



Original Article

Micronesian banana, taro, and other foods: newly recognized sources of provitamin A and other carotenoids

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Abstract

Vitamin A deficiency (VAD) and chronic diseases are serious problems in the Federated States of Micronesia and other Pacific island countries. Nutrition education programs to address these in Micronesia have had limited success, partly due to lack of information on nutrient content in local foods. The study objective was to identify local plant foods rich in provitamin A and other carotenoids that have high levels of cultural acceptability. Food cultivars likely to be carotenoid-rich (suggested by coloration) were identified using an ethnographic approach including key informant interviews. Raw and cooked samples (mostly cultivars previously not analyzed) of 12 banana, 13 giant swamp taro, 10 breadfruit cultivars and four other local foods were analyzed by high-performance liquid chromatography. Many banana and taro cultivars were found with significant levels of β - and α -carotene; the β -carotene levels ranged from 30 to 2780 $\mu\text{g}/100\text{ g}$ (banana) and 50 to 2040 $\mu\text{g}/100\text{ g}$ (taro). The results highlight the potential significance of cultivar differences in human nutrition, important for evaluation of the diet, establishment of locally relevant dietary guidelines, and research on the relationship between diet, health, and disease. These highly acceptable food cultivars could play an important role in VAD and chronic disease prevention programs in the Pacific.

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1. Introduction

Vitamin A deficiency (VAD) is a serious problem in all four states of the island country of the Federated States of Micronesia (FSM), Chuuk, Pohnpei, Yap, and Kosrae, and some other

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Pacific island countries (Lloyd-Puryear et al., 1991; Auerbach, 1994; Centers for Disease Control and Prevention, 2001; Palafox, 1995; Ross & Trowbridge, 1994; Schaumberg et al., 1995). Chronic disease is also a growing problem (Shmulewitz et al., 2001; Coyne, Badcock, & Taylor, 1984). Provitamin A carotenoids are important for the prevention and cure of VAD (McLaren & Frigg, 2001). Epidemiological evidence suggests that carotenoid-rich foods protect against some chronic diseases, including certain types of cancer, cardiovascular disease, diabetes, and age-related macular degeneration (World Cancer Research Fund, 1997; Bertram, 2002; Mares-Perlman, Millen, Ficek, & Hankinson, 2002). There is, however, little accurate information on the composition, use, and acceptability of local FSM foods that might address these health issues. Such an information is important for the evaluation of the diet, the establishment of locally relevant dietary guidelines, and future nutritional research on the relationship between diet, health, and disease.

The problem of VAD in FSM was first documented in the late 1980s. It appears that the problem is new (Lloyd-Puryear et al., 1989) and is related to great dietary changes in the past four decades (Englberger, Marks, & Fitzgerald, 2003c). Imported foods containing little or no provitamin A carotenoids, such as white rice, flour, and sugar, have increasingly replaced local staple foods, including banana, giant swamp taro, and breadfruit. Factors relating to this diet transition have been attributed to convenience, cost, and prestige of imported foods, changing lifestyles, tastes, and family structure, transition from a subsistence to market economy, urbanization, government policies and food aid (Hezel, 2001; Coyne et al., 1984; Rody, 1978).

It is not clear which foods protected the FSM population from VAD in the past. Vitamin-A-rich sources such as milk (only available as imported), liver, chicken eggs, and dark green leafy vegetables (McLaren & Frigg, 2001) were not commonly eaten (Englberger et al., 2003c). Dark green leafy vegetables were considered food for animals; they were promoted in recent nutrition programs, but were not well accepted and did not make a significant impact on food consumption habits (Barker, 1996; Englberger, Elymore, Meyshine, & Hawley, 1999). Mango and papaya are often eaten green (a stage in which carotenoid content is low). The most common local plant foods are breadfruit, banana, and giant swamp taro (Fischer & Fischer, 1957). The edible portions of some cultivars of these foods have different grades of orange and yellow coloration, indicating carotenoids (Rodriguez-Amaya, 1997). However, most of these staple foods have never been analyzed for carotenoid content.

Thus, a study on local plant foods potentially rich in provitamin A carotenoids and with high levels of cultural acceptability was undertaken. One stage of the study was to identify orange- or yellow-colored foods and cultivars having the most potential for carotenoid content, and then to analyze them by high-performance liquid chromatography (HPLC).

The plan was to analyze for β - and α -carotene, the carotenoids contributing most to vitamin A (VA) (McLaren & Frigg, 2001), and lutein, zeaxanthin, and total carotenoids due to their suggested protective role against some chronic diseases.

2. Materials and methods

The study used ethnographic methods (Kuhnlein & Pelto, 1997; Blum, Pelto, Pelto, & Kuhnlein, 1997; Fitzgerald, 1997) to identify the foods to investigate. The identified foods were

then prepared in raw and cooked form for an HPLC-analysis at Roche Vitamins Ltd., Basel, Switzerland. Sample collection and preparation took place in late 2000 and early 2001. Samples were analyzed in March 2001.

2.1. Selection and preparation of samples

Samples of the staple foods were selected from cultivars with the greatest yellow coloring and from other cultivars with little yellow coloring for purposes of comparison. Four other foods for which no carotenoid data were available were also selected for analysis.

