



## Original Article

## Carotenoid and vitamin content of Micronesian atoll foods: Pandanus (*Pandanus tectorius*) and garlic pear (*Crataeva speciosa*) fruit

Lois Englberger<sup>a,\*</sup>, Joseph Schierle<sup>b</sup>, Peter Hofmann<sup>b</sup>, Adelino Lorens<sup>a,c</sup>, Kiped Albert<sup>a,c</sup>, Amy Levendusky<sup>a</sup>, Yumiko Paul<sup>d</sup>, Edgar Lickaneth<sup>e</sup>, Amato Elymore<sup>f</sup>, Marie Maddison<sup>g,h</sup>, Ione deBrum<sup>i</sup>, Janet Nemra<sup>i</sup>, Julia Alfred<sup>j</sup>, Nancy Vander Velde<sup>k</sup>, Klaus Kraemer<sup>b</sup>

<sup>a</sup> Island Food Community of Pohnpei, Kolonia, Pohnpei, Federated States of Micronesia (FSM)

<sup>b</sup> DSM Nutritional Products Ltd., Kaiseraugst, Switzerland

<sup>c</sup> Pohnpei Agriculture of the Office of Economic Affairs, Kolonia, Pohnpei, Federated States of Micronesia

<sup>d</sup> Pohnpei Department of Health, Kolonia, Pohnpei, Federated States of Micronesia

<sup>e</sup> Pohnpei Legislature, Kolonia, Pohnpei, Federated States of Micronesia

<sup>f</sup> FSM Department of Health and Social Services, Palikir, Pohnpei, Federated States of Micronesia

<sup>g</sup> National Training Council, Majuro, Marshall Islands

<sup>h</sup> Women United Together Marshall Islands, Majuro, Marshall Islands

<sup>i</sup> Ministry of Health, Majuro, Marshall Islands

<sup>j</sup> Youth to Youth in Health, Majuro, Marshall Islands

<sup>k</sup> Biological Consultant, Majuro, Marshall Islands

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## ABSTRACT

The fruit of pandanus (*Pandanus tectorius*) and garlic pear (*Crataeva speciosa*) are important indigenous Micronesian atoll foods, but are increasingly neglected due to dietary and lifestyle changes. Previous studies have shown considerable differences in carotenoid concentrations in some pandanus cultivars. There are many Micronesian pandanus cultivars, most of which have not been assessed. Carotenoid-rich foods protect against vitamin A deficiency, anemia, and chronic disease, including cancer, heart disease and diabetes, which are serious problems in Micronesia. Eleven pandanus cultivars of Mwoakilloa and Kapingamarangi Atolls, Pohnpei, Federated States of Micronesia (FSM) (assessed for the first time), dried pandanus paste of the Marshall Islands, and garlic pear of Mortlock Atolls, Chuuk, FSM, were analyzed for carotenoids ( $\beta$ - and  $\alpha$ -carotene,  $\beta$ -cryptoxanthin, lutein, zeaxanthin, and lycopene). Pandanus paste was assessed for 11 vitamins. The pandanus cultivars contained substantial concentrations of provitamin A carotenoids (110–370  $\mu\text{g}$   $\beta$ -carotene/100 g) and total carotenoids (990–5200  $\mu\text{g}$ /100 g). Pandanus paste contained 1400  $\mu\text{g}$   $\beta$ -carotene/100 g, 5620  $\mu\text{g}$  total carotenoids/100 g, and 10 vitamins (including 10.8 mg/100 g vitamin C). Garlic pear contained 1070  $\mu\text{g}$   $\beta$ -carotene/100 g and 1460  $\mu\text{g}$  total carotenoids/100 g. These cultivars and foods should be promoted in Micronesia and possibly elsewhere in the Pacific and other contexts in order to reduce vitamin A deficiency and provide further health benefits and enjoyment.

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### 1. Introduction

Vitamin A deficiency (VAD) is a serious health problem in the Federated States of Micronesia (FSM) and the Republic of the Marshall Islands (CDC, 2001; Kim, 2002; Palafox et al., 2003; Yamamura et al., 2004). These two independent neighboring island

countries are located in the central and northern Pacific Ocean and have populations, respectively, of 107,665 and 63,174 (July 2008 est.) (CIA, 2008). Chronic diseases, in particular diabetes, heart disease and cancer, are other serious public health problems in these regions. They are related to lifestyle changes, including the increased consumption of rice, flour, sugar, fatty foods and other imported processed foods of inferior nutritional quality; decreased physical activity; and increased rates of obesity and overweight (Coyne, 2000; Englberger, 2003; Hezel, 2004; Hughes, 2003; Pohnpei STEPS, 2002; SPC, 2002).

\* Corresponding author at: P.O. Box 1995, Kolonia, Pohnpei, 96941 FM, Federated States of Micronesia. Tel.: +691 320 3259; fax: +691 320 2127.

E-mail address: [nutrition@mail.fm](mailto:nutrition@mail.fm) (L. Englberger).

