Carotenoid-rich bananas: A potential food source for alleviating vitamin A deficiency

Lois Englberger, Ian Darnton-Hill, Terry Coyne, Maureen H. Fitzgerald, and Geoffrey C. Marks

Editor's note

As vitamin A and carotenes are inextricably bound by precursor or provitamin/vitamin status, newer research on the bioavailability and conversion of dietary carotenes to retinol takes on increasing importance. The recent edition of the Dietary Reference Intakes (DRIs) in the United States adds a suggestion to our nomenclature in this regard with the use of retinol activity equivalent (RAE), which reflects newer data on bioconversion. The Food and Nutrition Bulletin *will note the alternative conversion where appropriate as an aid to our readers. We invite readers' comments on this issue.*

Abstract

This review article points out that bananas are an important food for many people in the world. Thus, banana cultivars rich in provitamin A carotenoids may offer a potential food source for alleviating vitamin A deficiency, particularly in developing countries. Many factors are associated with the presently known food sources of vitamin A that limit their effectiveness in improving vitamin A status. Acceptable carotenoid-rich banana cultivars have been identified in Micronesia, and some carotenoid-rich bananas have been identified elsewhere. Bananas are an ideal food for young children and families for many regions of the world, because of their sweetness, texture, portion size, familiarity, availability, convenience, versatility, and cost. Foods containing high levels of carotenoids have been shown to protect against chronic disease, including certain cancers, cardiovascular disease, and diabetes. Because the coloration of the edible flesh of the banana appears to be a good indicator of likely carotenoid content, it may be possible to develop a simple method for selecting carotenoid-rich banana cultivars in the community. Research is needed on the identification of carotenoid-rich cultivars, targeting those areas of the world where bananas are a major staple food; investigating factors affecting production, consumption, and acceptability; and determining the impact that carotenoid-rich bananas may have on improving vitamin A status. Based on these results, interventions should be undertaken for initiating or increasing homestead and commercial production.

Key words: Banana, carotenoids, chronic disease, community nutrition, cultivar differences, staple foods, vitamin A, vitamin A deficiency

Introduction

Vitamin A deficiency is considered a priority among global health problems [1–3], since it can be related to increased mortality among children and women, particularly in developing countries [4, 5]. The underlying cause of vitamin A deficiency is a lack of vitamin A in the diet. Food sources of vitamin A include animal foods rich in vitamin A (retinol) and plant foods containing provitamin A carotenoids, such as β-carotene, the carotenoid contributing most to vitamin A status [6]. Previous food-based strategies for decreasing vitamin A deficiency, such as horticultural programs and nutrition education, have focused on the production and promotion of vitamin A-rich foods, including eggs; milk; liver; dark-green leafy vegetables; orange and yellow fruits and vegetables such as papaya, mango, pumpkin, squash, carrot, and orange-fleshed sweet potatoes; red palm oil; and other foods such as *buriti*

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palm fruit and *gac* fruit, which are not known outside their home countries of Brazil and Vietnam [7–17]. Reference books and papers also list these foods as sources of vitamin A [4, 6, 18–24].

Only a few references list banana or plantain cultivars (*Musa* spp.) as good sources of vitamin A (a cultivar refers to a variety produced by cultivation) [25–28]. A major vitamin A resource book lists bananas as a poor source of vitamin A [10]. This would be a correct statement with reference to bananas analyzed in the United States and United Kingdom, which contain 21 μg of β-carotene/100 g [29, 30]. Although the US and UK bananas are not documented by cultivar name, they are most likely *Cavendish*, the primary banana cultivar marketed globally [31].

As a result, people in developed countries are mostly familiar with *Cavendish* bananas. Internationally this cultivar accounts for 41% of all banana production [32]. However, there are over 30 banana species, with around 500 varieties having edible fruits, which make up the remaining world production (the total annual production is approximately 98 million tonnes) [31, 32]. Recently some banana cultivars rich in provitamin A carotenoids were identified in the Federated States of Micronesia [33–35]. One, *Uht en Yap,* contains 6,110 μg of β-carotene/100 g, which is 275 times the level noted for *Cavendish*. The Pohnpei *Karat* banana, a traditional weaning food in the Federated States of Micronesia [36], contains 867 μg of β-carotene/100 g (average of several samples analyzed by two laboratories) [37]. Some Southeast Asia banana cultivars contain 300 to 400 μg of β-carotene/100 g [38–40]. These commonly eaten bananas have over 10 times the β-carotene level of the common *Cavendish*.

This paper reviews difficulties with the present food-based vitamin A deficiency–prevention strategies and the foods being promoted. (Breastmilk is an important source of vitamin A for breastfed children, but this paper discusses vitamin A–rich foods that are complementary to breastmilk or that are eaten by older children and adults.) It sets forth an argument as to why consumption of carotenoid-rich banana cultivars may be a meaningful alternative that could have a significant impact on improving vitamin A status and general health in many areas of the world. The increase in consumption of carotenoid-rich bananas among children and women is targeted due to their vulnerability to vitamin A–deficiency disorders.