An ethnographic approach was undertaken to select the cultivars to be analyzed. The primary researcher spent 5 weeks in Kosrae (October–November 2000) and 12 weeks in Pohnpei (September–December 2000 and January 2001) for interviews, sample collection, and field notes preparation. Interviews with key informants ranged from 15 min to 3 h. Some key informants were interviewed repeatedly throughout data collection. Key informants, including men and women, agriculture, education, and health officers, non-governmental organization officers, farmers, and elder people, were asked to freely list all cultivars that they knew and to name which had the most yellow-colored edible portion. Information was collected on production, acquisition, consumption, and cultural acceptability of the foods. Photos were taken to assist in identifying and documenting foods and food practices.

To assist in identification of cultivars to analyze and to locate data on carotenoid analyses carried out elsewhere on banana, giant swamp taro, and breadfruit for purposes of comparison, three Pacific e-mail networks (PacNut-Pacific Nutritionists, RootcropsNet and PestNet), and the FAO-based INFOODS network were contacted. Lists of local cultivar names were collected from published documents (Merlin et al., 1992; Merlin, Taulung, & Javik, 1993; Raynor, 1991; Debusse, 1996; Kosrae Department of Agriculture, 2001) and the unpublished food list of the Kosrae Food Systems Study 1992–3 (Nero, Burton, Jonas, & Taulung, 2000). Due to rarity, seasonality, and a lack of marketing of many of the foods for which samples were sought, the collection of the samples required considerable time and effort. Government agriculture officers assisted in the visits to farmers.

When possible, three or more pieces per food sample, all of high quality, were collected to achieve a representative sample. Banana and breadfruit samples were taken at the ripest edible stage. Giant swamp taro samples were taken from corms of older more mature plants (over 3 years age). Peelings, inedible portions, and low-quality spots were removed. Cooked and raw samples were prepared for a number of banana, taro, and breadfruit cultivars to study the effect of cooking on carotenoid content.

Because there are no HPLC analytical facilities in the country, samples were sealed in zip-lock plastic bags, frozen and transported to the laboratory (continuous cold chain). As strict quarantine regulations had to be met, some food items were sent only in the cooked state. All samples were identified by a local name, place of collection, maturity, if cooked or raw, cooking method and length. One set of samples was prepared from September to November 2000 and hand carried to the laboratory in December 2000. The other set was prepared in January 2001 and hand carried to the laboratory in February 2001.

2.2. Chemical analysis

In the analytical laboratory, the samples were stored frozen at -20°C until the day of analysis.

Acetone extraction: After thawing, each of the fruits or vegetables available per sample (2–4 items) was cut into two parts of similar size using a knife. One half was taken from each item; the halves were pooled and homogenized in a food mixer (Grindomix[®] GM200, Retsch). Approximately 2 g homogenate was exactly weighed into an empty 10 ml SPE plastic column fitted with a single 10- μm pore frit and mounted on an SPE manifold (Visiprep[®], Supelco). The sample was extracted with 8 ml acetone by dispersion with a rotation mixer (RT 1300 D, Polytron) and the extract filtered by vacuum into a 25-ml volumetric flask. The procedure was repeated twice with two further 8-ml portions of acetone. A previous experiment had shown that a further repetition of this extraction step did not increase the measurable amount of total carotenoid. The extracts were combined in the volumetric flask and made up to volume with acetone. Four-milliliter portions of the acetone extract were pipetted into two 10-ml test tubes and evaporated in a SpeedVac[®] (Plus SC210A, Savant) under reduced pressure at approximately 45°C . Each of the dry residues was dissolved in 1 ml of the different mobile phases of the normal- and reversed-phase HPLC-systems used to quantify the amount of total carotenoid. Before injection, the extracts were purified in the LC-vials by centrifugation at 3000 *g* for 5 min.

Saponification: Fifteen milliliters of the acetone extract were evaporated in a 100-ml round-bottom volumetric flask by means of a rotavapor at 50°C and reduced pressure. The residue was dissolved in 40 ml ethanol and 6.5 ml *t*-butyl-methyl-ether (added to decrease the boiling point of the mixture). Three and a half milliliters of aqueous potassium hydroxide (50%, w:w) were added and the mixture refluxed at a water bath temperature of 80°C for 15 min. After cooling, 27 ml of demineralized water were added and the mixture adjusted to volume with ethanol. One-milliliter portions of the alkaline solution were then pipetted onto two separate Extrelut[®] 1 columns. After soaking for 15 min, the carotenoids were eluted from each of the columns with 6 ml cyclohexane. The eluates were collected in 10-ml test tubes and evaporated in a SpeedVac[®] (Plus SC210A, Savant) under reduced pressure at approximately 45°C . Each of the residues was dissolved in 1 ml of the different mobile phases of the normal- and reversed-phase HPLC-systems used to quantify the amount of the xanthophylls and carotenes, respectively. The solutions were injected without further purification.

HPLC: In order to determine the content of the xanthophylls lutein and zeaxanthin, an earlier published normal-phase HPLC-system was used involving an LiChrosorb-Si60-column (Merck) and an *n*-hexane/acetone (81:19, v:v) as a mobile phase (Weber, 1988). In contrast, α - and β -carotene were quantified by means of a C18-column (Suplex pKb-100, Supleco) and a methanol/ acetonitrile-based mobile phase as earlier used in an interlaboratory study [laboratory no. 4] (Schüep and Schierle, 1997). The amount of total carotenoid (including cryptoxanthin) was estimated by calculating the total peak areas recorded in the chromatograms of the normal- or reversed-phase HPLCs with the response factor of either lutein or β -carotene, on which depended the main carotenoid in the extract. All carotenoid results reported represent means of two complete analyses performed with the same homogenate. The standard error of the mean (S.E.M.) of these double determinations averaged from 8.5 to 9.4%, depending on the carotenoid. The recovery of the method was $>95\%$.

