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CAROTENOID CONTENTS IN FRESH, DRIED AND PROCESSED SWEETPOTATO PRODUCTS

V. HAGENIMANA[1,*], E.E. CAREY[1], S.T. GICHUKI[1], M.A. OYUNGA[2] and J.K. IMUNGI[3]

[1]*International Potato Center (CIP), Sub-Saharan Africa, P.O. Box 25171, Nairobi, Kenya;*
[2]*KARI-National Potato Research Centre, P.O. Box 338, Limuru, Kenya;*
[3]*Dept. of Food Technology and Nutrition, University of Nairobi, P.O. Box 29053, Nairobi, Kenya*

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In order to understand the effects of drying and processing sweetpotato storage roots into traditional baked food products on their pro-vitamin A contents, total carotenoids and β-carotene were colorimetrically determined. Fresh and cooked storage roots, dried and stored chips, and sweetpotato processed products were used. Flesh colors of the storage roots were white, yellow, cream, orange, and purple. Total carotenoids ranged from trace to above 9 mg β-carotene equiv./100 g of fresh storage root. Storage roots of high carotenoid content cultivars had consistently orange flesh; those with low to very low carotenoid contents were yellow or white. Hunter "b" values were high and consistent for flours from orange- and cream-fleshed root cultivars, which could easily be used to predict total carotenoid and β-carotene contents. Drying sweetpotato storage roots at 65°C for 12 h reduced total carotenoid contents by 30%. Storing dried chips in ambient conditions for 11 months induced a 10% loss. Incorporation of flour made from orange-fleshed sweetpotato roots into buns, chapatis, and mandazis enriched the products in total carotenoids from 0.1 mg to 2.3 mg β-carotene equivalents per 100 g product. 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.

* Corresponding author. E-mail: v.hagenimana@cgnet.com.

KEY WORDS: β-carotene, vitamin A, drying, flour, *Ipomoea batatas*, postharvest, Africa

INTRODUCTION

Millions of people in many developing countries suffer from vitamin A deficiency, an affliction leading to night blindness, xerophthalmia, and keratomalacia (Smith *et al*., 1996). Subclinical deficiency also reduces immune functions thereby increasing the risk of a range of secondary diseases (Bates, 1995; Underwood, 1994).

Since the early 1990s, the main strategy for combating vitamin A deficiency has been to distribute massive-dose capsules (Kennedy and Oniango, 1993). However, a similar effect could be achieved by increased consumption of β-carotene- and vitamin A-rich foodstuffs (Rahmathullah *et al*., 1990). Dairy and meat products containing preformed vitamin A are often too expensive for most people in developing countries. Foods providing concentrated pro-vitamin A carotenoids can make a tremendous contribution to improved human health. The challenge is to increase their availability, shelf life, and consumer acceptance.

Sweetpotato (*Ipomoea batatas*) roots are one of the major food sources of carotenoids (Henkel, 1996; Woolfe, 1992). The color intensity of the root flesh differs from one cultivar to another, and varies from white to deep orange. The intensity of orange color is attributed to carotenoid content (Ameny and Wilson, 1997). Carotenoids act as vitamin A precursors. When consumed, they are enzymatically transformed to retinol (vitamin A) (Simon, 1997). The vitamin A activity of β-carotene is substantially greater than that of other carotenoids (Almeida and Penteado, 1988).

In Africa, sweetpotato is an important staple consumed by all age-groups but is particularly liked by children, the group most vulnerable to vitamin A deficiency. The carotenoids of orange-fleshed sweetpotato storage roots are highly vitamin A active and almost exclusively β-carotene (Purcell, 1962; Purcell and Walter, 1968; Simonne *et al.*, 1993; and Takahata *et al.*, 1993). Yet the varieties most widely consumed are white or pale yellow and contain very little β-carotene (Takahata *et al.*, 1993; Ameny and Wilson, 1997). Increasing the consumption of orange-fleshed sweetpotato roots would provide sustainable, cost-effective sources of vitamin A.

Fresh sweetpotato roots are bulky and highly perishable, and in Africa, they are commonly consumed fresh, usually boiled. The only storage regularly practised is in-ground storage whereby unharvested mature sweetpotatoes are left in the field until they are needed for consumption or local sale (Smit and Ocitti p'Obwoya, 1994). 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 developing countries (Gichuki *et al.*, 1997). Chipping, drying and storing orange-fleshed sweetpotato can overcome the seasonal shortages of vitamin A, a micronutrient which is critically short in the diets of many low-income households during the dry season when there are no fresh, green vegetables. However, little is known about the effect of indigenous drying on the carotenoid content in sweetpotato roots.