Factors limiting the potential of known food sources of vitamin A

There have been successes in strategies that focus on previously identified foods for alleviating vitamin A deficiency, which indicates the importance of continuing such programs [8, 9, 14, 41–46]. However, there are a number of factors that appear to limit the production or consumption of certain of these foods.

Animal foods

Animal foods as sources of vitamin A are often too expensive for low-income people, unacceptable for religious reasons, or less available [6, 13, 19, 21, 41, 47–54]. In many countries, there are cultural beliefs restricting egg consumption among children and women of childbearing age; for example, eggs (or other protein foods) may be avoided in pregnancy to restrict fetal growth and avoid difficult deliveries [55, 56], and some people believe that feeding eggs to children can cause death [57] or that giving eggs to children under 18 months of age may prevent them from talking [58]. In many countries, cow's milk and its products are often not consumed for various reasons, including lack of availability in the past, cost, lactose intolerance, perception of milk as an unpleasant secretion, and the idea that it is a food for calves only [37, 48, 55, 59, 60]. Chickens' eggs and cow's milk are common food allergens in children [61, 62]. Liver is often not liked because of its taste or texture. In one study on young children's food preferences, liver was the most disliked of any meat [63]. Nevertheless, it is difficult to reverse a deficient state without the use of animal sources of vitamin A or supplements [23].

Dark-green leafy vegetables

In many regions of the world, dark-green leafy vegetables may not be given to young children, particularly those under one year of age, because of concern that children may not be able to digest them and might develop indigestion, diarrhea, or severe sicknesses, or that an illness might worsen [27, 57, 58, 64–70]. In many countries, children are allowed much control over what they eat [36, 51, 71, 72]. Children often do not like the bitter taste and coarse texture of dark-green leafy vegetables and therefore often refuse to eat them [13, 19, 21, 66, 73]. The usual portion size of dark-green leafy vegetables that is eaten may be too small to meet the estimated vitamin A requirements [6, 68, 69, 74–76]. Perhaps more importantly, recent research has shown that the provitamin A carotenoids of dark-green leafy vegetables do not contribute to vitamin A status as much as was once thought [77–80]. In addition, there are carotenoid losses (as with other vegetables and fruits) in handling, preservation, and cooking [48, 54, 81].

Dark-green leafy vegetables, particularly certain types, are often associated with poverty and, hence, are often considered low-status foods or even foods for animals, making the promotion of these foods very difficult [21, 27, 37, 48, 64–66, 68, 82–84]. Excessive time may be needed for gathering dark-green leafy vegetables, especially those gathered from the wild [48, 84, 85]. Among some people, dark-green leafy vegetables may not be considered food for humans [37, 86–88] or may not be regularly eaten [41, 89]. In Indonesia, pregnant women may avoid increased consumption of food, including dark-green leafy vegetables, in order to restrict fetal growth, which is thought to lead to easier deliveries [69]. In Nepal, pregnant and lactating women often avoid dark-green leafy vegetables because they think that babies of women who eat them will be born green or yellow and that lactating women will experience swelling [57].

For some people, there are major obstacles to growing dark-green leafy vegetables (and other vegetables), including the cost of fencing, nonavailability of planting material or seeds, limited land availability, women's workloads, and inadequate water supply [82, 89–95]. Gardening in urban slums is possible but difficult [46]. Nevertheless, by increasing the number of varieties grown, small home gardens have been able to significantly increase vitamin A intake and help reduce night-blindness [46].

Papaya

Papaya is avoided by many in southern India because of a widespread and strong belief that a pregnant woman will have a miscarriage if she eats it [48, 52, 76, 96]. Some people in India see it as a food that causes dysmenorrhea in women and impotence in men [48]. In one African country, women avoid papaya because it is associated with worms, which are thought to cause sterility [55]. Many people do not like ripe papayas and consider them food for pigs, chickens, or wild birds [26, 37] or baby food [36, 37]. Many people prefer eating green papayas, which have little carotenoid content [25, 37, 38, 55, 97–99]. Papayas (and mangoes) were rarely eaten by preschool children in a study in Malawi [100]. In rural Bangladesh, papayas were rarely eaten by mothers in a seven-month study [101]. Papayas are seasonal in some areas or may not be grown [10, 48, 64]. When people grow their own papayas, theft of the fruits is sometimes a problem [82]. Papayas may be prohibitive in price for many people [13, 37].

Furthermore, the carotenoid content of many cultivars of papaya is low. West and Poortvliet showed that most cultivars contain less than 300 μg of β-carotene/100 g [102]. Six of the 10 ripe papaya entries had less than 100 retinol equivalents (RE)/100 g [102], which is the cutoff value used by Helen Keller International to define vitamin A–rich foods [103].* One cultivar contained 71 μg of β-carotene/100 g (total RE value, 32 μg/100 g, which included β-cryptoxanthin content, the other major provitamin A carotenoid in papaya). Other studies have also reported papaya cultivars with low carotenoid values [6, 38, 104, 105].