Water content: A total amount of approximately 15 g tissue was cut in small pieces (of approximately 0.2–0.5 g) from the residual halves of food items, weighed and incubated at 60°C and reduced pressure of approximately 20 bar. After 7 days, the dried samples were weighed again and the water content was calculated as mass difference to the initial fresh weight. It was previously shown with some of the samples that the dry weight was already constant between a 5- and 6-day incubation.

3. Results and discussion

3.1. Banana *Musa troglodytarum* and *Musal* spp.

Table 1 presents the carotenoid content and coloration of edible portion for the 12 banana cultivars analyzed. Fig. 1 presents a reversed-phase HPLC-chromatogram for the banana cultivar with the highest carotenoid content.

Some of these Micronesian banana cultivars have among the highest levels of carotenoid in the world compared to other banana cultivars (West & Poortvliet, 1993; Holden et al., 1999; Dignan, Burlingame, Arthur, Quigley, & Milligan, 1994; Puwastien, Raroengwichit, Sungpuag, & Judprasong, 1999; Abdon & del Rosario, 1980; Siong, 1985). Five Micronesian banana cultivars had over 25 times the β -carotene level found in bananas analyzed in the United States and the United Kingdom (21 $\mu\text{g}/100\text{ g}$) (Holden et al., 1999; Holland et al., 1991). Four other banana cultivars had over 10 times that amount. Two cultivars had low levels in comparison to the high-carotenoid cultivars, but this was still three to nine times the amount of β -carotene in the common banana. The white-fleshed cultivar analyzed for purposes of comparison had a carotenoid content similar to the common banana.

A deep orange-colored banana flesh, determined by visual and photographic assessments, indicated a greater carotenoid content. There was a corresponding decrease in intensity of flesh color with decreasing levels of carotenoid.

There was no consistent difference of carotenoid content attributable to cooking. Six sets of banana samples were prepared as raw and cooked samples, all similarly ripe and from the same respective bunch. Five samples were boiled or steamed for 10 min, whereas one sample was baked for 60 min. For four sets, the cooked sample had higher carotenoid content, but for two, the raw sample had higher carotenoid content. For *uht en yap* (the sample that was baked), the raw sample carotenoid content was more than twice that of the cooked, which may be explained by the longer cooking time. The lack of consistency in differences of carotenoid content attributable to cooking factors has been documented elsewhere (Rodriguez-Amaya, 1997; Mangels, Holden, Beecher, Forman, & Lanza, 1993). Also documented is that carotenoids are destroyed by long periods of cooking (Wasantwisut & Attig, 1995; Rahman, Wahed, & Ali, 1990).

The *uht en yap* and *karat* (Kosrae *kulasr*) had very high β -carotene contents. They are both Fe'i cultivars of the *Australimusa* series, characterized by an erect bunch, purple sap, red-colored skin of ripe fingers, and a deep-colored flesh. *Karat* was once the traditional weaning food in Pohnpei, but became rare in FSM (as *uht en yap*), due to neglect and reliance on more easily growing banana cultivars. Production increased somewhat since the year 2000 due to a *karat* campaign (Englberger, 1999). Of the nine cultivars with high carotenoid content, all were rare, with the

Table 1
Carotenoid content of selected cultivars of ripe Micronesian bananas *Musa troglodytarum* and *Musa* spp.

Sn ^a	Local name	Source	Color of raw flesh	Sample ^b	N ^c	β-carotene ^d (µg/100 g)	α-carotene (µg/100 g)	Lutein (µg/100 g)	Zeaxanthin (µg/100 g)	Total carotenoid (µg/100 g)	Water (%)
Mt	<i>Uht en yap</i>	Pohnpei	Orange	Raw	4	2780	830	40	10	5370	69.5
Mt	<i>Uht en yap</i>	Pohnpei	Orange	Baked	4	1250	400	70	10	3130	69.5
Ms	<i>Usr wac</i>	Kosrae	Orange	Boiled	3	2300	950	130	e	3740	78.2
Ms	<i>Uht ipali</i>	Pohnpei	Orange	Boiled	2	940	610	100	20	1770	66.5
Mt	<i>Uht karat^f</i>	Pohnpei	Orange ^g	Steamed	3	710	100	160	<10	1140	68.0
Mt	<i>Uht karat^f</i>	Pohnpei	Orange ^g	Raw	3	520	90	150	10	880	67.0
Mt	<i>Usr kulasar^f</i>	Kosrae	Orange ^g	Boiled	3	670	210	260	40	1260	76.7
Mt	<i>Usr kulasar^f</i>	Kosrae	Orange ^g	Raw	3	660	150	230	20	990	75.8
Ms	<i>Usr macao^h</i>	Kosrae	Orange ^g	Boiled	3	620	550	180	e	480	67.2
Ms	<i>Usr taiwang^h</i>	Kosrae	Yellow	Boiled	3	400	180	50	e	630	74.0
Ms	<i>Usr taiwang^h</i>	Kosrae	Yellow	Raw	3	270	130	40	<10	480	73.6
Ms	<i>Usr taiwang wild^h</i>	Kosrae	Yellow	Raw	3	330	170	70	e	500	68.0
Ms	<i>Usr in yeur</i>	Kosrae	Yellow	Raw	3	340	220	110	e	740	67.3
Ms	<i>Usr in yeur</i>	Kosrae	Yellow	Boiled	3	240	160	110	e	60	70.6
Ms	<i>Usr lakatan</i>	Kosrae	Yellow	Raw	3	330	280	120	e	900	75.7
Ms	<i>Usr apact fususⁱ #1</i>	Kosrae	Creamy	Boiled	3	200	10	10	10	280	67.1
Ms	<i>Usr apact fususⁱ #2</i>	Kosrae	Creamy	Boiled	3	80	10	20	e	140	63.8
Ms	<i>Uht en rukⁱ</i>	Pohnpei	Creamy	Boiled	3	150	10	30	10	240	69.3
Ms	<i>Uht en rukⁱ</i>	Pohnpei	Creamy	Raw	3	90	10	<10	e	110	63.7
Ms	<i>Usr apact poel</i>	Kosrae	Creamy	Boiled	3	150	10	20	10	250	66.3
Ms	<i>Usr kufajfa</i>	Kosrae	White	Boiled	4	30	20	230	e	290	88.1