Limited research has been conducted on sweetpotato flour production. Flour was assayed by Walter *et al.* (1983) for protein efficiency ratio, amino acid content, nonprotein nitrogen, and available lysine. Truong (1992), Collado and Corke (1996) evaluated sweetpotato flour used in noodle processing. Collins and Abdul (1982) evaluated sweetpotato flour and puree as ingredients in yeast-raised doughnuts. Gakonyo (1993), Hagenimana and Owori (1997), and Omosa (1997) showed that mixing sweetpotato with wheat flour in processing "chapatis" (flat unleavened bread) and "mandazis" (doughnuts) reduced the cost of the products and improved the acceptability by consumers. Already in western Kenya and Lira, Uganda, such fried, processed sweetpotato products are being produced on a small-scale. They may eventually constitute an important source of vitamin A in these regions.

Understanding carotenoid stability during processing is essential to achieve products with the desired color and nutritional quality. This study was undertaken to measure the changes in total carotenoid content of orange-fleshed sweetpotato after the storage roots are dried for use as an ingredient in processed indigenous foods.

MATERIALS AND METHODS

Sweetpotatoes. Thirty two sweetpotato cultivars from CIP's pathogen-tested collection (CIP, 1994) were grown for five months at the university farm in Kabete, Nairobi. No irrigation, fungicides, or fertilizers were applied to the plots. Visually, root flesh colors were white, yellow, orange, and purple (Table I). Medium and large sweetpotato roots of each cultivar were maintained under ambient air conditions, washed, and used within two days after harvest.

Chipping and drying. A 10-kg sample of medium and large sweetpotato roots from each cultivar were washed, air dried overnight, hand-peeled, and cut into approximately 2–4 mm thick chips. The chips were dried at 65°C in a forced-air oven to a moisture content of 6–8%. The process of producing dried chips is shown in Figure 1. 1.5 kg of dried chips from each cultivar were stored in an 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.

Bun baking procedure. 120 g of sweetpotato flour, or 400 g of fresh raw hand-grated, or 400 g of cooked and mashed sweetpotato (refers to peeled roots maintained in boiling water for 30 min and then hand-mashed into a puree) were mixed with 400 g homebaking wheat flour (Unga Millers Ltd., Nakuru, Kenya), and 1 teaspoon (about 1.5 g) of baking dry yeast (Saflevure, S.I. Lesaffre 59703 Marcq, France) reactivated in warm solution of 20% sugar in water, $2\frac{1}{4}$ tablespoons (about 20 g) sugar and a

TABLE I

Some characteristics, total carotenoids, β-carotene contents of fresh storage roots and Hunter color values of flour made from different sweetpotato cultivars

Cultivar name*	Flesh color	Dry matter, (%)	β-carotene to total carotenoids, (%)	Carotenoids*** (mg/100 g fresh root tissue)		Color value of the flour		
				Total**	β-carotene**	L**	a**	b**
Camote Amarillo (CIP400014)	Orange (deep)	20.4	88	7.2±2.2	6.3±1.3	83.7±0.6	5.3±0.3	19.5±0.2
Japon Tresmesino Selecto (CIP420009)	Orange (deep)	21.8	90	6.9±4.6	6.2±4.3	81.2±0.9	4.0±0.4	16.5±6.4
Teoboza (CIP420010)	Orange (deep)	26.5	58	8.9±2.0	5.1±1.0	81.3±1.1	4.2±0.2	22.4±1.4
Zapallo (CIP420027)	Orange (deep)	24.3	87	4.7±6.0	4.1±0.0	79.8±1.4	4.4±0.9	20.8±0.5
Mamala (CIP420004)	Orange (light)	27.8	83	2.7±0.1	2.2±0.3	79.9±0.5	4.3±0.1	19.5±0.5
SPK 004	Orange (light)	32.3	78	2.7±0.2	2.1±0.1	78.9±2.3	3.2±0.3	16.9±1.4
LM87.009 (CIP187004.1)	Cream	28.4	65	1.7±0.1	1.1±0.1	86.5±1.7	4.1±0.1	13.8±0.4
NG 7570 (CIP440377)	Cream	28.0	84	1.0±0.5	0.8±0.3	83.1±1.0	4.0±0.1	15.3±0.3
Tainan No 15 (CIP440186)	Cream	30.8	49	1.7±0.2	0.8±0.3	82.3±2.3	3.1±0.5	14.1±2.0
LM87.045 (CIP187004.2)	Cream	34.5	58	1.3±0.1	0.7±0.1	82.4±1.5	3.2±0.2	17.6±1.3
KEMB 10	Yellow (deep)	32.3	62	1.0±0.4	0.6±0.2	80.0±2.4	3.2±0.4	11.3±1.2
Estrella (CIP420047)	Cream/purple	20.3	80	0.6±0.1	0.5±0.0	82.0±0.9	3.6±0.1	17.8±0.6
K148	Cream/yellow	33.9	57	0.8±0.1	0.5±0.1	81.3±0.2	3.4±0.1	17.1±0.4
CN1517-139 (CIP440224)	Cream/yellow	30.6	61	0.7±0.1	0.4±0.1	77.9±0.2	3.2±0.1	12.2±0.3
Xiang Shu 6 (CIP440154)	Cream/white	18.8	60	0.5±0.1	0.3±0.0	82.6±1.6	4.4±0.9	16.5±2.2
Capadito (CIP420053)	Purple/white	30.2	35	0.7±0.1	0.2±0.1	86.9±0.3	5.8±0.1	11.1±0.1
Cascajo Morado (CIP420031)	Purple/cream	34.3	25	0.8±0.1	0.2±0.1	88.1±0.3	7.9±0.1	9.9±0.1
CARI 9 (CIP440228)	Cream/yellow	24.0	57	0.5±0.1	0.2±0.1	82.3±1.4	3.0±0.2	14.8±1.5