Mango

Ripe mangoes generally have a higher provitamin A content than papayas, although some cultivars contain less than 100 μg RE/100 g [102]. However, mangoes are seasonal and may be available for only two months in the year, they are relatively expensive for many people [13, 21, 25, 37, 106], and the usual portion size is less than the amount needed for the estimated vitamin A requirements for a young child [75]. Mangoes, like papayas, may often be eaten green, at the stage of maturation in which the carotenoid content is low [37, 38, 54, 85]. Some lactating mothers do not eat mangoes because they believe that lactating mothers who eat mangoes (and pumpkins) will have babies with yellow skin [107]. Fibrous mangoes can cause diarrhea in infants if fed in large quantities (although small slices do not) [81]. Mangoes can also cause serious allergic reactions [108].

Other plant sources of vitamin A

Pumpkins and squash have been reported to be hard to store, seasonal, expensive, and either unpopular or unfamiliar vegetables [37, 52, 81, 109]. Some people believe that pumpkins can exacerbate illnesses such as measles, diarrhea, and protein–energy malnutrition and that pregnant women must avoid pumpkins to prevent colds and diarrhea [57]. Carrots are still not commonly available in many developing countries [6, 54, 109], or they may be expensive and purchased only for festive occasions [48, 52]. In some tropical areas, carrots do not grow because of the hot climate [37]. Tomatoes are sometimes listed as a source of vitamin A, but the content of vitamin A varies among tomato cultivars, some containing minimal levels of vitamin A (the red color is from lycopene, a carotenoid with no vitamin A activity) [6, 48].

Orange-fleshed sweet potatoes have important potential as a staple food for improving vitamin A status in Africa [9, 110] and the Pacific [111] and have been shown to raise serum retinol levels in young children [112]. The challenge remains in introducing the new varieties to other areas that grow sweet potatoes. Because sweet potatoes are considered a woman's crop in Africa (and other communities), there is the limitation of women's workloads [9, 110]. Moreover, sweet

* Two units are currently used for quantifying vitamin A activity in foods, as a result of recent research findings. Both refer to 1 μg of all-*trans*-retinol (vitamin A). The retinol equivalent (RE) is defined as equivalent to 6 μg of dietary all-*trans*-β-carotene. The more recently recommended retinol activity equivalent (RAE) is defined as equivalent to 12 μg of dietary all-*trans*-β-carotene [80]. Current food-composition research may still use the 6:1 ratio, since that is what is available in food-composition tables.

potatoes are not a major food in many countries [54, 91, 113].

Refined red palm oil has acceptable organoleptic characteristics (taste and smell) and the potential to provide needed fat, energy, and other nutrients and phytochemicals in the diet that may decrease heart disease and cancer [13, 114–116]. Red palm oil has been shown to improve vitamin A status in children and women [4, 116–118]. Its use as a traditional food has spread from West Africa [119, 120] to other parts of Africa and many other countries in Asia, especially Malaysia, and to South America [113, 120, 121]. However, crude red palm oil is disliked for its taste, smell, and red color. When it is processed to remove the color and the distasteful characteristics, the vitamin A activity is lost, except when processed by a new method now used in Southeast Asia. Refined red palm oil (Carotino) has several obstacles to acceptability, including its red color, competition from locally established oils, cost, and concern about its saturated fatty acid content [4, 106, 121, 122].

The *buriti* palm fruit from Brazil and the *gac* fruit from Vietnam have very high levels of provitamin A carotenoids and have been shown to improve vitamin A status [4, 17, 21, 113, 123], but these plant products are still not widely known or available. The oily *gac* fruit is not normally eaten as a food, but it has been used in Vietnam to impart coloring and flavor [17].

Bananas: Scope for a significant impact on global health

Given some of the issues associated with the production and consumption of foods that are the current focus of many nutrition programs to alleviate vitamin A deficiency and the lack of success of many of these programs, we suggest that consideration be given to the promotion of carotenoid-rich banana cultivars in communities where they could be readily available and culturally acceptable as human food.

Bananas: A major staple food

Bananas, a major global food staple, are the fourth most important food in the world, after rice, wheat, and maize [124]. The term "banana" as used here includes plantain [125]. Plantains are just types of bananas that are commonly more starchy at ripeness. Bananas are eaten as ripe raw fruit or cooked as a staple food, green or ripe. Plantains are usually eaten cooked. However, the use of the terms differs among countries, indicating that care is needed in communications about bananas and interpretations of studies on "banana" and global "banana" production data [125]. Bananas and plantains have both been classified as fruits in global Food and Agriculture Organization (FAO) reports [126] and FAO Food Balance Sheets, although they are both eaten as cooked staple foods. This underestimates their use as staple foods and presents a particular challenge in the interpretation of global data on the production and consumption of these foods.