Note: HPLC-analysis March 2001, Roche Vitamins Ltd, Basel, Switzerland.

^aScientific name: Mt—*M. troglodytarum* (Fe'i cultivars of *Australimusa* series); Ms—*Musa* spp. (cultivars of *Eumusa* series).

^bRaw and cooked banana samples were prepared from the same banana bunch. Boiled samples were boiled 10 min unpeeled and with pot covered.

Baked sample was baked 60 min in the traditional earth oven, unpeeled and wrapped in banana leaves. Samples were analyzed without peelings.

^cNumber of fruits in sample.

^dCultivars are listed in order of greater to lesser β-carotene content.

^eBelow detection limit.

^fThe *uht karat* from Pohnpei and *usr kulasar* from Kosrae are considered to be synonym cultivars with different names from the different states.

^gColor is between orange and yellow.

^hThe *usr taiwang* exists as two cultivars, the common one with a larger finger size, and a wild one with a small finger known to be sweeter.

ⁱThe *uht apact fusus* from Kosrae and *uht en ruk* from Pohnpei are considered to be synonym cultivars with different names from the different states.

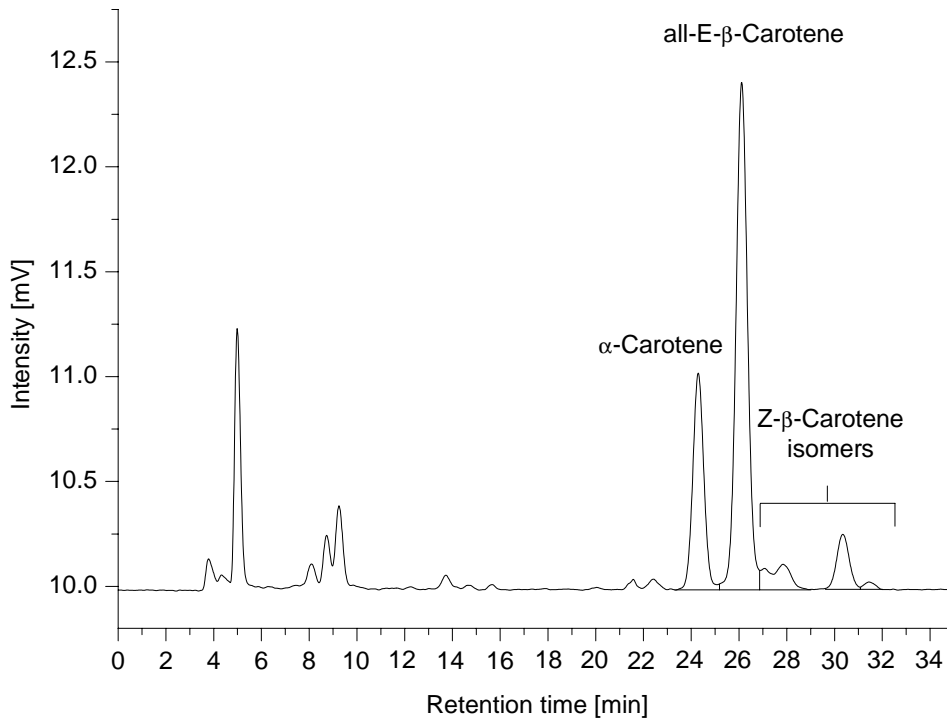


Fig. 1. Reversed-phase HPLC-chromatogram of a saponified extract of banana, *uht en yap*. The chromatogram was used to quantify α and β -carotene.

exception of the *lakatan*, which is relatively common, and the *taiwang* (*common*), which is well-liked for its sweet taste, and is very common, but has low status evidently due to its common availability. Also informants explained that some avoided eating ripe *taiwang* due to a belief that *taiwang* causes worm infections.

3.2. Giant swamp taro *Cyrtosperma chamissonis*

Table 2 presents the carotenoid content and coloration of edible portion for the 13 giant swamp taro cultivars analyzed. Fig. 2 presents the normal-phase chromatogram for the taro cultivar with the highest carotenoid content.