TABLE I (*continued*)

Cultivar name*	Flesh color	Dry matter, (%)	β-carotene to total carotenoids, (%)	Carotenoids*** (mg/100 g fresh root tissue)		Color value of the flour		
				Total**	β-carotene**	L**	a**	b**
Morado Maravi (CIP400002)	Purple/white	22.1	76	0.2±0.0	0.2±0.0	89.4±1.3	5.8±0.2	13.8±1.1
Xushu 18 (CIP440025)	Yellow (light)	33.1	79	0.1±0.0	0.1±0.0	88.6±0.4	3.3±0.1	10.3±0.7
KEMB 33	Yellow (light)	34.6	30	0.3±0.0	0.1±0.0	78.2±0.6	3.1±0.1	10.9±0.2
Mabrouka (CIP440162)	Yellow (light)	27.7	36	0.1±0.0	<0.1	84.7±0.5	4.1±0.1	14.5±0.2
W-228 (CIP440023)	White/yellow	23.3	16	0.2±0.1	<0.1	78.6±0.6	3.2±0.1	12.1±0.4
Ihuanco (CIP440066)	White	21.8	4	0.1±0.0	<0.1	79.9±0.5	3.4±0.0	13.4±0.3
NC1582 (CIP440094)	White	25.4	10	0.1±0.0	<0.1	83.8±0.5	3.9±0.2	12.4±0.1
KEMB 20	White/yellow	31.4	12	0.1±0.0	<0.1	80.7±3.0	3.5±0.7	11.1±0.3
IRA502 (CIP440144)	Yellow/purple	25.1	2	0.1±0.0	<0.1	80.9±0.7	3.6±0.2	12.8±0.2
Naveto (CIP440131)	White/yellow	29.0	0	0.1±0.0	<0.1	79.9±0.3	3.7±0.2	10.3±0.2
K51/3251 (CIP440164)	White/yellow	22.5	0	0.1±0.0	<0.1	80.3±0.4	3.8±0.1	13.7±0.2
LM88.014 (CIP188001.2)	White	29.2	5	0.1±0.0	<0.1	79.4±0.5	3.4±0.2	11.2±0.9
KSP 20	White	28.9	0	<0.1	<0.1	83.0±2.8	4.1±0.3	13.7±0.8
Mugande	White	33.1	0	<0.1	<0.1	82.6±0.0	3.7±0.1	10.0±0.1

* Names in parenthesis are from CIP (International Potato Center) (1994). Pathogen-tested sweetpotato cultivars for distribution. Third edition. Lima, Peru.

** Mean ± STD

*** Values less than 0.05 mg/100 g fresh root tissue are considered as <0.1.

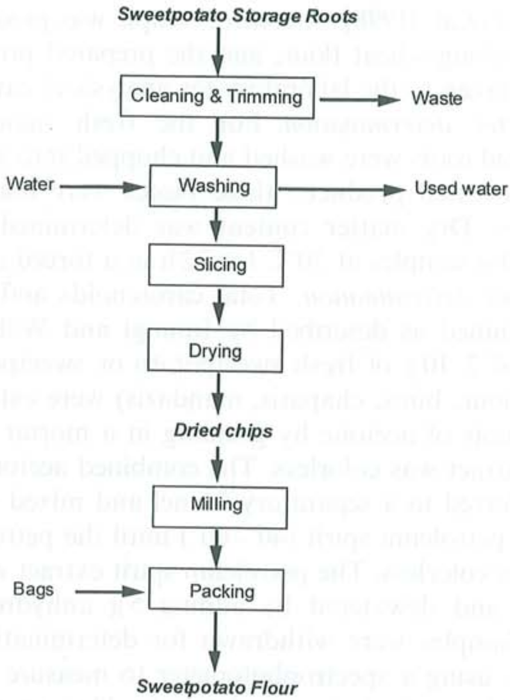

FIGURE 1 Process flow diagram for producing dried sweetpotato chips and flour.

quarter of total necessary water added and thoroughly mixed. The dough was kneaded using an electric kitchen mixer at the slow speed, and cooking oil slowly added. The mixer continued at this speed for some time. The remaining water was slowly added to the mixture and mixing continued for 10 min until an elastic dough was formed. The dough was cut into equal pieces which give a normal bun weight of 45–50 g after baking, moulded, and then left in ambient conditions for rising. The raised dough was then baked in a kitchen oven for 25–30 min. A control was processed using only wheat flour. The buns were packed in plastic bags and then taken the following day to the laboratory for carotenoid analysis.