More than 400 million people in developing countries consume bananas as a staple food; 100 million of these people are in Africa [124]. The greatest diversity of bananas is in Southeast Asia, including Papua New Guinea, where bananas are believed to have their origin [124, 125]. This is reflected by a number of banana cultivars in the food-composition tables in that region: 8 Thai [39], 19 Malaysian [40], and 11 Philippine banana cultivar entries [38]. The two secondary centers of banana diversity in the world are West and Central Africa and the East African Highlands [31]. In Uganda, Burundi, and Rwanda, banana consumption is from 250 to 400 kg per person per year (3 to 11 bananas daily, depending on the size of the bananas) [124, 125, 127].

The main export areas are in Central and South America and the Philippines. There are 12.7 million tonnes of bananas in world trade, worth US$4,306 million [32]. However, this represents only about 13% of the bananas grown worldwide. The remainder is grown in household gardens for home consumption and local trade [32, 124, 128]. Farmers are also likely to grow a diversity of cultivars, which has been important in the past for disease control, climate adaptation, and provision of a variety of tastes and nutrients [37, 129]. Bananas have been called a "humble" food and a "poor man's food" [37, 130–132], indicating their importance for low-income people and a common cultural attitude toward bananas.

Vitamin A deficiency is common in areas where bananas are grown as a staple food crop [133]. A shift from low-carotenoid to high-carotenoid banana cultivars would lead to increased vitamin A content of the diet and thus possibly lead to improved vitamin A status in those areas. The Micronesian high-carotenoid bananas are well liked for their good taste, and a number of them have been eaten for many years, indicating high acceptability [34] (see also the section on the *Karat* banana). McLaren suggested that for understanding the cause of vitamin A deficiency, investigation of the staple food eaten is important, particularly since rice-eating communities are prone to vitamin A deficiency disorders [6]. Bouis argued that the strategy of improving the vitamin and mineral content of staple foods has several advantages: little behavioral change on the part of the people is required, and large amounts of these foods are consistently eaten on a daily basis by all family members [134]. There has been considerable success in the introduction of orange-fleshed sweet potatoes in parts of Africa [9, 110], providing an example of a successful shift from a low-carotenoid to a high-carotenoid staple food cultivar [135].

Work is also being carried out on plant-breeding strategies to increase the nutrient density of β-carotene, iron, and zinc in wheat, rice, maize, cassava, and the common bean [136]. Golden rice is rice that has been genetically modified to increase its β-carotene content. Nonmodified rice normally contains no provitamin A carotenoids and is the staple food eaten by most societies that have the worst vitamin A deficiency.

Golden rice was developed as a solution to vitamin A deficiency, but there are questions about the acceptability of rice with a different color [137]. Some analyses suggest that golden rice is relatively low in carotenoid content and could meet only 6% to 12% of the estimated vitamin A requirements for infants and small children [138]. This calculation is based on the assumption that the conversion of dietary β-carotene to vitamin A in the rice would be at the standard ratios (12:1 or 6:1). However, the rice matrix is known to be very digestible. Thus, the bioavailability may be much higher. The β-carotene bioavailability in banana may be higher than the 12:1 or 6:1 ratio, because the banana matrix is almost totally digestible. However, this has not yet been demonstrated.

Virtually all people do not choose their food for its vitamin A content but eat what they like and what is most available [37, 67, 139, 140]. People often do not associate the concept of nutrition and diet with illness or good growth [50, 139, 141, 142]; some believe that illness is contracted because of supernatural or other events [36, 50, 90, 143–145], making it more difficult to effect dietary change on the basis of a healthier diet.

Table 1 presents the β-carotene and α-carotene content of ripe Micronesian banana cultivars and their possible impact on vitamin A requirements [146] according to different consumption levels. The daily amount of local starch foods traditionally eaten by an adult Pacific Islander is estimated at 750 to 1,000 g [111], and thus it is reasonable that bananas could be eaten at this level of consumption. Thirteen banana cultivars were identified in Micronesia that contain significant levels of the provitamin A carotenoids β-carotene and α-carotene [37], meeting half or all of the estimated vitamin A requirements for a nonpregnant, nonlactating woman. Some can also meet the estimated vitamin A requirements for young children. One banana, *Karat*, was also analyzed separately for the provitamin A carotenoid β-cryptoxanthin and was found to contain 35.6 μg/100 g [147].

Table 2 presents the β-carotene and α-carotene contents of selected banana cultivars from Southeast Asia to show examples of carotenoid-rich cultivars from those areas and to show the range in carotenoid content.

As noted earlier, recent research has shown that β-carotene from some plant sources has a lower bioavailability than was once thought; e.g., dark-green leafy vegetables might provide only 1 μg of vitamin A from 26 μg of β-carotene [78]. Previously it was accepted that dark-green leafy vegetables had a greater bioavailability, providing the same amount of vitamin A from a smaller amount of β-carotene (6 μg). However, the bioavailability of β-carotene in orange and yellow fruits and tubers has been found to be greater than that in dark-green leafy vegetables, and the ratios have now been set at 12 μg of β-carotene to 1 RAE and 24 μg of other provitamin A carotenoids to 1 RAE [78, 80]. Thus, it is likely that orange and yellow-orange colored bananas would have a significant impact on improving vitamin A status.

