Sweetpotato potential in reducing vitamin A deficiency in Africa

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Key words: β–carotene, *Ipomoea batatas*, piecemeal harvesting, utilization, post-harvest

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INTRODUCTION

Recent studies associating consumption of foods rich in carotenoids with a decreased incidence of certain cancers in humans (Gester, 1993), and the possible role of carotenoids in immunity, fertility, and early prophylaxis of cardiovascular diseases in livestock have generated interest in these compounds (Pfander, 1992). Carotenoids represent the most widespread group of naturally-occurring pigments in nature. They are primarily of plant origin and β–carotene, with few exceptions, predominates (Chandler and Schwartz, 1988). β–Carotene serves as an important nutritional component in foods, as a major precursor of vitamin A, and it provides pleasant yellow-orange colors to foods (Simon, 1997).

Dietary vitamin A deficiency causes debilitating health problems such as xerophthalmia, corneal lesions, keratomalace, and, in many instances death (Olson, 1989). Frequent reports about these problems affecting young children from Africa continue (WHO, 1995).

Since the early 1990s, the main strategy for combating vitamin A deficiency has been to distribute massive dose capsules (Kennedy and Oniango, 1993). However, the same effect could be achieved by consuming sufficient quantities of β–carotene- and vitamin A-rich foodstuffs. This is the safest approach to controlling vitamin A deficiency, and also the most sustainable in many rural areas of Africa where chronic deficiencies are still common (Jalal et al., 1998; Roels et al. 1958). Foods such as dairy and meat products containing pre-formed vitamin A are often too expensive for most people in African countries. Therefore, it is important to make more potent and sustainable food sources of pro-vitamin A carotenoids available and improve their production, shelf life, and consumer acceptance. This could make a tremendous contribution to improving human nutrition and health.

Sweetpotato has been receiving increasing attention from agriculturalists and ecologists interested in developing sustainable food production systems in the tropics, in part because it can grow on soils with limited fertility, is relatively drought tolerant, provides good ground cover, and is usually cultivated without fertilizer or pesticide (Ewell, 1990). Also, it has remarkable pro-vitamin A quantities (Woolfe, 1992). In parts of West, Central, and East Africa, sweetpotato is an important staple food source of calories and is consumed by all age-groups, but is particularly liked by children, who also are at most risk of vitamin A deficiency (Low et al., 1997). Widely consumed varieties, however, are white or pale yellow in flesh color and contain very little β–carotene (Ameny and Wilson, 1997; Takahata et al., 1993). Orange-fleshed sweetpotato storage roots high in carotenoids and vitamin A active, β–carotene (Simonne et al., 1993; Takahata et al., 1993), are less eaten. Consumption of orange-fleshed sweetpotato roots and sweetpotato-based processed foods would provide sustainable, cost-effective, and necessary vitamin A. In fact, consumption of β–carotene-rich foods mainly in the form of orange-fleshed sweetpotato has recently been shown to increase low serum retinol concentrations in children from Indonesia and to alleviate signs of vitamin A deficiency (Jalal et al., 1998). Therefore, the use of orange-fleshed sweetpotatoes as a food source of carotenoids merits further attention.

Fresh sweetpotato roots are bulky and highly perishable, and in Africa, they are commonly consumed fresh, usually boiled. They are generally not harvested and stored for extended periods (Karuri and Ojijo, 1994). Instead, farmers piecemeal harvest the crop. The only kind of storage regularly practiced in Africa is in-ground storage, by which farmers keep unharvested mature sweetpotatoes in the field until they are needed for consumption or sale (Smit, 1997). Some inconclusive reports say that carotenoid content changes during sweetpotato storage root growth and development (Abubakar, 1981; Data *et al*., 1987).

Studying variation in carotenoid content, especially pro-vitamin A carotenoid content, during storage root development is relevant in the process of maximizing the availability of that nutrient. Proper recommendations could then be made to farmers to start practicing piecemeal harvesting.