Continued efforts are needed for understanding the nutrient composition of indigenous foods, identifying foods to alleviate VAD and other nutritionally related problems, developing educational programs relating to local food promotion, and protecting the biodiversity of traditional food systems (Greenfield and Southgate, 2003; Kuhnlein, 2000; IPGRI, 2006). Foods rich in provitamin A carotenoids, including  $\beta$ -carotene (the carotenoid with the most provitamin A activity),  $\alpha$ -carotene and  $\beta$ -cryptoxanthin, protect against VAD and anemia (McLaren and Frigg, 2001). Lutein, zeaxanthin, and lycopene are other carotenoids showing demonstrated health benefits, for example, carotenoid-rich food may protect against cancer, heart disease, and diabetes (WCRF/AICR, 2007; Mares-Perlman et al., 2002; Coyne et al., 2005). Carotenoids may increase absorption of iron from cereal-based diets, which can be related to protection against anemia (Garcia-Casal, 2006).

Atolls, comprised of low-lying rings of islands typically with limited land, are subject to harsh environments. Their soil is often sandy and thin, and they are regularly subjected to droughts, salt-spray and inundation by the sea. This results in increased concerns regarding the possible effects of climate change (World Bank, 2000). These and other conditions relating to atolls make agriculture production and provision of a nutrient-rich diet a great challenge now and into the future. Thus, it is critical to have a good understanding of the carotenoid content of indigenous atoll foods.

FSM is comprised of four states (each having its own cultural identity and language or languages): Pohnpei State with its main island (mountainous), also called Pohnpei, where the national capital is located, and five atolls including Mwoakilloa and Kapingamarangi; Chuuk State consisting of a cluster of volcanic islands and 24 inhabited outer island atolls; Yap State with 11 inhabited outer island atolls; and Kosrae State, a single mountainous island. The Republic of the Marshall Islands is made up of 29 atolls (24 inhabited) and five single islands; a single

language (Marshallese) is spoken, with two slightly different dialects, for the Ralik and Ratak Chains (Ridgell, 1995).

Pandanus (*Pandanus tectorius*) is a plant that grows on both mountainous islands and flat atolls, but is particularly important on atolls as it can withstand the harsh climate and sandy saline soils. It is important for its leaves, wood, and roots, which are used for handicrafts, construction, medicine, fuel and other purposes (Merlin et al., 1997; Murai et al., 1958; Hiyane, 1971; Thomson et al., 2006). Most pandanus cultivars provide edible seasonal fruits. On Micronesia atolls, in particular those of the Marshall Islands, Kiribati and FSM, there are many pandanus cultivars used for food (Damas, 1994; Englberger et al., 2003a,b, 2006a,b). The unique composite edible fruits (Fig. 1) are made up of individual pieces called “keys” (Fig. 2) attached to a fibrous core (Thomson et al., 2006). The term “bunch” refers to the entire composite fruit (including keys and the core). The inner parts of the keys are chewed and sucked for their sweet pulp. Pandanus chewing is often considered as entertainment and the fruit is underrated for its value as a food (Bentzen, 1949) and potential health benefits.

In the Marshall Islands, pandanus (*bōb*), with over 100 documented pandanus cultivars, is a major staple food and still an integral part of life and culture (Merlin et al., 1997; Cortes et al., 2001; Pollock, 1992). In Mwoakilloa there are 23 documented cultivars of pandanus (*kipar*), 17 with edible fruits, several of which were introduced from the Marshall Islands (Bentzen, 1949). In Kapingamarangi, over 20 pandanus (*heleheu*) cultivars are documented (Miller, 1953; Englberger et al., 2003b).

Carotenoids are characterized by a yellow and orange coloration. The edible part of the pandanus key has a distinct yellow to orange coloration, varying in pattern and intensity from cultivar to cultivar. Previous work identified a number of carotenoid-rich pandanus cultivars from the Marshall Islands, Kiribati, and Kosrae (Englberger et al., 2003a, 2006a,b). However, no Pohnpei atoll pandanus cultivars were previously assessed for carotenoid



Fig. 1. A ripe bunch of the pandanus cultivar Mwajak from Mwoakilloa Atoll, still unharvested on the tree.



Fig. 2. A comparison of keys of five Mwoakilloa Atoll pandanus cultivars, showing different size, shape, and coloration: Juaiipwehpw, Luarmwe, En Kehlen, Nehnkedak, Doahpwoahdin.





**Fig. 3.** A cut open roll of Marshallese pandanus paste, as wrapped in the dried pandanus leaves, showing the brown coloration and date-like appearance.

content. Marshallese pandanus paste (*mokwan*) (Fig. 3), a product made by cooking the keys, extracting the pulp and then drying the pulp, was not assessed for a full range of vitamins using present-day standard analytical methods (Murai et al., 1958; Englberger et al., 2006a).

Garlic pear (*Crataeva speciosa*) (Fig. 4), known as *apuch* or *afuch* (Merlin and Juvik, 1996), *apuchs* (Harrison and Albert, 1977), or *abiich*, *yafuch*, *abyuuch* (Merlin et al., 1996) is a less widely grown indigenous tree crop, but has been valued as an important food in Chuuk, Pohnpei, and Yap, mainly on atoll islands (Englberger,



**Fig. 4.** (a) *Afuch* fruits still unharvested on the tree. (b) The cut pieces of *afuch* fruit, showing the orange-fleshed coloration, are presently commonly used in ornamental wreathes.