Karat and other banana cultivars

Two of the carotenoid-rich cultivars from the Federated States of Micronesia, *Karat* and *Uht en Yap*, are Fe'i bananas, sometimes referred to as *Musa troglodytarum* or *Musa (Australimusa* Series) [148]. These bananas are characterized by an erect bunch (fig. 1) and red sap [149, 150]. The fruits and bunches have varying shapes and appearances (figs. 2 and 3). Different types of Fe'i bananas have been reported in other Pacific islands, including Papua New Guinea, Fiji, Rotuma, Tahiti, and Tonga [149–153]. Another Fe'i cultivar analyzed, the Samoa *Soa'a*, had a relatively low carotenoid content (108 μg of β-carotene equivalents/100 g) [154].

Karat has been eaten in Micronesia for hundreds of years. A study of flora was carried out in Kosrae, one of the four Federated States of Micronesia, in the 1830s [155]. At that time four banana cultivars were documented: *Usr Kulasr* (Kosraean for *Karat*), *Usr Kolontol* (*Uht en Yap* in Pohnpei), and two non-Fe'i cultivars, *Usr Wac* and *Usr Kuria*. All four cultivars are carotenoid-rich (table 1). Informants emphasize that there was greater consumption of these in the past.

FIG. 1. Fe'i banana plant (*Karat*) with erect bunch.

TABLE 1. Comparison of ripe Micronesian banana cultivars for impact on vitamin A requirements according to level of consumption

Local name[a]	Classification[b]	Color[c]	Sample[d]	*N*[e]	Laboratory[f]	β-Carotene eq[g] (µg/100 g)
Uht en Yap/Usr Kolonto[h, i, j]	Fe'i	Orange	Baked	3	I, R	4,960
Usr Wac[h, i, j]	AAB; plantain-like	Orange	Boiled	2	I, R	2,598
Ipali[h, i, j] =*Usr Wac Es Sie*?	AAB; plantain-like	Orange	Boiled	2	I, R	1,349
Usr Kuria[h, i, j]	NA	Yellow	Steamed	1	I	892
Karat/Usr Kulasr[h, i, j]	Fe'i	Yellow-orange	Steamed or boiled	3	I, R	867
Usr Wac Es Sie[h, i, j]	AAB; plantain-like	Yellow-orange	Steamed	1	I	859
Usr Macao[h, i, j]	AA; *Lakatan*	Yellow-orange	Boiled	2	I, R	837
Uht Akatan/Usr Lakatan[h, i, j, k]	AAA; *Green Red*	Yellow	Steamed	1	I	773
Mangat[h, i, j]	NA	Yellow	Raw	1	C	575
Usr Taiwang[h, i, j]	AAB; *Pisang Kelat*	Yellow	Boiled	1	R	490
Uht en Kerinis[h, i]	AAB; *Pisang Raja*?	Yellow	Raw	1	I	415
Usr in Yeir[h,i]	AAB; *Popoulu*	Yellow	Boiled	2	I, R	390
Marech	NA	Yellow	Raw	1	I	232
Usr Apat Poel/Uht Inasio	ABB; *Bluggoe*	Creamy	Boiled	1	R	155
Uht en Ruk/Usr Apat Fusus	ABB; *Saba*	Creamy	Boiled	3	R	148
Usr Fiji/Uht en Fiji	AAB; *Mysore*	White	Raw	1	I	77
Usr Kufafa/Uht en Menihla	AAB; *Silk*	White	Raw	1	R	40

Source: refs. 33 and 34 for all data except for those on *Mangat*, for which data are from ref. 35. NA, Not available. Daily vitamin A recommended safe
women 19–65 years of age; 400 µg RE for children 1–3 years of age; 450 µg RE for children 4–6 years of age. β-Carotene equivalents are defined as
equivalent (RE) is 1 µg of all-*trans*-retinol defined to equal 6 µg of all-*trans*-β-carotene, and a retinol activity equivalent (RAE) is 1 µg of all-*trans*-

a. Pohnpei, Kosrae, or Chuuk names are given; for cultivars having different names, the name presented first is for the sample analyzed or that for
b. The Stover and Simmonds [148] classification by genome and subgroup is used.
c. Color of edible portion was identified by visual comparison.
d. The cooking method used in preparing the sample is given. If no cooked sample was analyzed for the cultivar, the results of analysis of the raw
e. The number of duplicate analyses of composite samples from which β-carotene equivalents were calculated is given. Most composite samples by less than 10% from each other (Fiji laboratory); the standard error of the mean for the Swiss analyses ranged from 8.5% to 9.4%.
f. The following laboratories carried out the analyses: I, Institute of Applied Sciences/University of the South Pacific, Suva, Fiji; R, Roche Vitamins,
g. β-Carotene equivalents were calculated from averages of the β- and α-carotene values for results of multiple analyses or from values of results of
h. Cultivar providing half or more of the daily vitamin A requirement for nonpregnant, nonlactating women 19–65 years of age, if 1,000 g (4 cups)
i. Cultivar providing half or more of the daily vitamin A requirement for a child from 4 to 6 years of age, if 500 g (2 cups) is eaten per day.
j. Cultivar providing half or more of the daily vitamin A requirement for a child from 1 to 3 years of age, if 250 g (1 cup) is eaten per day.
k. This cultivar, called *Uht Akatan* or *Usr Lakatan* in the Federated States of Micronesia, is different from the *Lakatan* in the Philippines because of