Chapati and mandazi processing. Chapatis (flat unleavened bread) and mandazis (doughnuts) were prepared as described by

Hagenimana *et al.* (1998). A control sample was processed using only homebaking wheat flour, and the prepared products were cooled and taken to the laboratory for analysis of carotenoids.

Dry matter determination. For the fresh material, three medium-sized roots were washed and chopped into small cubes. For the processed products, three pieces were hand cut into small pieces. Dry matter content was determined by drying triplicate 20-g samples at 70°C for 72 h in a forced-air oven.

Carotenoid determination. Total carotenoids and β-carotene were determined as described by Imungi and Wabule (1990). A sample of 2–10 g of fresh sweetpotato or sweetpotato-based products (flour, buns, chapatis, mandazis) were extracted with 20 mL aliquots of acetone by grinding in a mortar with pestle until the extract was colorless. The combined acetone fractions were transferred to a separatory funnel and mixed with 20 mL aliquots of petroleum spirit (40°–60°) until the petroleum spirit fraction was colorless. The petroleum spirit extract was brought to 100 mL and dewatered by adding 5 g anhydrous sodium sulphate. Samples were withdrawn for determination of total carotenoids using a spectrophotometer to measure absorbance at 450 nm. Concentrations were determined by comparison with a standard curve developed using pure β-carotene from Sigma, St. Louis, USA. Then, 25 mL of the petroleum spirit extract was concentrated using a rotary vacuum evaporator at 30°C, the residue dissolved in 1 mL of petroleum spirit, and eluted through a silica gel chromatographic column with β-carotene from Sigma as standard. Separation was run using petroleum spirit and the first yellow fraction which constituted the β-carotene was collected and made to 25 mL. Absorbance was read at 450 nm as above.

*Sweetpotato flour Hunter L*a*b value determination.* A Minolta Chroma Meter CR-200B was used to determine flour color and color differences. The meter was calibrated before each measurement using the calibration plate provided with the Yxy values as 93.1, 0.3139 and 0.3213. During the calibration, the plate was wrapped with a plastic film which was also used during analysis of the sweetpotato storage root flour samples. Flour samples were carefully mixed and then triplicate 10-g samples taken for readings. The color of the flours was measured as L (white), a (red), and b (yellow) components.

Data analysis. All the data on carotenoid contents were subjected to analysis of variance using the MSTAT-C program (MSTAT-C, 1991).

RESULTS AND DISCUSSION

1. *Carotenoids and dry weight in fresh sweetpotato roots*

Total carotenoids and *β*-carotene contents in storage roots of 32 sweetpotato cultivars were determined (Figure 2). Cultivars had different flesh colors ranging from white, yellow, cream, orange to purple (Table I). Total carotenoids ranged from traces in the white-fleshed cultivars to 9 mg *β*-carotene equivalents per 100 g

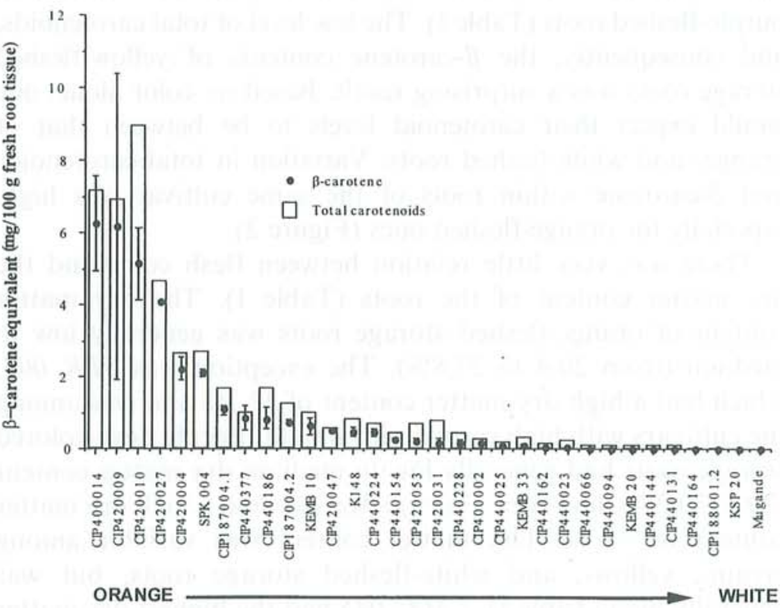

FIGURE 2 Relationship between the flesh color and carotenoid contents of different sweetpotato cultivars.

of fresh storage root tissue in deep orange-fleshed cultivars (Figure 2). β-Carotene contents on the other hand ranged from traces to about 6 mg/100 g fresh root. The average calculated percent total carotenoids that were β-carotene ranged between almost 0% in *Mugande* to about 90% in *Japon. Tresmesino Selecto*. The β-carotene contents were, however, highly correlated with total carotenoid contents (Table I). β-Carotene contents of some orange-fleshed sweetpotato storage roots were even higher than those of carrots sold in the Nairobi markets (Low *et al*., 1997). Our results are in agreement with those of Takahata *et al*. (1993) that showed sweetpotato carotenoids to be almost exclusively β-carotene.