In semi-arid areas with a long dry season, in-ground storage is limited by attacks from sweetpotato weevils (*Cylas spp*.). Farmers have traditionally chipped or crushed sweetpotato roots, sun-dried, and stored them for year-round use. The International Potato Center (CIP) has been working to make more nutritious sweetpotato varieties available to African countries (Gichuki et al., 1997). Chipping, drying and storing orange-fleshed sweetpotato can overcome the seasonal shortages of pro-vitamin A, a micronutrient short in the diets of many low-income African households during the dry season when there are no fresh, green vegetables. However, limited research has been conducted on sweetpotato flour production, and little is known about the effect of drying on the carotenoid content in sweetpotato roots.

Carotenoids are susceptible to degradation upon exposure to heat, light, metal ions, acids, and even alkali, because of their highly conjugated structure (Goodwin, 1980; Wong, 1989). Understanding carotenoids stability during the sweetpotato cooking and processing into flour and flour related products, which usually expose foods and their carotenoid content to these degradation agents, is essential to achieve and maintain products with the desired nutritionally quality.

MATERIALS AND METHODS

Plant material. Sweetpotato cultivars from CIP's pathogen-tested collection (CIP, 1994) with storage root flesh colors ranging from white to orange were selected and used in this study.

Storage root sampling. Roots were peeled, and about 2-cm thick medial transverse slices were taken from each root, and finely grated lengthwise using a cheese grater. The samples were thoroughly mixed, packed under nitrogen into plastic bags, and stored at −20ºC until used for carotenoid extraction.

The effect of root age on carotenoid content was assessed by sampling sweetpotato roots grown at 12, 16, 20, and 24 weeks after planting. At each stage, three plants were randomly selected and the largest storage roots piecemeal harvested from each randomly selected plant. Different plants were sampled at each harvest.

The effect of cooking on carotenoids was evaluated using fresh roots grown for six months at Kabete. Unpeeled medium-sized roots from four cultivars were boiled in water for 30, 45, and 60 minutes. Three boiled roots per cultivar were cooled, peeled and sampled for carotenoid determination as above described.

Chipping and drying. A 10-kg sample of medium and large sweetpotato roots from each cultivar was washed, air dried overnight, hand-peeled, and cut into approximately 2-4 mm thick chips. Chips were dried at 65°C in a forced-air oven to a moisture content of 6-8%. The process of producing dried sweetpotato chips used, was that described by Hagenimana et al. (1998b). 1.5-Kg of the dried chips from each cultivar were stored in opaque paper bag and samples were taken after 3, 6, and 11 months of storage under ambient air conditions to check for changes in total carotenoid contents. Flour was produced by hammer milling dried chips to pass through a 180 micron sieve.

Preparation of buns, chapatis and mandazis. Buns, chapatis (flat unleavened bread), and mandazis (doughnuts) were prepared as described by Hagenimana et al. (1998).

Carotenoid extraction. Extraction procedure from Khachik et al. (1992) was used.

Spectrophotometric determination of total carotenoid and β–carotene contents. Total carotenoids and β–carotene were determined spectrophotometrically as described by Imungi and Wabule (1990).

HPLC carotenoid analysis. One ml of total carotenoid extract from 2 g of grated sweetpotato sample was freeze-dried and reconstituted in HPLC mobile phase of 90% Methanol:10% Tetrahydrofuran. The reconstituted samples were ultra-filtered through 0.5 µm microfilters before injection into the HPLC system. HPLC analyses were done as described by Ruddat and Will III (1985) at the laboratory of the International Livestock Research Institute (ILRI), Nairobi, Kenya.

Standards used to identify different HPLC carotenoid chromatographic peaks were: β-carotene, α-carotene, lycopene from Sigma, St-Louis, ζ-carotene, β-cryptoxanthin were kindly donated by Drs. W. Schuep and J. Schierle from Hoffmann La Roche, Switzerland, β-carotene-5,6-monoepoxide and β-carotene-5,6,5',6'-diepoxide were kindly donated by Dr. Peter Molnar from the University of Pecs, Hungary. Identification of the various HPLC carotenoid peaks was based on consistent retention times and co-chromatography.