Although *Karat*, a traditional weaning food in the Federated States of Micronesia, had been neglected, it has been recently promoted in Pohnpei State. Following a one-year campaign in 1999, production increased and the cultivar was then marketed, although it had not been marketed prior to the campaign, showing that even short-term food-based campaigns can be successful if planned carefully, taking cultural beliefs and practices into account [43]. Apparently vitamin A deficiency is a new problem in the Federated States of Micronesia [156, 157]. Thus, these banana cultivars may have protected against vitamin A deficiency in the past and could again play important roles in preventing vitamin A deficiency [37, 157]. We suggest the same could occur in other communities.

Other potential health benefits

Epidemiological studies suggest that carotenoid-rich food protects against chronic diseases, including certain cancers, cardiovascular disease, diabetes, some inflammatory diseases, and age-related macular degeneration [158–161]. This is in contrast to two studies showing that β-carotene as a supplement had harmful effects by producing more lung cancers [162, 163). Consumption of carotenoid-rich bananas should help protect against those diseases, which are growing problems throughout the world [164–166]. Increased consumption of carotenoid-rich foods may be more likely if they are promoted for protection against both vitamin A deficiency disorders and chronic diseases, since chronic diseases are more visible in the community.

µg RE if 1,000 g eaten/ day	µg RE if 500 g eaten/ day	µg RE if 250 g eaten/ day	µg RAE if 1,000 g eaten/ day	µg RAE if 500 g eaten/ day	µg RAE if 250 g eaten/ day
8,267	4,133	2,067	4,133	2,067	1,033
4,330	2,165	1,083	2,165	1,083	541
2,248	1,124	562	1,124	562	281
1,487	743	372	743	372	186
1,445	723	361	723	361	181
1,431	716	358	716	358	179
1,395	698	349	698	349	174
1,288	644	322	644	322	161
958	479	240	479	240	120
816	408	204	408	204	102
692	346	173	346	173	86
650	325	163	325	163	81
387	193	97	193	97	48
258	129	65	129	65	32
247	123	62	123	62	31
128	64	32	64	32	16
67	33	17	33	17	8

intake (FAO/WHO, 2002)[146]: 500 µg RE for nonpregnant, nonlactating
the sum of the β-carotene and one-half the α-carotene content. A retinol
retinol defined to equal 12 µg of all-*trans*-β-carotene.
which the greatest number was analyzed.

sample are presented.
consisted of 3 fruits (range, 2 to 16). The results of the duplicate analyses varied

Basel, Switzerland; C, Covance Laboratories, Madison, Wisconsin, USA.
single analyses.
is eaten per day.

possible misnaming or misidentification.

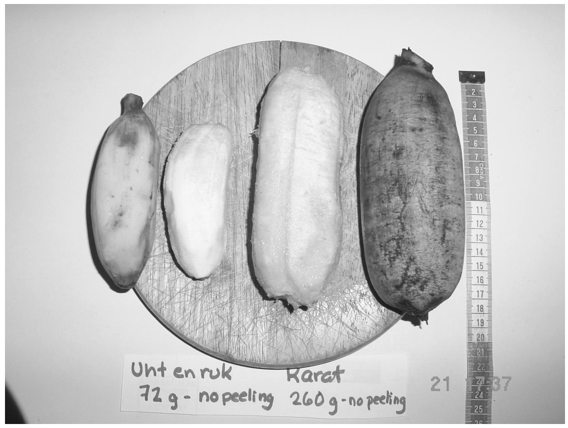

FIG. 2. Fe'i bananas (*Karat*), one unpeeled (far right) and one peeled (second from right), showing shape, size, and darker shades of skin and flesh compared to a common Micronesian banana, unpeeled (far left) and peeled (second from left).

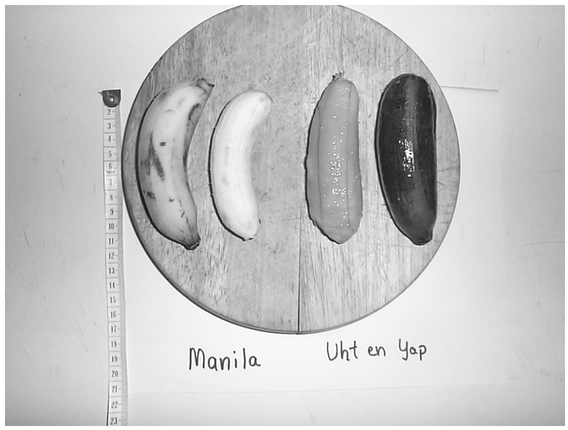

FIG. 3. Fe'i bananas (*Uht en Yap*), one unpeeled (far right) and one peeled (second from right), showing shape, size, and darker shades of skin and flesh compared to a common Micronesian banana, unpeeled (far left) and peeled (second from left).

