± 10	102	26	4	125	100

Analyses by the Institute of Applied Science/University of the South Pacific (IAS/USP), Suva, Fiji.

* Name of Kiribati pandanus cultivar, confirmed by several informants.
† Reported by several key informants. Note that key size also varies from bunch to bunch, and by position on the bunch, in addition to cultivar variation. Note: No measurements for key size were made on the *Tearaari-ikiroa* keys.
‡ Mean calculated from measuring keys selected for the composite sample, $n = 5-9$. Measured from outer part of inedible portion to end of the edible portion.
§ Mean calculated from measuring keys selected for the composite sample, $n = 5-9$. Measured at widest point around the edible portion of the key.
¶ Mean calculated from weighing keys selected for the composite sample, $n = 5-9$. Weight of the whole key, edible and inedible portions, using a Soehnle electronic scale.
|| Weight of edible portion of the key, estimated as half the whole key size.
||| β-Carotene equivalents for the selected cultivar from sample analyses (Table 1).
†† Calculated using the mean sample key size, edible portion and the content of β-carotene equivalents per 100 g (i.e. for *Tearabukitaba*: $36 \times 941 \div 100 = 339$ β-carotene equivalents per key).
‡‡ Retinol equivalents (conversion factor 6:1 from β-carotene equivalents to RE).
§§ Calculated using the RE per key‡‡ and the estimated RSI for a non-pregnant, non-lactating female ($500 \mu\text{g RE day}^{-1}$)⁴².
¶¶ Informants report normal pandanus consumption ranging from 1 to 50 keys per day. Murali *et al.*²¹ recorded pandanus consumption for 138 people 1 year of age or over, finding that 1 to 25 keys were consumed daily, with 10 keys very common. The same study recorded that nine children, 2-3 years old, consumed 2-10 keys (mean 5 keys) daily.
||| Calculated using the RE per key‡‡ and the estimated RSI for a child 1-3 years old ($400 \mu\text{g RE day}^{-1}$)⁴².
*** Calculated as the mean of the two raw samples analysed for the *Teatinakawae* cultivar.

Table 5 Descriptions of the Kiribati pandanus cultivars selected for analysis for carotenoid content

Local name of cultivar*	Alternative name†	Key size‡	Bunch size§	Texture¶	Use	Other comments**
<i>Tearabukitaba</i>	–	Medium	Medium	Soft	Raw	Part of a legend about a man from Makin Island who woke from death and asked for a pandanus to be planted. The ripe bunch splits at the bottom, letting a few keys fall off and allowing the remaining keys to enlarge. Has a tasty white edible nut about 1 cm long in the outer part of the key. May be the same as the Marshall Islands <i>Lipjenmede</i>
<i>Tekaureiko</i>	<i>Kaureiko</i> , <i>Teraeraeti</i> , <i>Tearabuatoro</i> (in north), <i>Tearantebwe</i> (in south)	Medium	Big	Soft to hard	Raw, cooked	
<i>Tearaonimaai</i>	<i>Tearamwaorimaai</i>	Big	Big	Soft	Raw	Some informants described the texture as a bit hard
<i>Tearabaikiaro</i>	–	Big	Big	Soft	Raw, cooked	Some informants described it as a bit itchy when consumed raw
<i>Teiribubura</i>	–	Big	Big	Medium	Raw	Season is longer than for other pandanus. Distal inedible end of the key is very flat. May be the same as the Marshall Islands <i>Joiibeb</i>
<i>Teantinakarawe</i>	One name for two types	Big	Big	Soft	Raw	The two types vary by the key and bunch size. Very popular, grown on most islands. Known to be very sweet
<i>Tearauriamaere</i>	–	Small	Small	Soft	Raw	Some informants described it as a bit itchy when consumed raw
<i>Teannaewati</i>	–	Big	Big	Soft	Raw	May be the same as the Marshall Islands <i>Łojmao</i>

Data collected from key informant interviews and informal focus group discussions.

* Primary name of Kiribati pandanus cultivar listed in the order of Table 1 by greatest to lowest β -carotene content.

† Additional names by which the cultivar is known.

‡ Reported size of the whole key, including the inedible and edible portions.

§ Reported size of the bunch.

¶ Reported texture of the edible portion.

|| Reported use by consumption, either raw or cooked.

** Comments include input by key informants from the Marshall Islands after viewing either the actual Kiribati pandanus cultivars or the photographs.

Informants also pointed out that the different atolls are known for specific pandanus cultivars and that availability of the cultivars is not easy to specify, as some cultivars may be common on one island but rare on another.

The yellow-fleshed *Te Katutu* was reported as well-liked but less tasty than the white-fleshed giant swamp taro *Te Ikaraot*¹⁹. According to key informants and the literature, *te bero* is often looked upon as a last resource food²⁷, but it was marketed at the time of this data collection and showed high acceptability. The *te bero* berry (1–2 cm in diameter) is a starchy fruit with yellow-orange coloration; berries are cooked, mashed and eaten cooked in several recipes, and are also dried and stored¹⁸. This food might offer particular potential for people on the southern islands, where there are harsh growing climates and food shortages. The yellow-fleshed ripe breadfruit *Te Mai Kora* is a popular snack and is potentially a nutritious addition to the diet.

Conclusions

As far as the authors are aware, this is the first systematic screening of Kiribati pandanus cultivars and other Kiribati foods for carotenoid content using HPLC. The results of the primary study laboratory (Fiji) showed that seven Kiribati pandanus cultivars, one taro cultivar and native fig, all culturally acceptable, contain significant levels of provitamin A carotenoids capable of meeting all or half of estimated daily vitamin A requirements for non-pregnant, non-lactating adult women within normal consumption patterns. The seeded breadfruit and pumpkin contain moderate carotenoid levels for contributing to the overall dietary intake and are important on atoll island environments where vitamin A sources are scarce. Thus, these acceptable carotenoid-rich foods should be promoted for alleviating VAD. The results of the Australian laboratory confirm that preparation, handling and analytical techniques can alter the exact estimates quite significantly, so comparison of data between this and other similar papers needs to be done with this in mind and interpreted accordingly.

The ethnographic approach to selecting cultivars for the study and collecting data relating to production, consumption and acceptability factors is also essential in the process of developing food-based strategies for alleviating VAD. Finally, the approach may be of importance in planning dietary improvement in other Pacific contexts where there has been a significant shift from indigenous to imported foods and/or there is evidence of VAD.

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