RESULTS and DISCUSSION

Carotenoids and vitamin A values of sweetpotato roots

HPLC results indicated that a good number of carotenoids occur in sweetpotato root extracts. Six of these were present in significant amounts with the predominance for more than 80% of all-*trans*-β-carotene in most orange-fleshed sweetpotato roots analysed (Figure 1). All-*trans*-β-carotene, β-carotene-5,6-monoepoxide, β-carotene-5,6,5',6'-diepoxide and unidentified carotenoid, denoted P1, were present in all cultivars analysed. The amount was, however,

dependent on the cultivar. Comparisons of chromatographic profiles of the sweetpotato extracts from different cultivars and the co-chromatography (Figure 2) with carotenoid identified the presence of all-*trans*-β-carotene, β-carotene-5,6-monoepoxide, and β-carotene-5,6,5',6'-diepoxide (Table 1).

P1 predominated in white- or cream-fleshed cultivars like KSP 20, Naveto (CIP440131), and KEMB 10 where it formed a significant proportion of total carotenoids. The possible identity of this carotenoid was able to be postulated on basis of its elution pattern. Early elution of P1, as well as that of P2, strongly suggests that it is a xanthophyll, possibly lutein, and P2, zeaxanthin. Large variation was observed in carotenoid content among the cultivars studied. This was a reflection of the wide spectrum of the root flesh color of sweetpotato. White-flesh roots like those from cultivars Mugande, TIS 2534 (CIP440062), LM88.014 (CIP188001.2), and KSP 20 had the lowest total carotenoid, while orange-fleshed cultivars like Camote amarillo (CIP400014), Japon Tresimesino Selecto (CIP420009), Kakamega 4 (SPK004), Zapallo (CIP420027) had the highest (Figure 3). Our results agree with the conclusion that carotenoids, especially β-carotene, are largely responsible for the orange flesh color in sweetpotato storage roots (Almeida-Muradian et al., 1992; Garcia *et al*., 1970; Picha, 1985; Takahata *et al*., 1993). The depth of orange flesh color was mainly a function of the concentration of all *trans* β-carotene, as was similarly reported by Simonne et al. (1993). These results indicate that carotenoids from orange-fleshed sweetpotato are highly vitamin A active and their consumption should be encouraged.

Low et al. (1997) suggested that cultivars having more than 100 µg retinol equivalent per 100 g fresh roots were good sources of vitamin A. Table 2 shows the vitamin A values of some 17 cultivars. Cultivars like TIB 11 (CIP440057), W-220 (CIP440015), Unknown, Japon Tresimesino Selecto (CIP420009), Zapallo (CIP420027), and Kakamega 4 (SPK004) have

sufficient levels of retinol equivalents to meet this criteria. Their cultivation, consumption, and utilization in different dishes should be encouraged in combating nutritional vitamin A deficiency in Africa.

Effect of root age

Sixteen to twenty week old roots contained higher carotenoid concentrations than younger roots (Figure 4). These differences in total carotenoid content between young and older roots depended on the cultivar. Sixteen-week old roots from Kakamega 4 (SPK004) were two-fold higher in total carotenoid content than 12-week old roots. Orange-fleshed cultivar Japon Tresimesino Selecto (CIP420009) had two-thirds of its total carotenoid content available after just 12 weeks. Concentration of total carotenoid continued to increase up to the 24th week in low-carotenoid-content cultivars TIS 2534 (CIP440062) and Kemb 10 (Figure 4). Therefore, to receive the maximum pro-vitamin A benefits from the sweetpotato, piecemeal harvesting and consumption of roots from Japon Tresimesino Selecto (CIP420009) could begin after 12 weeks, after 16 weeks from Kakamega 4 (SPK004), and after 20 to 24 weeks from the lower carotenoid content cultivars.

Effect of boiling

Boiling sweetpotato roots reduced the carotenoid contents for all the cultivars studied (Table 3); the magnitude of reduction was important only for the first 30 min, and varied with cultivar. Carotenoid content from cultivar KEMB 10 was highly reduced after boiling for 30 min whereas orange-fleshed Japon Tresimesino Selecto (CIP420009) and Kakamega 4 (SPK004) were less affected by boiling for 60 minutes. Chandler and Schwartz (1988) also noted that carotenoids in cultivars less rich in carotenoids are more susceptible to degradation than richer ones. Reduction in carotenoid content could be explained by the fact that carotenoids compounds undergo oxidation and degradation upon exposure to heat, light, acids, peroxides,