Bananas are also a good source of energy, vitamin C, potassium, and fiber [19, 111, 124, 167] and therefore provide a variety of important nutrients for good health. Although the common banana is low in calcium, the *Karat* cultivar has a relatively high content of calcium [33].

Other positive factors related to bananas as a crop and a food

Bananas are a crop that is easy to grow in a tropical climate. They do not require replanting or seed purchase, and they generally bear fruit throughout the year, providing ongoing availability, unlike some other crops [124]. Although there is no "perfect banana cultivar," when pest and disease resistance, yield, taste, and nutritional content are taken into consideration cultivars can be selected with the most positive characteristics that are suitable for the particular environment [168]. Fungal diseases (e.g., black Sigatoka) threaten global banana production, in particular that of the *Cavendish* cultivar [125], but some cultivars, including *Karat*, have been found to show resistance to these diseases [168], emphasizing the need to maintain a diversity of banana cultivars. Obtaining planting material may be difficult for rare banana cultivars, but banana tissue culture offers many advantages to ensure that cultivars are maintained free from dangers of the environment, pests, or disease. Tissue culture can provide planting material as pathogen-tested plantlets to be sent all over the world. A program in Kosrae has now started providing *Karat* (*Usr Kulasr*) banana for their community [169].

TABLE 2. β-Carotene and α-carotene content of selected banana cultivars from Southeast Asia compared with the common banana

Scientific name[a]	Local name[a]	Origin	Ref.	Classification[b]	β-Carotene eq (μg/100 g)[c]
Musa sapientum var. *tuldoc*	*Tundok*	Philippines	38	AAB; *Horn Plantain*	1,370
Musa sp.	*Pisang Rajah Buluh*	Malaysia	40	AAB; *Pisang Raja*	420
Musa sp.	*Pisang Mas*	Malaysia	40	AA; *Sucrier*	420
Musa sp.	*Pisang Tandok*	Malaysia	40	AAB; *Horn Plantain*	370
Musa sp.	*Pisang Kelat*	Malaysia	40	AAB; *Pisang Kelat*	370
Musa sp.	*Lakatan*	Philippines	38	AA; *Lakatan*	360
Musa sp.	*Kluai Khai*	Thailand	39	AA; *Sucrier*	345
Musa sp.	*Pisang Susu*	Malaysia	40	AAA; *Pisang Susu*	330
Musa sapientum var. *ternantensis*	*Ternate*	Philippines	38	AAB; *Pisang Raja?*	325
Musa sp.	*Pisang Rajah Udang*	Malaysia	40	AAA; *Red*	290
Musa sp.	*Hug-mook, Silver Bluggoe*	Thailand	39	ABB; *Bluggoe*	279
Musa sp.	*Pisang Berangan*	Malaysia	40	AA; *Lakatan*	230
Musa sp.	Common banana	Unspecified	29, 30	AAA; *Cavendish*[d]	21

a The name provided in the reference is given.
b. The Stover and Simmonds [148] classification by genome and subgroup is used.
c. β-Carotene equivalents are defined as the sum of the β-carotene and one-half of the α-carotene content.
d. It is likely that the banana documented as the common banana in these references is the *Cavendish*.

Young children are fed bananas in many cultures because of their sweet taste and soft texture and because children seem almost universally to like them [56, 63, 107, 170–172]. Bananas have great versatility and are prepared in a variety of recipes, including baby food preparations, puddings, pancakes, and breads. In the Pacific, bananas are mixed with taro or yam, along with coconut cream, and baked in several recipes. Because they can be eaten raw, bananas provide a convenient food for busy mothers and a ready-to-eat, hygienically packed food for the child. Bananas can be considered a healthful “fast food.” Even when ripe bananas are cooked as a staple food, the cooking time is relatively short and they can be prepared without milling or grinding into flour, as must be done with cereal products.

The coloration of the edible portion of the banana fruit appears to be a good indicator of its carotenoid content [33, 34]. Five grades of color have been identified: white, creamy, yellow, yellow-orange, and orange. Thus, banana fruit coloration might be used in the community to select banana cultivars with the greatest potential for health benefits. However, further work is needed to verify that color does consistently reflect the carotenoid content in different banana cultivars.

Lack of data on composition of foods in the diet

Although the identification of vitamin A–rich foods is critical to food-based vitamin A deficiency programs [48, 102, 173], there are few data on the carotenoid content of many foods [21, 47, 48]. Table 3 presents information on many banana cultivars from Africa and other regions that are potentially carotenoid-rich, based on the reported yellow or orange coloration [174], and that thus may be good sources of vitamin A, depending on a number of factors, including the number of varieties and volume of production [46]. Another banana, *Nendran* of India [175], was described by Kerala informants to be similar in appearance to the *Ipali* of Pohnpei (table 1) and as having an orange-colored flesh. *Nendran* is a popular banana in Kerala and other parts of southern India, is widely eaten by people of all ages, is traditionally given to babies from four months of age, and is said to be good for the eyesight. In two studies carried out in India, *Nendran* was found to contain 310 and 336 μg of β-carotene/100 g [176, 177], which are high levels compared with those in the common banana. Indian food-composition tables provide data on carotenoid content for only the common banana [99]. The *Champa* of Bangladesh is reported to have a very yellow-colored flesh, but no known analyses have been done on this banana (Ahmed F, personal communication, 2003). The *Pisang Raja,* King Banana, was identified in an Indonesian study as one of the 47 foods contributing most of the vitamin A to the diet of 265 preschool children [178]. Such examples indicate the need for research on and awareness of the nutrient contents of selected banana cultivars.