2004; Merlin et al., 1996; Murai et al., 1958). The fruits grow on a tree and are oblong in shape, about 8 cm in length (Murai et al., 1958). The skin is light green with white spots scattered over the surface. Murai et al. (1958) analyzed this fruit for several vitamins and minerals, finding it rich in vitamin C (45 mg/100 g), comparable to citrus fruit. However, despite its orange flesh coloration, indicating carotenoid content, it was not analyzed for carotenoids.

Thus, the purpose of this study was (1) to identify carotenoid-rich pandanus cultivars of Mwoakilloa and Kapingamarangi Atolls of Pohnpei State, analyzing for  $\beta$ - and  $\alpha$ -carotene,  $\beta$ -cryptoxanthin, lutein, zeaxanthin, and lycopene; (2) to assess garlic pear for its carotenoid content; (3) to assess dried Marshallese pandanus paste for its carotenoid and vitamin content (thiamine, riboflavin, nicotinic acid, Vitamin B6, vitamin B12, folic acid, calcium-D-pantothenate, vitamin C, Vitamin D3, Vitamin E, Vitamin K1); and (4) to explore factors related to production, consumption and acceptability.

## 2. Methods

A systematic ethnographic approach was used for collecting information and selecting cultivars for analysis, including key informant interviews, informal focus group discussions, observation, photography, structured sample collection and literature review (Blum et al., 1997; Fitzgerald, 1997; Kuhnlein, 2000; Kuhnlein et al., 2005). This multiple methodology ethnographic approach (Fitzgerald, 1997) was used in order to gain in-depth understanding about people's behaviors and activities and information on cultivar production, consumption, acceptability, and distinguishing characteristics relating to these pandanus cultivars. Observation and photography were used to compare and document flesh color and distinguishing characteristics of pandanus fruit. Cultivar information on samples (key length, key girth, weights with and without the inedible portion, flesh color) was recorded in a structured form. A review of past literature provided previously documented information for comparison of pandanus cultivars (Englberger et al., 2003a, 2006a,b). The sample collection kit included: an interview guide, formatted documentation list, labeling tape and marker, zip-lock sample bags, DSM Yolk Color Fan, digital camera, measuring tape, and vacuum-pack sealing machine (FoodSaver Vac 750/Ultra).

### 2.1. Material

Key informants indicated the availability of a number of pandanus cultivars on Mwoakilloa Atoll, which was accessible by a short airplane trip. Representatives from the island indicated the willingness of the Mwoakilloa community to participate in the study. Samples of fruit of six pandanus cultivars (from 6 to 10 keys per sample) were collected from Mwoakilloa Atoll in November 2003, with three further cultivar samples (from one to six keys per sample) collected in November 2004. Visits to the atoll were scheduled to match the primary pandanus season (from November to January) and available flights, but pandanus cultivars also vary for seasonality. Due to the difficulties of getting raw pandanus samples from this remote atoll and lack of information on the cultivars, a sample comprised of just one key was also accepted in the sample set.

The lead author was present during the collection of both sample sets. Key informants also indicated that there would be many pandanus cultivars on Kapingamarangi Atoll. Due to the remoteness of Kapingamarangi Atoll (accessible only by ship with irregular schedules), samples of pandanus cultivars were obtained in 2003 by a person collecting the whole bunches and bringing them by ship. The garlic pear sample was obtained in 2003 by a person collecting the fruit from the Mortlocks atolls of Chuuk and

bringing them by ship. A large roll (~3 kg) of Marshallese cooked dried pandanus paste, *mokwan*, packaged traditionally in dried pandanus leaves and tied tightly with hand-woven coconut rope, was obtained in 2006. This roll is made by cooking the flesh of many keys of pandanus and therefore represents a composite sample of pandanus.

## 2.2. Selection, documentation and preparation of samples

Efforts were made to collect at least six keys (the individual pieces or fruits of the bunch) for each pandanus cultivar sample. Due to rarity of cultivars, seasonality, and the remote location of the atoll, not easily allowing follow-up visits for sample collection, the six keys were collected from the same bunch and plant.

For the sample preparation, the inedible portions of the keys were removed and the edible portions were weighed (Table 1), to provide understanding about the size of the edible portions per key. As samples had to be transported long distances and space was relatively limited, equal parts of the edible portions were cut depending on the size of the keys, in order to have a composite sample of around 250–350 g per cultivar. The raw samples were prepared and frozen in a home freezer (–10 °C) until it was possible to hand-carry the samples to the laboratory where the samples were stored in laboratory freezers (–20 °C). The time period for storing the samples in the home freezer was 2 months for the first set of eight sample cultivars and 12 months for the remaining three sample cultivars.