metals, and enzymes. Carotenoids are easily oxidized because of the large number of conjugated double bonds found in the compounds (Krinsky *et al*., 1990). β-carotene formed a significant proportion of total carotenoids in most of the cultivars studied, especially orange- and yellow-fleshed ones. Carotenoid degradation products would consist mainly of β-carotene degradation compounds. Thermally-mediated *cis*-isomerization may not necessarily lead to the complete loss of vitamin A activity of carotenoids. In *vivo* studies with the ferret model have shown that 9-*cis*-β-carotene has good bioavailability and is a precursor of 9-*cis*-retinoic acid, which can be converted to vitamin A (Kays et al., 1992). If such metabolism occurs in human then boiling-associated *cis* isomerization did only cause minor loss of vitamin A value.

Effect of drying and storage of sweetpotato chips on total carotenoid contents

Drying sweetpotato storage roots at 65°C for 12 hours reduced the total carotenoid contents by 30%, while storage of dried chips for 11 months reduced the total carotenoid contents from 70 to 59% (Figure 5, and more details from Hagenimana et al., 1998b).

Total carotenoids in processed sweetpotato products

Figure 6 (from Hagenimana et al., 1998b) shows that the incorporation of orange-fleshed sweetpotato roots significantly increased the total carotenoid contents of the products over those containing no sweetpotato, and improve the color of the products, giving them an attractive egg-like appearance.

CONCLUSION

- Orange-fleshed roots contained higher total carotenoid and β–carotene content than white- and cream- fleshed lines, and all *trans*-β–carotene predominated for more than 80%. Carotenoids from orange-fleshed sweetpotato are highly vitamin A active and their consumption in Africa where vitamin A deficiency is prevalent should be encouraged.

- Twelve weeks after planting, the yield and amount of pro-vitamin A present in roots of orange-fleshed cultivars evaluated were high enough to provide adequate dietary pro-vitamin A and suggest the start of piecemeal harvesting.
- Incorporation of flour made from orange-fleshed sweetpotato roots into buns, chapatis, and mandazis significantly enriched the products in pro-vitamin A.
- Results of this study suggest that increased consumption of orange-fleshed sweetpotatoes in either fresh or processed form can contribute in alleviating dietary deficiency of vitamin A.

Acknowledgement

Author Hagenimana is partially funded by the Department for International Development (DFID) of the United Kingdom, the Crop Postharvest Research Programme [R7036]. However, the DFID can accept no responsibility for any information provided or views expressed. HPLC carotenoid analyses were conducted at the International Livestock Research Institute (ILRI), Nairobi. β-carotene-5,6-monoepoxide, β-carotene-5,6,5',6'-diepoxide standards were kindly donated by Dr. Peter Molnar from University of Pecs, Hungary. ζ-carotene and β-cryptoxanthin were kindly donated by Drs. W. Schuep and J. Schierle from Hoffmann La Roche Ltd., Switzerland.

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Table 1. Retention Times of Carotenoid Standards and Sweetpotato Extract during HPLC Cochromatography

Peak identity	Carotenoid standards, Retention time, min [a]	Sweetpotato extract (Cultivar SPK 004), Retention time, min [a]	Sweetpotato extract + carotenoid standard, Retention time, min [a]
P1 (Unidentified)	–	2.69 ± 0.10	2.89 ± 0.09
P2 (Unidentified)	–	3.75 ± 0.15	4.05 ± 0.07
P3 (β–carotene-5,6,5',6'-diepoxide)	5.28 ± 0.5	5.36 ± 0.22	5.83 ± 0.21
P4 (β–cryptoxanthin)	6.30 ± 0.14	–	6.30 ± 0.14
P5 (Unidentified)	6.50 ± 0.05	–	6.50 ± 0.05
P6 (β-carotene-5,6-monoepoxide)	9.19 ± 0.08	8.61 ± 0.40	9.00 ± 0.05
P7 (ζ-carotene)	12.42 ± 0.18	–	12.57 ± 0.20
P8 (Lycopene)	13.89 ± 0.20	–	13.68 ± 0.14
P9 (α-carotene)	14.36 ± 0.06	–	14.43 ± 0.07
P10 (All-trans-β-carotene)	15.72 ± 0.49	14.60 ± 0.87	15.21 ± 0.08
P11 (Unidentified)	–	15.44 ± 0.33	15.70 ± 0.19

[a] **mean ± SD**

Table 2. Carotenoids and Vitamin A Values of 17 Sweetpotato Cultivars Evaluated in Kenya, in 1996.