TABLE 3. Selected banana cultivars listed according to reported color of flesh and country of origin

Yellow-colored flesh		Orange-colored flesh	
Origin	Cultivars	Origin	Cultivars
Cameroon	*Kelong Mekintu*[a]; *Ntie*[b]; *Nyombe 1*[b]	Cameroon	*2 Hands Planty*[b]; *Batard*[b]; *Big Ebanga*[b]; *Biya 2*[b]; *Corne Type*[b]; *Ebang*[b]; *Ekona 1*[b]; *Elat*[b]; *Esang*[b];*French Clair*[b]; *French Sombre*[b]; *Kar Ngou*[b]; *Mbouroukou 1*[b]; *Messiatso*[b]; *Moto Ebanga*[b]; *Moto Mo Liko*[b]; *Njock Kon*[b]; *Nzorba*[b]; *Red Ebanga*[b]; *Red Yade*[b]; *Rose d'Ekona*[b]; *Rouge de Loum*[b]
Papua New Guinea	*Karoina*[b]; *Pisang Jari Buaya*[a]; *Sar*[b]; *Udiwasi*[c]; *Umbuba*[b]; *Ungota*[b]; *Wain*[b]	Papua New Guinea	*Ato*[d]; *Gorop*[a]; *Kekiau*[b]; *Mala*[b] ; *Marau*[b]; *Ta*[d]
Guadeloupe	*Gros Michel*[a]	Congo	*Corne Rouge 18*[b]; *Didiedi*[b]; *3 Vert*[b]
Malaysia	*Pisang Mas*[a]	Ghana	*Abomienu*[b]; *Osoaboaso*[b]
Philippines	*Inarnibal*[a]	Nigeria	*Orishele*[b]; *76–17 (Ubok Iba)*[b]
Rwanda	*Igihobe*[b]	Côte d'Ivoire	*Digby1*[b]
		Cook Islands	*Mangaro Torotea*[b]
		Indonesia	*Pisang Raja Bulu*[a]
		No origin listed	*Atia Ndjokou*[b]

Source: ref. 174. More extensive information on further yellow- and orange-colored cultivars is available from the Musa Germplasm Information System (MGIS) database from the International Network of Banana and Plantain Improvement (INIBAP), including 92 further orange-colored cultivars from a range of countries, including India and China. Cultivars with white, ivory, cream, or beige-pink colored pulp are not included in this table. Flesh or pulp are both terms used for the edible portion of the fruit.
a. Mainly eaten raw
b. Mainly eaten cooked.
c. Eaten raw and cooked.
c. Information on use not given

Discussion and conclusions

The success of a food-based vitamin A deficiency–prevention strategy based on locally grown foods depends largely on the food that is promoted. Numerous factors limit the potential of presently known vitamin A–rich foods, including the vitamin A activity of the food, acceptability of taste, cost, availability, status and prestige, familiarity, seasonality, and size of the commonly eaten portion. This review has shown that there are constraints in promoting commonly recommended sources of vitamin A, despite demonstrated success in some settings.

At the same time, bananas are one of the world's most common staple foods, and several carotenoid-rich cultivars have been identified. It is stressed that there is a great need for the identification of other banana cultivars that are likely to be carotenoid-rich, based on the color of the edible portion, and that these should be analyzed for provitamin A and other carotenoids by state-of-the-art methods with high-performance liquid chromatography [104]. Ethnography is suggested to be an important research method that could be used in identifying the potential carotenoid-rich cultivars and in gathering information needed for planning food-based vitamin A deficiency–prevention strategies, including data on factors such as production, consumption, and acceptability. Efforts should be focused on those areas of the world where bananas are an accepted staple food. Studies are needed to determine the impact that carotenoid-rich cultivars will have on improving vitamin A status.

If these results are as we suggest, plans should be made for promoting the most acceptable carotenoid-rich cultivars using participatory methods and taking into account cultural beliefs and practices. It is likely that there are carotenoid-rich cultivars in some countries that could play a more important role in protecting against vitamin A deficiency and certain chronic diseases. Some success in Pohnpei with yellow-fleshed bananas (and with orange-fleshed sweet potatoes in East Africa) suggests a potentially important role for high vitamin A–content bananas and plantains, especially where these are staple foods. In conclusion, shifting from consumption of low-carotenoid banana cultivars to those richer in provitamin A carotenoids could potentially have a great impact on the elimination of vitamin A deficiency and the improvement of general health.

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