The raw garlic pear fruits were peeled and frozen. In order to ensure stability of the nutrients in the stored samples prior to analysis, the air was manually removed from the sample bags for the first set of sample pandanus cultivars and garlic pear to decrease oxidation and samples were double bagged. For the second sample set, vacuum sealing was used for decreasing oxidation and better preserving carotenoids. For the first set of sample pandanus cultivars and garlic pear, samples were placed in ziplock plastic sample bags and air manually removed prior to freezing, whereas vacuum sealing was used for the second sample set of pandanus cultivars in order to decrease oxidation and better preserve carotenoids (as noted below samples from the two sealing methods are not fully comparable). The cooked dried pandanus paste, as packaged traditionally, is reported by local informants to

keep at room temperature for many years (Merlin et al., 1997). Thus, this paste was carried and delivered to the laboratory in its traditional wrapping of pandanus leaves. Samples were labeled by name, source, description, and date of sampling.

The edible portion of raw keys of each pandanus cultivar was assessed visually for its color and the color was also estimated using the DSM (formerly Roche) Yolk Color Fan (manufactured in Basel, Switzerland, available at DSM Nutritional Products, Model number-2004-HMB 5148). It is composed of 15 segments of increasing intensities of yellow, orange, and orange-red numbered from 1 to 15. This fan was developed for objectively judging egg yolk color (Vuilleumier, 1969), but has been useful for standardizing assessment of flesh color of plant foods, including pandanus (Englberger et al., 2006a,b).

## 2.3. Sample allotments, storage, and transport to the laboratory

As there are no laboratories on the islands where the study was conducted, the samples were taken overseas to the DSM Nutritional Products (formerly Roche Vitamins Ltd.), Kaiseraugst, Switzerland, for analyses. Due to the lack of direct flights, the samples could not be air-freighted to the laboratory, but were hand-carried, aiming at keeping samples frozen throughout the transport by wrapping in paper and packing with gel-ice (dry ice not allowed by airlines) inside a styrofoam container. It is possible that some samples thawed during long in-transit periods during transport (samples were checked when possible and when opening the cooler did not endanger the samples to thaw further, e.g. no freezer availability). As carotenoids are destroyed during thawing (Rodriguez-Amaya, 1999), it is important to avoid repetitions of freezing, thawing and refreezing. Quarantine requirements for transporting the samples were met.

## 2.4. Chemical analysis

Standard methods of analysis were used (AOAC, 2005), including high-performance liquid chromatography (HPLC) for carotenoids using an Agilent 1100 system equipped with a DAD detector, produced in Santa Clara, USA. Prior papers describe the details for the carotenoid analyses and quality control measures (Englberger et al., 2003c, 2006a,b). The laboratory conducted

**Table 1**

Comparison of Mwoakilloa and Kapingamarangi pandanus cultivars for key size and impact on vitamin A intake in terms of Recommended Safe Intake (RSI), using composition estimates from Table 2.

Pandanus cultivar <sup>a</sup>	Sample key length (cm) <sup>b</sup>	Sample key girth (cm) <sup>c</sup>	Sample edible portion weight (g) <sup>d</sup>	β-Carotene equivalents μg/100 g <sup>e</sup>	β-Carotene equivalents μg/key <sup>f</sup>	RE μg/key <sup>g</sup>	# of keys to meet RSI μg RE/day for non-pregnant, non-lactating female adult <sup>h</sup>
<i>Juaipwehpw</i>	8	20	62	405	251	42	12
<i>Luarmwe</i>	9	17	58	345	200	33	15
<i>Binu-Dolongahai</i>	9	14	70	335	235	39	13
<i>Nehnkedak</i>	8	17	50	330	165	28	18
<i>Kipar en Majal</i>	10	20	83	295	245	41	12
<i>Mwajak</i>	9	20	72	260	187	31	16
<i>Jorum</i>	8	16	45	265	119	20	25
<i>Mehkilkil</i>	7	14	32	210	67	11	45
<i>Doapwoadin</i>	11	18	78	195	152	25	20
<i>Binu-Dalinga</i>	7	12	40	190	76	13	38
<i>En Kehlen</i>	9	17	56	125	70	12	42

<sup>a</sup> Local name of pandanus cultivar where sample was collected. All cultivars are from Mwoakilloa except Binu-Dolongahai and Binu-Dalinga, which are from Kapingamarangi.

<sup>b</sup> Mean key length calculated from the sample keys.

<sup>c</sup> Mean girth calculated from the sample keys.

<sup>d</sup> Mean edible portion weight calculated from weighing keys with inedible portion removed.

<sup>e</sup> Taken from Table 1.

<sup>f</sup> Calculated from sample key size (edible portion) and the content of β-carotene equivalents per 100 g.

<sup>g</sup> Retinol equivalents (RE) (conversion factor 6:1 from β-carotene equivalents to RE).