Flesh color of the storage roots from high carotenoid content cultivars was consistently orange (*Camote Amarillo, Japon. Tresmesino Selecto, Teoboza, Zapallo, Mamala,* and *SPK 004*). Cream-colored roots had medium carotenoid contents (*LM87.009, NG7570, Tainan No 15*, and *LM87.045)*. Carotenoid content was low to very low in yellow-, white-, and purple-fleshed roots (Table I). The low level of total carotenoids, and consequently, the β-carotene contents of yellow-fleshed storage roots was a surprising result. Based on color alone, one would expect their carotenoid levels to be between that of orange- and white-fleshed roots. Variation in total carotenoids and β-carotene within roots of the same cultivar was high, especially for orange-fleshed ones (Figure 2).

There was very little relation between flesh color and the dry matter content of the roots (Table I). The dry matter content of orange-fleshed storage roots was generally low to medium (from 20.4 to 27.8%). The exception was *SPK 004*, which had a high dry matter content of 32.3% and was among the cultivars with high carotenoid content. Purple flesh-colored storage roots had generally low to medium dry matter content (20.3–30.2%); however, *Cascajo Morado* had a high dry matter content of 34.3%. Dry matter content was variable among cream-, yellow-, and white-fleshed storage roots, but was generally high (Table I). *LM87.045* had the highest dry matter content of 34.5% while *Xiang Shu 6* had the lowest (18.8%).

TABLE II

Effect of drying and storage length on carotenoid content in sweetpotato storage roots

Cultivar name*	Total carotenoid content, (mg β-carotene equiv./100 g dry weight)				
	Fresh roots	Dried chips stored			
		0 month	3 months	6 months	11 months
Camote Amarillo (CIP400014)	42.8	22.6	22.7	22.1	21.2
Teoboza (CIP420010)	33.8	22.6	21.6	21.5	20.6
Japon. Tresmesino Selecto (CIP420009)	63.2	29.9	28.7	28.7	28.7
Zapallo (CIP420027)	20.9	17.1	17.0	—	16.3
Mamala (CIP420004)	9.6	7.8	7.6	7.6	6.7
SPK 004	9.0	7.7	7.5	7.2	6.7
LM87.009 (CIP187004.1)	5.1	3.4	3.3	3.3	3.2
NG 7570 (CIP440377)	4.4	2.7	2.5	2.5	2.5
LM87.045 (CIP187004.2)	3.7	2.9	2.5	2.4	2.2
KEMB 10	3.1	1.8	—	—	1.8
Estrella (CIP420047)	3.0	2.1	1.7	1.5	1.5
Xiang Shu 6 (CIP440154)	2.5	1.5	1.3	1.3	1.0
Capadito (CIP420053)	2.4	1.7	1.5	1.4	0.9
Cascajo Morado (CIP420031)	2.5	1.7	1.5	1.5	0.9
Morado Maravi (CIP400002)	1.3	1.1	1.0	0.9	0.8
W-228 (CIP440023)	1.0	0.7	0.6	0.6	0.7
Xushu 18 (CIP440025)	0.5	0.5	0.4	0.4	0.4

TABLE II (*continued*)

Cultivar name*	Total carotenoid content, (mg β-carotene equiv./100 g dry weight)				
	Fresh roots	Dried chips stored			
		0 month	3 months	6 months	11 months
Mabrouka (CIP440162)	0.5	0.1	0.2	0.2	0.2
Ihuanco (CIP440066)	0.5	0.3	0.2	0.2	0.2
IRA502 (CIP440144)	0.3	0.3	0.3	0.2	0.2
Naveto (CIP440131)	0.6	0.3	0.3	0.3	0.2
K51/3251 (CIP440164)	0.3	0.1	0.1	0.1	0.1
LM88.014 (CIP188001.2)	0.2	0.2	0.2	0.2	0.2
KSP 20	Trace	0.2	0.2	0.1	0.1
Mugande	Trace	0.1	0.1	0.1	0.1
Mean change in total carotenoids, (%)	100	70 ± 21	70 ± 20	64 ± 20	57 ± 18

* Names in parenthesis are from CIP (International Potato Center). 1994. Pathogen-tested sweetpotato cultivars for distribution. Third edition. Lima, Peru.