Giant swamp taro is distinctive for its large plant size and edible corm. As it withstands saline soils, it is commonly grown on atoll islands. It is not seasonal, withstands strong winds, and the corm can remain in the soil for 10 years or more, and still be edible, thus providing food security. It is differentiated from common taro, *Colocasia esculenta*, and other edible taro, *Alocasia macrorrhiza*, and *Xanthosoma sagittifolium* (Secretariat of the Pacific Community, 1999). Giant swamp taro is a root crop staple that is eaten cooked. It is prepared by boiling or grinding and is often mixed with other foods. In a number of recipes, coconut cream is used and, sometimes banana or pandanus, and then it is baked.

All 11 cultivars with yellow-colored corms had a high β -carotene content. The two cultivars with creamy-colored corms, which were selected for analysis for purposes of comparison, had a

Table 2
Carotenoid content of selected cultivars of Micronesian giant swamp taro *C. chamissonis*

Local name ^a	Source	Color of raw corm	Sample ^b	N ^c	β-carotene ^d (μg/100 g)	α-carotene (μg/100 g)	Lutein (μg/100 g)	Zeaxanthin (μg/100 g)	Total carotenoid (μg/100 g)	Water (%)
<i>Mwashei</i>	Pohnpei ^e	Yellow	Raw	3	2040	830	150	<10	3290	57.5
<i>Mwashei</i>	Pohnpei ^e	Yellow	Boiled	3	940	300	110	f	2160	60.4
Six-moon	Pohnpei ^e	Yellow	Boiled	3	1700	670	130	f	2940	77.5
Six-moon	Pohnpei ^e	Yellow	Raw	3	1220	480	80	<10	2450	60.6
<i>Pasruk kirngesi</i> older	Kosrae	Yellow	Boiled	3	1120	660	150	f	2260	70.3
<i>Pasruk kirngesi</i> younger	Kosrae	Yellow	Raw	3	580	420	140	f	1260	54.4
<i>Pasruk kirngesi</i> younger	Kosrae	Yellow	Boiled	3	340	250	80	f	780	57.4
<i>Pasruk siminton</i>	Kosrae	Yellow	Boiled	2	1070	390	200	10	1870	78.7
<i>Fanal</i>	Pohnpei ^e	Yellow	Raw	3	880	580	110	f	1720	50.2
<i>Fanal</i>	Pohnpei ^e	Yellow	Boiled	3	170	90	40	f	330	80.8
<i>Simihden</i>	Pohnpei ^e	Yellow	Raw	3	840	330	10	f	1500	62.0
<i>Simihden</i>	Pohnpei ^e	Yellow	Boiled	3	700	270	100	f	1300	65.3
<i>Ponon</i>	Pohnpei ^e	Yellow	Boiled	3	820	450	130	f	1790	52.6
<i>Ponon</i>	Pohnpei ^e	Yellow	Raw	3	550	350	140	<10	1290	56.7
<i>Pasruk wasrwasr</i>	Kosrae	Yellow	Boiled	3	630	470	80	f	1360	54.5
<i>Pasruk wasrwasr</i>	Kosrae	Yellow	Raw	3	410	400	40	f	1030	65.6
<i>Anechimou</i>	Pohnpei ^e	Yellow	Boiled	3	490	270	40	f	840	53.6
<i>Anechimou</i>	Pohnpei ^e	Yellow	Raw	3	330	260	40	f	700	65.4
<i>Pasruk fukeh</i>	Kosrae	Yellow	Boiled	3	440	370	220	f	1190	65.3
<i>Mwang medel</i>	Pohnpei	Yellow	Boiled	3	400	210	50	f	68	57.9
<i>Mwang medel</i>	Pohnpei	Yellow	Raw	3	360	200	70	f	870	67.1
<i>Pasruk tepat</i>	Kosrae	Creamy	Boiled	3	60	20	80	f	160	65.1
<i>Pasruk ebon</i>	Kosrae	Creamy	Boiled	1	50	30	60	<10	170	74.5

Note: HPLC analysis March 2001, Roche Vitamins Ltd, Basel, Switzerland.

^a Local English and vernacular names differ by state: Kosrae—hard taro/*pasruk*, Pohnpei—giant taro/*mwang*.

^b Raw and boiled samples taken from same taro corm, peeled, cut in pieces ~3 cm thick and ~10 cm in diameter; cooked samples were boiled for 30–40 min with the pot covered. Relating to maturity, taro corms do not ripen as do fruits, and can be eaten once grown to a size large enough for eating.

^c Number of corms in sample.

^d Cultivars are listed in order of greater to lesser β-carotene content.

^e Cultivar was grown in Pohnpei, but originated from the Mortlock Islands (outer islands of Chuuk State).

^f Below detection limit.