<sup>h</sup> Calculated using RE/key and the estimated Recommended Safe Intake (RSI) for a non-pregnant, non-lactating female, 500 μg/day (WHO/FAO, 2004). Note that normal pandanus consumption can range from 20 to 50 keys per day for adults as reported in this study and previous studies (Murai et al., 1958).

duplicate analyses and reported the means of the two complete analyses performed with the same homogenate. The homogenates were prepared by mixing approximately 30 g of sample for 30 s at 5000 rpm using a knife mill (Grindomix, Retsch Ltd.). Immediately after grinding portions of 1–2 g of the homogenate were extracted. The standard error of the mean (S.E.M.) of the double determinations were <10% for all measured carotenoids. The recovery of the method was >95% for all measured carotenoids: beta- and alpha-carotene, beta-cryptoxanthin, lutein, zeaxanthin, and lycopene. Most vitamins were analyzed by HPLC, folate acid by a microbiological method and vitamin C by titration (Keller, 1988). Thiamine was extracted using 0.1N sulphuric acid. Quantification was done with reversed-phase HPLC and post-column derivatization with fluorescence detection. Riboflavin and its coenzyme forms were extracted with 0.1N sulphuric acid in an autoclave at 120 °C. After neutralization, the enzyme treatment removed the phosphate groups. The riboflavin content in the extract was determined by reversed-phase HPLC and fluorescence detection. Nicotinic acid was determined by reversed-phase HPLC and UV detection after extraction with 0.001N sulphuric acid. Vitamin B6 was extracted using sodium acetate buffer and analyzed using reversed-phase HPLC with fluorescence detection (Bergaentzle et al., 1995). Vitamin B12 and folic acid were analyzed after aqueous extraction by means of microbiological assays. Calcium pantothenate was analyzed after aqueous extraction by an LC–MS method. Ascorbic acid was extracted with aqueous oxalic acid and quantified titrimetrically with potentiometric end point determination. Vitamin D3 was extracted with hexane after alkaline saponification. D2 was used as internal standard. The crude extract was cleaned in a semi-preparative HPLC. The fraction containing D2 and D3 was quantified by HPLC with UV detection (Comité Européen de normalization, 2008). Vitamin E was analyzed after alkaline saponification and extraction with hexane by HPLC and fluorescence detection (Comité Européen de normalization, 2008). Vitamin K1 was determined following enzymatic digestion, extraction and subsequent HPLC with post-column reduction with zinc and fluorescence detection (Indyk and Woollard, 1997). Percent recoveries were performed with regard to the vitamin analyses, showing around 90% (estimated).

Although the analysis of certified reference materials for vitamins and carotenoids is not part of the regular quality control of the DSM laboratory, the laboratory regularly takes part in National Institute of Standards and Technology (NIST) programs, e.g. round robins for carotenoids, ensuring good quality control.

The first set of pandanus cultivar samples were collected in November 2003 and analyzed March 2004. The second set of pandanus cultivar samples were collected November 2004 and analyzed May 2006. The pandanus paste was collected September 2005 and analyzed January 2006.

### 2.5. Assessment of carotenoid content and impact on vitamin A requirements

The pandanus and garlic pear items were assessed for provitamin A carotenoid content and potential contribution for meeting the estimated vitamin A requirements (WHO/FAO, 2004) for non-pregnant, non-lactating women as this population groups are particularly vulnerable to vitamin A deficiency (McLaren and Frigg, 2001). The  $\beta$ -carotene equivalent value was calculated from the HPLC analyses by adding the  $\beta$ -carotene content and half the sum of  $\alpha$ -carotene and  $\beta$ -cryptoxanthin content. The retinol equivalent (RE) value was calculated according to the conversion factor 6  $\mu$ g  $\beta$ -carotene to 1  $\mu$ g retinol (WHO/FAO, 2004). The retinol activity equivalent (RAE) was calculated for each cultivar, using the conversion factors 12:1 for  $\beta$ -carotene equivalents (Institute of Medicine, 2001).

## 3. Results and discussion

Of the 21 pandanus cultivars reported for Mwoakilloa, nine cultivar samples were collected, confirming cultivar identity with local pandanus experts. The two pandanus cultivars from Kapingamarangi were confirmed by local pandanus experts as different from those cultivars collected from Mwoakilloa.

### 3.1. Reconciliation for pandanus and garlic pear name spellings

The spellings for the local names for the pandanus cultivars and garlic pear were taken from current spelling systems (Harrison and Albert, 1977; Abo et al., 1976; Lieber and Dikepa, 1974; Merlin et al., 1996; Merlin and Juvik, 1996).

### 3.2. Assessment of carotenoid content of the pandanus samples

Of the 11 pandanus cultivars, the  $\beta$ -carotene concentrations ranged from 110 to 370  $\mu$ g/100 g (Table 2). Concentrations of  $\alpha$ -carotene and  $\beta$ -cryptoxanthin were low (from <10 to 60  $\mu$ g/100 g) and were similar for most cultivars. Concentrations of lutein and zeaxanthin significantly exceeded  $\alpha$ -carotene and  $\beta$ -cryptoxanthin concentrations for most cultivars and in one cultivar the zeaxanthin concentration exceeded that of  $\beta$ -carotene (*Juapwehpw*). In general, the zeaxanthin concentrations of the pandanus samples were considerably greater than lutein concentrations, similar to Marshallese pandanus (Englberger et al., 2006b). This is in contrast to other Micronesian staple foods (such as banana, giant swamp taro and breadfruit), for which lutein concentrations are generally greater than zeaxanthin concentrations (Englberger et al., 2003c). Lycopene was not found in these pandanus samples.

The total carotenoid concentrations of these pandanus cultivars ranged from 990 to 5200  $\mu$ g/100 g. Compared to previous studies using similar analytical methods, the lowest in this study was 990  $\mu$ g/100 g, whereas the lowest in the previous studies was 154 and 260 (of nine Kiribati cultivars concentrations ranged from 154 to 3602  $\mu$ g/100 g and of 13 Marshallese cultivars concentrations ranged from 260 to 3130  $\mu$ g/100 g) (Englberger et al., 2006a,b).