2. *Carotenoids and hunter color values of sweetpotato flours*

Hunter color analysis showed there were variations among "L" (white) values for sweetpotato flours from different cultivars (Table I). White-fleshed cultivars had low "L" values, indicating the high level of browning during chip drying and flour processing. Hagenimana *et al*. (1992) reported that the discoloration or darkening may be attributed to the reaction between polyphenoloxidase and o-dihydroxy-phenols or to Maillard type reactions between reducing sugars and aminoacids in sweetpotato roots. Also, both enzymatic and non-enzymatic oxidation of flesh root pigments with concurrent color loss have been reported in other dehydrated foods (Edwards and Lee, 1986). The high correlation between "L" values of the flours and the purple flesh color of the roots (Table I) was interesting. Cultivars *Cascajo Morado, Capadito, Morado Maravi*, and *Estrella* had purple flesh and high "L" values, suggesting a high content of anthocyanins. Bassa and Francis (1987) used the "L" values to predict the pigment changes in anthocyanin contents of beverages. Sweetpotato anthocyanins were found to be more stable to heat than commercial food colorants.

The "a" (red) values of the sweetpotato flours differed for all cultivars. There was a good correlation ($r = 0.74$) between the "a" values of the flours from orange- and cream-fleshed cultivars and total carotenoids from the fresh roots. That suggests total carotenoids and consequently β-carotene in a given orange- or cream-fleshed cultivars might be predicted simply by reading the "a" value of its flour.

The "b" (yellow) values also differed for all cultivars. They were high and consistent for flours from orange- and cream-fleshed root cultivars (Table I), and low but erratic for yellow-, white-, and purple-fleshed cultivars. The correlation between the "b" values for the sweetpotato flours and the total carotenoids from orange- and cream-fleshed root cultivars was high ($r = 0.77$). The "b" color value seems to be the best measure for correlation between color value of orange- and cream-fleshed root flours and the concentration of total carotenoids and β-carotene in fresh storage roots. The "b" values can easily be

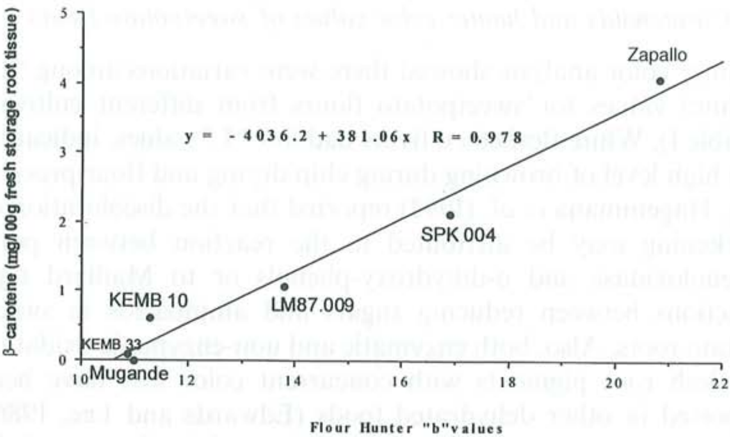

FIGURE 3 Correlation between sweetpotato flour Hunter b values and β-carotene content for selected sweetpotato cultivars.

used by breeders with less equipped laboratory facilities to predict total carotenoid and β-carotene contents in different sweetpotato cultivars. Figure 3 shows how the "b" values can be used to evaluate β-carotene content in fresh sweetpotato storage roots.

3. *Effect of drying and storage of sweetpotato chips on total carotenoid contents*

Drying sweetpotato storage roots at 65°C for 12 h reduced total carotenoid contents by 30%. Storing sweetpotato dried chips reduced total carotenoid contents from 70 to 59% after 11 months (Table II). Losses differed by cultivar, however, storage induced a loss in total carotenoids for all cultivars. The reduction in total carotenoids was generally low in high dry matter content cultivars. Our results are in disagreement with Collins and Gurkin (1990) who previously reported that a 6-week storage increased the β-carotene content by 21% in sweetpotato flour.

Our preliminary work indicated that chipping followed by drying gave the best colored flour compared with grating fresh roots and drying them. Both enzymatic and non-enzymatic oxidations of carotenoids (Edwards and Lee, 1986) and other browning phenomena (Hagenimana *et al.*, 1992) occur concurrently in the whole mass of grated and dehydrated storage roots. Those phenomena are restricted to the chip surfaces in chipped sweetpotato roots. The best way of conserving carotenoids would therefore be to chip, dry, and store the chips, and then mill the chips only when flour is needed.

4. *Total carotenoids in processed sweetpotato products*

The total carotenoid content changes in processed products when cultivar *Zapallo* was partially substituted for wheat flour in chapatis, mandazis, and buns are shown in Table III. Roots were used boiled and mashed, fresh grated, or as flour. Boiling the roots induced a 20% loss in total carotenoid contents from the initial content in fresh roots; drying the roots into chips reduced the amount of total carotenoids by 30%. Carotenoids were reported to be heat-stable and insensitive to pH changes (Sian and Ishak, 1991). Color changes that occured during blanching, cooking, or heat sterilization were attributed to the isomerization of *trans*-carotenoids to the less intensely colored *cis*-form (Sian and Ishak, 1991). The loss of color observed in dried chips and flours is likely due to the same effect.