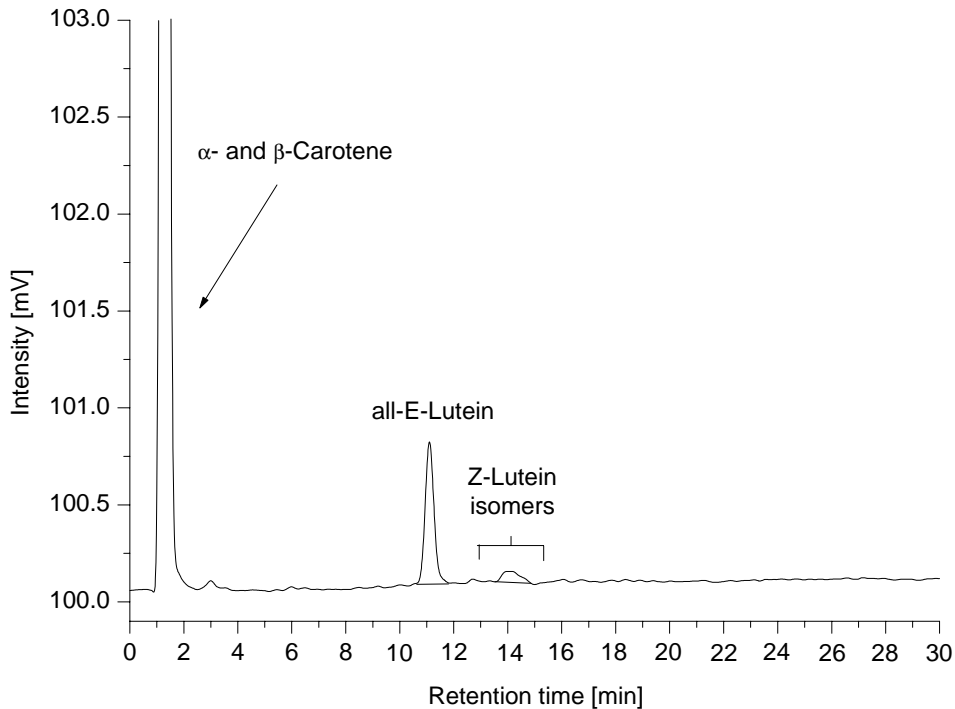


Fig. 2. Normal-phase HPLC-chromatogram of a saponified extract of giant swamp taro, *mwashei*. The chromatogram was used to quantify lutein (zeaxanthin was not detectable).

low β-carotene content. Thus, yellow-colored corms consistently had higher carotenoid content, but there were no clear differences in color gradation between taro corms with high and medium carotenoid levels. Informants reported that the corm color of a cultivar varies according to the soil and location.

There was no consistent difference of taro carotenoid content attributable to cooking. Nine sets of giant swamp taro were taken from the same corm and same area of the corm, with similar age, and prepared as raw and cooked samples, boiling for a similar time (40 min, the time needed for cooking). In five sets, the cooked sample had a higher β-carotene content (234 μg/100 g mean difference) and in four sets the raw sample had a higher β-carotene content (547 μg/100 g mean difference).

A Yap cultivar of giant swamp taro was recently found to contain a high carotenoid content (Englberger, 2001). As far as the authors are aware, the Yap taro and the taro cultivars of this study are the first taros that have been found to have high carotenoid content.

3.3. Breadfruit *Artocarpus mariannensis* and *Artocarpus altilis*

Table 3 presents the carotenoid content and coloration of the edible portion for the 10 cultivars of breadfruit that were analyzed.

Breadfruit is most commonly eaten in the mature green (hard) stage, and most previous breadfruit analyses have been of the mature breadfruit, not ripe; however, some people in FSM

Table 3
Carotenoid content of selected cultivars of Micronesian breadfruit *A. mariannensis* and *A. altilis*

Sn ^a	Local name	Source	Color of raw flesh	Sample ^b	N ^c	β -carotene ^d ($\mu\text{g}/100\text{ g}$)	α -carotene ($\mu\text{g}/100\text{ g}$)	Lutein ($\mu\text{g}/100\text{ g}$)	Zeaxanthin ($\mu\text{g}/100\text{ g}$)	Total carotenoid ($\mu\text{g}/100\text{ g}$)	Water (%)
<i>Am</i>	<i>Mei kole</i>	Pohnpei	Yellow	Ripe, boiled	2	150	10	750	70	1260	76.6
<i>Am</i>	<i>Mei kole</i>	Pohnpei	Yellow	Ripe, raw	2	140	<10	590	60	920	67.8
<i>Aa</i>	<i>Meitoal</i>	Pohnpei	Yellow	Ripe, boiled	3	60	<10	470	40	670	62.8
<i>Aa</i>	<i>Meitoal</i>	Pohnpei	Yellow	Mature, boiled	3	40	^e	250	10	360	62.6
<i>Aa</i>	<i>Mos mesunvac</i>	Kosrae	Creamy	Ripe, mature, fermented, baked	na	40	10	210	10	300	53.2
<i>Aa</i>	<i>Mos mesunvac</i>	Kosrae	Creamy	Ripe, boiled	1	30	30	310	10	460	64.6
<i>Aa</i>	<i>Mei ulupw</i>	Pohnpei	Creamy	Ripe, boiled	3	30	30	310	<10	470	66.3
<i>Aa</i>	<i>Meisaip</i>	Pohnpei	Yellow	Ripe, raw	3	30	20	90	20	140	60.5
<i>Aa</i>	<i>Meisaip</i>	Pohnpei	Yellow	Ripe, boiled	3	20	<10	120	<10	170	64.2
<i>Aa</i>	<i>Mos puhtaktaak</i>	Kosrae	Creamy	Ripe, boiled	1	20	30	390	30	530	66.2
<i>Aa</i>	<i>Meiniwe</i>	Pohnpei	Creamy	Ripe, boiled	3	20	30	290	<10	410	64.2
<i>Aa</i>	<i>Mos ikantal</i>	Kosrae	Creamy	Ripe, boiled	1	10	20	250	10	330	60.9
<i>Aa</i>	<i>Mos parkas</i>	Kosrae	Yellow	Ripe, boiled	3	10	10	410	10	510	68.8
<i>Aa</i>	<i>Mei kalik</i>	Pohnpei	Creamy	Ripe, boiled	2	10	10	160	<10	200	66.1

Note: HPLC-analysis March 2001, Roche Vitamins Ltd, Basel, Switzerland.