Water content was similar among samples (from 79 to 82%), allowing comparisons of nutrient content in relation to moisture. Two of the samples prepared with vacuum-sealing (*Juapwehpw* and *Luarmwe*) ranked among the top two concentrations of  $\beta$ -carotene and the third, *Nehnkedak*, had the fourth highest concentrations. There were no striking color differences among the samples that would indicate differences in carotenoid concentrations. Thus, it is likely that the vacuum sealing protected carotenoid content due to reduced sample oxidation during the sample storage and transport.

In comparison to past studies of pandanus cultivars analyzed using similar analytical methods, none had concentrations as high as the Kiribati cultivar, *Tearabukitaba* (896  $\mu$ g beta-carotene/100 g), or the Marshallese cultivar, *Lañlōñ* (670  $\mu$ g beta-carotene/100 g), and none had low  $\beta$ -carotene concentrations such as the Marshallese *Ĵōjmao* (30  $\mu$ g beta-carotene/100 g) or Kosrae *Mweng Choipep* (19  $\mu$ g beta-carotene/100 g) (comparing raw samples only) (Englberger, 2003; Englberger et al., 2006a,b). Flesh color assessments showed that there were no cultivars with deep orange or light yellow coloration, which would indicate substantial and low concentrations respectively, confirming the concentrations found by the laboratories in this study. However, it should be noted that factors of sample preparation (including if vacuum sealing was used or not), transport (if frozen samples thawed), storage, natural variation, and environment, may substantially affect analysis results of carotenoid content, in addition to cultivar



**Table 2**  
Carotenoid content of ripe raw Micronesian pandanus (*Pandanus tectorius*) cultivars, pandanus paste, and garlic pear (*Crataeva speciosa*) ( $\mu\text{g}/100\text{ g}$  edible portion, means of duplicate analyses).

Pandanus cultivar and other items <sup>a</sup>	Source <sup>b</sup>	N <sup>c</sup>	Color of flesh <sup>d</sup>	$\beta$ -Carotene	$\alpha$ -Carotene	$\beta$ -Cryptoxanthin	$\beta$ -Carotene eq <sup>e</sup>	RE <sup>f</sup>	RAE <sup>g</sup>	Lutein	Zeaxanthin	Lycopene	Total carotenoid <sup>h</sup>	Water (%)
<i>Juaipwehpw</i> <sup>i</sup>	Mwoakilloa	1	Yellow/Orange (Y/O)	370	60	<10	405	68	34	170	390	na	990	77
<i>Luarmwe</i> <sup>i</sup>	Mwoakilloa	6	Y/O	310	50	20	345	58	29	110	290	na	5200	82
<i>Binu-Dolongahai</i>	Kapinga	10	Y/O: 5–14, mostly 9	300	50	20	335	56	28	130	220	<sup>j</sup>	2510	80
<i>Nehnkedak</i> <sup>i</sup>	Mwoakilloa	6	Y/O	290	60	20	330	55	28	150	140	na	1930	79
<i>Kipar en Majal</i>	Mwoakilloa	7	Y/O: 8–11, mostly 8	280	10	20	295	49	25	20	110	<sup>j</sup>	1470	79
<i>Mwajak</i>	Mwoakilloa	6	Y/O: 9–14, mostly 10	250	10	10	260	43	22	20	160	<sup>j</sup>	1670	80
<i>Jorum</i>	Mwoakilloa	6	Y/O: 9–11, mostly 9	240	40	<10	265	44	22	180	160	<sup>j</sup>	1500	80
<i>Mehkilkil</i>	Mwoakilloa	7	Y/O: 5–9, mixture	190	30	<10	210	35	18	90	<sup>j</sup>	<sup>j</sup>	1510	82
<i>Doapwoadin</i>	Mwoakilloa	6	Y/O: 3–14, mixture	180	20	10	195	33	16	70	110	<sup>j</sup>	1170	78
<i>Binu-Dalinga</i>	Kapinga	6	Y/O: 8–14, mostly 9	180	10	10	190	32	16	40	100	<sup>j</sup>	1920	79
<i>En Kehlen</i>	Mwoakilloa	6	Y/O: 9–14, mostly 9	110	<10	20	125	21	10	40	20	<sup>j</sup>	1100	81
Dried pandanus paste, <i>mokwan</i>	Marshall Islands	–	Dark brown	1400	120	na	1460	243	122	1420	2680	na	5620	na <sup>k</sup>
Garlic pear, <i>apuch</i> <sup>i</sup>	Mortlocks	2	Orange: 6–100%	1070	10	10	1080	180	90	30	20	40	1460	83

Note: HPLC analyses by DSM Nutritional Products, Switzerland. na: not analyzed. The first set of pandanus cultivars and the garlic pear were collected November 2003, and analyzed March 2004. The second set of pandanus cultivars was collected November 2004 and analyzed May 2006. The dried pandanus paste was collected September 2005 and analyzed May 2006.