Addition of orange-fleshed sweetpotato storage roots to processed products tremendously increased total carotenoid contents and consequently β-carotene in the products (Table III). Sweetpotato flour was the best form for carotenoid-enrichment of buns, chapatis, and mandazis. Adding sweetpotato flour into buns resulted in the increase of total carotenoids from 0.1 mg β-carotene equivalents per 100 g of buns made from pure wheat flour to 2.2, 1.2, and 0.8 mg β-carotene equivalents per 100 g product when, respectively, sweetpotato flour, boiled and mashed, or raw and grated sweetpotato were used in enriching the product in carotenoids. The pattern of carotenoid-enrichment of chapatis and mandazis by sweetpotato was similar to that of buns (Table III).

TABLE III
Total carotenoids contents of processed food products containing sweetpotato, cultivar *Zapallo*

Product	Dry matter, (%)	Total carotenoids*, (mg β-carotene equiv./100 g product)**	Total carotenoids*, (mg β-carotene equiv./100 g dry matter)**
Raw material:			
Fresh roots	21.6	4.9 ± 0.1	22.7 ± 0.5
Boiled and mashed roots	18.9	3.4 ± 0.0	18.0 ± 0.2
Sweetpotato flour	88.7	13.9 ± 0.0	15.7 ± 0.0
"Elianto" cooking oil	99.5	0.1 ± 0.0	0.1 ± 0.0
Chapatis from:			
Raw and grated	68.4	1.5 ± 0.2	2.2 ± 0.3
Boiled and mashed	60.3	1.1 ± 0.0	1.8 ± 0.0
Sweet potato flour	68.6	2.3 ± 0.0	3.3 ± 0.0
Wheat flour	69.0	0.1 ± 0.0	0.2 ± 0.0
Mandazis from:			
Raw and grated	69.5	1.5 ± 0.3	2.1 ± 0.5
Boiled and mashed	59.8	1.6 ± 0.1	2.7 ± 0.2
Sweet potato flour	66.2	2.1 ± 0.1	3.2 ± 0.1
Wheat flour	68.3	0.1 ± 0.0	0.2 ± 0.0
Buns from:			
Raw and grated	67.2	0.8 ± 0.0	1.2 ± 0.0
Boiled and mashed	66.8	1.2 ± 0.0	1.8 ± 0.0
Sweet potato flour	70.3	2.2 ± 0.0	3.2 ± 0.1
Wheat flour	69.3	0.1 ± 0.0	0.2 ± 0.0

* Values less than 0.05 mg/100 g product are indicated as 0.0.
** Mean ± STD

CONCLUSION

The study showed that Hunter "b" values for sweetpotato storage root flour provide a reliable estimation of β-carotene contents in sweetpotato cultivars. Partially substituting sweet-potato storage roots for wheat flour (either as purees, flours, or fresh-grated forms) in buns, chapatis, and mandazis can increase the provitamin A content in such foods and help combat vitamin A deficiency in developing countries.

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REFERENCES

Almeida, L.B. and M.V.C. Penteado (1988). Carotenoids and provitamin A value of white-fleshed Brazilian sweetpotatoes (*Ipomoea batatas* L.). *J. Food Compos. Anal.* **1**, 341–352.

Ameny, M.A. and P.W. Wilson (1997). Relationship between Hunter color values and β-carotene contents in white-fleshed African sweetpotatoes (*Ipomoea batatas* Lam). *J. Sci. Food Agric.* **73**, 301–306.

Bassa, I.A. and F.J. Francis (1987). Stability of anthocyanins from sweetpotato in a model beverage. *J. Food Sci.* **52**, 1753–1754.

Bates, C.J. (1995). Vitamin A. *The Lancet* **345**, 31–35.

CIP (International Potato Center) (1994). Pathogen-tested sweetpotato cultivars for distribution. Third edition. Lima, Peru.

Collado, L.S. and H. Corke (1996). Use of wheat-sweetpotato composite flours in yellow-alkaline and white-salted noodles. *Cereal Chem.* **73**, 439–444.

Collins, J.L. and N.A. Abdul Aziz (1982). Sweetpotato as an ingredient of yeast raised doughnuts. *J. Food Sci.* **47**, 1133–1139.

Collins, J.L. and S.U. Gurkin (1990). Effect of storage conditions on quality of sweetpotato flour. *Tennessee Farm and Home Science*, Fall 1990, pp. 20–24.

Edwards, C.G. and C.Y. Lee (1986). Measurement of provitamin A carotenoids in fresh and canned carrots and green peas. *J. Food Sci.* **51**, 534–535.

Gakonyo, N. (1993). Processed sweetpotato: responding to Kenya's urban food needs. Working papers in Agricultural Economics. Cornell University, Ithaca, New York.