^aScientific name: *Am*—*A. mariannensis* (seeded breadfruit); *Aa*—*A. altilis* (unseeded breadfruit).

^bSample maturity and if raw, cooked, or fermented. Raw and cooked samples taken from same breadfruit. Samples boiled unpeeled for 10 min with the lid on. Baked sample was made from fermented breadfruit and baked for 1 hour.

^cNumber of fruits in sample.

^dCultivars are listed in order of greater to lesser β -carotene content.

^eBelow detection limit.

eat breadfruit in the soft ripe stage, at which time the edible flesh becomes more yellow. Because of this, the study focused on analyzing ripe breadfruit samples.

Ripe seeded breadfruit (*mei kole*), which is eaten both raw and cooked and is most common in FSM on atoll islands, had a medium β -carotene content. It appears that this is the first time that ripe seeded breadfruit has been analyzed. Its β -carotene content is over six times the content of breadfruit analyzed elsewhere (compared to 22 $\mu\text{g}/100\text{ g}$, the average of findings elsewhere: 10, 22, 25, and 30 $\mu\text{g}/100\text{ g}$) (Aalbersberg, Lovelace, Madhoji, & Parkinson, 1988; Siong, 1985; Leung, Butrum, & Chang, 1972; Dignan et al., 1994). The nine ripe unseeded breadfruit cultivars, which are eaten cooked, never raw, had a low β - and α -carotene content.

Lutein and zeaxanthin content was higher in breadfruit than in the banana and taro samples. Among the breadfruit samples, the highest content of lutein and zeaxanthin was found in the seeded breadfruit, which also had the highest β -carotene content. Medium lutein levels were also found in breadfruit with low β -carotene content.

A deep-colored ripe breadfruit flesh was not consistent with a higher carotenoid content. The seeded ripe breadfruit, which had a high carotenoid content, had a yellow flesh, but the ripe *meitoal* also had a yellow flesh, but did not contain high carotenoid levels. It was expected that breadfruit in the ripest stage would have a higher carotenoid content because in most carotenogenic fruits, ripening is accompanied by an increased carotenoid biosynthesis (Rodriguez-Amaya, 1997). This result was found in the comparison of the β -carotene content of the mature and ripe *meitoal* samples. However, the difference in carotenoid content was small (20 $\mu\text{g}/100\text{ g}$), perhaps because the carotenoid content of the ripe cultivar was low.

There was no consistent difference in breadfruit carotenoid content attributable to cooking. Two sample sets were prepared with both raw and cooked samples, both boiled for 10 min. Compared to the raw samples, the cooked *mei kole* sample had a slightly higher β -carotene content, but the cooked *meisaip* sample had a lower β -carotene content.

Fermented breadfruit was commonly prepared in the past, as a means of food preservation, and is still prepared, although in smaller amounts. This sample made of breadfruit fermented at two states of maturity, mature and ripe, did not have a high carotenoid content.

3.4. Other selected foods

Table 4 presents the carotenoid content and coloration of edible portion for the other four selected foods analyzed. The dark green leafy vegetable, bird's nest fern, which is eaten in Yap, had a medium content of β - and α -carotene, but a high content of lutein and zeaxanthin. As far as the authors are aware, this is the first analysis for carotenoid content of bird's nest fern.

Pandanus fruit, which is eaten commonly on atolls and some other FSM islands, had a medium content of β - and α -carotene, but a high content of lutein and zeaxanthin. Samples from different pandanus cultivars were collected for analysis in a later part of this study. The results of these analyses and an ethnographic study on pandanus are reported separately (Englberger, Aalbersberg, Fitzgerald, Marks, & Chand, 2003a,b). On the main island of Pohnpei, local people do not recognize different cultivars of pandanus, and thus, this sample, which was obtained from a Pohnpei market, was not identified by a cultivar name.

False durian, *Pangium edule*, is a wild fruit that is occasionally eaten in Pohnpei and Kosrae. Older people indicated that they ate it more often in the past. It has a distinctively yellow edible

Table 4
Carotenoid content of other selected Micronesian foods

Sn ^a English and local name	Source	Color of edible portion	Sample ^b	N ^c	β -carotene ^d ($\mu\text{g}/100$)	α -carotene ($\mu\text{g}/100$ g)	Lutein ($\mu\text{g}/100$ g)	Zeaxanthin ($\mu\text{g}/100$ g)	Total carotenoid ($\mu\text{g}/100$ g)	Water (%)
<i>An</i> Bird's nest fern; <i>tehnlik</i>	Pohnpei	Light green	Young shoots, boiled	12	410	190	2110	170	3740	92.6
<i>Pt</i> Pandanus fruit; <i>kipar or deipw</i>	Pohnpei	Orange	Ripe, raw	3	270	30	350	370	5340	74.8
<i>Pe</i> False durian fruit; <i>dahrien</i>	Pohnpei	Yellow	Ripe, boiled	1	140	30	40	^e	370	78.4
<i>Pe</i> False durian fruit; <i>durten</i>	Kosrae	Yellow	Partially ripe, raw	3	60	<10	50	20	160	82.0
<i>Cr</i> Tangerine fruit; <i>mo srisrik</i>	Kosrae	Orange	Ripe, boiled	4	40	^e	60	^e	450	69.2

Note: HPLC-analysis March 2001, Roche Vitamins Ltd, Basel, Switzerland.