<sup>a</sup> Local name where sample was collected. The pandanus paste was prepared by baking the keys, extracting the pulp, drying in a thin layer in the sun. The garlic pear sample was ripe and raw.

<sup>b</sup> Samples are from Mwoakilloa and Kapingamarangi (Kapinga) Atolls, Pohnpei, Federated States of Micronesia (FSM); Republic of the Marshall Islands; and Mortlock Islands, Chuuk, FSM.

<sup>c</sup> Number of keys or fruits in sample (inedible portions were discarded).

<sup>d</sup> Raw flesh color was described visually on all items. Coloration was estimated on some items using the DSM Yolk Color Fan, numbers ranging from 1 to 15 for increasing coloration of yellow and orange (Y/O).

<sup>e</sup> Content of  $\beta$ -carotene plus half of the content of  $\alpha$ -carotene and  $\beta$ -cryptoxanthin.

<sup>f</sup> Retinol Equivalents (RE) (conversion factor 6:1 from  $\beta$ -carotene equivalents to RE).

<sup>g</sup> Retinol Activity Equivalents (RAE) (conversion factor 12:1 from  $\beta$ -carotene equivalents to RAE).

<sup>h</sup> Estimated by calculating total peak area recorded in the chromatograms (using the response factor of  $\beta$ -carotene); this includes xanthophyll- and cryptoxanthin-like compounds.

<sup>i</sup> Sample prepared using vacuum sealing.

<sup>j</sup> Not detected.

<sup>k</sup> Similar samples of pandanus paste contained 14 and 17% water content in previous analyses (Englberger et al., 2006a,b).

differences (Rodriguez-Amaya, 1999), so care should be taken in making cultivar comparisons.

The dried Marshallese pandanus paste contained 1400  $\mu\text{g}$   $\beta$ -carotene, 1420  $\mu\text{g}$  lutein, 2680  $\mu\text{g}$  zeaxanthin and 5620  $\mu\text{g}$  total carotenoids/100 g, much higher than in previous analyses of this product using similar analytical methods (724 and 140  $\mu\text{g}$   $\beta$ -carotene, 210  $\mu\text{g}$  lutein, 120  $\mu\text{g}$  zeaxanthin, and 540 and 1321  $\mu\text{g}$  total carotenoids/100 g) (Englberger et al., 2006b).

The carotenoid concentrations in this paste were higher than those in a Kiribati pandanus paste also analyzed by HPLC (444 and 390  $\mu\text{g}$   $\beta$ -carotene, 310  $\mu\text{g}$  lutein, 190  $\mu\text{g}$  zeaxanthin, and 1200  $\mu\text{g}$  total carotenoids) (Englberger et al., 2006a), which may reflect many factors as listed above. In particular, this sample was transported to the laboratory in its traditional wrapping, without opening to the air or freezing, whereas previous samples transported to the laboratory were first cut from a large piece, and then re-packed and frozen. Present-day Marshallese and Kiribati pandanus paste vary greatly by their packaging, with the Marshallese paste generally wrapped tightly in the traditional pandanus leaf wrapping, whereas modern-day Kiribati paste is often cut into small pieces (typically 200 g) and stored loosely in various types of containers with little protective wrapping, thus allowing greater oxidation and possibility for carotenoid destruction. Further studies are needed in order to determine nutrient content differences in the products and preparation and storage methods that may maximize nutrient content preservation.

Overall, these results show that despite the sun-drying used to make pandanus paste (sun-drying is known to destroy carotenoids) (Rodriguez-Amaya, 1999), the paste is still carotenoid-rich. The method of preparing pandanus paste, first cooking keys and sometimes cooking the extracted pulp a

second time (with cooking allowing better extraction of carotenoids) (Rodriguez-Amaya, 1999), may contribute to producing a carotenoid-rich product.

### 3.3. Relationship of color to carotenoid content

The estimates of darker and lighter orange/yellow coloration did not clearly correspond with higher and lower carotenoid content. However, it was difficult to estimate coloration in these pandanus keys due to the subtle nature of the coloration patterns, the difficulties in estimating coloration in both inner and outer parts, and the coloration differences were not subtle and difficult to compare.

### 3.4. Assessment of impact on vitamin A requirements

Key informants in this and other studies indicate that consuming 20–50 keys in a day would be within normal patterns of consumption, particularly on atolls where there are few other foods (Englberger et al., 2003a, 2006b; Murai et al., 1958). Table 2 shows that the recommended safe intakes for vitamin A for a non-pregnant, non-lactating woman could be met with normal patterns of consumption of all cultivars, assuming that a woman may consume up to 50 keys. However, it should be pointed out that pandanus is a seasonal crop and is available in large amounts only during limited periods of time (about 4–5 months per year, including the major and minor seasons).

### 3.5. Assessment of vitamin content of pandanus paste

Pandanus paste contained 10 vitamins, including a similar concentration of vitamin C as that found in common banana, but

**Table 3**

Vitamin content of cooked dried pandanus paste *mokwan* (mg/100 g edible portion, means of duplicate analyses) compared with the content of dried pandanus paste, garlic pear and common banana determined in other studies.