Cultivar	Flesh color	Total carotenoid content* *(mg/100g fresh root ± SD)*	β-Carotene content* *(mg/100g fresh root ± SD)*	β-Carotene-5,6-monoepoxide content *(μg/100g fresh root ± SD)*	β-Carotene to Total carotenoids, *% ± SD*	Vitamin A Value *(RE/100g fresh root ± SD)*
Naveto (CIP440131)	White	< 0.1	< 0.1	1.5 ± 0.3	0.1	0.1 ± 0.0
LM88.002 (CIP188001.1)	White	0.1 ± 0.0	< 0.1	0.1 ± 0.0	4.5	0.9 ± 0.6
KSP 11	White	0.2 ± 0.0	< 0.1	< 0.1	12.5	3.3 ± 0.3
TIS 2534 (CIP440062)	White	0.1 ± 0.0	< 0.1	0.1 ± 0.0	12.1	2.8 ± 0.3
Ex-Diani	White	0.2 ± 0.0	< 0.1	0.1 ± 0.1	10.1	3.2 ± 0.6
Phillippine (CIP440160)	Dark cream	0.2 ± 0.0	< 0.1	0.3 ± 0.2	3.2	0.9 ± 0.3
TIS 70357 (CIP440078)	Cream	0.2 ± 0.0	< 0.1	0.2 ± 0.0	15.8	6.6 ± 1.2
NG 7570 (CIP440377)	White	0.2 ± 0.0	< 0.1	0.1 ± 0.0	9.9	3.4 ± 0.8
Capadito (CIP420053)	Pigmented	0.2 ± 0.0	< 0.1	ND	15.0	6.0 ± 1.0
KEMB 10	Cream	0.4 ± 0.0	0.1 ± 0.0	2.3 ± 0.2	39.6	21.1 ± 1.8
Maria Angola (CIP420008)	Pale orange	0.4 ± 0.0	0.1 ± 0.0	0.5 ± 0.1	28.4	18.5 ± 1.6
Kakamega 4 (SPK 004)	Orange	2.6 ± 0.2	1.5 ± 0.1	68.0 ± 0.0	59.0	258.2 ± 23.3
Zapallo (CIP420027)	Pale orange	4.3 ± 0.0	2.9 ± 0.5	111 ± 19.3	67.7	493.8 ± 80.2
Japon Tresmesino Selecto (CIP420009)	Interme-diate orange	5.5 ± 0.3	4.6 ± 1.4	90.2 ± 2.7	82.7	768.4 ± 228.8
Unknown	Pale orange	7.5 ± 0.7	6.2 ± 0.0	98.5 ± 5.8	83.1	1047.3 ± 15.8
W-220 (CIP440015)	Interme-diate orange	8.4 ± 0.4	6.0 ± 0.5	208.9 ± 56.9	71.7	1021.3 ± 82.1
TIB 11 (CIP440057)	Orange	8.8 ± 0.7	8.0 ± 0.3	91.0 ± 4.7	90.8	1338.2 ± 56.9

* Values less than 0.05 mg/100 g fresh root are indicated as 0.0

Table 3. Total Carotenoid Content of Boiled Sweetpotato Storage Roots from 4 Cultivars.

Cultivar	**Total carotenoid content*** *(mg/100g boiled root ± SD)*			
	Raw sweetpotato	Roots boiled for 30 min.	Roots boiled for 45 min.	Roots boiled for 60 min.
KEMB 10	0.9 ± 0.0	0.6 ± 0.1	0.6 ± 0.0	0.4 ± 0.1
Kakamega 4 (SPK 004)	3.1 ± 0.1	1.2 ± 0.1	1.7 ± 0.0	1.7 ± 0.3
Japon Tresimesino Selecto (CIP420009)	6.7 ± 0.0	5.0 ± 0.1	6.6 ± 0.1	6.6 ± 0.1
TIS 2534 (CIP440062)	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0

* Values less than 0.05 mg/100 g fresh root are indicated as 0.0