^aScientific name: *An*—*Asplenium nidus*; *Pt*—*Pandanus tectorium*; *Pe*—*Pangium edule*; *Cr*—*Cirrus reticulata*.

^bThese fruits are normally eaten raw in Kosrae; but cooking was carried out to transport samples to laboratory and meet quarantine requirements; samples were boiled for 10 min with the lid on the pot. Fern greens were cut in 1-in lengths. Durian and tangerine flesh were removed from skin before boiling. The inedible part of the pandanus key was cut off before boiling and removed from the sample.

^cNumber of shoots or fruits in sample.

^dFoods are listed in order of greater to lesser β -carotene content.

^eBelow detection limit.

portion, but the sample contained only a low content of β -carotene, α -carotene and lutein, and a non-detectable amount of zeaxanthin. This food should not be confused with true durian, *Durio zibethinus*. As far as the authors are aware, this is the first analysis for carotenoid content of *P. edule*.

The Kosrae tangerine, *Citrus reticulata*, sample was selected for analysis as there were no available data for its carotenoid content although eaten commonly. The total carotenoid content was found to be medium, but the contents of β -carotene and lutein were low, and α -carotene and zeaxanthin were not detectable. However, cryptoxanthin was estimated to contribute 70 $\mu\text{g}/100\text{ g}$ to the total carotenoid. A relatively high concentration of this provitamin A carotenoid was also found in other tangerine cultivars (Holden et al., 1999).

3.5. Impact on VA status

Banana, giant swamp taro, and breadfruit are major staples in the Micronesian diet. Adults often consume from 750–1000 g daily (Secretariat of the Pacific Community, 1999). A 5-year-old child also commonly eats 500 g daily, which is about 2 cups; this is easily eaten, divided in 1-cup portions over two main meals in the day (personal observations). The FAO/WHO estimated requirements for VA are 500 and 400 μg Retinol Equivalents (REs), respectively, for a non-lactating non-pregnant adult woman and a child 1–10 years of age (FAO/WHO, 1988). Thus, using the newly suggested conversion factors of 12:1 for β -carotene and 24:1 for α -carotene to RAE (US Institute of Medicine, Food and Nutrition Board, & Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, 2001), the impact of these staple foods on VA status may be calculated, using the results of this study. The impact of cryptoxanthin may be negligible as this provitamin A carotenoid was present in all samples at very low concentrations ($<30\ \mu\text{g}/100\text{ g}$, except the Kosrae tangerine).

Nine banana and 11 giant swamp taro cultivars would provide over one-third of the estimated daily VA requirements for a non-pregnant non-lactating woman and young child, assuming daily consumption of 750 g of those respective foods for the woman and 500 g for the child, which is within normal dietary patterns. Some of these cultivars even provide the total VA requirements in these amounts. The *mei kole* breadfruit had a much lower provitamin A content compared to the carotenoid-rich banana and taro cultivars; however, breadfruit is often eaten in large quantities. The *mei kole* could provide over a quarter of the estimated daily VA requirements for a non-pregnant non-lactating woman if 1000 g were eaten, which is within normal dietary patterns.

4. Conclusions

These findings indicate that a number of cultivars of Micronesian staple foods contain significant levels of provitamin A and total carotenoids, which could protect against vitamin A deficiency and certain chronic diseases. These includes nine banana cultivars, 11 giant swamp taro cultivars, and one breadfruit cultivar.

Banana is particularly suited for young children, having a sweet taste, soft texture, easy preparation, and natural hygienic covering. It is eaten both raw and cooked, and is well liked by all population groups, including pregnant and lactating mothers at risk of vitamin A deficiency.

Banana is also easily grown in FSM. These factors lend to the appropriateness of promoting carotenoid-rich banana cultivars for their health benefits where such bananas are available. The orange-colored fruit was found highly bioavailable elsewhere (de Pee et al., 1998); thus, orange-colored banana might also be highly bioavailable, although research on this is still needed. However, those Micronesian banana cultivars highest in provitamin A content are rare. There is concern about losing some cultivars to the modern westernized diet, and there is an urgent need for promoting carotenoid-rich banana cultivars, particularly those having the greatest acceptability and production potential, such as *karat* banana, and for exploring increased marketing and export possibilities which would provide income generation. There is also the need for promoting banana cultivars that are rich in carotenoids but have low status, such as the *taiwang*, and for clarifying misconceptions, such as the belief that ripe *taiwang* banana causes worm infections.

Giant swamp taro and seeded breadfruit cultivars rich in carotenoids should be promoted for their contribution to vitamin A status and protection against chronic disease. Particular attention should be given to those cultivars having high acceptability.

Further research is needed to identify other possible carotenoid-rich banana, taro, breadfruit, and pandanus cultivars in FSM, other Pacific countries, and other areas of the world where these foods are commonly grown and consumed. Further research is needed on developing a method of estimating carotenoid content based on color differences, particularly in banana, and on elucidating the cooking effect on carotenoid content of these staple foods. Research is needed to establish the bioavailability of carotenoids in banana, taro, and breadfruit. Finally, this paper suggests that the use of an ethnographic approach in identifying carotenoid-rich cultivars of foods suitable for promotion in dietary improvement programs is valuable, and that consideration to aspects of production, acquisition, consumption, and cultural acceptability is essential.essential.

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