Food Item	Thiamine	Riboflavin	Nicotinic acid <sup>a</sup>	Vitamin B <sub>6</sub> pyridoxines	Vitamin B <sub>12</sub> cyanocobalamin	Folic acid	Calcium-D-pantothenate	Vitamin C	Vitamin D <sub>3</sub>	Vitamin E	Vitamin K <sub>1</sub>
Marshallese dried pandanus paste, present study <sup>c</sup>	0.55	0.04	1.49	1.13	0.0073	0.008	0.46	10.8	<sup>b</sup>	0.31	0.0039
Marshallese dried pandanus paste, past study <sup>d</sup>	0.04	0.06	2.5	na	na	na	na	1.5	na	na	na
Garlic pear, <i>apuch</i> , fresh <sup>d</sup>	0.03	0.04	0.5	na	na	na	na	45.3	na	na	na
Common banana, fresh <sup>e,f</sup>	0.04, 0.07	0.06, 0.08	0.7	0.29	0	0.014	0.36	11, 17.3	0	0.27, 0.4	na

Note: Pandanus paste (*mokwan*) of present study collected in September 2005. Analyses of *mokwan* carried out by DSM Nutritional Products Ltd., Switzerland, May 2006. na: not analyzed.

<sup>a</sup> Nicotinamide was analyzed, but not detected.

<sup>b</sup> Not detected.

<sup>c</sup> Paste prepared by baking keys, extracting pulp, sun-drying (in ~0.3 cm thick layer), rolling and wrapping tightly in dried pandanus leaves.

<sup>d</sup> Murai et al. (1958).

<sup>e</sup> Dignan et al. (2004).

<sup>f</sup> Holland et al. (1991).

considerably less than that in garlic pear, which reflects the importance of that fruit nutritionally (Table 3).

### 3.6. Assessment of carotenoid content of garlic pear

The raw garlic pear sample contained significant concentrations of  $\beta$ -carotene and total carotenoids (1070 and 1460  $\mu\text{g}/100\text{ g}$ , respectively). Concentrations of  $\alpha$ -carotene,  $\beta$ -cryptoxanthin, lutein, zeaxanthin, and lycopene were low, but still present. It was remarkable that the concentration of lycopene was slightly greater than those of  $\alpha$ -carotene, lutein, and zeaxanthin, as lycopene has generally not been detected in other Micronesian atoll crops or cultivars, including pandanus, giant swamp taro and banana (Englberger et al., 2006b,c, 2008).

### 3.7. Assessment of factors of production, consumption and acceptability

Key informants from the Pohnpei atolls of Mwoakilloa and Kapingamarangi and from the Marshall Islands pointed out that although pandanus fruit is still highly valued on their islands, the consumption has greatly declined in comparison to the past, and there is a trend for the fruit to be consumed as the raw key, whereas in the past much cooked pandanus was consumed. There is still considerable indigenous knowledge relating to pandanus cultivars and their production and food preparation methods, but there is concern about the loss of this knowledge, especially among the youth. A similar situation for garlic pear was reported by key informants from those islands where garlic pear has been an important food, eaten raw or cooked in coconut cream, in particular in the Mortlocks of Chuuk, Mwoakilloa of Pohnpei, and in Yap. Garlic pear may have a repugnant taste to those not used to eating it, but has been considered a delicacy by those who grew up eating this food.

## 4. Conclusions

This study enriches previous studies on Micronesian pandanus, showing that 11 pandanus cultivars from Pohnpei atolls (Mwoakilloa and Kapingamarangi) (analyzed for the first time), contain substantial concentrations of provitamin A and total carotenoids. Garlic pear from the Mortlock Atolls of Chuuk (analyzed here for the first time for carotenoid content as far as these authors are aware) also has substantial concentrations of carotenoids. These

pandanus cultivars and garlic pear should therefore be promoted for their potential health benefits, including protection against vitamin A deficiency, as well as anemia, cancer, heart disease, and diabetes (McLaren and Frigg, 2001; WCRF/AICR, 2007; Mares-Perlman et al., 2002; Coyne et al., 2005; Garcia-Casal, 2006).

The carotenoid concentrations in the pandanus paste sample in this study were considerably higher than those in previous analyses, which may be at least partly due to sample preparation, storage and transport differences. The results indicate that it is likely that the vacuum-pack sealing of the pandanus cultivars (prepared as frozen samples) protected the samples from carotenoid destruction. This presents the likelihood that those cultivars sampled and analyzed in the past, and prepared without vacuum sealing, may have greater carotenoid concentrations in fresh samples than reflected in the results now available. The logistics of collecting samples from remote atolls and storing and transporting as frozen samples to far-away laboratories are a challenge, but in order to promote these food crops for their maximum potential benefits, it is important to repeat the studies carried out previously, this time using vacuum sealing and standardizing sampling, storage, transport, and analysis methods as best as possible. This is particularly important for atolls where agriculture production has such restraints.

Further work is needed in characterizing the cultivars and determining those cultivars with multiple names. The findings of this study may be important to other Pacific Island countries where pandanus is an important food. The ethnographic approach to identifying the cultivars and understanding the factors of production, consumption, and acceptability continues to be an essential part of the documentation and promotion of this important food crop.

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