Gichuki, S.T., V. Hagenimana, J. Low, M.A. Oyunga, E. Carey and J.N. Kabira (1997). Involving women groups in the evaluation of introduced high β-carotene sweetpotato varieties. Paper presented at the

4th triennial congress of the African Potato Association, Feb. 23–March 02, 1997, Pretoria, South Africa.

Hagenimana, V. and C. Owori (1997). Feasibility, acceptability, and production costs of sweetpotato-based products in Uganda. CIP Program report 1995–1996, pp. 276–281, Lima, Peru.

Hagenimana, V., E.G. Karuri, E.G. and M.A. Oyunga (1998). Oil content in fried sweetpotato processed products. *J. Food Proces. Preserv.* **22**, 123–137.

Hagenimana, V., L.P. Vezina and R.E. Simard (1992). Distribution of amylases within sweetpotato (*Ipomoea batatas* L.) root tissue. *J. Agric. Food Chem.* **40**, 1777–1783.

Henkel Co. (1996). Recent research on carotenoids. Lagrange, Illinois.

Imungi, J.K. and M.N. Wabule (1990). Some chemical characteristics and availability of vitamin A and vitamin C from Kenyan varieties of papayas (*Carica papaya* L.). *Ecol. Food Nutr*. **24**, 115–120.

Low, J., P. Kinyae, S. Gichuki, M.A. Oyunga, V. Hagenimana and J.N. Kabira (1997). Combating vitamin A deficiency through the use of β-carotene-rich sweetpotato varieties: Results of an action research project in South Nyanza, Kenya. International Potato Center (CIP), Lima, Peru.

Kennedy, E.T. and R. Oniango (1993). Household and preschooler vitamin A consumption in southwestern Kenya. *J. Nutr*. **123**, 841–846.

MSTAT-C Program. (1991). A software program for the design, management, and analysis of agronomic research experiments. Michigan State University.

Omosa, M. (1997). Current and potential demand for fresh and processed sweetpotato products in Nairobi and Kisumu, Kenya. Social Science Department Working Paper No. 1997-1. Postharvest Management, Marketing Program, International Potato Center (CIP). Lima, Peru.

Purcell, A.E. (1962). Carotenoids of *Goldrush* sweetpotato flakes. *Food Technol*. **16**, 99–102.

Purcell, A.E. and W.M. Jr. Walter (1968). Carotenoids of *Centennial* variety sweetpotato *Ipomoea batatas* L. *J. Agric. Food Chem*. **16**, 769–770.

Rahmathullah, L., B.A. Underwood, R.D. Thulasiraj, R.C. Milton, K. Ramaswamy, R. Rahmathulla and G. Babu (1990). Reduced mortality among children in southern India receiving a small weekly dose of vitamin A. *N. Engl. J. Med*. **323**, 929–935.

Sian, N.K. and S. Ishak (1991). Carotenoid and antocyanin contents of papaya and pineapple: Influence of blanching and predrying treatments. *Food Chem*. **39**, 175–185.

Simon, P.W. (1997). Plant pigments for color and nutrition. *HortScience*. **32**, 12–13.

Simonne, A.H., S.J. Kays, P.E. Koehler and R.R. Eitenmiller (1993). Assessment of β-carotene content in sweetpotato breeding lines in relation to dietary requirements. *J. Food Compos. Anal*. **6**, 336–345.

Smit, N.E. and C.N. Ocitti p'Obwoya (1994). Piecemeal harvesting of sweetpotato: Its effect on yield loss due to sweetpotato weevils. Paper presented at the Third Triennial Conference of the African Potato Association, 9–13 May 1994, Sousse, Tunisia.

Smith, G.C., S.R. Dueker, A.J. Clifford and L.E. Grivetti (1996). Carotenoid values of selected plant foods common to southern Burkina Faso, West Africa. *Ecol. Food Nutr.* **35**, 43–58.

Takahata, Y., T. Noda and T. Nagata (1993). HPLC determination of β-carotene content of sweetpotato cultivars and its relationship with color values. *Japan J. Breed.* **43**, 421–427.

Truong, V.D. (1992). A consumer-oriented approach for the development of processed sweetpotato food products for low and middle income urban groups, pp. 76–82. In: SAPPRAD First Year of Phase III. Annual Reports 1991–1992. Southeast Asian Program for Potato Research and Development (SAPPRAD); International Potato Center (CIP). Philippines.

Underwood, B.A. (1994). Hypovitaminosis A: International programmatic issues. *J. Nutr.* **124**, 1467S–1472S.

Walter, W.M. Jr., G.L. Catignani, L.L. Yow and D.H. Porter. (1983). Protein nutritional value of sweetpotato. *J. Agric. Food Chem.* **31**, 947–949.

Woolfe, J.A. (1992). Sweetpotato: An untapped food resource. Cambridge University Press, Cambridge.